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PROGRAM

REPORT 534

Guidelines for Inspection and Strength Evaluation of Suspension Bridge Parallel Wire Cables

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Guidelines for Inspection and Strength Evaluation of Suspension Bridge Parallel Wire Cables

R. M. MAYRBAURL
S. CAMO
Weidlinger Associates, Inc.
New York, NY

SUBJECT AREAS
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By David B. Beal
Senior Program Officer
Transportation Research Board

This report contains recommendations for the inspection and strength evaluation of suspension bridge parallel-wire cables. A companion CD-ROM provides details of the research program undertaken to develop the guidelines and explanations of the guidelines' recommendations. The material in this report will be of immediate interest to suspension bridge owners and suspension bridge main cable inspectors.

There are nearly 50 major suspension bridges in the United States, and more than half of them are more than 50 years old. These bridges represent major investments and are essential transportation links for regional and national commerce and lifelines. As this group of major structures advances in age, the number of in-depth evaluations to determine their condition and load-carrying capacity is expected to increase. The need to estimate remaining service life and to take preventative steps to extend service life will also increase.

There has been no reliable and nationally recognized procedure, either practical or theoretical, to inspect and evaluate the condition and strength of suspension bridge parallel-wire cables. At the NCHRP-sponsored "Workshop on Safety Appraisal of Suspension Bridge Main Cables" held in Newark, New Jersey, in 1998, the highest priority research needs identified were (1) development of cable inspection, sampling, and testing guidelines and (2) development of models to predict the strength of deteriorated cables. Unreliable methods of inspection and evaluation could result in unnecessary replacement or in unexpected failures.

The objective of this research was to develop the needed guidelines for inspection and evaluation of suspension bridge parallel-wire cables. These guidelines provide details of the cable inspection process, including wire sampling and testing. Complete instructions, illustrated with examples, are provided for using the condition and properties of the cable wire, determined by inspection and subsequent laboratory testing, for estimating cable strength. An accompanying CD-ROM (CRP-CD-54) contains a full account of the research leading to the development of the recommended guidelines and provides derivations of all equations.

The research was performed by Weidlinger Associates, Inc., with the assistance of Altran Corporation and Foster-Miller, Inc.

PREFACE

The Guidelines were written as a general resource for all persons who have responsibility for assessing cable integrity and to clarify and standardize the process of evaluating a cable in service for an extended period of time. They will not make a suspension bridge expert out of a novice, but are intended for use by engineering professionals who are already versed in the design and analysis of suspension bridges and have some knowledge of bridge cables. A cable evaluation team should consist of the following:

- Chief investigator, a professional engineer with expertise in suspension bridges who leads all phases of the project
- Chief inspector, a professional engineer with experience in bridge inspections, preferably cable inspections
- One or more cable inspectors, graduate engineers with two to three years of design or inspection experience
- Office staff, graduate engineers with experience in computer analysis, spreadsheets and applying mathematical equations.
- Qualified testing laboratory
- Metallurgical and corrosion consultants
- Statistician (as needed)

The Guidelines present a series of orderly steps that define a thorough cable evaluation from planning inspections through strength estimation. They concern parallel-wire cables only, although portions of the text may be applied to helical strand cables. If inspection is limited to only a few panels, the Guidelines cannot provide information about the strength of the weakest point in the cable. However, they do contain recommendations for when more thorough investigations are needed.

The Guidelines are arranged in two columns, as are other specifications and manuals published by AASHTO. In general, a description of the required tasks is on the left, pertinent comments and background information are on the right. The columns are merged in Section 1, which is introductory. Figures and tables appear at the end of each section. They are numbered consecutively, prefixed by the article numbers in which they are described (e.g., Figure 1.4.2.1-1).

Section 1 is mostly a general description of bridge cables, including their internal construction, connections to the bridge structure, and protection systems. Figures are used to illustrate the various parts of the cable system. The causes of corrosion are discussed, as well as investigative techniques to locate corrosion. Of special interest are photographs showing the visual rating scale for corroded wires. The section also includes a list of persons who should use the Guidelines, a glossary of technical terms, and information on health and safety requirements.

Section 2 presents three levels of inspection: routine visual inspections by maintenance personnel, biennial inspections, and internal inspections that expose the wires inside the cable. The section also contains instructions about the data to be recorded and measured, and the requirements for removal of wire samples. Recommendations for frequency and locations of internal inspections are based primarily on the data from a limited number of cable inspections in which a significant number of panels was opened. As more cables are inspected, the results can be combined with existing data to justify or modify these recommendations.

Acoustic monitoring of wire breaks, a recent development, is referred to briefly in Section 2. The sound of a wire as it breaks inside the cable is recorded and the catalog of recent breaks is used to decide when, and especially where, to perform the next inspection. This is very helpful with older cables, because timing of inspections and selection of the best locations are critical.

Section 3 lists the requirements for the physical and chemical tests that are made on samples removed from the cable, including tensile tests, and tests to determine the chemical composition of wires and the condition of the zinc coating.

Section 4 focuses on the techniques used to catalog the damage inside the cable and the statistical analysis of test results. The calculations for obtaining the mean values and standard deviations of wire properties that are needed for strength estimation (tensile strength and, in some cases, ultimate elongation) do not require advanced knowledge of statistics, but can be performed using standard spreadsheet programs, or even by hand. A slightly more sophisticated statistical analysis is used to estimate the probable minimum value of these properties in a given length of wire, which is much the same as estimating the strength of the weakest link in a chain. The graphs that are provided reduce the complexity of the latter analysis substantially.

It has been noted during internal cable inspections that friction among the wires introduces tension back into a broken wire as the distance from the break location increases. A method of estimating the force that is reintroduced as the wire passes through a cable band is presented in Section 4. In this analysis, the effects of wrapping wire, which are not negligible, are conservatively ignored.

Three models for estimating cable strength are given in Section 5 based on the following assumptions. All wires are subject to the same elongation between cable bands. An individual wire breaks at its ultimate elongation and thereafter ceases to share in the cable tension. Only after some wires have broken does the cable attain its strength, which is smaller than the product of its area and the mean tensile strength of the wires. These suppositions are borne out by strand efficiency tests performed during the design of the Bear Mountain Bridge and Benjamin Franklin Bridge.

Section 5 presents methods for assigning wires to groups that differentiate increasing levels of deterioration. Wherever appropriate, graphs are inserted to assist in estimating the effects of deterioration in panels adjacent to the evaluated panel, including the effects of broken wires. The statistics in this section are more advanced than in the previous section. The Weibull distribution of the ultimate strain or tensile strength of the wires, included in some spreadsheet programs, simplifies the calculation. The equations for the distribution are given in Appendix A, as well as an iterative method for calculating the parameters of the distribution. An alternative method using Weibull paper is not presented here, but can be found in statistical texts, Rao [1] for example. The equations used for estimating the cable strength are also included in Appendix A.

Section 6 lists the points to be covered in written reports for all three levels of inspection.

Appendix B shows the rationale for calculating the effects of deterioration in adjacent panels on cable strength in the evaluated panel. The calculation is extremely tedious if all the cable panels have been inspected; therefore, it should be reserved for the worst panel found in an inspection, or eliminated, unless it is essential to take all sources of cable strength into account. The assumption that all panels are in the same condition as the evaluated panel leads to a lower estimate of cable strength; graphs are provided to simplify the calculation.

Three examples of a strength calculation are given in Appendix C, all using the same inspection data. The first two examples use the Simplified and Brittle-Wire Models, with the assumption that all panels are in the same condition. The third example assumes that all panels have been inspected and employs, in part, a very large spreadsheet that requires 16 pages to print and is tedious to set up, demonstrating the reasons for not using it except in extreme cases.

The method that is commonly used to replace broken wires or sample wires is presented in Appendix D.

REFERENCE

1. Rao, S.S., *Reliability-Based Design*. 1st ed, ed. R. Hauserman. 1992: McGraw-Hill, Inc. 569.

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FIGURES

SECTION 1

GENERAL

1.1 INTRODUCTION

1.1.1 Scope of Guidelines

The purpose of the Guidelines is to provide the following:

- Methods of inspecting bridge cables,
- Criteria for gathering data to obtain the best statistical sample for the least effort and cost,
- Criteria for testing wire, and
- Methods of estimating cable strength.

The Guidelines apply to suspension bridge parallel wire cables only. This is especially true of the articles that describe wedging and interior inspection of the cable and estimation of cable strength. However, much of the contents has relevance in a broad sense to helical strand cables.

1.1.2 Users of Guidelines

The Guidelines are intended for use by the following:

- Suspension bridge owners, in planning inspections and preparing specifications for scopes of work;
- Investigators and subordinate personnel, in planning inspections and evaluating the information gathered in inspections;
- Field inspection personnel, in executing inspections;
- Construction crews, in providing access, unwrapping and wedging the cable, and rewrapping or replacing the protection system; and
- Laboratory personnel, in testing wire samples.

The recommended intervals between inspections and locations for inspection are especially useful to bridge owners, as are the codes and standards and procedures for cable inspection and evaluation. The Guidelines are not intended, however, to be used as a substitute for hiring experienced staff to inspect or evaluate cables. An engineer who is practiced in the evaluation of cable elements should always be in charge of a cable investigation.

Mathematical proficiency at the college graduate level is needed for the estimation of cable strength.

1.1.3 Glossary

A

Adjustment (during cable spinning)—Correcting the length of wires in a strand or of strands in a cable so that all the wires have the same dead load tension.

Anchorage—Structure that dead ends the main cable. Also, the material that fastens the cable to it.

B

Bottom of the Cable—Lowest wires in a cross-section.

Bridge Wire—Wire that usually conforms to standard specifications of ASTM A586 for suspension bridge cables.

Bright—Uncoated, or ungalvanized (wire).

C

Cable—Main supporting element of a suspension bridge.

Cable Bands—Steel castings that hold the suspenders in place over the cable.

Cable Band Bolts—Bolts that press the two halves of a cable band against the cable to provide the normal force that prevents sliding.

Cable Capacity—See Cable Strength.

Cable Opening—Length of cable that is unwrapped for inspection.

Cable Strength—Total force at which the cable fails.

Cast—Curvature imparted to a wire during its manufacture.

Cast Diameter—Diameter (or radius) of the circle freely adopted by unstressed wire lying on the ground. Also called Free Coil Radius.

Cold Drawing—Wire manufacturing method of pulling rods through successively smaller dies at room temperature.

Compaction—Compressing the cable to the densest possible circular cross-section.

Continuous Wire—Cable wire that is not broken.

Controlled Tension—Method of maintaining cable wires at a constant tension as they are aerially spun and laid into strands.

Corroded Wire—Wire that exhibits ferrous corrosion on some of its surfaces (section loss is not implied). See also Corrosion Stage.

Corrosion Stage—Four categories of increasing severity that describe deterioration of the zinc coating and ferrous corrosion on a bridge wire, based on visual examination.

Cracked Wire—Wire that contains a crack but is not broken, detectable by visual observation of the fracture surfaces during laboratory testing of samples (almost impossible to see inside wedged cable).

Crossing Wires—Cable erection fault in which some of the wires cross over other wires.

D

Dehumidification—Reduction of ambient relative humidity to prevent condensation.

Distribution—Mathematical expression used to represent the variation of strength or ultimate elongation of cable wires.

E

Effective Development Length—Length of a cable outside of which a broken wire will not affect the cable strength in the panel at the center of this length.

Elongation—Increase of wire length due to changes in stress and/or temperature.

Environmentally Assisted Cracking (EAC)—Cracking caused by electrochemical mechanisms associated with the environment inside the cable.

Error, Systematic—Repeating error caused by improper calculation, observation or testing.

Error, Random—Error due to the difference between the sample and the “real universe” being studied.

Evaluated Panel—Panel of a cable that has been inspected and for which the cable strength is calculated.

F

Free Coil Radius—See Cast Diameter.

G

Galvanized Wire—Wire with an applied zinc coating.

Gaussian Distribution—Normal probability distribution.

Gross Metallic Area—Cross-sectional area of a galvanized wire that includes the zinc coating.

H

Helical Strand—Strand composed of wires that are wound around a central straight wire, each layer wound in the direction opposite the layer below it. Also called Bridge Strand or Structural Strand.

Helical Strand Cable—Cable made of helical strands that are placed parallel to one another, generally used for suspension bridges with shorter spans.

Hydrogen Embrittlement (HE)—Brittleness and low strength caused by the penetration of steel by hydrogen.

Hydrogen-Assisted Cracking (HAC)—Cracking processes that require the presence of hydrogen.

I

Investigator—Professional engineer in charge of performing the inspection and evaluation of a cable.

L

Low Point (of Cable)—The panels that are at the lowest elevations in the main and side spans.

M

Macroenvironment—Atmospheric conditions in the general area of a bridge, such as wind, salt spray, and de-icing salts and other roadway pollutants in the splash zone.

Mean—Average value of a property of cable wire.

Microenvironment—Factors affecting the wires inside a cable, including water, pollutants on wire surfaces, acid or alkaline conditions, and radicals such as sulfates, carbonates and nitrates.

Monte Carlo Technique—Statistical technique for calculating probable variation of minimum cable strength.

N

NDE—Nondestructive evaluation, usually used in reference to devices that detect internal damage without harming the structure.

Necking—Reduction of wire diameter at failure.

Net Steel Area—Area of the steel portion of an uncorroded galvanized wire.

Nominal Area—Specified area of a bridge wire, either gross metallic or net steel, to be distinguished from the actual measured area.

Normal Distribution—See Gaussian Distribution.

O

Octant—Portion of a cable equivalent to 1⁄8 of the total cable area lying between two radii and 1⁄8 of the circumference, or the wires enclosed in that portion.

Oiling—Introduction of oil (generally linseed oil) into the cable to protect cable wires from corrosion.

Owner—Public or private entity responsible for the operation and maintenance of a bridge.

P

Panel—Portion of a bridge or cable that lies between the centers of two adjacent suspenders or cable bands.

Panel Length—Length of a panel measured horizontally.

Panel Point—End point of a panel.

Parallelism—Degree to which cable wires are parallel, with good parallelism marked by very few crossed wires.

Percent Elongation—Length change between two gage points, measured under zero load across the break in a wire in a tension test, expressed as a percent of the pretest unstressed gage length, usually 10 inches.

Ply (of Wrapping Wire)—One wire wound around the cable, sometimes in multiple groups next to each other, forming a single layer. One and two ply wrappings are common, three and four less so; multiple plies do not imply multiple layers.

Polarization—Change in electrical potential of a component (relative to ground).

Preece Test—Standard method for determining the minimum remaining corrosion resistance of a zinc coating that has deteriorated irregularly.

Protection System—Methods used to prevent cable corrosion, including wire coating, impregnation with oil, wire wrapping, painting, neoprene or plastic sheathing, and injection of dried air.

Q

Quadrant—Portion of a cable equivalent to 1/4 of the total cable area lying between two radii and 1/4 of the circumference, or the wires enclosed in that portion.

R

Random Numbers—Numbers with no mathematical pattern. See Monte Carlo Technique.

Residual Stress—Stress in a wire with no applied axial or in-plane forces (i.e., lying flat on a level floor).

Raw Linseed Oil (RLO)—Linseed oil that does not contain a drying agent, used in red lead paste and as a corrosion inhibitor.

Redevelopment—Capacity of a broken wire to regain some or all its prefracture stress at a distance from the fracture.

Redevelopment Length—Distance at which a broken wire regains its full load capacity.

Red Lead Paste—Paste composed of lead oxide and linseed oil, placed under cable wrapping for additional protection.

Ring (of Cable)—Circular portion of a cable that includes all wires at a given distance from the center of the cable.

S

Safety Factor—Cable strength divided by the maximum cable tension under service loads.

Sag Control—Method of controlling the position of a wire in an aerially spun cable by controlling its final drape during the erection process.

Sample—Small group of wires that are expected to be representative of all such wires with the same characteristics (e.g., the same deterioration stage). See also Wire Sample.

Sector (of Cable)—Pie-shaped portion of a cable designated for calculation purposes.

Segment (of Cable)—Portion of a cable ring designated for calculation purposes.

Shakeout—Inspection of an aerially spun strand by removing all bindings and allowing it to hang free.

Shop-Fabricated Parallel Wire Strand (PWS)—Cable strand fabricated offsite that consists of wires placed parallel to each other.

Specimen—Single piece of wire, generally cut from a wire sample, on which a test is made.

Spinning (Aerial)—Cable erection by repeatedly pulling loops of wire across a bridge until there are sufficient wires to form a strand and sufficient strands to form a cable.

Splash Zone—Alternately wet and dry surfaces caused by stream flow, wave action, or traffic spray.

Standard Deviation—Statistical measure of the amount of variation in a property of cable wire.

Straightening Stress—Flexural stress induced in a wire by decreasing the wire curvature to match the cable curvature.

Strand—Independent bundle of wires, grouped together systematically to form the main cable.

Strength Test—Test in which a cable wire specimen is pulled to failure in a testing machine.

Stress Corrosion Cracking (SCC)—Wire cracking due to stress plus corrosion, with or without the assistance of hydrogen. See Hydrogen Assisted Cracking.

Stress-Strain Curve—Graph produced during a strength test showing the relationship between the stress and strain of a wire specimen.

Suspenders—Vertical wire ropes or strands connecting the suspended structure to the cable.

T

Tensile Strength—Maximum stress a wire can resist.

Tension Control—See Controlled Tension.

Tests—Field or laboratory procedures designed to identify wire properties and forces on cable wires.

Turning Point—Any location where a cable changes direction.

U

Ultimate Strain—Strain at which a wire fails.

Unloaded Side Spans—Side spans with no suspenders (the suspension bridge cable does not support the deck in the side spans).

UV—Ultraviolet radiation.

V

Variance—Statistical value of a property of cable wire, related to the Standard Deviation.

W

Wedging—Driving plastic or oak wedges between cable wires to open a space for observation of internal wires.

Weibull Distribution—Probability distribution commonly used for steel strength.

Weight of Coating Test—Standard test for determining the average weight of the zinc coating on a bridge wire.

Wire (in cables)—Thin longitudinal continuous high-strength steel elements up to 7 mm in diameter that make up a main cable.

Wire Rope—Steel tension element made of 6 or more helical steel strands that are wound around a single central core of hemp or another wire rope or strand.

Wire Sample—Length of wire removed from a cable for testing, from which individual specimens are cut.

Wire Strand—A steel tension element that differs from wire rope in that it is fabricated from layers of parallel longitudinal or helical wires. The latter is also called Bridge Strand.

Wire Strength—Force at which a wire breaks.

Wrapping (Wrapping Wire)—Continuous coil of soft steel wire that forms the protective covering on most cables.

Y

Yield Point—For bridge wire, the point on the stress-strain curve at which the residual strain is 0.2%.

Yield Strength—Wire stress at the yield point.

Z

Zinc Coating—Zinc layer deposited uniformly on a bridge wire to protect against corrosion, applied according to galvanizing process codes and standards.

1.1.4 Professional Organizations

The following professional organizations are referred to in the Guidelines with the acronyms listed:

AASHTO	American Association of State Highway and Transportation Officials
AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
AWS	American Welding Society
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
OSHA	Occupational Safety and Health Administration
USCG	United States Coast Guard

1.1.5 National Codes and Standards

General Publications—The Guidelines recommend experience-based cable inspection frequencies and provide specific criteria and guidelines for training and qualifying personnel, with reference to the following publications:

AASHTO Manual for Condition Evaluation of Bridges, 2nd Edition, 1994
FHWA Bridge Inspection Training Manual, 1990, 1991
FHWA Inspection of Fracture Critical Members, 1986
NBIS (National Bridge Inspection Standards), Federal Regulations Guide to Bridge Inspection, 1988

Public Safety Publications—The federal documents listed below contain codes and standards regarding public safety.

ARC (American Red Cross) Standard First Aid Workbook, 1991
FHWA Manual on Uniform Traffic Control Devices, 2000
FHWA Guide Design Specifications for Bridge Temporary Works, 1993
OSHA Code of Federal Regulations (CFR), Title 29
OSHA Code of Federal Regulations (CFR), Title 23 (parts dealing with highway safety)

1.2 HEALTH AND SAFETY REQUIREMENTS

1.2.1 General

Cable inspection over trafficked roadways and waterways involves risk to people and the environment. Therefore, protection of construction workers, inspectors, motorists, pedestrians, and marine traffic is an important consideration in planning and executing the work.

Owners often require that the contractor develop a Health and Safety Plan subject to their final approval and in accord with their specific health and safety practices. The plan must incorporate all governmental provisions along with those of the owner.

1.2.1.1 LEAD ON THE CABLE

Cable unwrapping releases dried lead oxide paste into the environment, which is prohibited by federal regulations. Protective enclosures must be provided. Monitoring the blood of inspectors and workers and following procedures to prevent lead absorption are mandated by both the EPA and OSHA. Work clothes must be replaced periodically and never taken home.

Smoking accelerates lead absorption and, if permitted, must be accompanied by strict hygiene. Smoking on the work platform, where there are flammable materials, should be prohibited.

As stipulated by OSHA in Title 29, Subpart D, 1926.62, containment, handling, and disposal procedures must be approved before the start of work.

1.2.1.2 OTHER OSHA REQUIREMENTS

OSHA requirements also cover work safety in a traffic environment (Title 23) and work under exposed conditions (Title 29 Subparts L and M).

Some owners require that inspectors wear a safety harness with two lanyards attached at all times to two handropes or other elements independent of the work platform. Other owners require latching onto the handropes while walking the cable but not while working inside an enclosed work platform.

1.2.1.3 PERSONNEL TRAINING PROGRAM

Personnel should be made familiar with the health hazards related to cable inspection and trained in the use of the equipment and monitoring procedures associated with health maintenance. They should refer to the OSHA Compliance Manual Training Requirements.

1.2.1.4 PEDESTRIAN AND VEHICULAR TRAFFIC

To protect traffic on the bridge and on roadways, waterways and areas beneath the bridge, all construction equipment, material, small tools, wedges that are sometimes ejected from the cables by wire pressure, etc., must be retained within the confines of the work platform. Work platforms should have kick plates and closed floor penetrations around suspenders for this reason. Fine netting or a fall shroud is recommended. It should be secured to the handropes and enclose the work space completely from one side of the platform to the other.

1.2.1.5 NAVIGATIONAL SAFETY

The USCG must approve all work over navigable waters. Plans for the protection of vessels must be part of the work specifications. The USCG regulates burning (falling sparks), construction over shipping, the quantity of flammable gases on the catwalk, dropped material, pollution of the waterway, etc. They are expected to impose security regulations, including those concerning communications between crews at the cable site and crews on approaching vessels.

1.2.1.6 BRIDGE SAFETY PLAN

The owner is generally responsible for following the construction-specific regulations of local authorities that concern work near railroad tracks or pedestrian sidewalks, maintenance of traffic and lane closings, etc. The owner also determines the various types of insurance needed for the cable work. The contractor and investigator bear responsibility to the owner for following regulations.

A stand-by boat is often required while inspectors or workers are on the platform above. Painting operations on cables have been reported to cause damage to vehicles. Removal of suspenders (for access to cable bands) may require work near active highways or railroad tracks, which may have to be closed for short periods of time to protect public safety.

1.3 SUSPENSION BRIDGES

Suspension bridges are large, unique structures with two or more cables that carry the immense weight of the deck and most of the imposed live load to the towers that support them. The suspension system is in tension and requires substantial anchorage at both ends. The cables are fracture critical and load path nonredundant. Figure 1.3-1 shows an elevation of a typical suspension bridge. The major elements are identified along with the low points of the cable, which are significant for cable evaluation and are referred to in Section 2.

1.3.1 Cables and Cable Wires

Most North American bridge cables consist of wire with a 0.192-inch diameter, a 0.002-inch zinc coating, a 6-foot cast (i.e., a 3-foot free coil radius), and approximately 0.8 percent carbon content. The specified minimum tensile strength varies between 215 ksi and 225 ksi, based on the gross metallic area of the wire, which includes the cross-sectional area of the zinc coating.

A notable exception is the Williamsburg Bridge in New York, which has cables composed of bright (ungalvanized) wire, with an average diameter of 0.1907 inches. Another exception is the Brooklyn Bridge, which has galvanized wire with a smaller than average diameter of 0.184 inches.

The free coil radius of the wire is the result of the manufacturing (i.e., drawing) methods; it is imparted to the wire as it is wrapped around the capstans that pull it through the dies. Some wire manufacturers are currently producing nearly straight wire with a free coil radius of 25 feet or more, and with a minimum strength of 260 ksi. This wire may be more crack resistant. The manufacturing process also results in residual stresses in the wire, which may be about 30 ksi tension at the inside of the cast.

1.3.1.1 WIRE MANUFACTURE AND CHEMICAL COMPOSITION

Cast

Small cast diameters imply high tensile stress on the inside of the coil when the wire is straightened in the cable. Cracks nearly always originate in this area of the wire, where the tensile bending stress caused by straightening the wire under service loads is at a maximum.

In contrast to the straightening stress in the span, the stress due to increased curvature around strand shoes reduces the effect of the residual wire stress in a wire with a cast. A hypothetical trouble-free cable would consist of straight (no cast) wires that eliminate the flexural stress caused by straightening the curved wire. The strands would be socketed, thus avoiding the introduction of high flexural stress as the wire bends around the strand shoe. Also, with socketed strands the wires would all be exactly the same length, assuming the manufacturer was competent, reducing the number of crossing wires inside the cable.

Chemistry

The wire's alloying elements affect its susceptibility to stress corrosion by governing hydrogen absorption rates.

Cr (chromium) increases and Ni (nickel) decreases the susceptibility to hydrogen embrittlement (HE). Si (silicon) and P (phosphorus) have little or no effect. Silicon is sometimes added to develop fine grain in the wire, while nickel and chromium are usually present as residual elements in the manufacture of the material.

The following table lists the elements in cable wire and their approximate weight by percent.

	Weight by Percent	
Element	Minimum	Maximum
Carbon	0.65	0.84
Sulfur		0.04
Phosphorus		0.04
Manganese		0.80
Silicon		0.15
Nickel		0.12
Chromium		0.10

Carbon content should be high enough to provide a pearlitic steel structure but not exceed 8%, the maximum when there is no free cementite. Exceeding 8% results in a structure that is hard but brittle and tends to fracture under cold drawing. The microcracks produced in cementite reduce toughness and provide traps for hydrogen to do its worst damage.

Galvanizing

Cold-drawn wires are traditionally acid-cleaned before galvanizing. Care must be taken to remove all hydrogen from the wire before galvanizing.

A hot-dipped zinc coating isolates the wire from the corrosive media; and, if steel is exposed (at a scratch or holiday in the coating), the zinc-iron cell provides cathodic protection to the exposed steel from the wet environment. This is a mixed blessing, because polarization will generate hydrogen ions in the electrolyte (the microenvironment) that can enter the steel.

The zinc coating must be applied after cold working and after the wire is treated to remove all possible hydrogen from the metal. Hydrogen passes through steel but not through zinc.

The zinc/steel interface is a brittle zinc-iron alloy, which may facilitate corrosion of the steel after the zinc coating has been depleted.

1.3.1.2 WIRE PROPERTIES

Strength

High strength wires are desirable, even though they are more susceptible to corrosion. Cold-drawn wires are more resistant to stress corrosion and hydrogen-assisted cracking than heat-treated wires having the same mechanical properties.

Hardness

Hardness is related to carbon content; yield strength increases with increasing hardness. Wires are generally not tested for this property.

Toughness

Unless notched by corrosion, bridge wires are not susceptible to fatigue from highway loading. The critical stress intensity factor, K_{IC}, is only meaningful if corrosion causes notches and the material has become embrittled.

The stress intensity factor for stress corrosion cracking, K_{ISCC}, which determines time to failure, varies depending on stress and environmental load intensity. There is no standard test for wire toughness, K_{ISCC} or K_{IC}, although Mayrbaurl [1] describes a possible technique of estimating K_{IC} from tensile tests of cracked wires.

K_{ISCC} is the stress corrosion equivalent of K_I, which is used for fatigue. It is the stress intensity at which a crack becomes unstable. The incubation time for corrosion in a constant environment is related to K_{ISCC}.

1.3.1.3 AERIALLY SPUN CABLES

Twenty-nine bridges with aerially spun cables in North America were erected before the end of the twentieth century. Making sure that the wires sag equally during erection ensures that all the wire tensions will be equal. Once all the wires in a strand are erected, that strand is adjusted to the other strands by this sag method, which is very accurate.

Cutting out or splicing in wire is the method used to correct the few wires found to have incorrect sags during the shakeout of a strand. The process occasionally connects a wire to another wire, causing crossing wires and small voids in the cable that allow water to enter and remain longer than in a well-compacted cable. Crossing wires creates points of contact where the zinc coating can be displaced by the pressure of compaction and become sites of local deterioration. Broken wires are often found at these points of contact. It is common to find some voids due to crossing wires during inspection. Modern cables that are aerially spun by a controlled tension method or made of shop-fabricated parallel wire strands should have few or no crossing wires. They are expected to be very compact and water-resistant.

1.3.1.4 PARALLEL WIRE STRAND CABLES

Cables that consist of shop-fabricated parallel wire strands may perform better than cables with aerially spun strands, because the strands are fabricated offsite, where the process can be controlled more easily than in the field. Moreover, the strands are often composed of nearly straight wires, with minimal residual stress, and have socketed ends, both distinct advantages in lowering tensile stress.

There are two bridges in the United States with cables that fit this description:

- Newport Bridge, Newport, Rhode Island; and
- William Preston Lane Jr. Memorial Bridge II, Sandy Point to Kent Island, Maryland.

1.3.1.5 HELICAL STRAND CABLES

In the United States and Canada, there are 21 suspension bridges with cables composed of helical wire strands. They are not covered by the Guidelines and are primarily bridges with shorter spans.

The spaces between the outer strands are filled with prismatic wood or metal shapes machined to fit between strands and provide a circular exterior shape. The Dunvegan (Peace River) Bridge in Alberta, Canada, is composed of separated helical strands with wide spaces for strand replacement and no fillers.

1.3.2 Bridge Cable Details

The parts of the cable system other than the cable itself, such as the hardware and fittings at the cable turning points and the connections of the suspenders to the cable, affect the performance of the wires and their inspectability. They are discussed below in relation to the bridge component they are part of.

1.3.2.1 TOWER SADDLES

The vertical forces on the tower tops are very large. They are, with few exceptions, greater than the total dead plus live load of the main span plus both side spans. Virtually the entire weight of the bridge is supported at the top of the tower where the cable changes direction. This force is transferred from the cable into the tower by the tower saddles.

The downward force that the anchorages exert on the cables (if the cables slope down toward the anchorages) is far greater than any possible side span reaction. Thus, the tower resists the entire weight of the bridge plus the downward force of the anchorage on the cable. There is no other component to resist this downward force.

The normal pressures delivered by the wires to the saddle are inversely proportional to the saddle radius. Wires in the lower strands touching the bottom surface of the saddle are subjected to the greatest normal pressure. These stresses theoretically reduce the yield capacity of the wire, but no damage will occur if reasonable saddle proportions are used.

Saddles are usually fixed to the tower tops, which deflect whenever side and center span forces differ. The deflection reduces the force differential to a negligibly small value that the flexible tower resists.

A typical tower saddle is shown in Figure 1.3.2.1-1. The saddle in Figure 1.3.2.6-1 had a cover plate bolted to it, which was removed for inspection, and a separate housing that covers the entire saddle. A layer of paraffin has been taken off the wires to facilitate inspection.

1.3.2.2 ANCHORAGE AND CABLE BENT SADDLES

Anchorages and cable bent saddles redirect the cable so that it comes into alignment with its anchoring mechanisms. Anchorage saddles, called splay saddles, sometimes have a variable vertical radius and a horizontal flare, so that the cable strands can splay directly from the saddle to their anchoring mechanisms. If the anchorage saddle is not flared, then a splay casting is applied between the saddle and the cable anchoring device. The saddles, splay castings, strand shoes and eyebars are all located in or near the cable anchorage. Figure 1.3.2.2-1 is an illustration of a typical anchorage.

Anchorage saddles are sometimes supported on an integral part of the anchorage. They bear on rollers to allow for changes due to stress and temperature in the length of cable that runs from saddle to anchor.

On several bridges, damaged and broken wires have been observed at the bottom of the cable at both ends of the saddle. They result from water that has entered the cable outside the anchorage and comes to rest at the upper end of the saddle or runs through the saddle and wets the wires at the bottom or condenses on the wires at either end. The condensation is often from humid spring air entering an anchorage that retains the cold of the previous season.

Cable bent saddles usually bisect the interior angle of the cable. The cable changes direction with a single vertical curve that proceeds from the saddle towards the anchorage without flaring to a splay casting.

The saddles are supported on independent struts that may be hinged at the base or, if the struts are flexible enough, fixed at the base.

Cable bent saddles are also located on separate cable bents at the ends of side spans whenever the anchorage structure does not extend to the roadway level. In this case, they do not bisect the interior cable angle, and additional strands are provided to prevent slippage of the cable on the saddles.

Figure 1.32.2-2 illustrates a typical cable bent saddle.

1.3.2.3 SPLAY CASTINGS

Splay castings are elements that control the direction of strands that flare out to their respective anchoring devices. The castings are designed to resist the outward force exerted by the strands and are anchored against upward slippage by a cable collar clamped above the splay casting.

Passage of water through the cable may cause corrosion in the wires inside the splay casting. It will take the form of a white or brown leachate at the lower end of the splay casting.

The inspection of wires within the splay casting area is a complex operation that requires the relocation, usually temporary, of the splay casting. The same tension is maintained in all the splayed strands by rerouting them through holding frames that move the splay point upward along the cable while both the length and the original stress of the wires are maintained.

A splay casting detail is illustrated in Figure 1.3.2.3-1.

1.3.2.4 CABLE ANCHORING DEVICES

1.3.2.4.1 Strand Shoes

Traditionally, cable wires loop around strand shoes, which are anchored to two eyebars by a pin. Later versions use a single eyebar and two strand shoes, one at each end of the pin, splitting the strand into four quarters. Other systems restrain the strand shoe with high-strength anchoring rods.

If the atmosphere in the anchorages is humid or water enters the anchorage through the deck, damage is often found in the lower half of the strands, particularly at the interface of the wires and the strand shoe where water tends to collect. The damage in this area is usually uniform corrosion that causes section loss.

The repair of the strands at the strand shoes depends on the extent of the damage. If there are only a few broken wires, they are generally repaired individually by cutting and splicing in new wires. Extensive damage is often repaired by cutting the damaged strand, socketing the end, and then reanchoring it.

A typical strand shoe is shown in Figure 1.3.2.4.1-1.

1.3.2.4.2 Parallel Wire Strand Terminations

Parallel wire strands are terminated in zinc or polyester thermoset resin sockets rather than in strand shoes. The sockets are connected to anchoring assemblies embedded in the anchorage concrete.

1.3.2.4.3 Eyebars

Eyebars are anchored to a grillage buried deep in the concrete mass of the anchorage. The focus of the eyebars may not be at the splay casting or cable bent saddle but slightly beyond to provide an inward component for the strand forces on the ends of the eyebars. To prevent the eyebars from bending, spacers are placed between the eyebars of each separate strand so that the eyebars bear against each other. They are often tied transversely with a center rod that passes through the holes in all the pins. In humid anchorages, eyebar corrosion is found at the interface with the concrete mass. The damage is often hidden behind pack rust. Figure 1.3.2.4.3-1 illustrates a typical array of eyebars.

1.3.2.5 SUSPENDERS AND CABLE BANDS

Suspenders are expected to last between 35 and 65 years. The suspenders with longer life spans have been prevented from rubbing against the structure, particularly at the lower ends.

Suspenders made of wire rope have two legs, but they are actually a single continuous piece that rises from the deck, loops over the cable band, and returns to the deck, using only two sockets.

If suspenders are designed to ride cross-saddle over the cable bands, then they contribute to the normal force provided by the cable band bolts and increase resistance to cable band sliding. This is true of most North American bridges.

Suspenders made of wire strands that cannot be bent over the cable require a socket. They are stronger and thus lighter than rope suspenders, and they simplify cable band detailing somewhat.

Cable bands consist of two cylinder halves bolted together over the circumference of the cable. The number of bolts per cable band is dependent on the slope of the cable at the suspender attachment point. The friction from squeezing against the cable prevents it from sliding down the cable. The steeper the cable, the more bolts are needed to prevent this sliding. If a cable band has to be removed, the suspenders on the band must also be removed.

The tension in the cable band bolt that squeezes the two halves together decreases with time due to creep of the zinc coating on the wires. The loss may average as much as 65% of the original tension.

Figure 1.3.2.5-1 illustrates a typical cable band.

1.3.2.6 PROTECTIVE APPURTENANCES

Cable wire areas that are exposed to the weather require additional protection. The cable wrapping or protection system stops short of the saddle, creating a significant gap in the system. The cable wires are also exposed at the upper surface of the saddles. A housing should enclose the entire saddle, or a plate should be bolted to the top of the saddle trough to create a weather-tight space for the cable. These provisions must be made in a manner that allows for inspection. Figure 1.3.2.6-1 shows a saddle that has both a plate bolted to the saddle and a separate housing.

If tower saddle troughs are hexagonal, then the transition of the cable from its usual circular shape to a hexagonal one complicates compaction and long watertight sleeves are used in place of wrapping. The sleeve must allow for cable slope changes relative to the saddle. A sleeve detail is shown in Figure 1.3.2.6-2.

1.3.3 Cable Protection Systems

1.3.3.1 ZINC COATING

With very few exceptions, cable wires are zinc-coated. Depending on the effectiveness of the exterior protective system, the coating may last indefinitely or could become depleted within 20 years on a large number of the wires.

Complete zinc depletion is equivalent to corrosion at the end of Stage 2 and the beginning of Stage 3 (see Article 1.4.2.2). This condition may describe the entire wire or a local holiday, which is a small discontinuity in the coating that encourages corrosion. In either case, it marks the start of embrittlement and environmentally assisted cracking.

1.3.3.2 GREASE AND OIL

The wires of some early bridges were greased during spinning or as the cable was being compacted. In some cases, the greased wires appeared almost new after nearly a century, despite the often deplorable condition of the exterior wrapping. The Brooklyn Bridge and the Manhattan Bridge are notable examples.

In other cases, despite the presence of grease, wires cracked and failed in localized zinc-depleted regions. It has been suggested that corrosion may attack holidays in greased or oiled wire for longer periods of time than holidays in ungreased wire. This could explain why corrosion in greased and oiled wire is limited to a very few small isolated islands of severe damage.

1.3.3.3 PASTES

In the past, various paste mixtures were used as a layer of protection under new wrapping wires to prevent water penetration. Red lead paste was the chief ingredient; zinc-based products have been used more recently.

- **Red lead paste**—The paste used traditionally under the wrapping wire was a mixture of lead oxide powder (Pb_2O_3) and raw linseed oil (RLO), specified in the following proportions by weight:

lead oxide	95%
raw linseed oil	5%

  These quantities translate roughly to 70% lead oxide and 30% RLO by volume.

  Freshly applied red lead paste releases many inhibitive ions that decrease the potential difference between cathode and anode. However, in time the oil polymerizes and shrinks and the paste cracks, becomes friable, and is no longer an impermeable barrier.
- **Zinc-based paste**—Due to the hazardous nature of red lead, zinc-rich pastes are now used in Europe and the United States.

  Moisture-cured urethane with pure zinc pigment was used on the Storebaelt Bridge in Denmark. In the United States, a material composed of zinc, zinc oxide, corrosion inhibitors, and organic-based oil that resists polymerization was used in several cable rehabilitation projects.
- **Lead and calcium-based paste**—A mixture of calcium plumbate, calcium carbonate, and linseed oil has been used on the Honshu-Shikoku Bridges in Japan.

1.3.3.4 WRAPPING AND PAINT

Several types of exterior cable protection systems have been used on North American bridges, including

- Paste, wire wrapping, and a paint system;
- An elastomeric membrane;
- Fiberglass-reinforced lucite composite; and
- Combinations of the above.

1.3.3.4.1 Wire Wrapping

Wrapping typically consists of soft galvanized No. 9 wires with Class A zinc coating. Some newer bridges in Japan use an S-shaped wire that interlocks with the other wires. Wrapping is installed by power-driven machines with multiple reels that are capable of placing from one to three wires at a time. Figure 1.3.3.4.1-1 shows a cable that is wrapped using two reels, which results in a two-ply wrapping. The wires are in a single layer, in side-by-side helices. In this figure, one of the two wrapping wires has broken, resulting in gaps between wires through which cable wires are visible.

Paint systems used to cover and seal the wrapping have changed over the years from alkyds to moisture-cured urethanes and then to water-based paints, which are excellent barriers against water entering the cable. Unfortunately, they also retain water inside the cable.

1.3.3.4.2 Elastomeric Membranes

Elastomeric membranes are also barriers against water penetration, and they also cause water that enters through the cable bands to be retained inside the cable, unless relief systems are provided.

Overlapped neoprene and hypalon are sometimes applied directly over the entire wrapping as a protective membrane for the wrapping wires. Protective paint is usually hypalon-based, because it is not as sensitive to ultraviolet (UV) rays as neoprene.

1.3.3.4.3 Fiberglass Reinforced Lucite Composites and Methacrylates

Two North American bridges are protected by a fiberglass reinforced lucite composite system. The glass fiber is used for reinforcement of the lucite, which is a transparent matrix belonging to the class of compounds known as methacrylates. The system is applied over a polyethylene sheet to separate the matrix from the bridge wires, and a pigment is added to obtain the desired color for the composite material. A well-designed caulking system at the cable bands is required, because the protective shell in each panel is not subject to the same strain as the cable wires. The performance of fiberglass-reinforced lucite cannot be confirmed at this time.

Methacrylates are UV insensitive and fresh methacrylates, unlike thermoset epoxies, will bond to an existing cured methacrylate. Eliminator, a methacrylate product that is sprayed on and forms a thick flexible membrane, was used over the poorly wire-wrapped cables of the Bosphorous Bridge and was somewhat effective.

1.3.3.5 DEHUMIDIFICATION

Pastes are not used in the most recently developed cable protective system, and the wires are not greased. First applied to the Akashi Kaikyo Bridge, the new system consists of an S-shaped steel wire wrapping interlocked with an elastomeric membrane cover. By injecting dehumidified air, the cable is kept at or below 40% relative humidity [2], which is believed to be the threshold below which corrosion does not occur.

1.4 CAUSES OF CORROSION

1.4.1 General

The fundamental cause of corrosion is the presence of water and its solutes. Without water, corrosion does not occur. Many conditions affect the quantity of water in the cable, its corrosive quality, and the wires' susceptibility to attack.

1.4.1.1 ENVIRONMENTAL FACTORS

The bridge atmosphere often contains moisture, pollutants, dissolved gases, and salt spray, all of which may cause corrosion or induce hydrogen attack. De-icing salts and the proximity of the cable to the vehicle splash zone at deck level are some of the other external factors that are grouped together under the term macroenvironment.

Water enters the cable as a liquid from precipitation or as vapor during periods of high temperature and humidity. Water vapor becomes liquid when the temperature falls, and condensation forms on the surface of the wires. Conditions inside the cable that can affect the wires are referred to as the microenvironment.

Five types of microenvironments observed in bridge cables cause cable wire to crack and break:

- Acid rain chemistry, leading to hydrogen evolution from reaction with zinc;
- Carbonate or bicarbonate chemistry, either alkaline or highly acidic;
- Nitrate chemistry, either alkaline or acidic;
- Alkaline chemistry; and
- Seawater or salt spray, moderately alkaline.

1.4.1.2 SOURCES OF WATER PENETRATION

- **Exterior protection system**—Water enters cables that are poorly wrapped or have cracked paint over the wrapping.
- **Lower cable band grooves**—Joints that are often completely or partially open to allow for weeping of internal water may become points of entry for water streaming along the underside of the cable or from wind-driven rain.
- **Enclosures**—Damaged or poorly maintained housings and flashing enclosures have been the source of many wire failures near saddles and anchorages.
- **Condensation**—Paint cracks and other entry points for water are also entry points for water vapor. The only effective way to prevent condensation is dehumidification.

1.4.1.3 CABLE INSTALLATION PRACTICES

Poor cable compaction and crossing wires cause un-usually large voids in the cable that lead water deep into the cable. Crossing wires also squeezes out zinc at their point of contact, providing opportunities for polarization, which is activated by the electrolytes in the water.

1.4.1.4. WIRE SUSCEPTIBILITY

The strength of cable wire is due to its high carbon content and the cold working of the steel. Both conditions render the wire more disposed to corrosion than mild rolled steel. A zinc coating that covers the entire surface of the wire is beneficial as long as it is not breached. Localized zinc depletion encourages the polarization that causes wire degradation.

1.4.1.5 WIRE STRESSES

Tensile stress reduces the resistance of wires to corrosion. The stress in the wires comes from residual bending stress due to cast, straightening stress due to removing the cast, and dead and live load tension.

Wires manufactured with small cast radii have a high residual bending stress, estimated to be 30 to 36 ksi by X-ray diffraction, which adds to the still higher bending stress induced by straightening the wire to the cable curvature. The resulting stresses, which can be greater than the dead load tension, are tensile inside the cast curvature and compressive outside of it. Combined with dead load, the total stress on the inside of the curvature is at or near the wire yield strength. It is not a coincidence that virtually all cable cracks occur on the inside of the cast circle.

Modern straight wires don't have this stress, but if they are aerially spun, then large diameter strand shoes must be used to minimize strain. Straight wire strands socketed at the ends are ideal. They have low bending and residual stress in the span, and the sockets eliminate the need for strand shoes.

1.4.2 Corrosion Mechanisms

1.4.2.1 ZINC CORROSION

Zinc oxidizes in dry air to zinc oxide (ZnO). Further reactions take place in the presence of moisture: e.g., atmospheric carbon dioxide and sulfur dioxide dissolved in water react with the zinc and the ZnO to produce zinc carbonate ($ZnCO_3$), zinc hydroxide ($Zn(OH)_2$) and zinc sulfate ($ZnSO_4$).

ZnO and $Zn(OH)_2$ are poor passivating films. In contrast, $ZnCO_3$ is effective. Environmental conditions that interfere with the formation of $ZnCO_3$ may lead to rapid degradation of the zinc coating. $ZnSO_4$ is very soluble and is easily removed by moving water. Hence, acid rain depletes the zinc coating.

Acid rain in contact with zinc generates hydrogen. For example, carbonic acid (H_2CO_3) is a weak acid that produces hydrogen.

The zinc depletion rate is governed by the extent of atmospheric pollution (industrial pollution is more aggressive than marine environments); the duration, frequency and quantity of moisture that enters the cable; and the rate of drying.

1.4.2.2 CORROSION STAGES OF ZINC-COATED WIRES

The following discussion applies to galvanized wires in the span. Galvanized wires in the anchorage and all ungalvanized wires undergo different corrosion mechanisms.

After the zinc coating is depleted, mechanisms that depend on wire stress and probably involve hydrogen begin to embrittle the wire and to attack it with surface corrosion, transverse cracks, and brittle fracture.

Wire corrosion is categorized visually by corrosion stage. The four corrosion stages are characterized by the presence of the following:

Stage 1—spots of zinc oxidation on the wires;
Stage 2—zinc oxidation on the entire wire surface;
Stage 3—spots of brown rust covering up to 30% of the surface of a 3-inch to 6-inch length of wire; and
Stage 4—brown rust covering more than 30% of the surface of a 3-inch to 6-inch length of wire.

The corrosion stages are illustrated in Figure 1.4.2.2-1. They were adopted from the research performed by Hopwood and Havens in 1984 [3]. Even if corrosion is highly localized, it is still as destructive as if it were widespread.

Stage 2 wire may have white surface dust, indicating zinc oxidation, but that does not necessarily imply depleted zinc. Depletion is indicated by a dull gray color, or a dark gray to black color if sulfur is involved.

Laboratory tests have shown that 5% to 20% of Stage 3 wires and 60% of Stage 4 wires may have cracks.

1.4.2.3 FRACTURE OF ZINC-COATED WIRES IN THE SPAN

Most wires inside a compacted cable display the flat-and-invert type of failure. At the same time, they do not show the necking (i.e., ductile failure) found in new wires.

The flat-and-invert type of failure is cracking that starts as a transverse fissure on the inside radius of the wire cast and then continues at an angle to the wire horizontal axis up the final break, which is transverse. The same type of wire failure was also found in the helical strand cables investigated by Hopwood. Completely transverse and spiraling failures have also been observed. Figure 1.4.2.3-1 illustrates the most frequently found failure mechanism.

1.4.2.4 UNCOATED CABLE WIRES

Some cables are composed of uncoated wires, also referred to as bright wires. They are damaged by pitting and reduction of section. Whenever zinc is present in the wrapping wire, however, the cracking described above is often present as well, as was the case with the Williamsburg Bridge cables. Very few interior wires were found broken and no definitive failure type was reported, although one photograph showed an internal wire with a square break, indicating the possibility that it was cracked.

1.4.2.5 ZINC-COATED WIRES IN ANCHORAGES

Wire failure mechanisms in the anchorages are typically not the same as those in the compacted cables on the bridge spans. In anchorage strands, which are exposed to an abundance of oxygen, wires display uniform and pitting corrosion with large reductions in cross-section. Failed ends have long needle-like points.

Tension tests made on wires removed from the cables in the anchorage of the Manhattan Bridge showed that the tensile strength in the steel where corrosion reduced the cross-section was unchanged from the tensile strength in the original wire; the individual wire strength was proportional to the remaining area. While this data is limited, it can be assumed that all bridge wires follow this pattern.

1.5 INVESTIGATIVE TECHNIQUES

1.5.1 General

The primary method of assessing cable damage is visual examination of the wires supplemented by laboratory analysis of representative wire samples removed from the cable.

There are no currently available methods for obtaining significant information based on nondestructive or remote technologies. Acoustic monitoring, which records wire failure, is effective, but it does not supply data on the number of failed wires that preceded monitoring or the capacity of degraded wires.

1.5.1.1 NDE TECHNOLOGIES

Nondestructive evaluation (NDE) provides information about conditions inside the cable without the investigator having to remove the covering or otherwise alter the condition of the cable. See the final report for NCHRP Project 10–57, on the accompanying CD, for a more detailed discussion.

1.5.1.1.1 Diagnostic Techniques

Current NDE technologies can be used to detect damage in strands up to 4 inches in diameter. Detectability in larger strands is theoretically possible but has not been substantially proved. NDE determines the loss of cross-section, but it will not necessarily identify cracks, and cannot distinguish among corrosion grades.

Many NDE technologies that apply to bridge cables exploit the basic principles of electromagnetism, such as the following:

- Flux leakage reactions,
- Magneto-restrictive reactions, and
- Eddy current effects.

They require cumbersome magnetic and electric circuitry. Also, calibration is necessary to distinguish between intact and damaged strands. They are best suited to assessing the condition of suspender ropes or strands outside the cables.

1.5.1.1.2 Monitoring Techniques

Acoustic Monitoring is a technology that uses sound to detect wire failures as they occur. Accelerometers are attached to the exterior of the cable at predetermined intervals and monitored continuously. Sonic data provide an inventory of wire failures, along with accurate data on the location of failures, which may be very useful in estimating the rate of cable degradation. Wires that have failed prior to installation cannot be detected.

Acoustic Emissions generally refers to the detection of sound emitted by degrading material at the microscopic level. Applicability to cables has not been demonstrated.

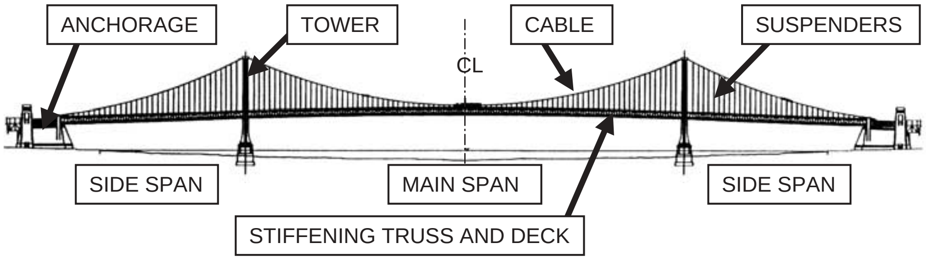
1.5.1.2 CABLE STRENGTH ANALYSIS

The estimation of cable strength is a probabilistic exercise, due to the impossibility of knowing the properties of each individual wire in the cable. The models for strength estimation depend on data gathered during internal inspections and on laboratory testing of samples removed during these inspections.

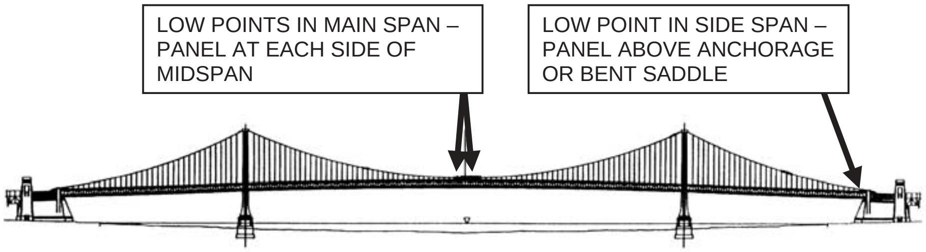
It may not be necessary to remove a full set of samples from the cable each time it is inspected, providing that the number of samples taken during earlier inspections is adequate, as described in Section 2.

Sections 3, 4 and 5 present the analytical techniques and strength models that should be used in estimating cable strength. Section 6 lists the information required in written reports for all levels of inspection.

1.6 FIGURES FOR SECTION 1

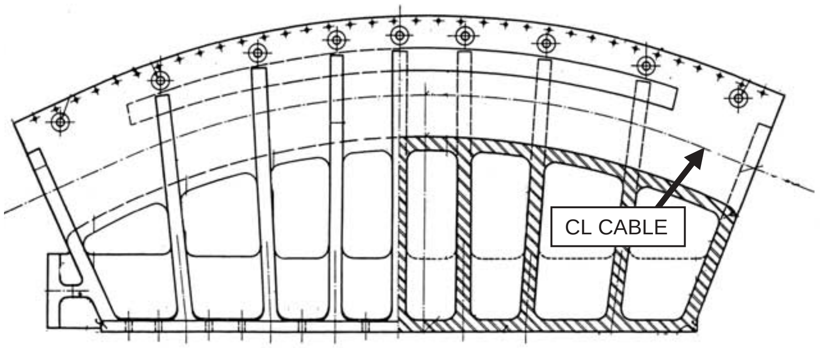


IDENTIFICATION OF MAJOR ELEMENTS

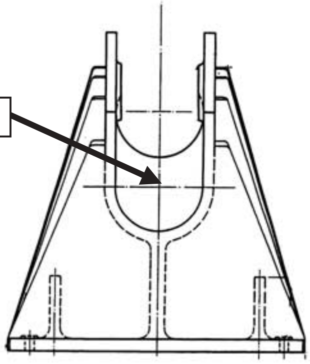


LOCATION OF LOW POINTS

Figure 1.3-1. Typical suspension bridge.



HALF ELEVATION HALF LONGITUDINAL SECTION



END VIEW

Figure 1.3.2.1-1. Tower saddle.

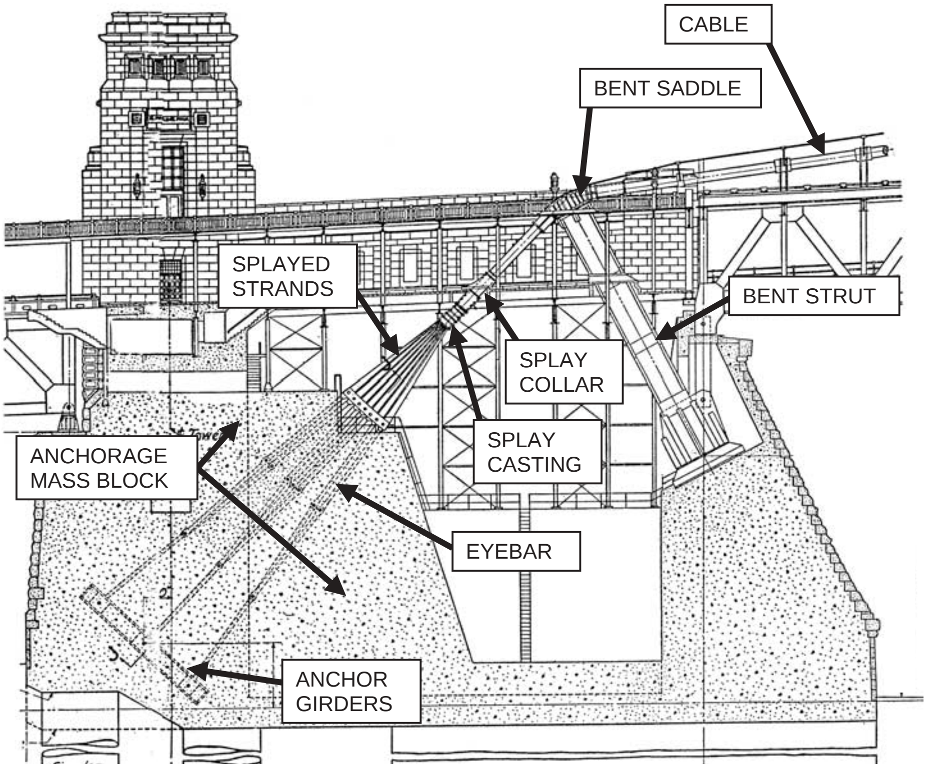


Figure 1.3.2.2-1. Cable anchorage.

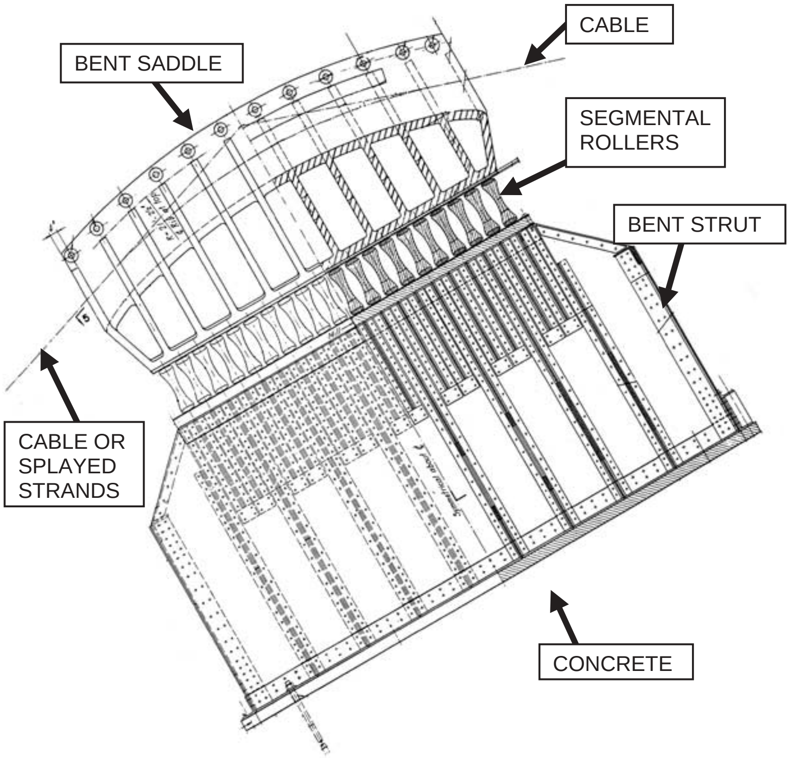
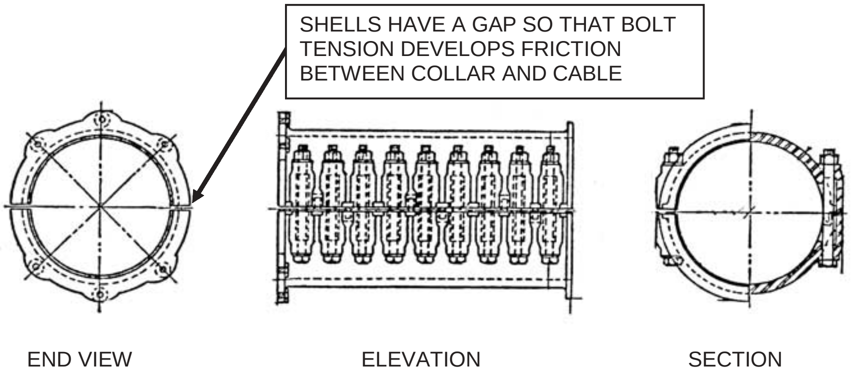
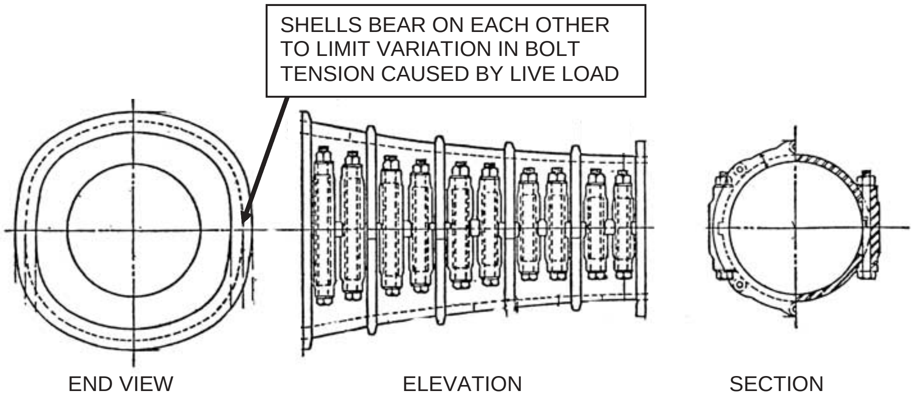


Figure 1.3.2.2-2. Bent strut and saddle.



SPLAY CASTING COLLAR



SPLAY CASTING

Figure 1.3.2.3-1. Splay casting and collar.

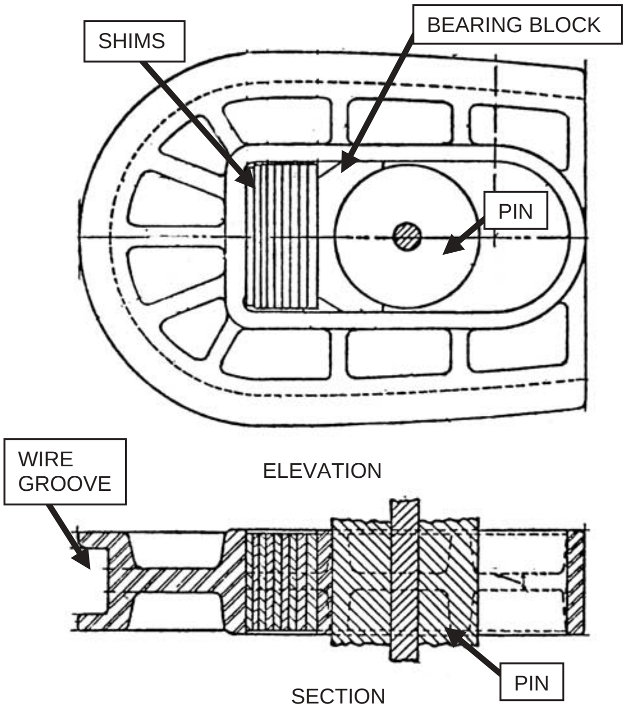


Figure 1.3.2.4.1-1. Strand shoe for spun cable.

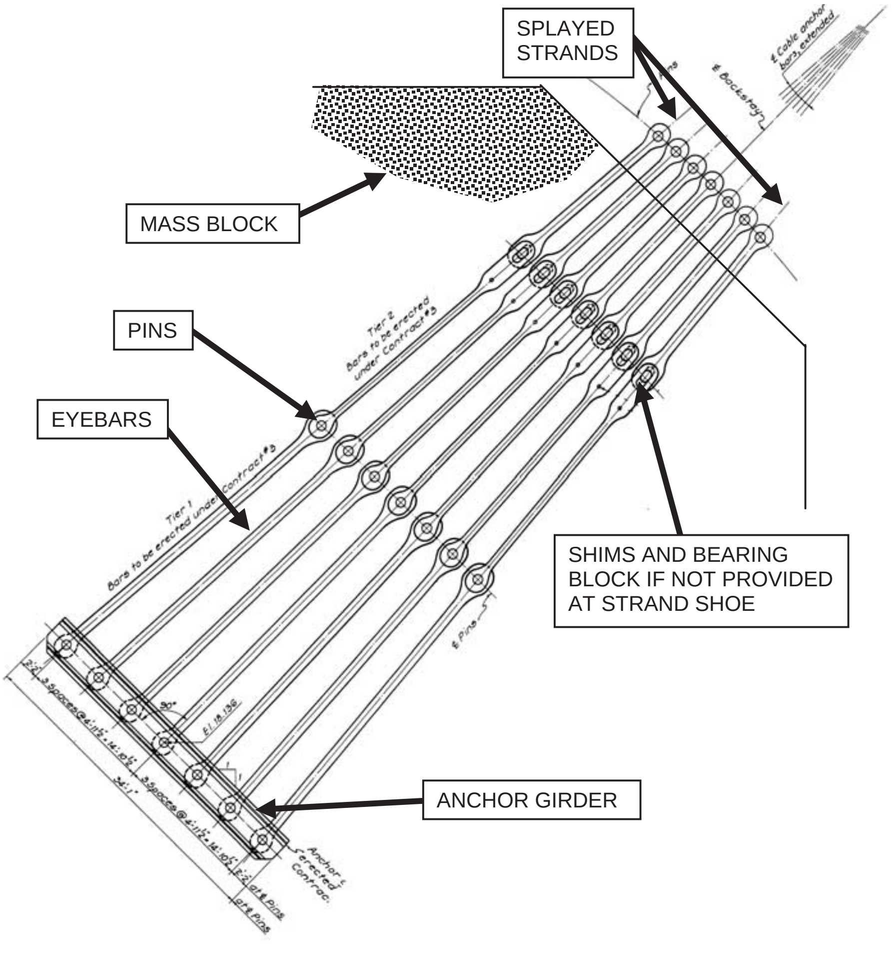


Figure 1.3.2.4.3-1. Eyebars.

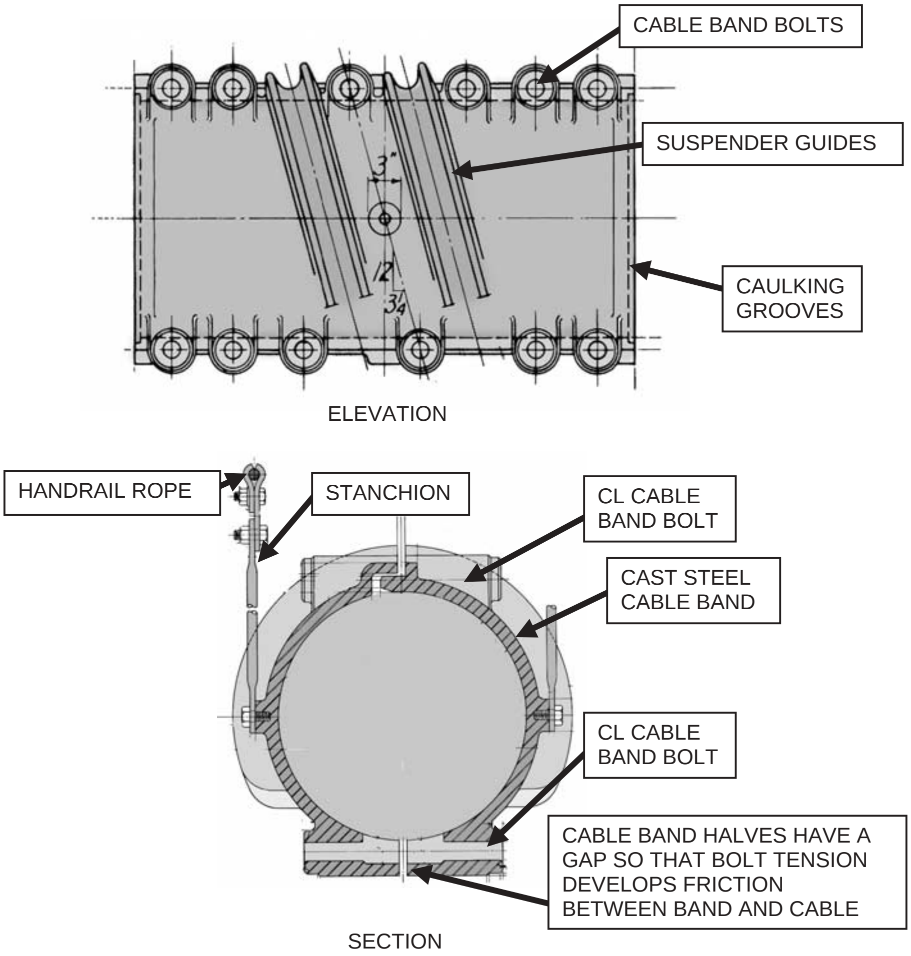


Figure 1.3.2.5-1. Cable band.

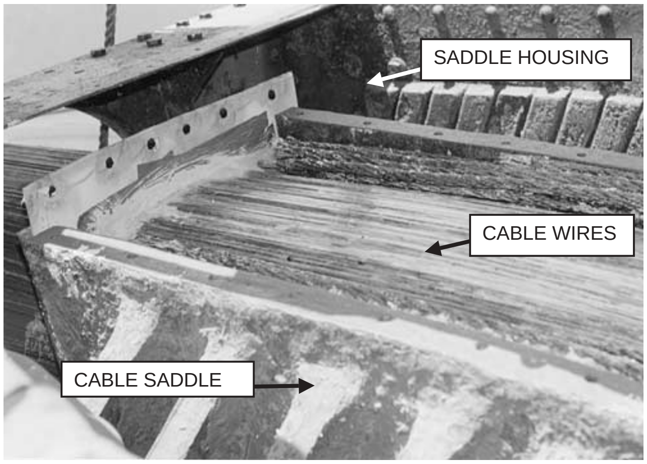


Figure 1.3.2.6-1. Tower saddle opened for cable inspection.

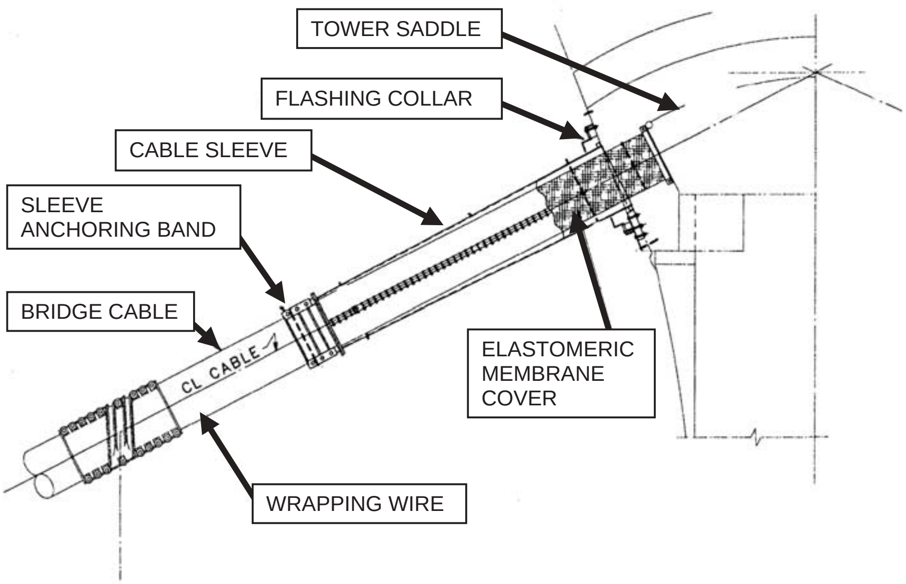


Figure 1.3.2.6-2. Protective sleeve adjacent to tower saddle.

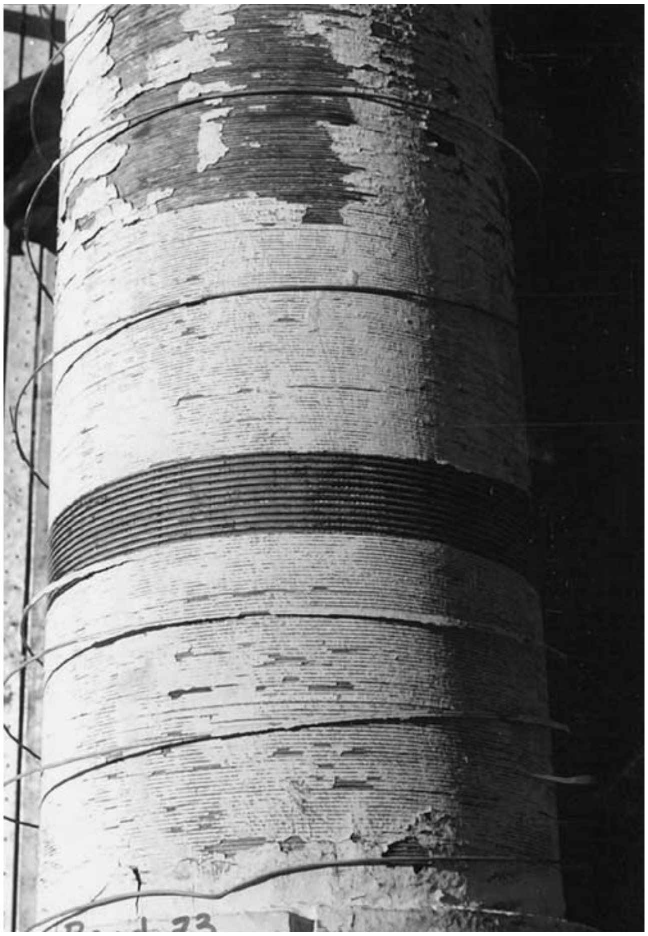


Figure 1.3.3.4.1-1. Two-ply wire wrapping.

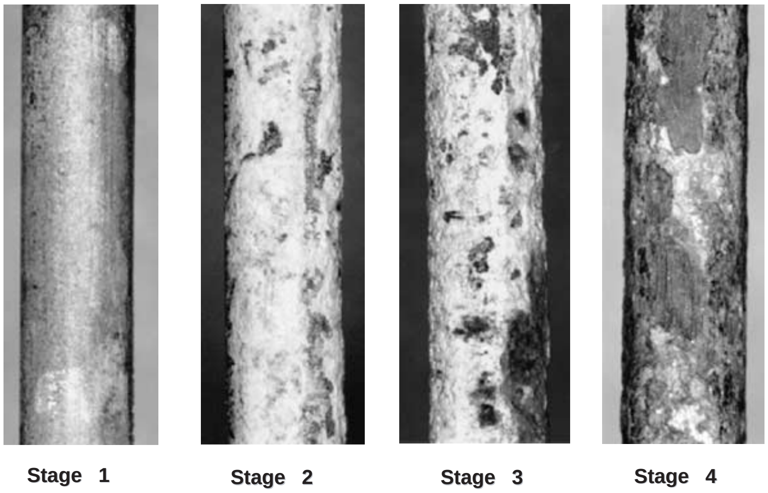


Figure 1.4.2.2-1. Corrosion stages of cable wires.

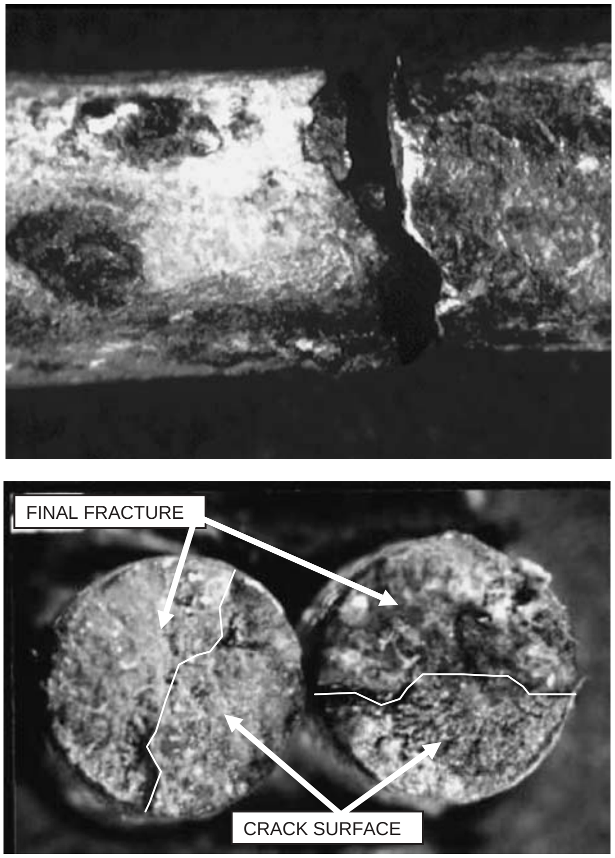


Figure 1.4.2.3-1. Typical wire break.

1.7 REFERENCES

1. Mayrbaurl, R. and S. Camo, *Cracking and Fracture of Suspension Bridge Wire.* ASCE Journal of Bridge Engineering, 2001. 6(6): p. 645–650.
2. Suzumura, K. and S.-I. Nakamura, Environmental Factors Affecting Corrosion of Galvanized Steel Wires (unpublished manuscript).
3. Hopwood, T. and J. H. Havens, *Corrosion of Cable Suspension Bridges.* 1984, Kentucky Transportation Research Program, University of Kentucky Lexington.

CONTENTS

FIGURES

TABLES

2.1 INTRODUCTION

The evaluation of a suspension bridge cable requires considerable information about the condition and strength of the cable wires. Obtaining this information is the goal of an inspection.

Several levels of inspection are performed on a single structure over time, but only internal inspections provide data for strength evaluation.

In this section, instructions are given for conducting a thorough internal inspection, and specific recommendations are made regarding inspection frequency and choice of locations. Sample forms are included, as well as photographs of cables being inspected and cable defects.

Inspections must be planned in advance. Preparing forms and hiring a contractor is part of getting ready. Sometimes the owner's staff takes on the contractor's tasks, such as constructing platforms and unwrapping and rewrapping the cable. The responsible parties, whoever they are, should be prepared for the removal of one or more suspenders and cable bands, if conditions require it. Some cable band bolt tensions should be checked by the team in either case.

Wedges are driven into the cable to separate the wires for visual inspection and to take samples from inside the "grooves." Measurements of wire retraction are used to estimate the capacity of the broken wires to redevelop their force.

Portions of the cable inside the anchorages, and visible portions where the cable passes over the saddles, must be inspected.

2.2 INSPECTION INTERVALS AND LOCATIONS

2.2.1 Levels of Inspection

Three levels of inspection are recommended: periodic routine visual inspections by maintenance personnel of the cable exterior, biennial hands-on inspections, and more thorough internal inspections.

2.2.2 Inspections by Maintenance Personnel

During normal maintenance operations such as ice removal, rinsing of splash zone residue, or touch-up painting, maintenance personnel should be observant of

C2.1

Information obtained from surveys of U.S. bridge owners during development of these Guidelines led to the conclusion that a baseline inspection should be performed on a bridge when it has been in service for 30 years.

C2.2.1

The inspector should walk the entire cable during a hands-on inspection. For an inspection to qualify as hands-on, the inspector must be sufficiently close to the cable to touch it, sound it or inspect it with a magnifying glass.

C2.2.2

Maintenance personnel, who are familiar with the cable, may observe changes in condition indicative of trouble more readily than an engineer or investigator changes in the appearance of the cable. This is especially true of changes that may indicate a potential problem, including: damage to the paint or wrapping caused by accidents, weathering of the paint system, corrosion or severe oxidation of the wrapping wires, loose caulking, and brown rust stains. Periodic inspection tours of the cable by maintenance personnel are recommended. Inspectors should begin by inspecting the underside of the cable with binoculars, and then walk the cable for its full length.

The best times of the year for inspection tours are at the end of winter (March or April) to observe damage due to frost or deicing salts in the splash zone, and at the end of summer (September or October) to observe the effects of extreme heat on paint and caulking. Additional tours should be scheduled after severe snow, ice, rain or wind storms. During these inspections, the underside of the cable should be examined for evidence of water inside, such as dripping from the wrapping wire or weep holes in the lower cable band grooves. Unusually damp areas should also be noted.

Observations of unusual conditions should be recorded and documented with color photographs. Both the date and location of the inspection are noted, along with the date of the storm that preceded the inspection, if applicable. This information may be extremely useful in determining sites for in-depth inspections.

2.2.3 Biennial Inspections

Federally-regulated biennial inspections require that non-redundant members receive hands-on inspection. During these inspections, the condition of the items listed in Articles 2.2.3.1 and 2.2.3.2 should be reported on and rated.

If a biennial inspection indicates the possible presence of internal corrosion, and the cable was never inspected internally in that particular area before, it should be in the near future.

2.2.3.1 CABLES IN SUSPENDED SPANS

The conditions of the following bridge components should be reported on and rated as follows:

- paint or surface protection, inspected for dried out, peeling, cracked and crazed paint, or puncture or tearing of the elastomeric barrier (rate 3 if localized and 1 if more than 12 inches long)

who visits the cable at intervals of two years or more. On-site observations can be instrumental in determining where internal inspections should take place.

While inspection tours are classified as hands-on, in that they are made by walking along the length of the cable, they are not intended to replace biennial inspections. Only if problems are noted need a report be filed, and a rating system is not required.

A database is highly recommended for summarizing actual maintenance operations (repair of damage, repainting, etc.) and inspection tour observations. The database should include:

- report number, part of a consistent reference system
- date of observation or maintenance operation
- location of maintenance operation, damage or repair
- description of maintenance operation, damage or repair (verbal description and numerical code for rapid searching of the database)
- recommended action
- reference to report of the action taken

C2.2.3

Biennial inspections should not be thought of as an opportunity for internal inspection, because the cable may be compromised by unwrapping sections of it every two years.

C2.2.3.1

Forms used by inspectors in the field, as well as summary forms, should be prepared for the specific bridge being inspected.

The ratings used in the Guidelines text and corresponding figures are specific to New York State. They progress from 1 (totally deteriorated, or in failed condition) to 7 (new condition, no deterioration). Unless the wrapping wire or other components are

- caulking at cable bands, for gaps or cracks (rate with the cable bands as indicated in Figure 2.2.3.1-2)
- handropes and stanchions, for broken wires, tightness and corrosion (rate 3 if broken wires are present or loose, rate 1 if handropes or stanchions are broken)
- wire wrapping, inspected for anomalies, including:
    - unequal tension of wire plies, indicated by unevenness in wrapping surface (rate 4)
    - bunching below or separating above the cable bands (rate 4)
    - gaps in wrapping, corroded or broken wrapping wire (rate 3 for small gaps, rate 1 for broken wrapping)
    - surface ridges, indicative of crossing wires and hollow areas (rate 4)
- cable saddles or anchorage penetrations, for damaged sleeves, bellows or flashing (rate 1 if cracks that can admit water are present)
- bottom of cable or cable bands, for rust stains or dripping water, indicative of internal corrosion (rate 1 or 2 and recommend internal inspection)

Figure 2.2.3.1-1 shows an example of an inspection form. Figures 2.2.3.1-2 and 2.2.3.1-3 show forms used to report the conditions found. Figure 2.2.3.1-2 summarizes the rating system for various types of defects in wrapping and cable bands, while Figure 2.2.3.1-3 is a more detailed listing for each cable panel or cable band. A bridge plan, tower elevation, and cable elevation (refer to Figure 2.3.1.2.4-1) should also be included in the inspection report.

2.2.3.2 CABLES INSIDE ANCHORAGES

The following anchorage features should be reported on and rated according to state specifications:

- strands inside the anchorages, for corrosion or broken wires, and swelling or bulges at the strand shoes
- anchorage walls and roof, for signs of water entry
- eyebars and strand wires, for signs of

actually new, the highest rating used is 5 (minor deterioration, but functioning as originally designed). Other agencies use a scale of 1 to 9, and ratings should be adjusted proportionally.

Ratings applied to paint are often specified by the bridge owner. If no such guide exists, the rating system recommended by the state in which the bridge is located should be used.

C2.2.3.2

Ratings for these items should follow the system specified by the state in which the bridge is located.

condensation

- points of contact between eyebars and the concrete mass, for signs of corrosion
- eyebars and anchorage strands, for paint anomalies

Figure 2.2.3.2-1 shows a typical form for recording the condition of strands and eyebars inside the anchorages.

2.2.4 Internal Inspections

Internal inspections are necessary at some point during the life of a cable. The inspection intervals given in Table 2.2.4-1 are suggested, regardless of the cable’s external condition. Access to internal wires requires removal ofthe external protective system. The details of conducting an internal inspection are described in Article 2.3.

Table 2.2.4-1 Interval between internal inspections

Inspection Number	Maximum Corrosion Stage Found in Previous Inspection*	Age of Bridge at Last Inspection (Years)	Interval (Years)
First			30
Additional	1-(2)	any age	30
	2-(3)	40 or more	20
	2-(3)	30	10
	3-(4)	60 or more	20
	3- (4)	less than 60	10
	4	any age	10
	broken wires	any age	5

* Each corrosion stage may include up to 25% of the surface layer of wires in the next higher stage, indicated by the number in parentheses. Stage 4 may include 5 broken surface layer wires.

At the discretion of the owner and the investigator, the suggested intervals could be adjusted based on the history of past internal inspections of the bridge, or special conditions encountered, e.g., the presence of dissimilar metals such as copper or bronze in contact with or in close proximity to the wires, local

C2.2.4

The recommended intervals of inspection reflect the data taken from condition inspections of 31 bridges of various ages.

Many of the bridge cables were opened only for a short distance, and the information is sketchy. In addition, the reported maximum corrosion stages may have been reached well before the cables were inspected. The data indicate that there is a grace period of about 10 years after a bridge is completed before deterioration begins.

The bridges have been separated into two groups according to mean trends of their rates of deterioration (see section 2.3.4 of the final report for NCHRP Project 10-57, on the accompanying CD. Eleven bridges with slowly deteriorating cables were designated Group A, for which the interval of time required to advance from one corrosion stage to the next was about 20 years. The 20 bridges that fall into Group B took only half that time to advance from stage to stage.

The rate of advancement from one stage to the next is nearly linear; it increases slightly (i.e., the interval from one stage to the next is slightly smaller) as the corrosion becomes worse. Figure 2.2.4-1 shows the linear rate of deterioration.

The recommended intervals between inspections are based on these rates of advancement, shown in Figure 1. In all cases, an internal inspection is recommended when the bridge is 30 years old, based on the observation that 7 bridges had Stage 3 or worse corrosion before the age of 40 years. The first inspection can be used to establish whether the cable is deteriorating rapidly or slowly.

Once Stage 4 corrosion is present, the interval between inspections should be shortened to 10 years for all bridges. Whenever broken wires are found, the interval to the next inspection should be 5 years. A large percentage of Stage 4 wires also merits another inspection in 5 years.

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deterioration from traffic collisions, or overheating the wires during a maintenance operation.

The interval between inspections should be shortened to 5 years when Stage 4 corrosion is found in more than 10% of the wires in the cable.

2.2.5 Locations of Internal Inspections

Internal inspections should be made where there are external signs of internal deterioration. These signs include:

- loose wrapping
- dripping water from the cable interior
- rust stains
- damaged caulking at the cable bands
- surface ridges that indicate crossing wires below the wrapping
- hollow sound when the cable surface is tapped

If no external indications of deterioration are found, then the inspection locations should be selected according to the method described below.

2.2.5.1 FIRST INTERNAL INSPECTION

The first internal cable inspections should be made at a minimum of 3 locations along each cable, selected as follows.

- one in each cable at a low point of the main span
- one in each cable at or near a low point of the side span
- one in the first cable in the main span, above the low point at a distance of from 30% to 70% of half the main span
- one in the other cable in a side span, above the low point at a distance of from 30% to 70% of the side span

The cables should be opened for a length of at least 16 feet at each location, and wedged as deeply as possible at 4 locations around the perimeter. If the corrosion of the wires exceeds Stage 2, wedging should take place at 8 locations around the perimeter, and the opening should be extended to a full panel length. This is to enable the driving of wedges far enough inside the cable to determine the depth of Stage 3 or worse

COMMENTARY

A description and photographs of the four corrosion stages can be found in Article 1.4.2.2 and Figure 1.4.2.2-1.

C2.2.5

No definitive statement can be made about where the worst conditions in the cable are most likely to be found. In only one of five bridges, for which data is available from at least 16 locations along the cable, did the greatest loss of strength occur at a low point of the cable. In the other four bridges, the maximum strength loss occurred near the quarter point of the main span or near the center of the side span. Furthermore, on one of the bridges, maximum strength loss above the low point of the cable was 3.5 times greater than at the low point.

C2.2.5.1

During inspections, Stage 3 corrosion has been found at one or more of the low points whenever there was significant strength loss at any location higher up. There are 4 low points on each cable: in the 2 panels adjacent to the lowest cable band in the main span, and in the lowest panel in each side span, usually that panel on the span side of the anchor or cable bent saddle where the least slope occurs. In cables that have 2 panel points at the same midspan elevation, there will be 5 low points, one of which is the entire center panel. It is recommended that 2 low points be inspected on each cable in the first inspection, and the other 2 (or 3) in the second inspection. The inspection of 1 location above the low point of each cable is recommended in the first inspection, and not less than 2 such locations in the second inspection.

When there are more than 2 cables on the bridge, the same inspection pattern described in Article 2.2.5.1 should be applied to each pair of cables.

It is not likely that wire corrosion on a 30-year-old bridge will exceed Stage 2, although some Stage 3 corrosion may be present in the exterior wires. Thus, the cable opening need only be long enough to remove corrosion and to remove 16-foot-long samples.

2.2.5.2 SECOND INTERNAL INSPECTION

When the first internal inspection reveals only Stage 1 or Stage 2 corrosion, the second internal inspection should be made at not less than 4 locations along each cable, following the logic of the previous choices.

The low point location in the main span should be adjacent to the low point location previously inspected, but the side span location should be in the side span opposite the one previously inspected. One location in the main span and one in a side span above the low points should also be inspected. A 16-foot-long opening will suffice, but if either Stage 3 or Stage 4 corrosion is found, opening and wedging should be increased (follow the instructions in Article 2.2.5.1).

When the first internal inspection reveals Stage 3 corrosion, or Stage 4 corrosion to a depth of 3 wires or less, each cable should be internally inspected at 6 locations, including any one of the 3 previously inspected panels that exhibited Stage 2 corrosion or greater, and 3 additional locations recommended for the first inspection.

Locations that exhibited only Stage 1 corrosion in the first inspection need not be reopened at this time, but additional locations above the low points should be selected to bring the total locations to 6. All 6 locations should be inspected for the full length between cable bands, with wedges driven to the center of the cable, or as deeply as possible. Whenever Stage 4 corrosion is present to a depth greater than one wire, and the center of the cable cannot be reached with a full panel length unwrapped, one cable band per cable should be removed to assess the condition of wires at the center of the cable.

When the first internal inspection reveals Stage 4 corrosion to a depth of more than 3 wires, at least 16% and preferably 20% of the panels in each cable should be inspected.

Four low points and 2 locations near the towers should be inspected; the balance of locations should be selected at random in the remainder of the cable between the low points and the towers, one each from contiguous groups of panels that are approximately

a 10-foot-long sample from the outer two layers for testing. The inspection team should, however, be prepared to open up a greater length of cable if more serious corrosion be found.

C2.2.5.2

If corrosion does not exceed Stage 1 during the first inspection, a bridge cable could be 60 years old when the second inspection takes place. The inspection team should be prepared to open additional locations higher up on the cable at that time, if Stage 4 corrosion is found at any of the 4 recommended locations.

In three of the inspection reports mentioned in Article C2.2.5, little deterioration was found adjacent to the towers. Therefore, only 2 locations near the towers are recommended for inspection when Stage 4 corrosion is found.

Whenever there is any sign of deterioration inside the cable adjacent to the saddles, or in the saddle housings, or if the housing or the sleeves at the saddles show signs of water entry, these locations should be added to the list of recommended inspection sites.

A method of estimating the minimum strength of a cable from the findings of an inspection presented in the final report for NCHRP Project 10-57, on the accompanying CD depends on the adequacy of the sampling. The estimated error in the minimum strength is 11% when 16% of the panels in the cable are inspected, and 8% when 20% of the panels are inspected. The method and the estimated error are based on the results from the only bridge for which sufficient data are available.

equal in number. The full length of panels between cable bands should be inspected, with wedges driven to the center of the cable, or as deeply as possible. At least 2 cable bands should be removed to facilitate inspection to the center of the cable and under the bands.

2.2.5.3 ADDITIONAL INTERNAL INSPECTIONS

The number of locations to be opened after the second inspection depends on the conditions revealed by previous inspections, and the sites should again be chosen following the instructions in Article 2.2.5.2.

2.2.5.4 INSPECTIONS IF STAGE 4 OR BROKEN WIRES ARE FOUND

When more than 10% of the wires in a cable panel are found to be Stage 4 in any inspection, the cable should be scheduled for a full interior inspection, and remedial action, such as the introduction of corrosion inhibitors, should be taken. Installation of an acoustic monitoring system is strongly recommended to listen for and locate continuing wire breaks.

2.2.5.5 ACOUSTIC MONITORING

When Stage 3 wires or worse were found in a previous inspection, it is recommended that an acoustic monitoring system be installed and monitored for a period of 12 to 18 months prior to the next internal inspection (see Article 2.3.1.4.1). The inspection locations should be selected to coincide with wire breaks, if any occur.

At the discretion of the investigator or owner, the same system could be installed even if the wires found in a previous inspection were only Stage 1 or Stage 2.

2.3 INTERNAL INSPECTIONS

2.3.1 Planning and Mobilization

Internal inspections require planning, but they also require the flexibility to respond as the inspection progresses and to alter initial plans if necessary. Contractor-assisted inspection must be managed so as not to compromise accessibility, even to areas not originally specified.

2.3.1.1 GENERAL

The review of drawings, specifications and documents from prior inspections is required to provide background for planning a successful cable

C2.2.5.4

Stage 4 corrosion is usually accompanied by cracked and broken wires. Whenever more than 10% of the wires in a cable panel are found to be in this condition, a full-length inspection of the cable is warranted, along with some cable band removal to inspect the wires underneath.

C2.2.5.5

Broken wires in the cable are an indication of active corrosion, and the sites of breaks are prime locations for future inspection.

investigation, defined in part as one that requires minimum alterations during execution.

2.3.1.2 INSPECTION PLANNING

Before determining inspection locations, the investigator should perform the series of actions described in this section.

2.3.1.2.1 Review of Available Documents

The investigator should review bridge design reports, and become familiar with the design details at cable bands and cable saddles. If available, the specifications of wire and eyebar materials should also be checked.

Records of previous inspections, however localized, may shed light on the causes of previous damage and suggest locations of potential damage, which could be important in the eventual assessment of cable capacity.

Review of maintenance records may be of use in pinpointing areas where caulking or wrapping have failed in the past, or where water has been observed to be leaking from the cable or through the anchorage roof.

The answers to the following questions may be useful in determining inspection locations, requirements for laboratory testing, and data needed for reliability analysis:

- Are the wires galvanized or bright? If they are galvanized, the zinc coating should be tested.
- Were the wires originally greased or oiled? If so, the wires may be less deteriorated, but corrosion may appear as short black sections on the wire.
- What is the specified wire cast diameter? Small cast diameters indicate that wire cracking is more likely.
- Are the original wire strengths and other mechanical properties available from acceptance testing or from specification records? If not, the full number of samples of Stage 1 and Stage 2 wires recommended in Article 2.4.3.5.1 should be taken during the first inspection. When original wire strengths are available, then at least 10 wires from these stages, for 3 tensile tests per sample, should be taken during the first inspection, with the balance of samples required taken during the

C2.3.1.2.1

A highly stressed cable (a safety factor below 2.5) has less margin for strength loss due to corrosion than a cable designed for lower stresses. A live to dead load ratio greater than 0.2 may indicate large deflections, especially if stiffening trusses or girders are slender. Such deflections may cause paint to crack or damage at the sleeves and caulking, and special attention to inspection of these details is indicated.

second inspection.

- Are test results of wire chemistry available? If not, chemical tests should be made.
- Was the cable aerially spun, or does it have shop-fabricated parallel wire strands, which tend to have fewer crossing wires because the cable is highly compacted?
- Is water penetration a possibility at the sleeves and flashings of the saddle housing, or at deck penetrations? If so, careful observations of these areas must be made.
- What is the dead load stress? What is the design live load stress? These values are needed in preparing the final report. If they are not available, or if there have been modifications to the bridge, or if there have been changes in the traffic load or pattern, the cable forces will have to be recalculated. High stress in the cables indicates that wire cracking is possible.
- Which paint systems were used according to painting records? The information may lead to a better analysis of the coating performance.

2.3.1.2.2 Preliminary Field Observations and Cable Walk

Walking on bridge sidewalks or maintenance walkways allows for observation of the lower portions of the cable. A cable walk is essential to make close observations of the external appearance of the cable. The items listed in Article 2.2.3.1 should be observed, along with the following:

- Paint cracks along wrapping wire valleys
- Poor compaction, evidenced by noticeable angularity of the cable
- Broken or torn elastomeric membranes or cracked Lucite cable shells on newer protection systems

Figures 1 through 5 illustrate some of these conditions.

2.3.1.2.3 Interviews of Maintenance Personnel

Interviews of on-site personnel are useful, especially when they have performed maintenance tasks such as cleaning and painting the bridge, removing ice, and rinsing the splash zone.

C2.3.1.2.2

These observations serve as general background and may help to establish inspection sites.

Rusted handropes may be a safety hazard and should be repaired prior to the inspection.

The information known to the maintenance staff may not have been formally recorded, but it could be valuable in determining the origin of damage and its time of inception.

2.3.1.2.4 Inspection Forms

A well-prepared inspection form facilitates the recording of data in the field. Sample forms are given in Figure 2.3.1.2.4-1, Figure 2.3.1.2.4-2 and Figure 2.3.1.2.4-3. Figure 2.3.1.2.4-1 shows the elevations of each cable, for indicating the locations of inspected panels.

Figure 2.3.1.2.4-2 shows an inspection form for a 9,990-wire cable. One or more copies are needed for each wedge line in each inspected panel. The observed conditions of the wires inside the wedged opening are recorded on these forms. A typical filled-in form is shown in Appendix C.

Figure 2.3.1.2.4-3 shows a cross-section of the cable that can be used to record the locations of broken wires near the surface of the cable, and also to map the internal conditions observed in the cable.

C2.3.1.2.4

Inspection forms must be tailored to the details of the cable to be inspected. The number of rings in the cable shown in Figure 2.3.1.2.4-2 and Figure 2.3.1.2.4-3 are calculated using Equation 4.3.1.1-1. If more or less than 9.990 wires are in the cable, the number of rings shown in the figures will vary accordingly.

2.3.1.2.5 Tool Kit

Investigators or inspectors should have a simple but practical set of tools that permit the observation and recording of all essential data. At minimum, it must include the following (other items to be added at the discretion of the investigator):

- Clipboard and supply of pens and pencils, fastened around neck or shoulder, or kept in a knapsack, but never carried loose in one’s hand.
- Adequate number of blank forms. An inspection of eight wedge lines per panel will require at least 24 sheets for each panel.
- Sturdy pocketknife to test wrapping or scrape corrosion products from wrapping and exposed wires. Among other uses, it aids in the collection of grease samples.
- Flashlight, the most powerful one that fits into a knapsack. Absolutely essential for observing wires, especially in the lower half of the cable, it also helps to focus a camera in a dark area before exposing the film with a flash.
- Steel ruler(s) and tapes, for various purposes.
- Steel tape, with sufficient rigidity to reach 18

C2.3.1.2.5

Cable environments are always breezy or windy places. Inspection forms need to be anchored to a clipboard at both ends (possibly with a rubber band at the bottom) for taking good notes and preventing the forms from flying away. Pens have a way of disappearing. The inspectors should have a supply of pens and pencils sufficient to ensure an uninterrupted inspection.

Although pens are preferable for filling in inspection forms, they may be useless on a humid day. HB graphite pencils can be used instead.

The break location in a wire is not always visible. Loose wires are evidence of a break nearby, and are revealed in response to prodding with a rigid implement. Long implements are required to test deep wires, in which case a rigid wooden stick can be used if the wire pick is too short.

A 1/16-inch-thick aluminum or brass sheet can be used to count the depth of a wire. The sheet should be drilled down the center with holes the same diameter as the wires and then split into two, so that notches are formed by the remaining parts of the holes. Numbers should be inscribed on the sheet next to the notches to aid in counting. Since most wires are very nearly 5 mm in diameter, a metric ruler can be carried to determine the depth of the wire from the surface. Dividing the inches into the cable. Wires are identified by counting from the surface of the cable or by measuring their distance from the surface.

- Wire pick, made from a screwdriver with a round shank and well-rounded edges at the tip, to prod for loose wires and pry at surface deteriorated wires to inspect the layer below. It should not be used on Stage 1 or Stage 2 wires, to avoid damaging the zinc coating.
- Small ruler, for proportioning the damage recorded in photographs.
- Flexible tape, to measure cable diameters for evaluating cable compaction.
- Dial gage caliper, to measure loss of section, especially in anchorage areas. For loss of section that is gradual, a micrometer is sufficient.
- A camera (traditional print or digital), required for a photographic record of conditions exposed by wedging.
- Good lighting (directed flash, ring flash or externally directed floodlight) for obtaining adequate photographic records. Conventional flash units flood the area outside the wedged opening and cannot illuminate the wedged cavity.
- Tags for identifying sampled wires, typically of Manila paper, and ballpoint pen or some kind of permanent marker that won’t be smudged by grease or water. Tags with wires or twine and reinforced holes for attachment to sampled wires are preferable.
- pH paper with a minimum range of 0.5 pH units, to determine the acidity of liquid on cable wires. They are usually available in small spools, with a calibration chart, from industrial supply houses.
- Several sterile, tightly sealable sample jars, in case water or corrosion products are found that require sampling.
- Industrial mirror with telescoping arm, 8 inches square, to observe the underside of the cable as the inspector walks on it.
- Attachment means immediately at hand, for

measured depth by 5, gives the depth into the cable in terms of wire diameters.

As a backup for identification tags, a strip of duct tape can be wrapped around the wire and marked with a ball point pen.

Pharmacies sell small sealable plastic jars that are used for urine samples but can be used also for collecting water and corrosion product samples from the cable.

ASA 400 color film is recommended for greater flexibility. A 50 mm or 28-80 mm zoom lens is recommended for recording objects at close range, especially those deep in the cable, which can be seen only by a camera positioned directly over the wedged opening. A minimum of 3 megapixels is recommended for digital cameras to provide sufficient resolution.

securing all tools, including clipboard, pens and pencils, to the handrails or platform.

2.3.1.2.6 Inspection QA Plan

Inspection and sampling must be done in a verifiable manner. For quality control, more than one inspector should make observations and both parties should agree on the identification and demarcation of corrosion stages. Inspectors should be trained by an experienced investigator.

The QA plan should identify the lead inspector and the assistant inspector, and describe what steps they will take to minimize error in data collection.

C2.3.1.2.6

It is crucial that sampled wires be representative of the damage, so that testing data result in sound statistics for wire properties.

2.3.1.2.7 Inspection Locations

Preparations for inspection include the selection of cable panels to be inspected. As the inspection proceeds, the investigator may alter this plan and choose to open different panels.

2.3.1.3 CONSTRUCTION PLANNING

Access to the cable is provided by a contractor in most cases, or maintenance personnel. Panel inspections follow a predetermined order to some extent. When construction contracts are used, they should be flexible enough to provide for unexpected inspection requirements.

2.3.1.3.1 Design of Work Platform

Work platforms are designed for the safety of construction and inspection personnel, and for containment of hazardous material. The platform should be constructed in a manner that safeguards tools and wedges, and prevents them from dropping onto the roadway or the waterway.

C2.3.1.3.1

Wedges have been known to be ejected from the cable and fall down onto the roadway. Tenting that encloses the platform should eliminate this potential hazard. Wedges can also be held in place with straps that wrap around the cable to protect personnel on the platform.

2.3.1.3.2 Construction Equipment

2.3.1.3.2.a Cable Compactors

It is essential that the compactor have sufficient capacity to recompact the unwrapped cable, to its original diameter. This may require a three- or four-jack assembly, depending on jack and cable size. Typical compactor details are illustrated in Figure 2.3.1.3.2.a-1.

To prevent cable band slippage, the compactor should be placed at least 1.5 cable diameters from the edge of a cable band.

C2.3.1.3.2.a

Placing the compactor immediately adjacent the cable band on its downward-sloping side could reduce the cable diameter within the band itself, possibly causing the band to slip.

2.3.1.3.2.b Steel Straps

In the last stages of compaction, the cable is held together with steel straps to help it keep its shape; the straps are removed as the wrapping proceeds. Reusable synthetic straps are also used for this purpose.

2.3.1.3.2.c Wire Wrapping Machines

Wire wrapping machines may be manually-driven or power-driven. With some quality supervision, manual devices can provide as tight a wrapping as power equipment, but they are recommended only for short lengths of cable. Figure 2.3.1.3.2.c-1 and Figure 2.3.1.3.2.c-2 show two kinds of wrapping machines.

Tension is controlled in the wrapping wires by opening the tensioner jaws of manual machines or by wire spool friction in power machines. Both tensioner jaws and spools are calibrated and must be monitored during the wrapping operation.

2.3.1.3.2.d Wedging Implements

Several types of wedging implements are employed during inspection, including wide bronze non-sparking chisels, and wood, plastic and hydraulic wedges. Chisel and wedge details are shown in Figure 2.3.1.3.2.d-1.

To prevent wire damage, flat non-sparking chisels, 3 to 4 inches wide and preferably bronze, should be used to initiate wedging. Long flat screwdrivers with square shanks are not recommended.

The best wedges for penetrating the cable are made of oak, rock maple, or high-molecular-weight polyethylene. The wedges should taper 1 inch for each 5 inches of length. To minimize wedge damage, wedge tips should be rounded approximately to a 1/8-inch diameter.

Hydraulic wedges can be used to provide wide openings with minimum effort. A hydraulic device is shown in Figure 2.3.1.3.2.d-2.

2.3.1.3.3 Preparations for Suspender Removal

Suspender removal requires an analysis of the forces that are necessary to dislocate the suspender from its anchored position and the forces that are transferred to adjacent suspenders. Capacity checks of the anchoring brackets and of the stiffeners and ropes at the adjacent remaining suspenders are mandatory to ensure safety.

The equipment required for removal of short suspenders includes framing, jacks, and tension rods to bring the truss and cable closer together. For long suspenders, special equipment must be designed to pull

C2.3.1.3.2.c

It is usually more efficient to use manual wrapping devices for small investigations, because of the relatively high cost of power-driven machines and the lengthy lead times required to obtain them.

C2.3.1.3.2.d

A suitable bronze starting chisel can be fabricated easily from a 3/8-inch x 4-inch flat bronze bar. The tip should match the one shown in Figure 2.3.1.3.2.d-1.

Wedge tips wear out or become bent out of shape in the course of wedging, and constant repair is necessary.

C2.3.1.3.3

The investigator and the contractor usually collaborate on the design of equipment. The engineer is responsible for capacity checks.

Suspender brackets on the stiffening trusses are typically designed to allow for suspender replacement. Capacity checks are a formality in most cases. However, increases in dead load unforeseen by the original designer may require such a check along with design of modifications.

the suspender against the truss for disconnecting the two.

Temporary suspenders may be required to carry the force of the removed suspenders, so as to avoid overstressing adjacent suspenders or the stiffening truss and girder.

2.3.1.3.4 Replacing Wire Wrapping

The wire tension should be high enough for the wire to remain in tight contact with the cable under all conceivable temperatures and live load conditions.

The wrapping wire loses tension by as much as two-thirds because of creep in the zinc coating. The following expression for wire tension during rewrapping can be used:

$$P = 3(\nu\sigma_{LL} + \alpha E\,\Delta T)\pi d_w^2/4$$

where:

ν = Poisson’s ratio

σ_{LL} = live load stress in the cable

α = coefficient of thermal expansion

ΔT = maximum estimated difference in temperature between the wrapping wire and average cable temperature

E = Modulus of Elasticity of the wrapping wire

d_w = diameter of the wire

ΔT will be larger for large cables than for smaller ones.

2.3.1.4 NON-DESTRUCTIVE EVALUATION (NDE) TECHNIQUES

Many private companies and institutions are marketing NDE equipment. Investigators should always be aware of what is available and what can be expected from NDE devices at the time they plan an investigation.

Technologies are developing at a fast pace. Often, willingness to try a new technology will lead to its modification, making it suitable for application to bridge cables. Public authorities and investigators must evaluate any proposed or potential technology by testing it against objective criteria that derive from the specific characteristics of bridge cables and information required for strength assessment.

2.3.1.4.1 Monitoring Devices

Acoustic monitoring devices should be installed on a

C2.3.1.4

Despite the great need for NDE diagnostic evaluation, existing devices are of limited value. New and improved technologies may be developed for determining the most damaged cable areas, but hands-on visual inspections are still required for the foreseeable future. A discussion of NDE techniques is included in the final report for NCHRP Project 10-57, on the accompanying CD.

Acoustic Monitoring is a good example of an existing technique that has been successfully adapted to cable work.

C2.3.1.4.1.a

There are devices that detect changes in the behavior of cable that has many Stage 4 or broken wires to determine whether deterioration is continuing and at what pace. If wires continue to break, or if the frequency of breaks accelerates, the inspection schedule should be revised. If an additional 0.5% of the wires in a panel break after an inspection, then an immediate re-inspection and evaluation of the panel is recommended.

cables or detect wire failures as they occur. Given known baseline behavior and damage information, a record of conditions may be constructed over time.

Acoustic Transmission (AT) technology is used to detect wire failures on large cables, because the sound waves of a break that travel through the steel can be detected at receptors placed on the cable surface. Wire failures have distinctive sound signatures that are easily differentiated from normal bridge noise. The arrival times of the sound at several different receptors are compared to pinpoint the location of the break.

Some U.S. bridges have been fitted with Acoustic Transmission equipment along both cables, or at least along parts of them. This service is provided under the generic technological name of “Acoustic Monitoring.”

Monitoring devices cannot determine existing conditions directly, and are not diagnostic. However, the technology can be used to determine which panels have wires that are breaking, and hence which panels are most likely to have damage. This could eliminate much of the current guesswork involved in selection of panels to be opened.

2.4 INSPECTION AND SAMPLING

2.4.1 Cable Unwrapping

Prior to unwrapping the cable, the investigator should record any notable surface defects, such as gaps in the wrapping wire, damaged paint, and white or brown rust emanating from the cable.

The circumference of the cable should be measured prior to unwrapping. If the steel tape is sensitive totemperature changes, the temperature should be recorded at the same time. A form that can be used to record these measurements is shown in Figure 2.4.1-1.

C2.4.1

The conditions listed apply to cables wrapped with wire, whereas other protection systems may exhibit different defects, which should also be noted (e.g., cracks in polymeric coverings or tears in neoprene wrapping).

2.4.1.1 WRAPPING WIRE TENSION TESTS

The wire should be strain-gaged before cutting if the tension in the existing wire is required. The loss in stress after cutting, while the wire is held to the cable circumference, provides the wire tension. The same procedure is used for single wrapping plies or for all the plies at once.

C2.4.1.1

If the original tension is known, then the tension in the unwrapped wire is compared to find out how much tension has been lost, and whether the existing tension is adequate.

Measurement of the shortening that occurs when the wrapping wire extends over several loops is difficult to accomplish and interpret because of the friction among the plies. Hence, strain gaging is recommended rather than measuring the shortening of a wire after cutting.

2.4.1.2 REMOVAL OF WRAPPING WIRE

Removal of the wrapping wire is a health hazard as well as an environmental one. Workers should wear masks and handle the wire in such a way that the lead waste is contained. Workers should also take care not to generate airborne dust, unless the entire panel is covered and enclosed, and then a filtering system should be used to protect workers from the dust that accumulates inside.

To avoid dispersal of lead and lead paint, wrapping wire should be handled carefully when it is transported to the temporary storage site. Figure 2.4.1.2-1 shows wrapping wire in the process of removal.

C2.4.1.2

Blood testing for lead toxicity of all personnel involved in cable unwrapping, inspection, and rewrapping is mandatory. See Article 1.3.2.

2.4.1.3 LEAD PASTE REMOVAL

The lead paste under the wrapping is usually dry and friable. Some of it falls onto the platform floor as the wrapping is removed. Some of it adheres weakly to the cable wires and may be dispersed by the lightest breeze. It should be dislodged by striking the cable with a wooden implement and the remainder removed with a soft wire brush.

Before wedging the cable, the unwrapped surface should be vacuumed. Wedging will cause additional lead dust and waste to be dislodged from the cable. Spraying or brushing on a light coating of oil will minimize the production of this additional dust.

C2.4.1.3

Monitoring of airborne dust must comply with environmental protection guidelines.

2.4.1.4 CABLE DIAMETER

The cable circumference should again be measured after the wrapping has been removed. Measurements should be taken immediately adjacent to the cable bands, 12 inches from the ends of the bands and at the center of the panel. The cable diameter without wrapping should be calculated, as well as the solids ratio of the cable, which is a comparison of the total metallic area of the steel wires to the area in the cable circumference without wrapping wire.

C2.4.1.4

The cable diameter, which is calculated from the circumference measurement, is required so that the cable can be rewrapped to its original degree of compaction or more. The solids ratio of a well-compacted cable usually varies between 0.80 and 0.82. If the value is significantly smaller, it may indicate that the reported number of wires in the cable is incorrect. In this case, the number must be verified by counting the wires inside the anchorage.

2.4.2 Cable Wedging

The cable is wedged radially at panel locations, as described in Article 2.4.2.1. In general, wedging should be done where damage is suspected.

2.4.2.1 RADIAL WEDGE LOCATIONS

When 8 wedge lines are required, they should be located at every 45 degrees around the cable circumference. When less than 8 wedge lines are required, the spacing is adjusted accordingly. The

C2.4.2.1

The upslope is sometimes used as a convenience for determining direction, because compass directions are not easily established inside an enclosure. Angular or other designations may be used instead of clock wedge lines are usually given clock designations to describe their angular positions from the top of the cable:

12:00	at top of cable
1:30	at 45°, clockwise from top of cable
3:00	at 90°, clockwise from top of cable
4:30	at 135°, clockwise from top of cable
6:00	at 180°, clockwise from top of cable
7:30	at 225°, clockwise from top of cable
9:00	at 270°, clockwise from top of cable
10:30	at 315°, clockwise from top of cable

Not all cable conditions require wedging on all 8 lines. On the other hand, some cables may need additional wedging to improve the statistical data, especially if the damage is severe. The following guidelines are recommended for determining the number and position of the wedge lines:

- Always start wedging at one of the bottom lines (4:30, 6:00, or 7:30), especially if nothing is known about the condition of the cable, or unless the plan is to open a minimum of 8 wedge lines.
- When only Stage 1 corrosion is found in all three of the lowest wedge lines, select 1 more wedge line in the splash zone, if there is one, at either 1:30, 3:00, 9:00 or 10:30.
- When no more than Stage 2 corrosion is found, a minimum of 6 wedge lines are recommended, including the bottom 3, plus 9:00 and 3:00 and either 1:30 or 10:30, preferably in the splash zone.
- When Stage 3 corrosion or worse is found, open all 8 wedge lines.
- When a significant number of broken wires are found, additional lines should be opened in the regions where Stage 4 wires are found. Figure 2.4.2.1-1 shows a cable with broken wires wedged for inspection.
- For cables with a diameter greater than 24 inches, 8 additional wedge lines between the 8 recommended above should be opened. They should extend deep enough to permit

designations.

The bottom of the cable is usually more deteriorated than the top or sides. By starting at the bottom, it is likely that the worst condition will be encountered. When the outer surface of the cable is in Stage 1 condition, wedging in the rest of the cross-section can be minimized, because the condition is usually worse at the surface than at the center.

Near the cable low points, the side of the cable facing a roadway will receive the most splash from passing cars and will often be more deteriorated than the side facing away from the roadway.

When many broken wires are found, Stage 4 corrosion is expected to extend deep inside the cable, and additional wedge lines are justified to determine its extent.

On larger cables, additional wedge lines are recommended in the outer half of the cable radius where the wedges are at maximum spacing, to avoid reducing the fraction of wires that are observed. This helps to minimize the margin of error in the calculations.

inspection of the wires at least halfway to the center of the cable.

2.4.2.2 WEDGE INITIATION AND ADVANCEMENT

Wedging should be initiated with one of the non-sparking implements recommended in Article 2.3.1.3.2.d. The wedges are then driven further into the cable with a sledgehammer. Photographs of cables wedged for inspection are shown in Figure 2.4.2.1-1.

Start wedging at the middle of the panel (or cable opening if less than a panel) and insert additional wedges about every 4 feet, working toward the cable bands. Drive all the wedges to a uniform depth of about 3 inches, then advance them in sequence for 3 inches at a time until the center of the cable or the recommended depth is reached. The following difficulties must be recognized and overcome to advance wedging.

- Gap crossing (i.e., the wire crosses the wedged opening) occurs whenever the wedge is being driven along a path on one side of a wire (or wires) that is opposite to the side where an adjacent wedge was driven. The condition has to be recognized quickly, because it impedes driving and may damage wires. The wedge should be pulled out and relocated on the same side of the wire as the prior wedge.
- Rejection occurs when a wire that lies in the middle of the path of the blunt edge of the wedge will not be pushed aside by the wedge. The worker experiences a loosening and regression of the wedge to a position that is further out than before the hammer blow. The wire is pushing the wedge back. Driving must cease to prevent wire damage, and the wire should be pushed aside on the same side as the other wedged wires with a non-sparking chisel.
- Strewing occurs whenever broken wires are present. Wedges will often drive the part of a broken wire nearest to the broken end into deeper layers of the cable, causing the broken wire to cross the paths of several intact wires, and often preventing the wire’s broken ends from being seen. This condition cannot always be prevented, but it can be minimized. Start at the center of the panel and drive all wedges to a short and uniform depth. Identify broken

C2.4.2.2

Sometimes lubrication of the wedge with petrolatum or linseed oil is helpful in driving the wedges. The investigator should be certain that the lubricant used is compatible with the corrosion-inhibitive coating, if there is one.

wires, and advance wedges first at locations away from the broken wire ends. Advance wedges at the ends last, while holding the wires with additional wedges near the break.

- Where broken wires are strewn, as evidenced by the wires turning inward at a wedge location, they should be returned to their original position after the inspection, using hooked wire picks. Failure to do so will cause voids inside the cable and crossing wires, both sources of additional damage.
- Wedge tip bending occurs where the cable offers excessive resistance to penetration. The wedge tip will select the easiest path, which is not necessarily radial. The first 3 inches of the wedge will sometimes bend until driving becomes impossible, even when the wedge has penetrated only a small distance into the cable. The problem can be corrected by pulling out the wedge and advancing it from the point where the opening is radial with a non-sparking implement, and then driving it radially again.

2.4.3 Wire Inspection and Sampling

The purpose of the inspection is to identify corrosion in the cable wires, and to quantify it according to defined stages by finding its limits in the cross-section of the cable.

Sampling of wires determines the physical properties of the wires in each stage, which are required for estimating cable capacity.

An example of a filled-in form for a cable cross-section in a panel is presented in Appendix C.

2.4.3.1 OBSERVATION AND RECORDING OF CORROSION STAGES

The inspector should identify the corrosion stage of the wires on both exposed faces of the wedged opening. This is done visually, using the photographs in Figure 1.4.2.2-1 as a guide. The wire condition is recorded for at least 3 segments, each approximately 6 feet long, along the length of a panel. An observed wire should be first assigned the highest observed stage in the segment. Each wire is then reassigned the highest corrosion stage found on that wire in the opening length, after comparing the recorded data for the wire in each segment.

Data are entered on inspection forms similar to the one

C2.4.3.1

A corrosion stage may cover only a very short length of wire, in some cases less than one inch. This is especially true of wires with black or gray rings of zinc depletion, which, whenever present, should be counted separately. Laboratory testing is used to determine the stage they belong to.

Only the highest stage found along the length of the wire is used in the analysis of cable capacity in Section 5; it is determined from the data on the forms after the inspection.

The object of keeping these records is to be able to shown in Figure 2.3.1.2.4-2. A typical record of data, using the form, is presented in Appendix C.

2.4.3.2 BROKEN WIRES

Wires found broken in the outer layers of the cable should be located on the cable cross-section shown in Figure 2.3.1.2.4-3. Both the tangential location and depth into the cable should be noted. The maximum cable depth at which broken wires are seen should also be noted.

The number and location of broken wires that are observed inside wedged openings more than a few layers from the surface of the cable are noted on the form shown in Figure 2.3.1.2.4-2.

2.4.3.2.1 Wedge Spacing

Wedges should be spaced at about 4-foot intervals. This allows for observing wire conditions deep inside the wedged cavity. After recording the wire conditions found, wedges should be removed so that the spacing is doubled. If there are loose wires, they tend to project out into the wedged opening or to respond to prodding. Investigators should experiment to determine the wedge spacing most suited to detecting loose wires.

Pullout of the intermediate wedges should be partial to facilitate the observation of loose wires deep inside the cable; otherwise, loose wires closer to the surface will hide the deeper ones from view.

2.4.3.2.2 Wire Tracing

Wires are identified by their distance from the surface of the cable. Many times the same wire will not show up at the same distance from the surface within the panel being inspected, because of poor parallelism or the formation of a surface lip during wedging. When there are several adjacent loose wires, to avoid double counting, it is necessary to prod the loose wire at one section and observe its longitudinal movement in other sections. Tracing should be done for all loose wires

develop a cross-sectional map of the wire stages, as shown in Appendix C, which is a useful visual tool to show the extent of damage. The map should represent the worst condition of all cable segments within the panel.

C2.4.3.2

Broken wires can usually be detected in the layer of wires below the outermost layer. If several adjacent wires are broken, then it is possible to detect wires up to 4 layers down. Wires broken at greater depths can only be seen inside the wedged openings.

C2.4.3.2.1

At a 4-foot spacing of wedges, loose wires are not visible. Prodding the wires will not give any indication that they are loose, because they are being tightly held by the wedges. Experience has shown that loose wires with a free coil radius of 4 to 6 feet will become evident at a minimum wedge spacing of 6 feet.

with unidentified ends.

2.4.3.2.3 Failed Wire Ends

Whenever a wire breaks, two wire ends are formed, one corresponding to each side of the break.

In the counting of broken wires, both ends of each wire should be accounted for. Avoid the double counting that occurs whenever the ends of the same wire are identified as belonging to two different wires. Whenever only one end is visible, probe to find the end of a loose wire nearby that is beneath the surface of the wedged opening.

C2.4.3.2.3

Not all ends of broken wires are visible. Often, wire breaks occur near or under cable bands, where wedging is impossible.

Several inspections have shown that there is roughly the same number of broken wires in a given length of cable under or near a cable band as in the observed portion of the panel before the cable band is removed. However, this may not be the case for each bridge and should be further investigated by the removal of one or more cable bands whenever numerous broken wires are found. In the process of recording, it is necessary to count all loose wires and all failed wire ends, and to eliminate all loose wires ends that have already been counted.

2.4.3.2.4 Sample Size

Broken or loose wires sometimes project from underneath the surface exposed by the wedges. This complicates the estimate of the size of the sample, and may lead to even larger errors in the estimate of broken wires in the cable.

To minimize this type of error, the investigator should count broken wire ends and loose wires that come from underneath the wedged surface as well as those from the wedged surface proper, and record them separately.

C2.4.3.2.4

In one experience, the broken wire ends from underneath the wedged surface were approximately equal to those on the surface. The origin of the loose wires could not be properly traced, due to the large quantity of broken wires. The size of the observed wire sample, for purposes of counting broken wires, was conservatively taken to be 3/2 times the wires on the surface of the exposed cavity. The assumption was that only surface loose wires were visible.

2.4.3.2.5 Other Forms of Corrosion

The inspector should look for and record all other significant types of corrosion on the same form that is used for reporting corrosion stages. Significant corrosion includes

- Pitting
- General corrosion, that causes a reduction in the diameter of the wire (report the diameter).
- Crevice corrosion, in which the attack and corrosion product are primarily along the contact surface of adjacent wires

When these conditions are prevalent (i.e., observed in more than one or two wires in a wedged opening), additional samples for testing should be removed to establish whether additional corrosion stages need to be created for strength evaluation. When these conditions are not prevalent, the recommended number of samples for each corrosion stage should include a number of these wires with the condition noted, proportional to their incidence.

2.4.3.3 PHOTOGRAPHIC RECORD

Typical as well as singular or atypical conditions should be photographed in color. For each photograph taken, the number given to the roll of film and the number of the exposure should be recorded on the inspection form. The direction of the view and the target wire or area should be noted.

2.4.3.4 MEASUREMENT OF GAPS AT WIRE BREAKS

As many ends of broken wires as possible should be brought into alignment and the gap between the ends measured. The record of information should include the depth into the cable of the measured separation and the panel in which it took place. It should also be noted whether the measurement occurred with the cable band or wrapping in adjacent panels removed.

Whenever a sample wire is removed from the cable for testing, the gap that forms after the first cut should be measured. A scratch is made on each side of the cut prior to making the cut. The distance between the two scratches is measured before and after cutting the wire.

2.4.3.5 WIRE SAMPLING

Sample locations should be recorded on the cable cross-section inspection form shown in Figure 2.3.1.2.4-3.

Samples from broken wires should not be used for strength testing or for determining the fraction of wires that are cracked.

A new wire should be spliced to the cut ends of a sampled wire to restore continuity. The new wire is tightened to the same tension as the other wires in the cable. The complete procedure for replacing a cut wire is given in Appendix D. Since sampling requires the removal of wires from the cable, it should be kept to a minimum because the splice between the replacement wire and the end of the existing wire is never as strong as the original wire.

C2.4.3.3

The condition of wires is better described with photographs than with words.

Cameras that date the exposure facilitate identification. Often, taking a photograph of an object not associated with wire inspection (e.g., an adjacent cable, the tower, or the roadway), and noting it on the form, is an aid to establishing the date and general location of the photographic record.

C2.4.3.4

Friction among the wires, especially under wide cable bands, can redevelop the force in a broken wire.

From measured gaps in broken wires, the capacity of the cable band to develop wire tension can be estimated on a statistical basis, based on known dead load and postulated live load at the time of measurement. Live load error will not create a large error in the wire tension estimate, because the live load is usually a small percentage of the total load.

C2.4.3.5

The object of sampling is to characterize the physical properties of wires in each of the various corrosion stages using laboratory tests. The properties that are of interest to the investigator are the following:

- The extent of and variation in zinc oxidation, to estimate the remaining usefulness of the protective coating and to evaluate the susceptibility of the wires to initiation of stress corrosion at the holidays in the zinc.
- The strength of the corroded wires, because degraded wire may be embrittled, or have surface corrosion, corrosion pits or propagating cracks. All these conditions, implying loss of strength, only start at Stage 3, with embrittlement. Stage 3 wires may contain pits and a few cracks; Stage 4 wires usually contain many cracks.

As the inspection proceeds, investigators have to become aware of all the possible anomalies that may reduce wire strength, for which wires will require testing.

Sampling of broken wires to test for strength may overestimate the capacity of continuous cracked wires, because whenever a wire breaks in the cable, the force in the wire drops to zero, possibly halting crack growth in the remainder of the wire. Also, broken wires are known to contain cracks, so that samples from these wires cannot be used to determine the number of Stage 4 wires that are cracked. Therefore, only unbroken wires should be sampled for strength testing. Broken wires removed from the cable during repairs, however, should be saved for testing corrosion products.

2.4.3.5.1 Number of Samples

The recommended number of samples to be taken for each corrosion stage is given in Table 2.4.3.5.1-1. The number of proposed samples has been selected to minimize the error in estimated cable strength.

A full set of Stage 1 samples and at least half the recommended number of Stage 2 samples (if Stage 2 is present) should be removed during the first inspection. These samples may be combined with additional samples removed during the second inspection to bring the total number of samples to the recommended number. No further samples of these stages are required in future inspections.

C2.4.3.5.1

The zinc coating tests recommended for Stage 2 wires should be performed on Stage 1 wires from the first inspection for use as a baseline in future inspections.

The proposed numbers of samples are calculated on the basis of test results that indicate a reduction in tensile strength and an increased variation of strength properties as corrosion advances.

The wire characteristics given in Table C2.4.3.5.1-1 and Table C2.4.3.5.1-2 were used to estimate the errors in cable strength at a 97.5% confidence level. These characteristics are from laboratory tests on the wires of two bridges, identified as Bridge X and Bridge Z.

Table C2.4.3.5.1-1 Wire characteristics, Bridge X

	% Loss of Strength	Coefficient %Variation	% of Wires Cracked
Stage 2	0%	2%	0%
Stage 3	1%	3%	5%
Stage 4	3%	4%	64%
Cracked	16%	13%	N/A

Table C2.4.3.5.1-2 Wire characteristics, Bridge Z

	% Loss of Strength	Coefficient %Variation	% of Wires Cracked
Stage 2	1%	3%	0%
Stage 3	5%	4%	5%
Stage 4	6%	4%	64%
Cracked	30%	26%	N/A

Whenever adjacent panels are assumed to be perfect (no deterioration), application of these wire characteristics result in the estimated strength losses given in Table 2.4.3.5.1-1. Whenever deteriorated wires are present in the adjacent panels, strength losses will be greater.

Table 2.4.3.5.1-1 Recommended number of wire samples for both cables

Corrosion Stages Present in Worst Panel Observed				Total Number of Samples				Estimated Error (97.5% confidence)		Estimated Cable Strength Loss	
								Bridge		Bridge	
Stage 1	Stage 2	Stage 3	Stage 4	Stage 1	Stage 2	Stage 3	Stage 4	X	Z	X	Z
100%	0%	0%	0%	10	--	--	--	3%	5%	0	0
	>0%	0%	0%	10	15	--	--	3%	5%	0%	0%
	>0%	10%	0%	10	15	35	--	3%	5%	1%	2%
	>0%	20%	10%	10	15	35	60	4%	5%	9%	10%
	>0%	40%	20%	10	15	35	60	4%	6%	16%	18%

2.4.3.5.2 Sample Location

2.4.3.5.2.a Stage 1 Wires

The first panels to be unwrapped should be at the low points: 2 samples of Stage 1 wires should be removed from each panel, one at 6:00 and one at 3:00 or 9:00, on the side facing the roadway, or splash zone. One sample should be removed at random locations from each of the two remaining panels opened during the first inspection.

2.4.3.5.2.b Stage 2 Wires

From 1 to 3 samples of Stage 2 wires should be taken from each panel. At the low points, one should be removed at 6:00 and one at 3:00 or 9:00 on the side facing the roadway. A third sample location may be randomly selected. If no Stage 2 wires are found at the first location, then the samples should be taken from another location where Stage 2 is found, and the number of samples in each panel increased to provide the recommended number.

2.4.3.5.2.c Stages 3 and Stage 4 Wires

The recommended number of samples given in Table 2.4.3.5.1-1 should be divided randomly among the planned number of inspection locations, with at least 0.5 and at most 1.5 times the average number of samples taken in any one panel. If no wires of the required stage are found in a panel, than the number assigned to that panel should be randomly added to the remaining uninspected panels. Not more than 10 samples of Stage 3 and 10 samples of Stage 4 should be taken in any one panel.

For planning purposes, the following percentages of Stage 3 and Stage 4 wires may be assumed in applying table 2.4.3.5.1-1:

- First inspection – 10% Stage 3, 0% Stage 4
- Second inspection – 20% Stage 3, 10% Stage 4
- Later inspections – percentages estimated by the investigator from previous inspections

Samples should be selected at random in each inspected panel, using tables of random sample locations prepared in advance for several different groupings of Stage 3 or Stage 4 wires.

2.4.3.5.3 Number of Specimens in Each Sample and Length of Samples

The recommended number of specimens to be cut from each sample for tensile and zinc loss testing, along with the recommended sample length, are found in Table 2.4.3.5.3-1.

Table 2.4.3.5.3-1 Sample lengths and number of specimens from each sample

Corrosion Stage of Sample	Minimum Number of Specimens from Each Sample			Sample Length (feet)
	Strength Tests	Weight of Zinc Tests	Preece Tests	
1	4	1	4	12
2	4	1	4	12
3	10	0	0	16 to 20
4	10	0	0	16 to 20

C2.4.3.5.2c

It is possible that in early inspections the total number of Stage 3 and/or Stage 4 wire samples will be smaller than recommended, especially if a large number of higher stage wires is found in the last panel opened. In this case, the error in estimated strength may be greater than is assumed in Table 2.4.3.5.1-1. The next inspection, however, should take place in 5 to 10 years, and the greater number of panels inspected at that time will provide enough samples.

C2.4.3.5.3

When the corrosion stage varies along the length of a sample wire, the specimens to be tested for strength should be cut from the worst areas of the wire.

When Stage 3 is found during the first inspection, or Stage 4 to a depth not greater than one wire, remove 12-foot-long samples of Stage 3 and Stage 4 and test 4 specimens. When Stage 4 is found to a depth greater than one wire during the first inspection, extend the length of cable that is unwrapped to remove 16-foot-long samples of Stage 4 wires.

2.4.4 Identification of Microenvironments

The field or laboratory tests described in this subsection may be useful in identifying the conditions inside the cables that are causing the observed deterioration.

C2.4.4

Researchers and engineers are trying to identify the microenvironments that produce wire corrosion. It is possible that many different types of environments attack bridges, causing wire deterioration at different rates. Therefore, it is useful to characterize the nature of the environment that is affecting the cable under inspection.

2.4.4.1 pH OF INTERSTITIAL WATER

During inspection, condensed droplets of moisture or even moving water may be seen on cable wires. The water should be tested with pH test paper strips. If possible, samples of the water should be collected and placed in new tightly-sealed inert containers and refrigerated to prevent gas loss. The samples should be sent to a laboratory to detect the presence of dissolved gasses and salts that are known pollutants, such as chlorides, sulfates and nitrates.

2.4.4.2 CORROSION PRODUCTS

Corrosion products can be removed from the bridge. It is useful to select specimens from these samples for the study of corrosion products. This can also be done for zinc compounds scraped from the wrapping wire

2.4.4.3 PERMANENT PROBES

Although not currently available, permanent probes could be inserted at critical locations inside the cable. They might be used to identify time-dependent wet-dry cycles and indicate the presence and pH of water, the availability of oxygen, and other factors.

C2.4.4.3

The presence of water is evidence that corrosion of the wires may be taking place. The pH of the water indicates the aggressiveness of the environment inside the cable. A low pH indicates high acidity, which could be responsible for rapid depletion of the zinc coating.

2.4.5 Cable Bands and Suspender Removals

Cable bands are an integral part of the suspension system. They also play a role in maintaining cable capacity once wires begin to fail. Cable band bolt tensions affect the capacity of the cable band to develop cable force in broken wires, as well as their ability to transfer the tangential component of cable force to the cable without slipping.

Cable bands have to be removed to compare the level of deterioration in areas of the cable that are near the cable band with areas in the middle of the panel.

C2.4.5

While wire damage in or near the cable bands has been found to approximately equal wire damage in the rest of the panel, this may not always be the case. It should be checked whenever Stage 4 or broken wires are present.

2.4.5.1 CABLE BAND BOLT TENSION

During wire inspections, it is customary to inspect cable band bolt tensions. This is accomplished by measuring bolt length, while the bolt is both tight and loose. The measurements are made with an

C2.4.5.1

During cable inspections, the cable band bolt tension may have to be determined for assessing reliability against band slippage. While this aspect of the work is not directly related to cable capacity, it is useful to

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extensometer, which has a sensitivity of 10^{-4} inches. Extensometers are provided with spherical tips that bear inside conical center holes provided at the bolt ends. One bolt is inspected at a time, and retightened immediately thereafter to the originally specified tension. All bolts of the cable band should be tested.

The caulking between cable band halves is removed prior to measuring bolt tension, and the center holes in the bolt cleaned of paint and debris.

A zero reading of the extensometer is made prior to loosening a bolt. Three to four readings are averaged to arrive at the zero reading. The bolt is then loosened, and three to four readings on the tension-free bolt are again averaged. The difference in these two sets of readings is the elongation of the bolt due to tensile stress. The bolt tension is computed from this elongation. The bolt length is taken from the underside of the head to the center of the nut.

If the original bolt tension installation force is known, the measured bolt tensions should provide an estimate of the force reduction over time, due to creep in the zinc on the bridge wires or gradual compaction of the cable.

2.4.5.2 SUSPENDER REMOVAL AND CABLE INSPECTION

Removal of a suspender and its cable band requires contractor assistance and must be carefully planned and executed.

Before removal, a suspender should be match-marked against the cable and its length recorded in such a way that the suspender and its socket can be reinstalled easily in its original location and orientation. The exact location of the cable band on the cable should also be marked.

Where inspection of two adjacent panels is performed for deeper access into the cable, the wedge line should be continuous through both panels and the cable band area.

A cable wedged to achieve this task is illustrated in Figure 2.4.2.2-1. The removed suspenders can be seen where they loop over the cable.

2.4.5.3 SUSPENDER REINSTALLATION

The cable must be recompacted before the band is reinstalled, and the band placed at the exact location on the cable it was in prior to removal. Failure to do so may result in a change of suspender tension. Bolts

COMMENTARY

know the cable band bolt clamping force and the friction among wires that it may generate.

There may be as much as a 15% error from the real average tension of the bolts in a band if 16 cable bands are inspected, but the safety factors and reliability against slippage are large enough to encompass the error.

A long-reach micrometer reading to 10^{-4} inch can be used instead of an extensometer reading, but spherical anvils are required, and they must be checked for compatibility with the holes at the bolt ends.

C2.4.5.2

Sections of the cable that can be inspected without band removal should be differentiated from sections that cannot. This is necessary to obtain estimates of unobservable defective wires in locations where the cable bands are not removed. Then, the worst damage for the entire panel can be mapped in the cable cross-section.

should be retightened to the bolt tension originally specified. The band grooves should be aligned in a vertical plane.

The reinstalled suspender should be aligned with match marks on the cable. The suspender should be jacked down so that the suspender sockets can be placed in the anchoring brackets while the original orientation of the entire suspender is maintained. This procedure should ensure that the tension in the suspender legs before removal is recovered.

2.4.6 Inspection Plan Reevaluation

After initial inspection of what are assumed to be the worst panels, the investigator should compare the predicted and actual damage. This may lead to a reduction of wedging or an increase in the number of panels to be inspected, or other alterations of the inspection plan.

2.4.7 Reinstallation of the Cable Protection System

Upon completion of inspection and sample removal, the cable must be recompacted and the cable protection replaced. Recompaction to the level of original compaction, based on previous measurements of the cable diameter, can be accomplished using a hydraulic compactor (see Article 2.3.1.3.2a). The cable diameter should be no more than that measured before removal of the wrapping less two times the wrapping wire diameter. Steel or stiff plastic (e.g., Kevlar) binding straps should be applied around the cable at intervals of 12 to 18 inches to hold the compaction until the wrapping is applied. A protective paste should be applied just ahead of the wrapping machine, and the cable rewrapped using a machine that can apply a tension of at least 300 pounds to each ply of the wrapping wire. The completed wrapping should then be painted using a paint system specified by the bridge owner, and the grooves at the cable bands caulked to exclude water.

C2.4.7

Generally, the protection system is replaced to meet current standards. Water-based paint systems or membranes provide excellent protection and prevent water from entering the cable through the wire-wrapped area. However, for partial protection that replaces only limited inspection areas, this may not be an advantage. If water has had the opportunity to enter an aging protection system in areas that have not been inspected, a good paint system on the newly wrapped area may cause the water to be retained inside the cable. It is important that at low cable points, the replacement protection system be provided with sufficient weep holes to allow the water to escape.

Many authorities are reexamining the use of red lead pastes and are experimenting with substitutes or even no paste at all, placing their confidence in the quality of the exterior protection system.

Many cable bands are caulked today with polyurethane or polysulfide caulking rather than the caulked lead wool that may have been used when the cable was first constructed.

For more information on protection systems, refer to Article 1.4.2. and Article 1.4.3.

2.4.8 Inspection During Cable Rehabilitation

2.4.8.1 GENERAL

When cables are damaged to a level of Stage 3

C2.4.8.1

The larger part of inspection work requires access to corrosion or worse, or when the wrapping system is deteriorated and requires replacement, some authorities opt for oiling the cables to arrest corrosion, albeit for a limited time, and replacing the exterior protection system, because it has to be removed to perform the oiling operation.

These conditions favor inspection of the wires in all cable panels, which can be done after removal of the wrapping. Figure 2.4.8.1-1 shows a cable wedged for a rehabilitation operation. While the wedge alignment is not radial as normally is the case, the openings provided can still be used successfully for internal inspection.

2.4.8.2 INSPECTION NEEDS VS. OILING OPERATIONS

Cable oiling starts at high cable locations and proceeds downward. To conduct inspections that are not affected by the oiling operation, wedging must be done several panels ahead of the oiling, so that the wedge locations are inspected before the oil arrives.

Wedging for oiling does not always offer adequate openings for assessing the worst cable damage. Therefore, auxiliary wedging at the bottom of the cable is necessary for inspection purposes. Since the wedging must be done before the oil gets there, wrapping should be removed far ahead of the oiling work, and bottom-of-cable wedging conducted independent of wedging for oiling.

2.4.9 Inspection and Testing in Anchorage Areas

The cables in the anchorages splay outward after passing over a splay saddle or through a splay casting. The wires are not wrapped in the splay, and thus are easier to inspect.

Cable strands are connected to the anchorage with strand shoes and eyebars, or with sockets and rods. The inspection of these components is discussed below.

Recently constructed suspension bridges often use shop-fabricated parallel wire strands (PWS) in place of aerially-spun strands. Anchorages on these bridges will look different from those described, and the inspection forms will also look different from the examples presented in these Guidelines, but the principles of inspection are the same. The inspector must prepare forms specific to each bridge, and the inspection should cover all items relevant to aerially-spun cables, substituting, for example, “strand sockets” for “strand

cable wires and replacement of the protection system. It would be wasteful to replace the protection system, which is associated with cable damage, and miss the opportunity of inspecting the wires for very little additional cost.

C2.4.9

Many anchorages are susceptible to water condensation, because their concrete masses serve as heat sinks. Furthermore, many anchorage roofs function as roadway decks with construction joints at or near the curb line. This allows surface water to penetrate the anchorage and drip on the splayed strands and eyebars closest to the roadway. Makeshift diversions for roof water have met with little success.

Field experience has demonstrated that corrosion mechanisms inside the anchorages are significantly different from the ones in the protected cable in the main span and side spans from bent saddle to bent saddle.

This is evidenced by the differences in appearance of corroded wires. In wet anchorages, there is considerable surface corrosion and wire failure occurs after significant section loss. In contrast, wire failure in the protected cable occurs after embrittlement and shoes” and “anchorage system” for “eyebars.”

The primary difference will be that PWS construction always uses a socket at the anchorage point of the strand instead of a strand shoe, and usually uses a steel framework instead of eyebars to anchor the sockets.

2.4.9.1 WIRES IN STRANDS

The strands inside the anchorage should be wedged open on at least one transverse and one vertical line. The investigator may add more wedging at locations that show the worst damage.

The minimum diameter of corroded wires should be measured and recorded.

2.4.9.2 WIRES NEAR AND AROUND STRAND SHOES

In wet anchorages, strand wires deteriorate the most where water collects over time. This generally occurs in the bottom half-strand, adjacent to or in contact with the strand shoe, as illustrated in Figure 2.4.9.2-1 (the end of the steel tape indicates the location of the front edge of the strand shoe).

The area is difficult to access, and wire damage can only be guessed at from the surface. This incomplete information is insufficient to estimate the total wire damage. Experience on some bridges indicates that if there are several broken wires at the edge of the strand shoe accompanied by section loss in surface wires that have not yet failed, then a worse condition is likely to be present in an inaccessible area of the strand. The investigator must exercise engineering judgment about the potential capacity of the strand, and whether the strand should be rehabilitated, in the context of overall strand group conditions and of the need to restore cable strength in the anchorage area.

2.4.9.3 EYEBARS

All eyebars should be carefully examined during biennial inspections, and the presence of corrosion products, exfoliating rust and loose paint reported. The corrosion product on some of the more accessible eyebars should be removed with hammer and chisel to a degree sufficient for determining section loss.

Where section loss on the eyebars is suspected, all paint and corrosion products on the eyebars should be removed by shot blasting. The extent of section loss is measured using specially designed calipers on a minimum of five equally spaced locations along the width of the eyebar. The loss on the narrow faces of the

pitting with “flat and invert” breaks and little or no section loss.

C2.4.9.1

In general, anchorage strands have more damage at the lower end of the strand (i.e., near their anchorage points), than at higher locations, although upper portions of the strands may also be damaged where water runs through the splay casting or drips into the cable just below the splay casting.

C2.4.9.2

Strand cutting and re-anchoring allows for estimating the condition and capacity of strands of similar exterior appearance. NDE devices, in use or in development, do not permit a reasonable estimate of damage in the wires in the area around the strand shoe.

C2.4.9.3

In wet anchorages, a heavy deposit of corrosion products is often found on the surface of the eyebars just above the point where they enter the concrete mass. The extent of the damage is visually deceiving, because the corrosion products may consist of a dense black oxide that adheres tightly to the metal, often not removed in preparation for painting. The corrosion normally does not extend below the surface of the concrete.

In some anchorages, access for visual observation may be so limited that a video camera is required.

eyebars should also be determined.

The surface of the corroded eyebar is usually too rough to allow the use of ultrasonic thickness-measuring devices, but a test should be conducted to determine their suitability.

The remaining area of the eyebars should be calculated from these measurements and used in turn to calculate the capacity of the eyebars to anchor the strands.

2.4.9.4 WIRES INSIDE SPLAY CASTINGS

Inspection is required if there is any indication of wire damage inside the splay castings. Engineering and construction planning are necessary for temporary upward relocation of the splay casting, which permits separation of the strands and provides access. Only competent contractors with experience in bridge wire and cable inspection should be engaged for this work.

The primary purpose of such inspection is to determine the condition of the wires. Wires that have significant section loss or are broken should be replaced. New zinc-coated wires are spliced to a sound point on the damaged wires. All ferrules should be outside the final splay casting location. The access that is provided should permit inspection of all wires, facilitating estimation of cable capacity in the splay casting area.

2.4.9.5 ANCHORAGE ROOFS

When the strands display significant damage, anchorage roofs should be inspected to identify sources of moisture.

2.4.9.6 INSTRUMENTATION OF EYEBARS

Whenever live load stress ranges coupled with temperature change effects on the cable are required by the investigator, it may be possible to instrument the eyebars to obtain the needed data. The effects on the

Removal of corrosion products manually is not advisable, regardless of accessibility, because the products are strongly adherent to the base metal and cannot be dislodged with a hammer.

Rust is best removed with shot blasting. Pack rust removal should be executed by a contractor.

The capacity of both strands and eyebars is estimated with a technique that is equivalent to calculating the cable capacity with the Limited Ductility Model, described in Section 5. All strands may be considered clamped at the splay casting or splay saddle, and this point is mathematically moved to strain the assembly of eyebars and strands. The force in each strand is calculated from the elongation. As an assembly of an eyebar plus attached strand reaches its strength, the eyebar yields or the strand fails, and part or all of the force in the assembly is distributed to the other elements. The sum of strand forces is the force in the cable; and the maximum force reached is the strength, which may be less than the sum of the individual strengths.

C2.4.9.4

The engineering work will most likely require installation of guide frames to maintain all the strands at the same length. Failure to adjust the strand alignment may result in undesirable movement of the cable and suspended structure. The procedure also seeks to maintain the same tension in all the wires at all times.

C2.4.9.6

AASHTO design loads and load factors are often not applicable to long span suspension bridges. Their use may lead to low safety indices, unrepresentative of real conditions.

eyebars can be translated to effects anywhere in the suspended span area, providing that the anchorage and tower saddles are free to move.

If necessary, temperature effects on the cable can be determined separately by installing instrumentation for temperature on the cable and calculating changes of stress on the cable by analytic means.

To eliminate the effect of temperature changes on the eyebars, one full bridge circuit per eyebar is recommended. Two gages should be placed on each eyebar at opposite ends of the horizontal centerline to determine the flexural stress component in the eyebar. A line of strands chosen diagonally across the strand group is a sufficiently large enough sample to guarantee good averages. The force in the outer strands should be corrected by multiplying by the cosine of the angle that the outer strand makes with the center strand.

2.4.9.7 DEHUMIDIFICATION

Whenever a dehumidification system is installed in the anchorage, the system should be inspected in the presence of maintenance personnel or a mechanical engineer familiar with its operation, according to the following procedure:

- Measure the relative humidity immediately upon opening the chamber.
- Measure the relative humidity for a 2-hour period on a humid or rainy day.
- Test the operation of the equipment to verify that it starts when the relative humidity is raised to the level the equipment is set for (an electric pot can be used to boil water in the chamber to accomplish this), and that it turns off when the humidity is reduced to normal levels by removing the source.
- Inspect gaskets at doors and other openings for leakage.

2.4.10 Inspection of Cables at Saddles

Cable wires inside saddles have not been inspected on any bridge to date. Observation of wires is possible only from the top of the saddle and at its ends, where the cable is visible all around its surface, but not inside.

No currently available or soon to be available NDE devices can assist in estimating wire damage in saddle areas.

Instrumentation and data acquisition is an effective means of estimating bridge loads, especially fatigue loading stress ranges and histograms.

More accurate live loads and stress ranges than those obtained from instrumenting eyebars can be obtained by instrumenting the cable wires directly while the cable is unwrapped. This should be done in the span beyond anchorages or cable-bent saddles. At least 8 strain gages should be attached to wires at 45-degree intervals around the cable.

C2.4.10

A saddle is a turning point of the cable; contact between the saddle and the cable is necessary to support the bridge. Based on past inspection experience, the surface wires in the saddle itself are usually in good condition, especially if they are covered with wax. There are exceptions: on one bridge, the top of the cable in the tower saddles was covered with bird excrement, despite the presence of a tower

GUIDELINES

The wires at the top of the saddle and inside protective sleeves should be inspected, starting with the second time the cable is inspected, unless signs of water entry are observed earlier. Half the saddle wires should be observed during the second inspection and half during the third.

2.4.10.1 TOWER SADDLES

There are two types of enclosures for tower saddles, requiring different access routes for observing wires.

2.4.10.1.1 Tower Top Enclosures

Tower top enclosures are extensions of the tower. They may consist of a penthouse covering the entire top surface of the tower, or of a series of separate enclosures, one for each saddle. The enclosures cover the entire saddle and permit observation of saddles and exposed wires by the mere opening of an access door.

2.4.10.1.2 Exposed Saddles with Plate Covers

The saddles are exposed at the tops of towers, but have top plates cap-bolted onto the sides of the saddle retainers, thus protecting the cable. Flashings are similarly mounted. To access the wires, plates and flashings must be removed temporarily.

Cables within saddles have often been protected with a layer of wax (beeswax and paraffin are used for this purpose). This protection should be replaced after inspection, either in kind or with another type of waterproof coating.

2.4.10.2 CABLE-BENT SADDLES

Cable-bent saddles are placed on top of a rigid frame structure or on separate columns to accommodate a change in the direction of a cable as it deflects downward into the anchorage at the end of the side spans. The enclosures for these saddles are of several types.

2.4.10.2.1 Saddles Inside Anchorages

Bent saddles reside inside the anchorage structure, where saddle and surface wires are exposed and observable.

2.4.10.2.2 Extended Anchorage Housing

Steel or concrete housings extend from the anchorage structure above the roadway and contain the bent strut

COMMENTARY

enclosure. There was no protective wax or other coating on the wires, and the upper layer of wires experienced section loss.

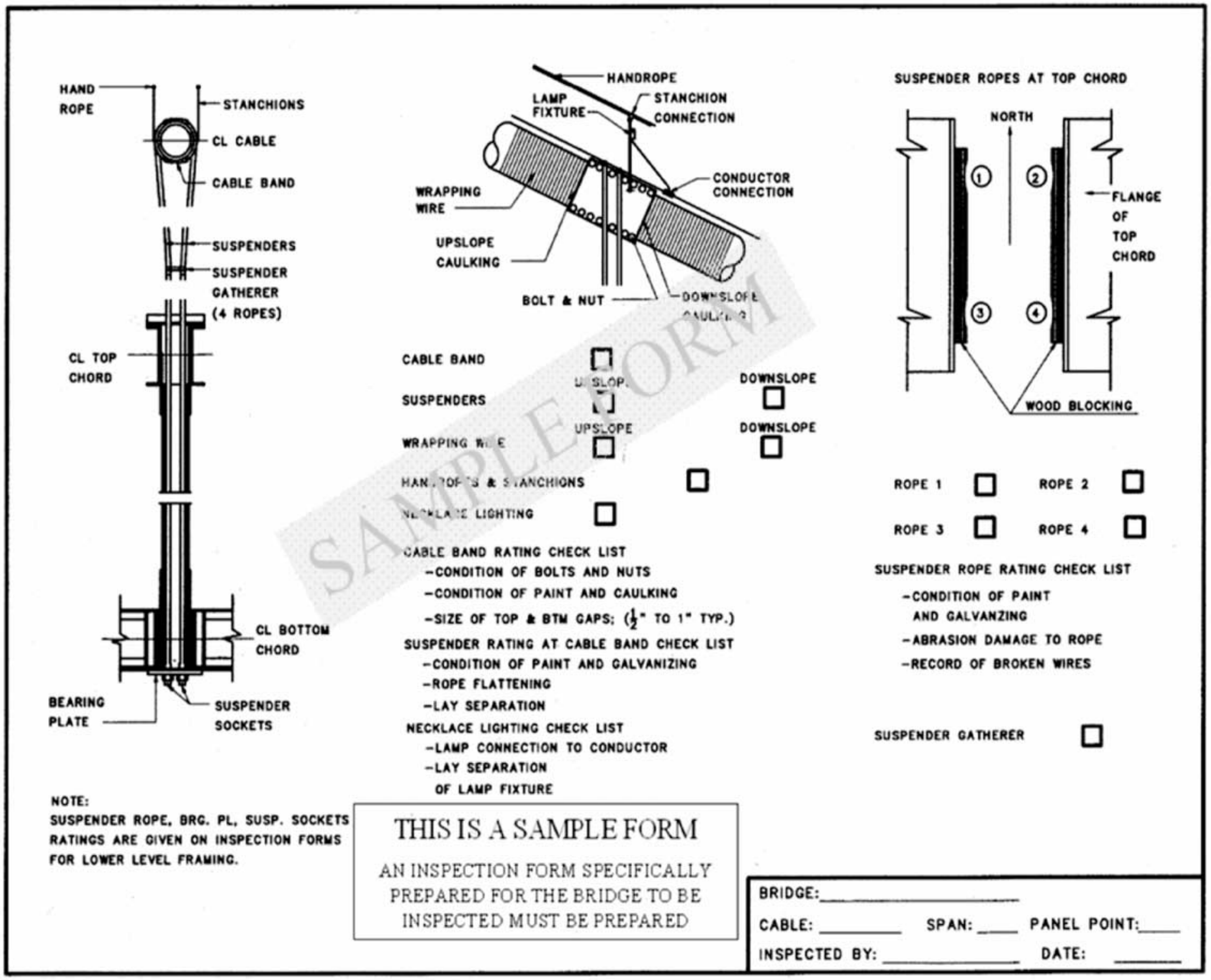
It is not necessary to observe inside the saddle cover or housing during the first inspection. The second inspection may occur as early as 35 or 40 years, or as late as 60 years, after completion of the bridge. In either event, these areas should be inspected starting with the second inspection.

and saddle. Within these housings, saddle and surface wires are observable.

2.4.10.2.3 Exposed Saddles and Plated Roofs

Exposed saddles with plated roofs create conditions similar to the ones described in Article 2.4.10.1.2. Cable bents with exposed saddles extend through the anchorage roof. Wires are protected by plated roofs bolted to the sides of the saddles. To access the wires, plates and flashings must be temporarily removed.

2.5 FIGURES FOR SECTION 2



NOTE:
SUSPENDER ROPE, BRG. PL, SUSP. SOCKETS RATINGS ARE GIVEN ON INSPECTION FORMS FOR LOWER LEVEL FRAMING.

CABLE BAND ☐

SUSPENDERS UPSLOPE ☐ DOWNSLOPE ☐

WRAPPING WIRE UPSLOPE ☐ DOWNSLOPE ☐

HANDROPES & STANCHIONS ☐

NECKLACE LIGHTING ☐

CABLE BAND RATING CHECK LIST
- CONDITION OF BOLTS AND NUTS
- CONDITION OF PAINT AND CAULKING
- SIZE OF TOP & BTM GAPS; ($\frac{1}{2}$" TO 1" TYP.)

SUSPENDER RATING AT CABLE BAND CHECK LIST
- CONDITION OF PAINT AND GALVANIZING
- ROPE FLATTENING
- LAY SEPARATION

NECKLACE LIGHTING CHECK LIST
- LAMP CONNECTION TO CONDUCTOR
- LAY SEPARATION OF LAMP FIXTURE

ROPE 1 ☐ ROPE 2 ☐

ROPE 3 ☐ ROPE 4 ☐

SUSPENDER ROPE RATING CHECK LIST
- CONDITION OF PAINT AND GALVANZING
- ABRASION DAMAGE TO ROPE
- RECORD OF BROKEN WIRES

SUSPENDER GATHERER ☐

THIS IS A SAMPLE FORM

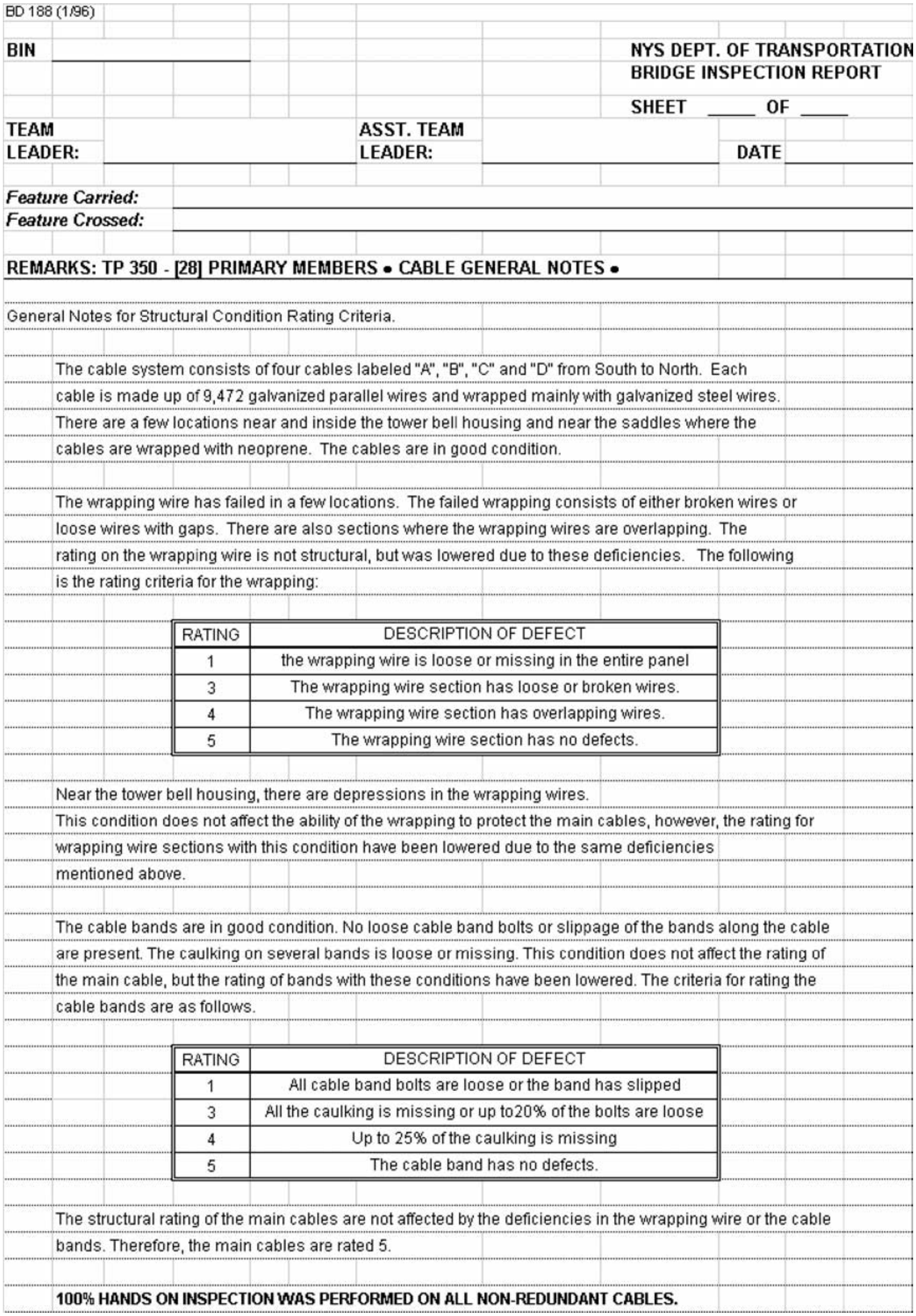
AN INSPECTION FORM SPECIFICALLY PREPARED FOR THE BRIDGE TO BE INSPECTED MUST BE PREPARED

BRIDGE: ____________________

CABLE: ________ SPAN: ____ PANEL POINT: ____

INSPECTED BY: ______________ DATE: ________

Figure 2.2.3.1-1. Typical cable biennial inspection form.



BD 188 (1/96)

BIN ____________

NYS DEPT. OF TRANSPORTATION
BRIDGE INSPECTION REPORT

SHEET _____ **OF** _____

TEAM LEADER: ____________ **ASST. TEAM LEADER:** ____________ **DATE** ________

Feature Carried: ____________

Feature Crossed: ____________

REMARKS: TP 350 - [28] PRIMARY MEMBERS • CABLE GENERAL NOTES •

General Notes for Structural Condition Rating Criteria.

The cable system consists of four cables labeled "A", "B", "C" and "D" from South to North. Each cable is made up of 9,472 galvanized parallel wires and wrapped mainly with galvanized steel wires. There are a few locations near and inside the tower bell housing and near the saddles where the cables are wrapped with neoprene. The cables are in good condition.

The wrapping wire has failed in a few locations. The failed wrapping consists of either broken wires or loose wires with gaps. There are also sections where the wrapping wires are overlapping. The rating on the wrapping wire is not structural, but was lowered due to these deficiencies. The following is the rating criteria for the wrapping:

RATING	DESCRIPTION OF DEFECT
1	the wrapping wire is loose or missing in the entire panel
3	The wrapping wire section has loose or broken wires.
4	The wrapping wire section has overlapping wires.
5	The wrapping wire section has no defects.

Near the tower bell housing, there are depressions in the wrapping wires. This condition does not affect the ability of the wrapping to protect the main cables, however, the rating for wrapping wire sections with this condition have been lowered due to the same deficiencies mentioned above.

The cable bands are in good condition. No loose cable band bolts or slippage of the bands along the cable are present. The caulking on several bands is loose or missing. This condition does not affect the rating of the main cable, but the rating of bands with these conditions have been lowered. The criteria for rating the cable bands are as follows.

RATING	DESCRIPTION OF DEFECT
1	All cable band bolts are loose or the band has slipped
3	All the caulking is missing or up to20% of the bolts are loose
4	Up to 25% of the caulking is missing
5	The cable band has no defects.

The structural rating of the main cables are not affected by the deficiencies in the wrapping wire or the cable bands. Therefore, the main cables are rated 5.

100% HANDS ON INSPECTION WAS PERFORMED ON ALL NON-REDUNDANT CABLES.

Figure 2.2.3.1-2. Typical summary form showing biennial inspection rating system.

BD 188 (1/96)

BIN ____________________

NYS DEPT. OF TRANSPORTATION
BRIDGE INSPECTION REPORT

SHEET ____ **OF** ____

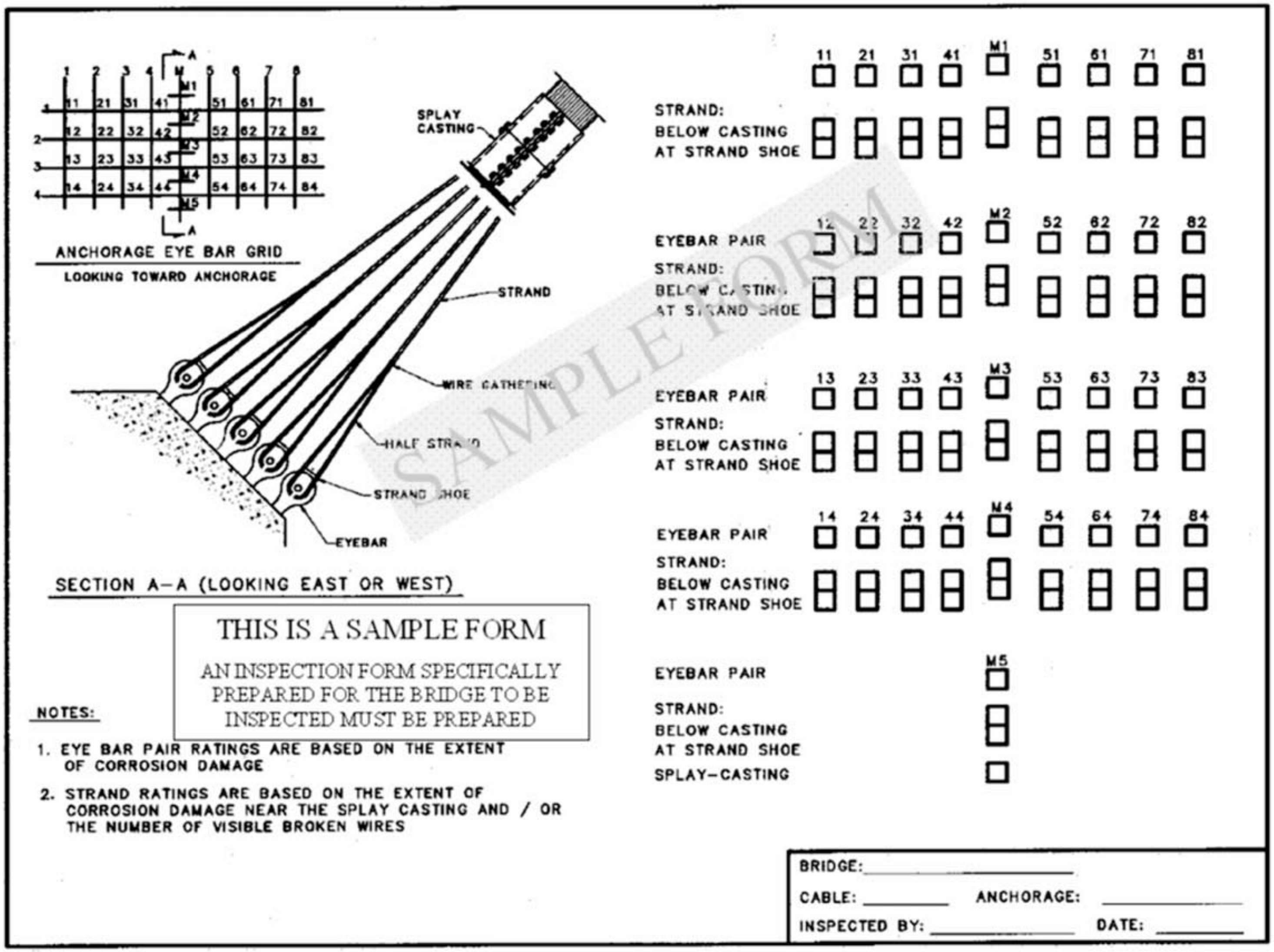
TEAM LEADER: ____________ L ____________ **ASST. TEAM EADER:** ____________________ **DATE** ____________

Feature Carried: ____________________

Feature Crossed: ____________________

TP 350 - [28] PRIMARY MEMBERS							
RATINGS			**PHOTO NO.**	**CABLE A**			
NEW	**PREV**	**PAINT**		**LOC. & SPAN**	**PP**	**MEMBER**	**<u>REMARKS</u>**
5	5	5		BMS/10	81	band	
5	5	3		BMS/10	81-82	wrap	
5	5	5		BMS/10	82	band	
5	5	4		MMS/10	81-82	wrap	
5	5	5		MMS/10	81	band	
5	5	3		MMS/10	80-81	wrap	
5	5	5		MMS/10	80	band	
4	4	3	89S	MMS/10	79-80	wrap	There are overlapping wires near PP 80.
4	5	5		MMS/10	79	band	The seal between the cable band and the bottom portion of the cable is missing.
5	5	3		MMS/10	78-79	wrap	
5	5	5		MMS/10	78	band	
5	5	3		MMS/10	77-78	wrap	
4	5	5		MMS/10	77	band	The seal between the cable band and the bottom portion of the cable is missing.
4	4	3	89S	MMS/10	76-77	wrap	There are overlapping wires near PP 80.
4	5	5		MMS/10	76	band	The seal between the cable band and the bottom portion of the cable is missing.
5	5	3		MMS/10	75-76	wrap	
5	5	5		MMS/10	75	band	
5	5	3		MMS/10	74-75	wrap	
5	5	5		MMS/10	74	band	
5	5	3		MMS/10	73-74	wrap	
5	5	5		MMS/10	73	band	
5	5	3		MMS/10	72-73	wrap	
5	5	5		MMS/10	72	band	
5	5	3		MMS/10	71-72	wrap	
5	5	5		MMS/10	71	band	
5	5	3		MMS/10	70-71	wrap	
5	5	5		MMS/10	70	band	
5	5	3		MMS/10	69-70	wrap	
5	5	5		MMS/10	69	band	
5	5	3		MMS/10	68-69	wrap	
5	5	5		MMS/10	68	band	
5	5	5		MMS/10	67-68	wrap	
5	5	5		MMS/10	67	band	

Figure 2.2.3.1-3. Typical form for biennial inspection showing detailed ratings.



	1	2	3	4	M	5	6	7	8
					M1				
1	11	21	31	41		51	61	71	81
					M2				
2	12	22	32	42		52	62	72	82
					M3				
3	13	23	33	43		53	63	73	83
					M4				
4	14	24	34	44		54	64	74	84
					M5				

ANCHORAGE EYE BAR GRID

LOOKING TOWARD ANCHORAGE

SECTION A–A (LOOKING EAST OR WEST)

THIS IS A SAMPLE FORM

AN INSPECTION FORM SPECIFICALLY PREPARED FOR THE BRIDGE TO BE INSPECTED MUST BE PREPARED

NOTES:

1. EYE BAR PAIR RATINGS ARE BASED ON THE EXTENT OF CORROSION DAMAGE
2. STRAND RATINGS ARE BASED ON THE EXTENT OF CORROSION DAMAGE NEAR THE SPLAY CASTING AND / OR THE NUMBER OF VISIBLE BROKEN WIRES

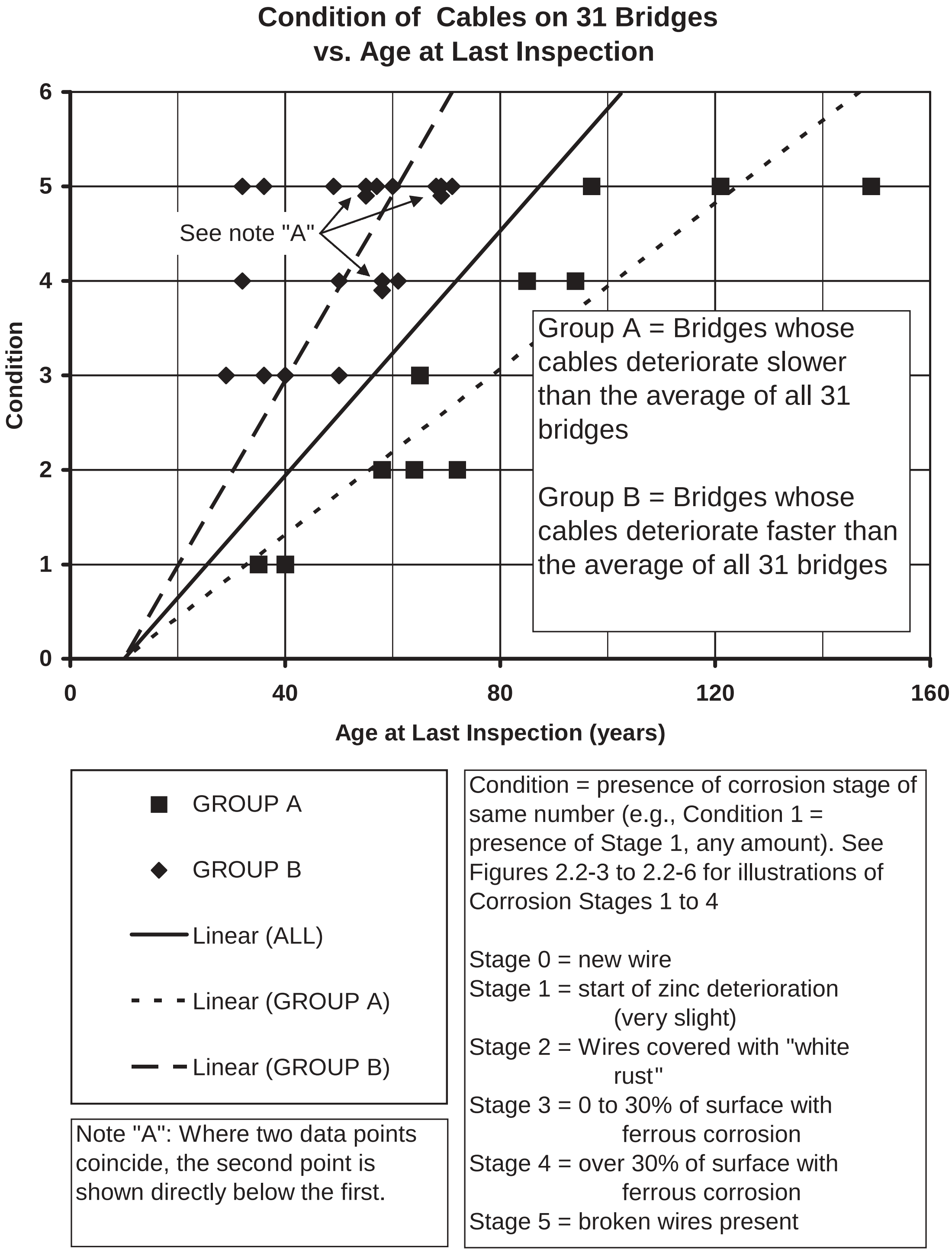
	11	21	31	41	M1	51	61	71	81
	☐	☐	☐	☐	☐	☐	☐	☐	☐
STRAND: BELOW CASTING AT STRAND SHOE	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐
	12	22	32	42	M2	52	62	72	82
EYEBAR PAIR	☐	☐	☐	☐	☐	☐	☐	☐	☐
STRAND: BELOW CASTING AT STRAND SHOE	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐
	13	23	33	43	M3	53	63	73	83
EYEBAR PAIR	☐	☐	☐	☐	☐	☐	☐	☐	☐
STRAND: BELOW CASTING AT STRAND SHOE	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐
	14	24	34	44	M4	54	64	74	84
EYEBAR PAIR	☐	☐	☐	☐	☐	☐	☐	☐	☐
STRAND: BELOW CASTING AT STRAND SHOE	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐
					M5				
EYEBAR PAIR					☐				
STRAND: BELOW CASTING AT STRAND SHOE					☐ ☐				
SPLAY–CASTING					☐				

BRIDGE: ____________

CABLE: ________ ANCHORAGE: ________

INSPECTED BY: ________ DATE: ________

Figure 2.2.3.2-1. Typical form for biennial inspection of cable inside anchorage.



Group A = Bridges whose cables deteriorate slower than the average of all 31 bridges

Group B = Bridges whose cables deteriorate faster than the average of all 31 bridges

Note "A": Where two data points coincide, the second point is shown directly below the first.

Condition = presence of corrosion stage of same number (e.g., Condition 1 = presence of Stage 1, any amount). See Figures 2.2-3 to 2.2-6 for illustrations of Corrosion Stages 1 to 4

Stage 0 = new wire
Stage 1 = start of zinc deterioration (very slight)
Stage 2 = Wires covered with "white rust"
Stage 3 = 0 to 30% of surface with ferrous corrosion
Stage 4 = over 30% of surface with ferrous corrosion
Stage 5 = broken wires present

Figure 2.2.4-1. Graph of cable condition vs. age at last inspection.

Figure 2.3.1.2.2-1 Damaged caulking and paint at cable band.

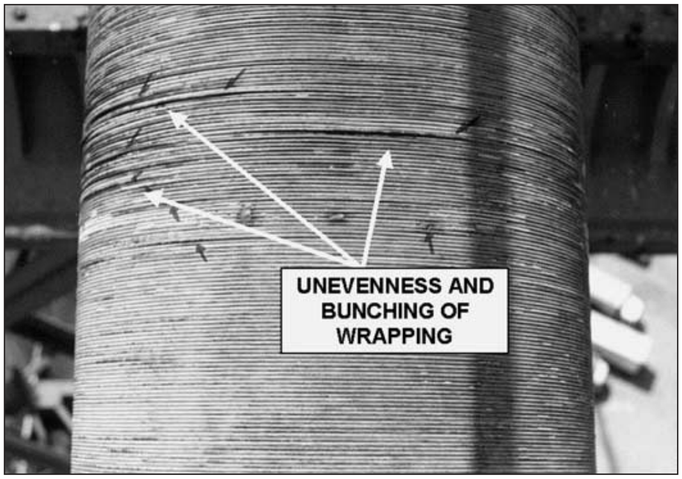


Figure 2.3.1.2.2-2. Uneven wrapping.

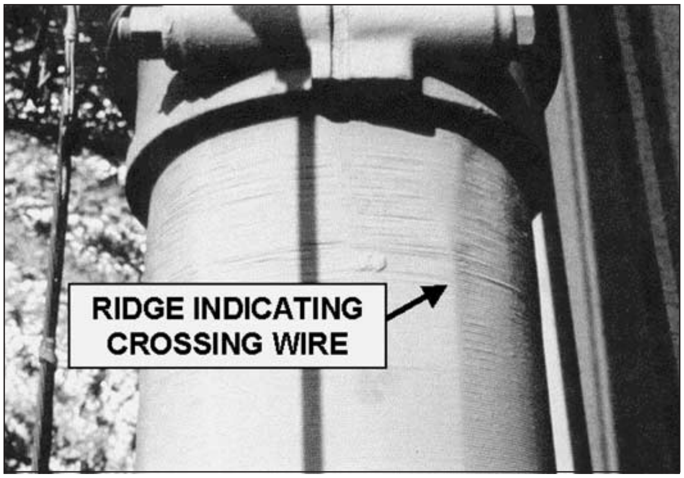


Figure 2.3.1.2.2-3. Ridge indicating crossing wires.

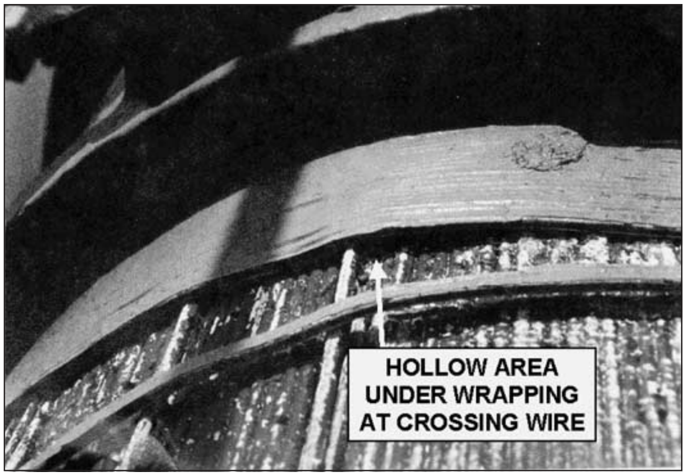


Figure 2.3.1.2.2-4. Hollow area indicating crossing wires.

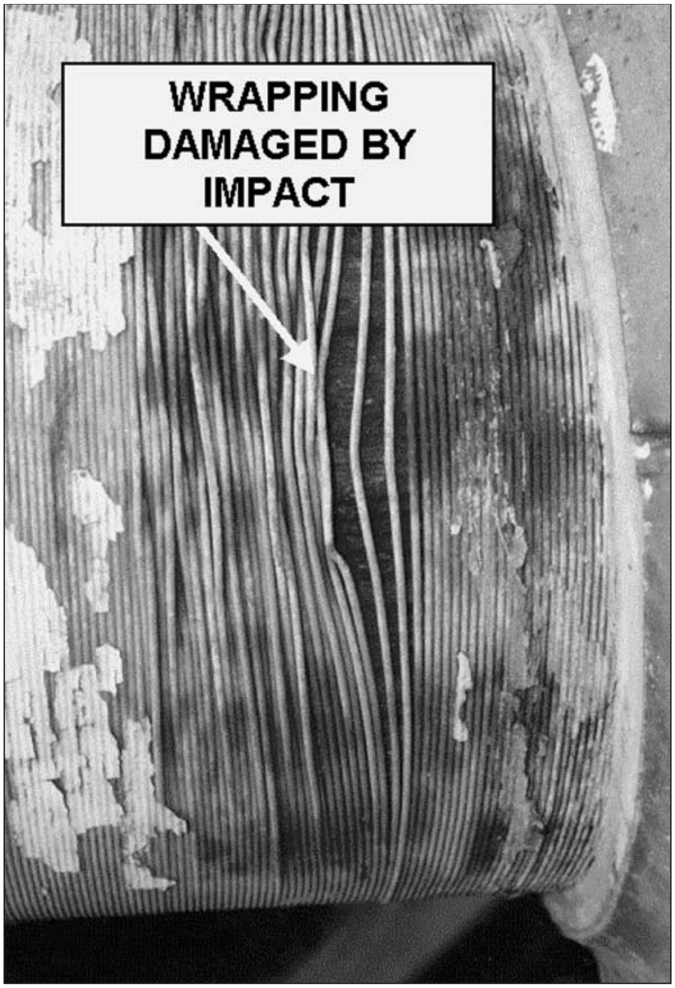
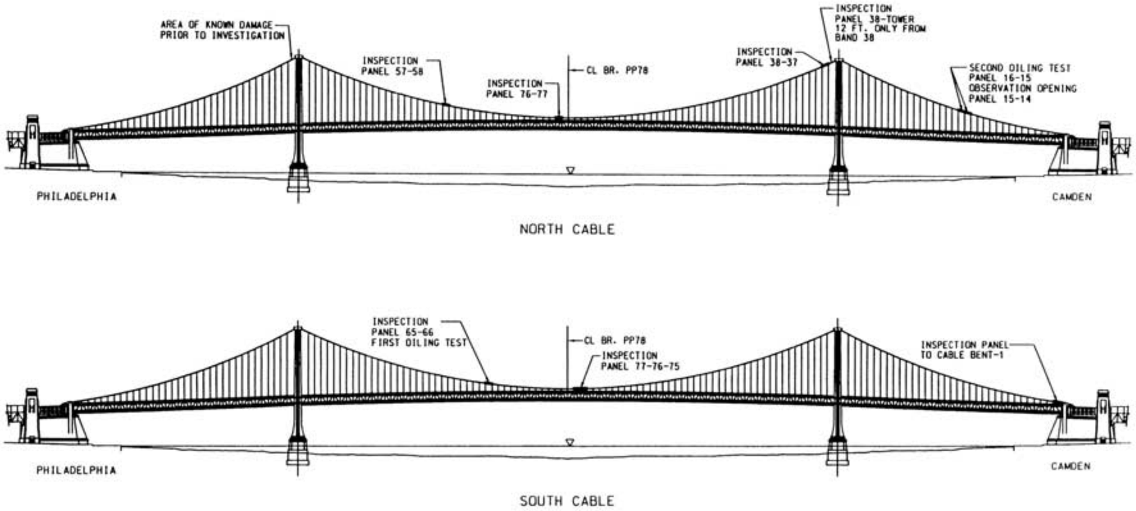


Figure 2.3.1.2.2-5. Damage to wrapping caused by vehicular impact.

Authority ____________________

Bridge ____________________



TYPICAL CABLE INSPECTION LOCATIONS DIAGRAM

Figure 2.3.1.2.4-1. Form for recording locations of internal cable inspections.

BRIDGE NAME: ______________________________ PREPARED BY: ________________

_______ CABLE _______ SIDE DATE ☐

PANEL ☐

DEPTH OF CABLE INSPECTED ___________

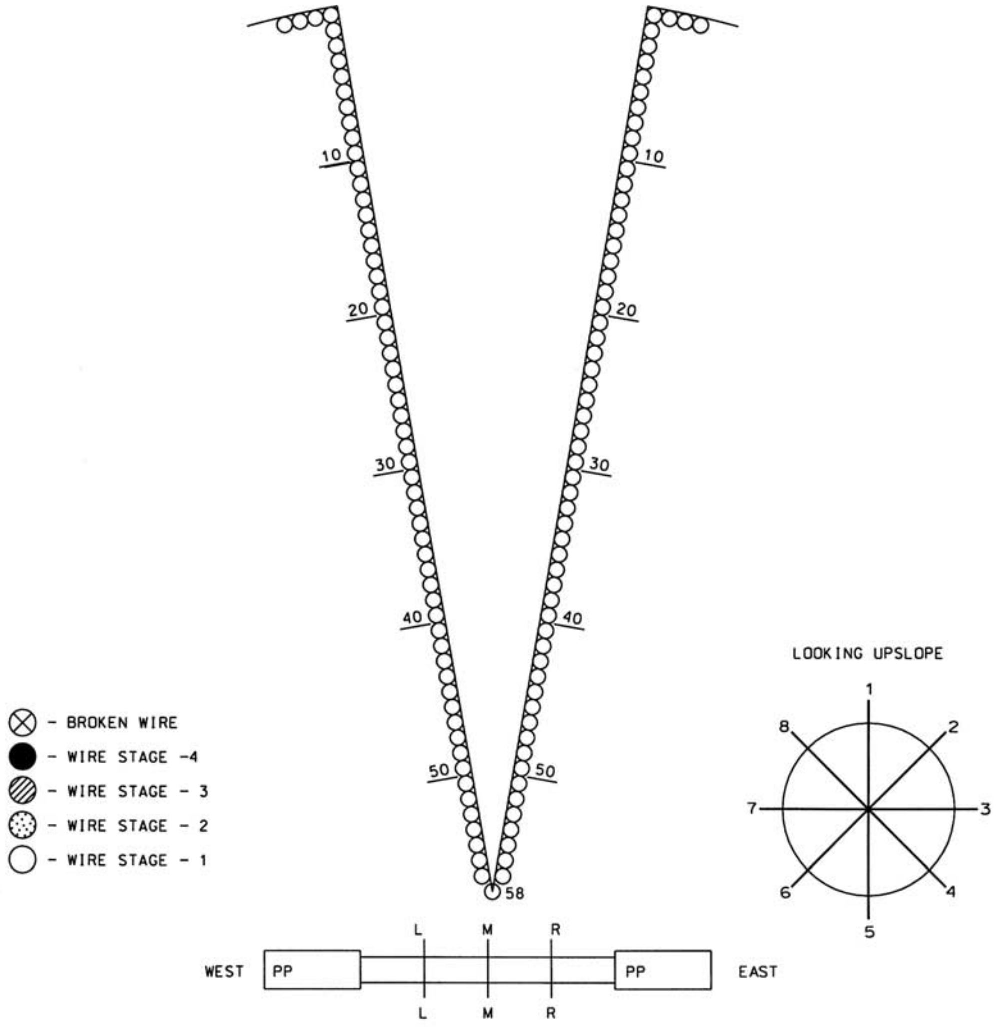
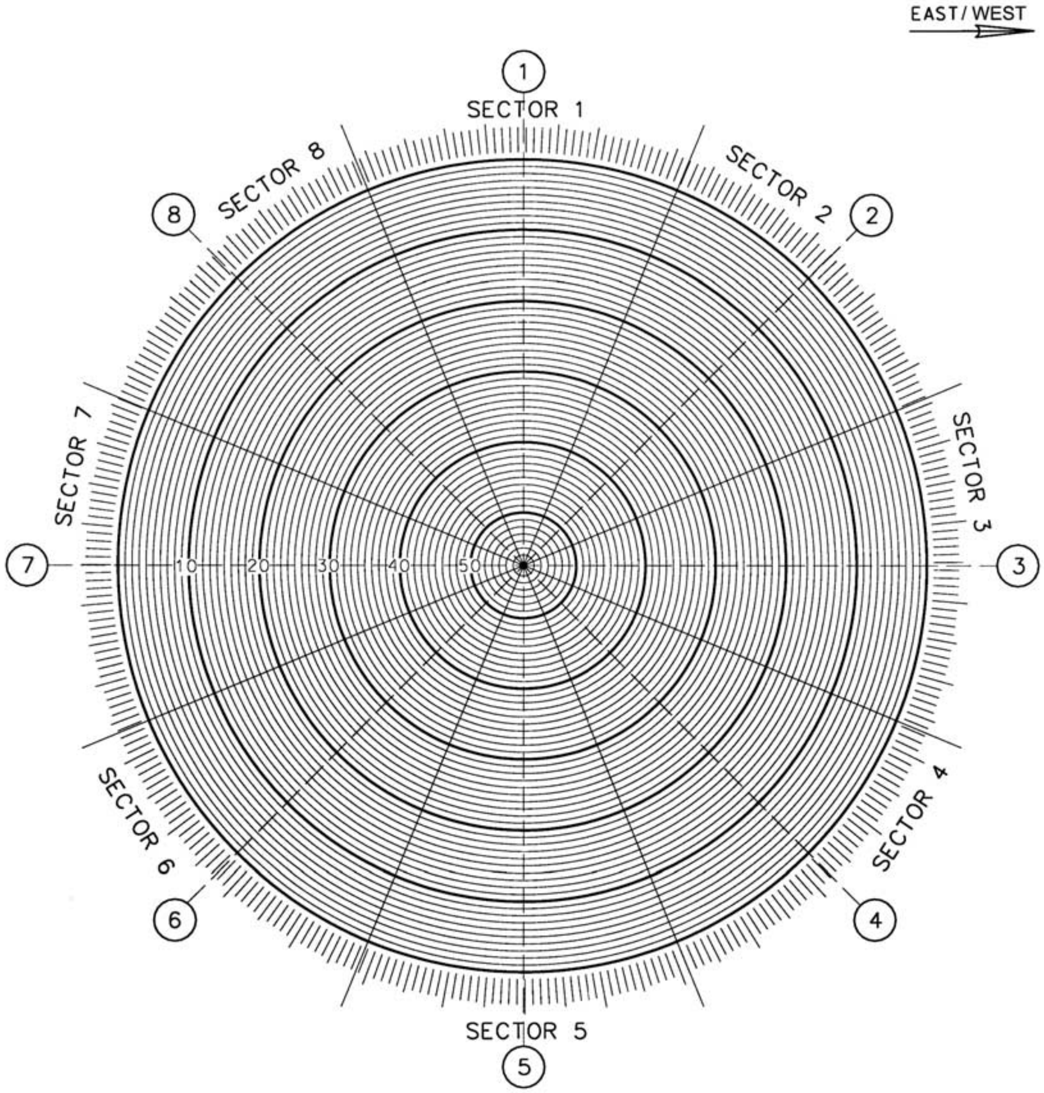


Figure 2.3.1.2.4-2. Form for recording observed wire damage inside wedged opening.



CABLE CROSS SECTION

BRIDGE: _____

_____ CABLE, LOOKING ________

SPAN ______

PANEL ______

LEGEND

- ● BROKEN WIRE NO. -
- ⑧ WEDGE LOCATION
- ◉ **SAMPLE FOR TESTING**

Figure 2.3.1.2.4-3. Form for recording locations of broken wires and samples for testing.

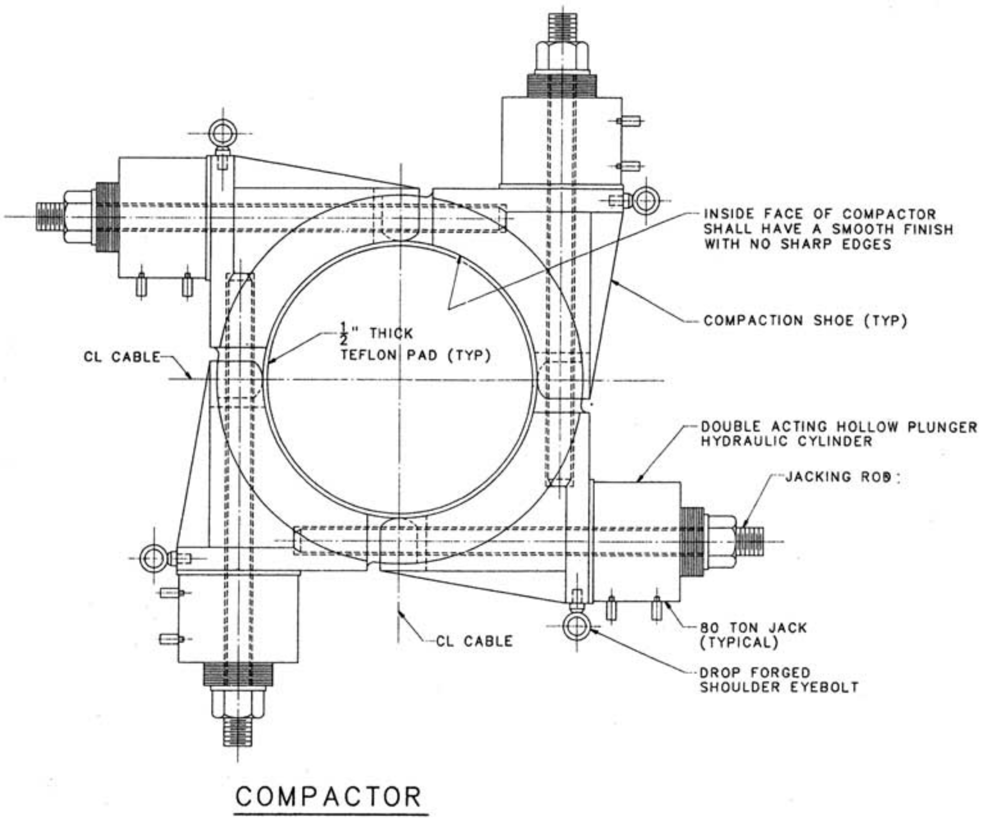
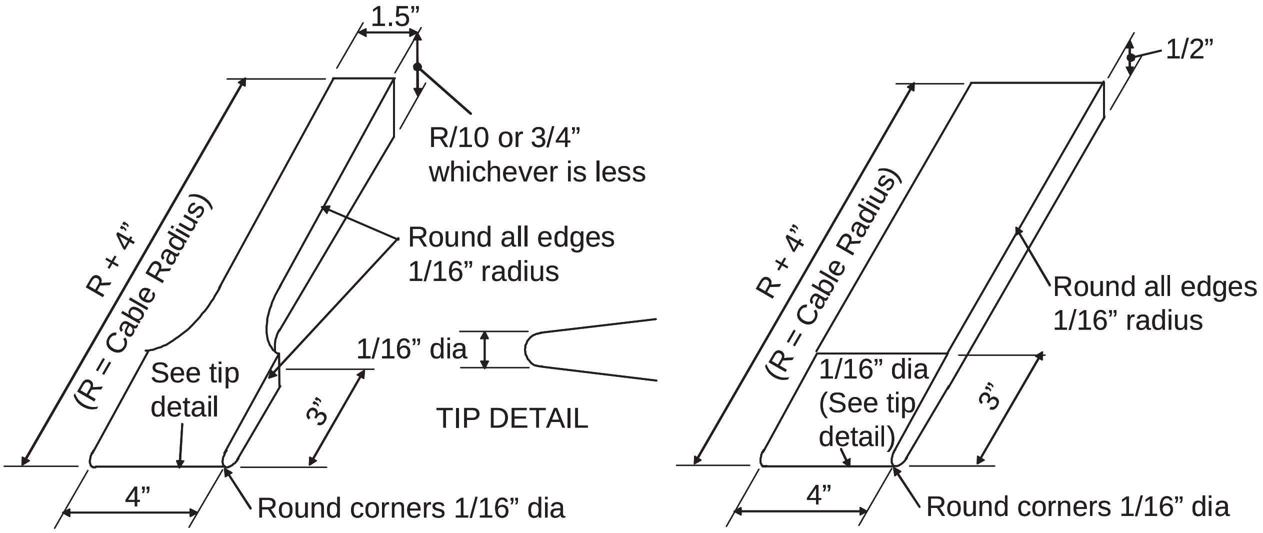


Figure 2.3.1.3.2.a-1. Cable compactor.

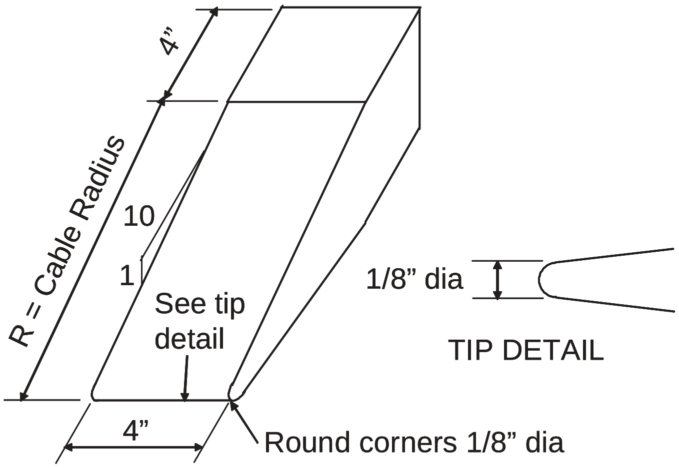
Figure 2.3.1.3.2.c-1. Power-driven wrapping machine.

Figure 2.3.1.3.2.c-2. Manual wrapping machine.



STARTING TOOL
Material: Bronze

ALTERNATE STARTING TOOL
Material: Bronze

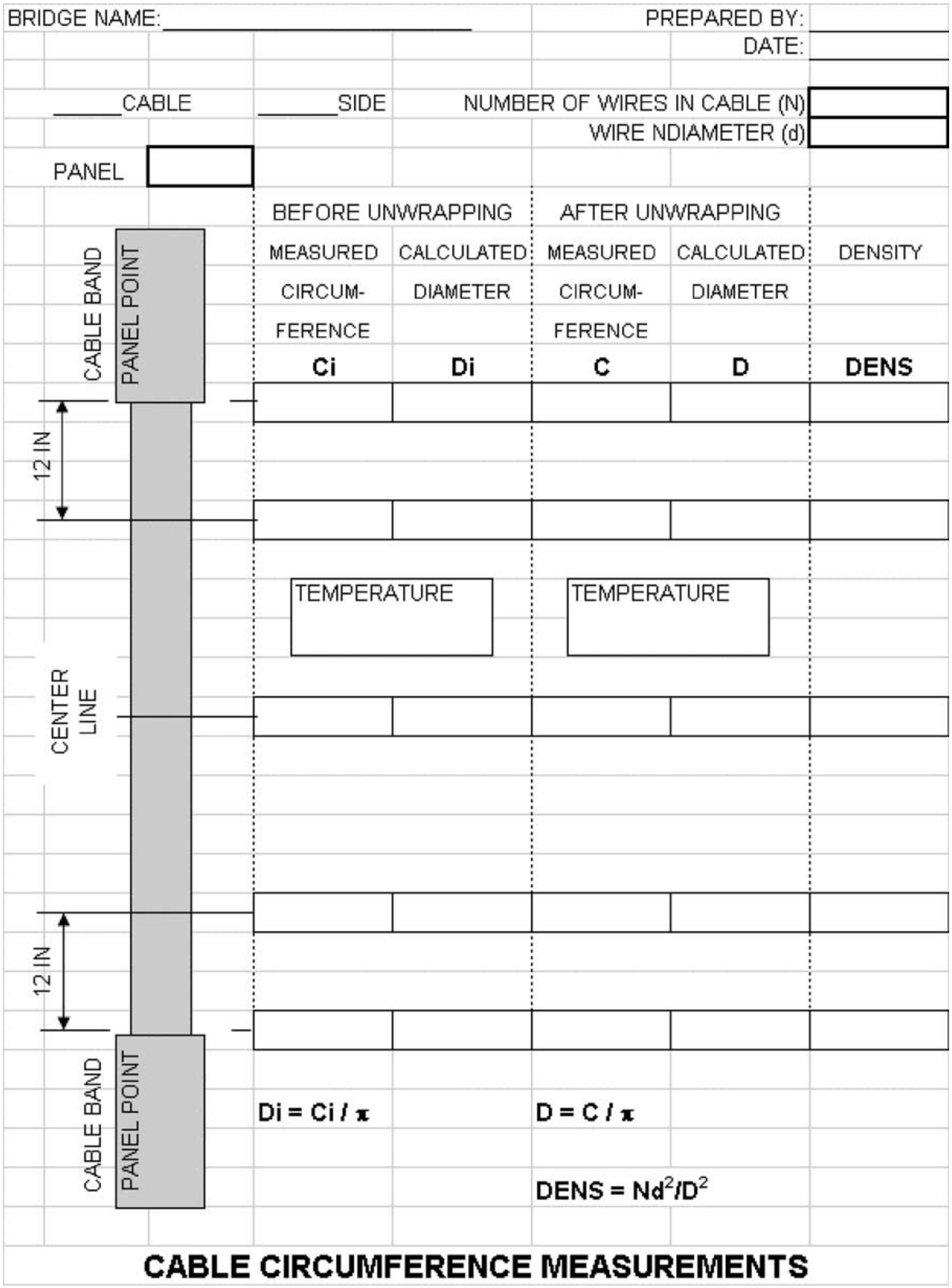


WEDGE
Material: Rock Maple or Oak

Figure 2.3.1.3.2.d-1. Chisels and wedges.

Note: For cables with a radius greater than 12 inches, wedges can have smaller slope, resulting in a maximum thickness of about 2.5 inches.

Figure 2.3.1.3.2.d-2. Hydraulic wedges.



BRIDGE NAME:________________________ PREPARED BY: ________

DATE: ________

______CABLE ______SIDE NUMBER OF WIRES IN CABLE (N) ☐

WIRE NDIAMETER (d) ☐

PANEL ☐

BEFORE UNWRAPPING		AFTER UNWRAPPING		
MEASURED CIRCUM-FERENCE	CALCULATED DIAMETER	MEASURED CIRCUM-FERENCE	CALCULATED DIAMETER	DENSITY
Ci	**Di**	**C**	**D**	**DENS**

TEMPERATURE ☐

TEMPERATURE ☐

Di = Ci / π

D = C / π

DENS = Nd^2/D^2

CABLE CIRCUMFERENCE MEASUREMENTS

Figure 2.4.1-1. Form for recording cable circumference.

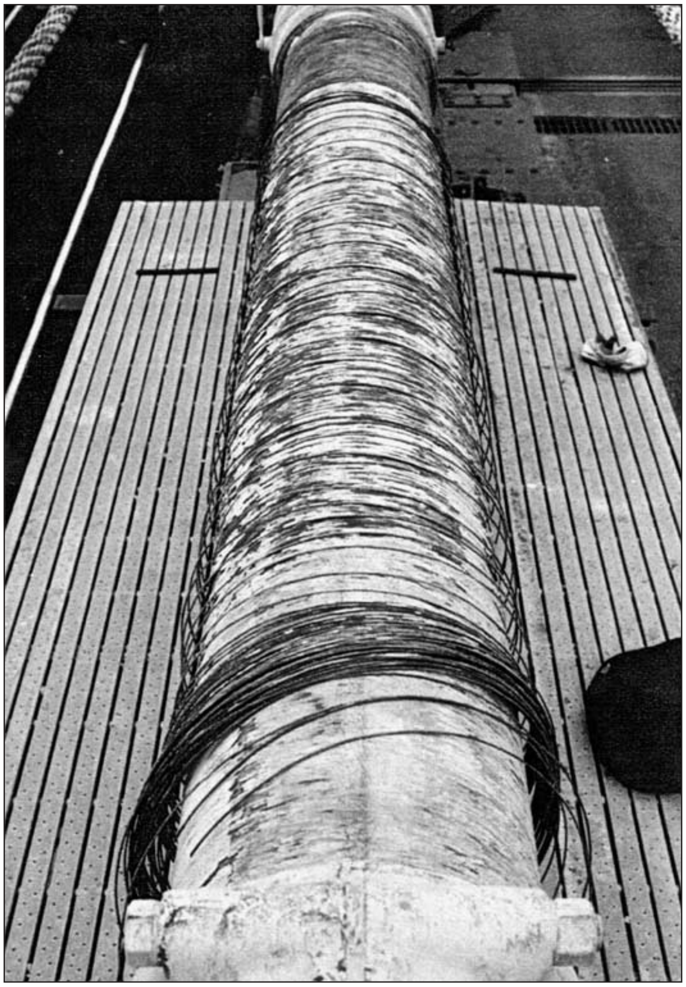


Figure 2.4.1.2-1. Removal of wire wrapping.

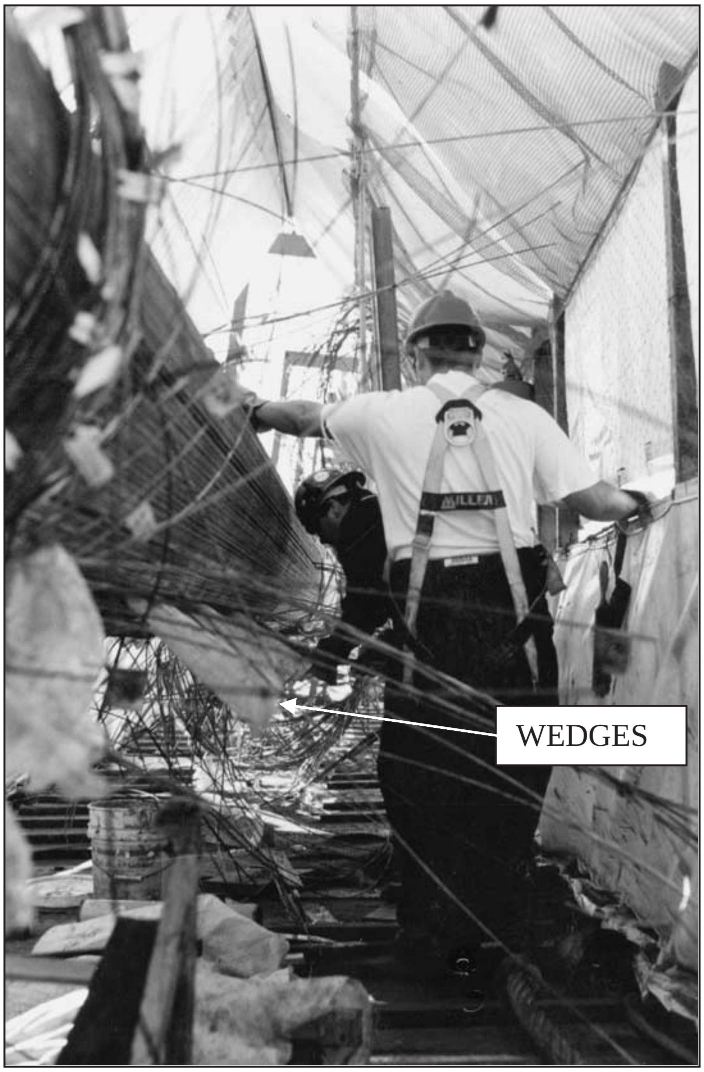


Figure 2.4.2.1-1. Additional wedges to inspect area with many broken wires.

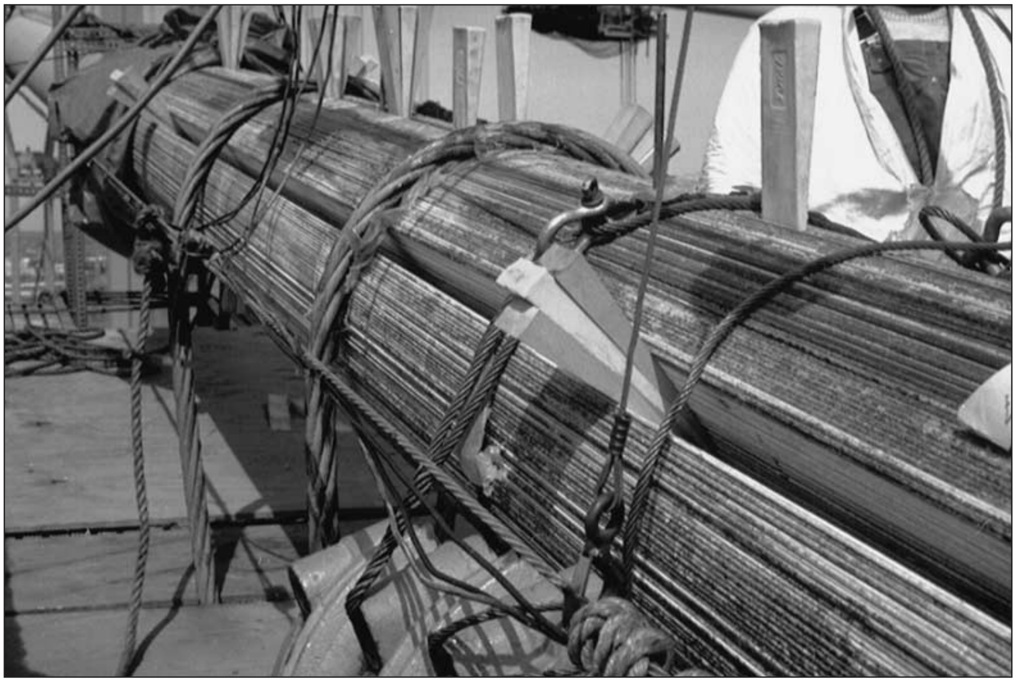


Figure 2.4.2.2-1. Cable wedged for inspection.

Figure 2.4.8.1-1. Inspection during cable rehabilitation.

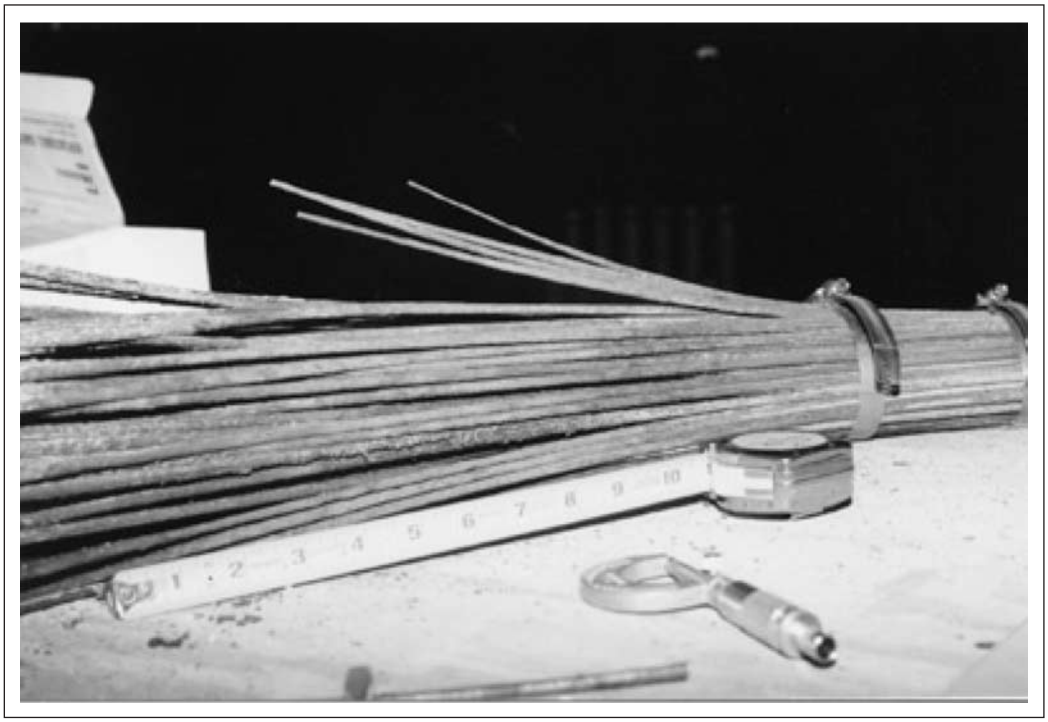


Figure 2.4.9.2-1. Deterioration of wires found inside strand shoe.

CONTENTS

3.1 INTRODUCTION

Laboratory testing is an integral part of cable inspection. The test results are used to estimate the strength of the wires and their stress vs. strain relationships, which are used in turn to evaluate cable strength. The same tests are used to determine the ultimate strain of the wires for the Limited Ductility Model. Other tests assess the remaining life of the zinc coating.

Additional tests are performed on cable wires to study the causes of corrosion. Although they are referred to in this section, they are irrelevant to the assessment of structural safety.

3.2 TESTS OF WIRE PROPERTIES

Strength testing is the most essential type of testing for the evaluation of cable capacity.

3.2.1 Specimen Preparation

A sample wire is a length of wire that has been removed from a cable for testing. A specimen is a piece of wire cut from the sample on which a specific test is performed. Sample wires obtained in the field should be long enough to provide the number of specimens recommended in Table 2.4.3.5.3-1. All of the specimens from a given sample should be at the same stage of corrosion, but it is understood this is not always possible.

The cast diameter should be determined prior to cutting specimens from the sample wires. If the sample is of sufficient length to form a complete circle as it lies on a flat surface, measure the cast diameter in two perpendicular directions and average the results. If the sample is not long enough to form a complete circle, measure the rise of the arc on each of two convenient chords of the curve, calculate the resulting diameters geometrically, and average the results.

The diameter d is given by

$$d = 2 \cdot \frac{4b^2 + c^2}{8b} \qquad \text{3.2.1-1}$$

where

b = offset between chord and arc

c = chord length

C3.2.1

A typical Stage 4 sample with no cracks has a standard deviation that is approximately 1% to 2% of the mean tensile strength. Ten specimens are sufficient to determine the sample mean tensile strength within 3% of the true mean with a 97.5% confidence level.

This number of specimens cannot be obtained during the first internal cable inspection, if the recommended 16 feet of cable are unwrapped. Longer lengths of cable should be unwrapped whenever corrosion is found to exceed Stage 3, so that Stage 4 wire samples that are at least 16 feet long can be removed.

Whenever corrosion is found not to exceed Stage 3, cracks are not likely to be present, and 12-foot-long samples providing 8 Stage 3 specimens are adequate.

Wires must be cleaned and all corrosion product must be removed prior to using a dye penetrant to find cracks. Even then, shallow pitting may obscure cracks or be confused with them. The most reliable method of identifying cracks is to inspect the fracture surface visually after testing. Optical microscopy prior to testing is the alternative to using dye or magnetic flux leakage. It is extremely time-consuming, and the human eye can fail to spot many cracks, even with a microscope.

GUIDELINES

Before sample wires are cut into specimens of suitable length for testing, they should be inspected and assigned to the appropriate corrosion stage. If possible, NDE testing to locate preexisting cracks should be performed on individual wires before they are cut, so that the worst cracks can be arranged to appear near the center of the specimen. Among the techniques that may be used to identify cracks are the application of a dye penetrant on cleaned wires and magnetic flux leakage inspection.

3.2.2 Tensile Tests

Wire strength derived from tensile tests is used to estimate cable strength. Tensile tests should be performed in accordance with ASTM A586 and ASTM A370 to determine the following wire properties:

breaking load in the wire
yield strength (0.2% offset method)
tensile strength
elongation in 10-inch-gage length
reduction of area
modulus of elasticity

The tensile strength should be based on the nominal area of the wire.

3.2.3 Obtaining Data for Force vs. Strain Curves

In addition to the tests listed above, wire elongation should be recorded at intervals of tensile force up to maximum force preceding failure. The data should be used to construct a full stress-strain curve, or force vs. strain curve, for each specimen. The ultimate strain corresponding to tensile strength should be determined as well.

3.2.4 Fractographic Examination of Suspect Wires

The fracture surface of the wires should be observed

COMMENTARY

C3.2.2

Many engineers prefer to use wire tensile strength rather than wire strength (a force) in calculations, and therefore strength equations in the Guidelines are derived using tensile strength, which is multiplied by the nominal area of the wire to calculate cable strength. For this reason, tensile strength test results should be based on the nominal area as well. Either gross metallic area (including the area of the zinc coating) or net steel area (not including the area of the zinc coating, which is equivalent to the nominal area of the uncoated wire) may be used, as long as the same area is used consistently in all cable strength calculations. The zinc coating is often degraded in the samples removed from the cable and the net steel area is preferred for the calculations, because the actual diameter of the wire without galvanizing can be measured more accurately in the laboratory.

Whenever section loss is observed in the specimen, the stress in the actual corroded wire cross-section may be of interest, because it provides the actual tensile strength of the steel in the corroded area. Tests on wires from the anchorages of the Manhattan Bridge have shown that this value does not change when section loss occurs. Significant variation may indicate hydrogen embrittlement cracking or pitting of the wires.

C.3.2.3

The testing laboratory selects the technique for determining elongations beyond 2%, because extensometers can be damaged whenever the wire fails. One option is to measure the motion of the head of the testing machine, adjusting the elongation for slippage at the time the grips are set. The measurement should include both the elastic and plastic components of the deformation.

C3.2.4

Techniques that are generally used to study the microstructure of metal can also be used to study failure to detect whether failure is ductile or brittle. A brittle failure is consistent with pitting or cracking, loss of ductility, a reduction in elongation and strength, and little or no reduction in area. Special attention should be focused on the causes of these phenomena. The instruments recommended for the task are a stereoscopic optical microscope and/or a scanning electron microscope.

It is also recommended that X-ray energy dispersion spectral analysis be performed on any fracture surface that displays traces of corrosion or contamination.

3.2.5 Examination of Fracture Surface for Preexisting Cracks

Cracked wires are treated as a separate group in estimating cable strength. Preexisting cracks are defined as cracks that are present in the specimen prior to testing. They are found by examining the fracture surface of all tension specimens under a

and corrosion morphologies.

- **Optical (Light) Microscopy**

A stereoscopic microscope with 20X magnification is the most efficient tool for the detection of preexisting cracks in the fracture surface. Crack depth can be measured directly, if the microscope is fitted with a reticle, or indirectly by taking a microphotograph of the fracture surface.

Longitudinal sections of wire that are microetched may be studied with an optical microscope at magnifications of 50X to 200X to identify corrosion morphologies in pits, both intergranular and intragranular, and to establish the paths of secondary cracks near the fracture surface.

- **Scanning Electron Microscopy (SEM)**

Any characteristic that can be studied with optical microscopy is more easily studied with SEM.

SEM allows greater depth of field and better resolution at higher enlargements than optical microscopy. At the same time, SEM allows simultaneous close study of the failed surface.

With SEM, failure surfaces are visible with sufficient detail to identify the failure mechanism**,** such as cleavage or ductile rupture. Corrosion residues are also discernible on the metal structure or fracture surface.

- **Machining, Polishing and Etching**

Bridge wires should be machined and polished in the plane of the cast radius. This method generally cuts across any transverse pits and cracks that initiate at the inner radius. The polished surface is etched with various reagents to reveal the steel microstructure in detail.

- **Image Interpretation**

Images of failure morphologies under enlargement should be interpreted by metallurgists or, if they are unusual, by corrosion experts. The images may indicate embrittlement, hydrogen-assisted cracking or other corrosion mechanisms, recognizable to experts in these fields.

C3.2.5

In Stage 1 and Stage 2 wires, preexisting cracks are usually due to a manufacturing flaw, while in Stage 3 and Stage 4 wires, the cracks are most often caused by hydrogen that results from galvanic action. The surfaces of the preexisting cracks in the Stage 3 and Stage 4 wires are usually black, and the cracks themselves are easily stereoscopic optical microscope at 20X magnification. A sample wire is considered to contain a crack if any of the specimens cut from the sample contains a preexisting crack.

The outer surfaces of the wire in the vicinity of a brittle fracture should also be examined under a stereoscopic optical microscope for the presence of additional preexisting cracks.

A cracked specimen should be photographed, and the crack depth should be measured. The wire diameter at the failure plane, as well as the crack depth, should be reported in both absolute terms and as a fraction of wire diameter.

Longitudinal sections of short wire segments in the vicinity of a brittle fracture should be examined under either an optical or scanning electron microscope. In preparation, the surface of the specimen section should be polished and etched. The recommended etchant is a 10% solution of nitric acid in ethyl alcohol.

3.3 ZINC COATING TESTS

Two types of tests are performed on the zinc coating during cable wire evaluation: Weight of Zinc Coating Tests and Preece Tests. The minimum depth of the coating determines its condition, not the average depth.

3.3.1 Weight of Zinc Test

The Weight of Zinc Coating Test, specified in ASTM A90, is a gravimetric test that measures the weight of the zinc removed from a unit length of wire. It is used to determine the average weight of zinc in that length, separate from variations in coating thickness.

Weight of Zinc Coating Tests should be conducted on Stage 1 and Stage 2 specimens that display uniform zinc or spotted zinc loss.

3.3.2 Preece Test for Uniformity

The Preece Test, specified in ASTM A239, is used to determine the uniformity of the zinc coating on Stage 1 and Stage 2 wires.

Preece Tests are chemical tests that depend on the reaction of copper sulfate and zinc. They are used to confirm whether the coating on the specimen is depleted uniformly or locally.

Preece Tests should be conducted on Stage 1 and

distinguished from the fracture surfaces caused by the testing load.

A cracked wire is shown in Figure 3.2.5-1.

C.3.3

Wires often display white spots on a shiny silvery field of sound zinc. If the white spots represent 30% of the surface area or more, then there may be significant variations in the depth of the zinc coating.

C3.3.1

The average weight of zinc in a unit length, determined by testing, can be converted to an average remaining thickness of zinc coating and used to predict when the zinc coating will be depleted.

C3.3.2

Preece Tests are performed in series. Wires are dipped in a copper sulfate solution for a standard time period. If sufficient zinc is present, then the wire retains its shiny surface from the intact zinc. If the zinc is insufficient, then the copper electroplates the steel, and the wire surface turns the color of copper.

The tests are terminated after the fourth dip.

Stage 2 specimens that display uniform zinc or spotted zinc loss.

3.4 CHEMICAL ANALYSIS

The chemical composition of the steel wire should be determined under any of these circumstances: tests were never performed, results from previous tests are unavailable, or tests reveal unusual variations in the tensile strength of samples. Percentages of the following elements should be obtained:

- carbon
- silicon
- manganese
- phosphorous
- sulfur
- copper
- nickel
- chromium
- aluminum

Five wires should be analyzed to provide a complete record for future inspections. If the chemistry of the steel is found to vary significantly, a metallurgist should be consulted to study the effects on the properties of the wire.

A chemical analysis of the surface deposits on the wire samples should be performed if corrosion is present, to detect harmful contaminants. The presence or absence of the following salts should be established:

- chloride
- sulfates
- nitrates

The results should be reported in absolute amounts, per unit of wire area.

3.5 CORROSION ANALYSIS

In some cases, the investigator may recommend studying the corrosion product on a wire or anchorage. Corrosion analysis can be performed on surface corrosion films, or on the fracture surfaces of the steel, or on corrosion by-products.

C3.4

Variations in the carbon content of the wires may cause wider than usual variations in tensile strength. The Williamsburg Bridge cable wires are an example of this phenomenon. In ensuing inspections of such bridges, the pattern of sample taking should differ from the recommended pattern so that the extent of the variation in carbon content, the tensile strength and the ultimate strain throughout the cable can be determined. The proper procedure to follow is described by Matteo [1].

Aluminum, the last element listed, is not usually present in bridge wire, unless it has been used as a killing agent in the production of the steel.

C3.5

Various types of electronic microscopy are used in corrosion analysis:

- **X-Ray Photoelectron Spectroscopy (ESCA)**

  Also referred to as Electron Spectroscopy for Chemical Analysis or ESCA, X-Ray

GUIDELINES

Chlorides from roadway salts; sulfates, and nitrates from acid rain are some of the causes of corrosion revealed by the analysis. Remedial measures may be recommended to eliminate polluting elements.

COMMENTARY

Photoelectron Spectroscopy is a surface-sensitive spectroscopic technique that provides information about the composition and structure of the outermost atomic layers (2 nm) of a solid material. ESCA detects all elements except hydrogen and helium. The element detection limit is typically about 0.5%. Sometimes it is possible to determine the chemical state of elements, including their bonding structure, using this technique.

- **Energy Dispersive X-Ray Analysis (EDAX)**

  The Energy Dispersive X-Ray Spectrometer is an attachment to the Scanning Electron Microscope that identifies elements on the surface from X-rays emitted by the specimen. EDAX can detect elements as light as boron (atomic number 5). It is particularly suited to identifying inorganic elements. The results are only semi-quantitative without the use of primary standards, which are recommended. This is due to the complex combinations of variables, such as sample size, surface condition, and orientation of the apparatus. However, the small peak-to-background ratio encountered in analysis of low concentrations of elements is an unavoidable occurrence that makes adequate quantitative analysis nearly unobtainable.

- **X-Ray Diffraction (XRD)**

X-Ray Diffraction is used to obtain information about the structure, composition and state of polycrystalline materials. It can be used to determine the exact composition and state of the corrosion products. For instance, if adequate amounts of the product are available, it can identify various oxides of a particular element (e.g., magnetite Fe_3O_4 and hematite Fe_2O_3).

3.6 FIGURE FOR SECTION 3

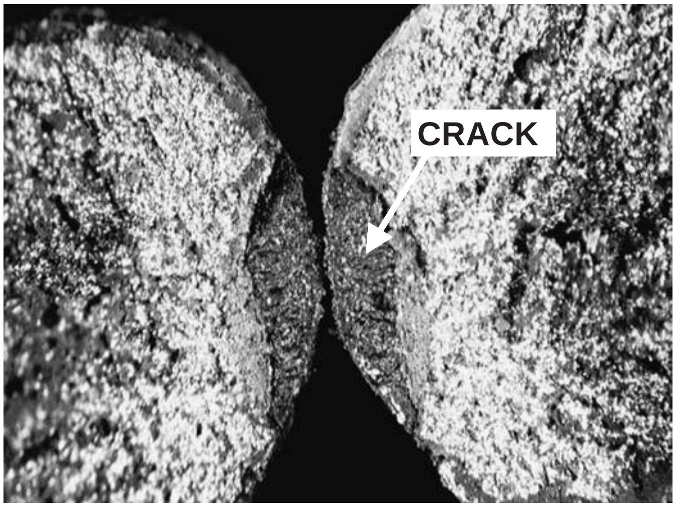


Figure 3.2.5-1. Cracked wire.

3.7 REFERENCE

1. Matteo, J., G. Deodatis, and D. P. Billington, *Safety Analysis of Suspension-Bridge Cables: Williamsburg Bridge*. Journal of Structural Engineering, 1994. 120(11): p. 3197–3211.

CONTENTS

FIGURES

4.1 INTRODUCTION

This section covers the tabulation of field observations and laboratory test results and their translation into a usable form for estimating cable strength. Instructions are given for determining the number of wires in each stage of corrosion, the effective development length, and the number of cracked wires in adjacent panels when the evaluated panel is the only panel inspected. If all the panels in the effective development length have been inspected, then the technique for evaluating cracked wires presented in Appendix B should be used instead.

4.2 NOTATION

a_j = fraction of a circle corresponding to the width of the sector that contains broken wire j (4.3.3.1)

a_{jk} = fraction of a circle corresponding to the width of the half sector that contains observed wire jk; where all sectors are of equal size, a_{jk} is a constant (4.3.2)

a_w = nominal area of one wire, used in lab analysis (4.5.1) (4.5.2)

B_{sm} = number of broken wires observed on the surfaces of the sector m wedged opening (4.3.3.1)

B_{um} = number of broken wires observed below the wedged surface layers of sector m (4.3.3.1)

C_d = redevelopment factor (fraction of 95% of the mean tensile strength of Group 2 wires that is developed in a broken wire at each cable band) (4.5.2)

d_0 = depth into cable at which no broken wires are found (4.3.3.2)

d_e = elastic deformation in length L due to force T (4.5.1)

d_{jk} = distance from center of surface wire to center of observed wire jk, expressed in the number of wires with $d_{jk} = 1$ for the surface wire (4.3.2)

d_w = average of measured gaps between the ends of a wire broken or cut in the cable in a panel or group of panels with the same length cable bands (4.5.1)

E = Young's modulus of wire (4.5.1)

e = ultimate strain of wire specimens; replaces x in Equations 4.4.3.1-1 and 4.4.3.1-2 (4.4.3.1)

F = wire force developed at each cable band (4.5.2)

i = panel number (4.3.3.1); number of a specimen (4.4.3.1)

j = identification number of an observed broken wire in sector m (4.3.3.1); number of a sample (4.4.3.1) (4.4.4)

jk = identification number of an observed wire in Stage k ($jk = 1$ to J_k)(4.3.2)

J_{bm} = total number of observed wires in sector m (4.3.3.1)

J_k = total number of observed wires in Stage k (4.3.2)

k = corrosion stage of wires (k = 1, 2, 3 and 4) (4.3.2); corrosion stage of a group of wires (k=2, 3, 4 and 5) (4.4.4)

L = length of a wire between centers of cable bands (4.4.3.2) (4.5.1)

L_0 = length of the test specimen between grips of the testing machine (4.4.3.2)

L_e = effective development length (4.5.2)

m = sector number (4.3.3.1)

M = number of sectors (4 for quadrants, 8 for octants, etc.) (4.3.3.1)

n_x = number of wires in ring x (4.3.1.2)

N = total number of wires in the cable (4.3.2); actual number of wires in the cable (4.3.1.1) (4.3.1.2) (4.3.2)

N_B = number of cable bands required to redevelop the wire (4.5.2)

$n_{b1,i}$ = number of broken wires in the outer ring of the cable in panel i (4.3.3.2)

n_{bi} = estimated total number of broken wires in cable panel i (4.3.3.1) (4.3.3.2)

n_{bm} = unfactored estimate of the number of broken wires in sector m (4.3.3.1)

n_j = number of wires in the ring that contains broken wire j (4.3.3.1); number of specimens tested from sample j (4.4.3.1)

n_{jk} = number of wires in the ring that contains observed wire jk (4.3.2)

N_{jk} = number of wires in cable represented by observed wire jk (4.3.2)

n_k = number of samples in Group k (4.4.4)

N_{sk} = number of Stage k wires in the cable (4.3.2)

N_T = number of panels on one side of a wire break in which the wire tension is less than T (4.5.1)

p_{sk} = fraction of wires in the cable represented by Stage k (4.3.2)

$p_{c,k}$ = fraction of Stage k wires that are cracked (4.4.2)

$p_{c,3}$ = fraction of Stage 3 wires that are cracked (4.4.2)

s = tensile strength of wire specimens; replaces x in Equations 4.4.3.1-1 and 4.4.3.1-2 (4.4.3.1)

T = tension in wire under service loads (4.5.1)

USF_m = weighting factor to adjust estimated number of broken wires for the number of layers observed in sector m (4.3.3.1)

X = number of rings of wires in the cable not including the center wire (4.3.1.1) (4.3.1.2) (4.3.2)

x = number of rings from the center of the cable to a specific ring (4.3.1.1); property of a wire (i.e., tensile strength or ultimate strain) (4.4.3.1) (4.4.4)

$x_{1,j}$ = probable minimum value of x_j in a length L of the wire from which sample j is removed (4.4.3.2) (4.4.4)

x_{ij} = property of specimen i cut from sample j (4.4.3.1)

x_{jk} = number of rings from the center of the cable to center of observed wire jk (4.3.2)

μ_{s2} = sample mean tensile strength of Group 2 wires (4.5.2)

μ_{sj} = sample mean of the property x for sample j (4.4.3.1) (4.4.4)

μ_{sk} = sample mean of property x of Group k wires (4.4.4)

σ_{sj} = sample standard deviation of the property x for sample j (4.4.3.1)

σ_{sk} = sample standard deviation of property x of Group k wires (4.4.4)

$\Phi^{-1}(L_0/L)$ = inverse of the standard normal cumulative distribution for the probability L_0/L (4.4.3.2)

4.3 MAPPING AND ESTIMATING DAMAGE

An observed wire is assumed to represent all the wires at the same depth on the same side of the wedged opening in the half-sector, either left or right of the opening, where the observation was made (see Figure 4.3-1). Field data recorded on inspection forms are analyzed to estimate the damage in each inspected panel of the cable. Wires can be either intact or broken and the calculations differ for each.

4.3.1 Number of Wires at a Specific Depth

For the purpose of analyzing data gathered in the field, it is assumed that the cable is composed of concentric rings of wires arranged around a central wire, as shown in Figure 4.3.1-1.

4.3.1.1 NUMBER OF RINGS IN THE CABLE

The number of rings in the cable is estimated by the following equation

$$X = \sqrt{\frac{N}{\pi}} + 0.5 \text{, rounded to the next higher integer} \qquad (4.3.1.1\text{-}1)$$

where

X = number of rings in the cable not including the center wire

N = actual number of wires in the cable

4.3.1.2 NUMBER OF WIRES IN EACH RING

The number of wires in each ring is given by

$$n_x = \frac{2x(N-1)}{X(X+1)} \qquad (4.3.1.2\text{-}1)$$

where

n_x = number of wires in ring x

C4.3

Spreadsheets similar to the illustrated ones are recommended for ease of calculation. One spreadsheet is used to analyze broken wires and one to analyze the stages of corrosion for each panel.

C4.3.1

The wires in a cable do not actually lie in precise rings, but it is assumed that they do because it facilitates estimating the number of wires at a specific depth inside the wedged opening.

It would be convenient to assume that the spacing from the center of one ring to the next is equivalent to one wire diameter. In fact, the spacing between rings is less than one wire diameter, because wires in one ring partially nest within the wires of the next inner ring. This more than offsets the spacing between wires in a specific ring, which is slightly greater than one wire diameter. The net effect is that the number of rings is greater than the distance from the surface of the center wire to the cable surface divided by the wire diameter.

C4.3.1.2

In most cases, wedge lines will be equally spaced around the cable. Each sector is a pie-shaped portion of the cable that embraces a wedge line and extends to a line midway to the next wedge line on either side (see Figure 4.3.1-1). The sample spreadsheets that accompany the Guidelines assume 8 wedge lines that form 8 sectors, but this is a convenience and does not apply automatically to every inspection. If wedge lines

x = number of rings from the center of the cable to a specific ring

The center wire in the cable lies at $x = 0$, and n_0 is taken as 1.

The number of wires in each ring is not rounded. Sample calculations of X and n are given in Figure 4.3.1.2-1.

4.3.2 Fraction of Cable in Each Stage of Corrosion

Each observed wire is assigned a corrosion stage; this is the highest observed stage in the length of wire exposed in the wedged opening.

The total number of cable wires in each stage of corrosion, k, is calculated by adding together the individual wires in each half-sector represented by an observed wire at that corrosion stage. The distance from the center of the cable to the center of each observed wire should be determined first. In Equation 4.3.1.2-1, the distance is expressed as x, or the number of rings from the center of the cable.

After x is determined, the number of wires in the ring, n_x, is multiplied by the fraction of the circle represented by the half-sector that contains the observed wire. For a cable inspected with four wedge lines (quadrants), the fraction is 1/8 (half of a quarter-circle); when eight wedge lines are used (octants), the fraction is 1/16. For other divisions, or unequal divisions that are the result of additional wedges being driven into the lower half of the cable, the appropriate fraction for each inspected wire should be used.

Let there be J_k wires observed in a specific corrosion Stage k. Each observed wire is given an identification number jk, starting with 1 and ending with J_k. Furthermore, the wire lies at a specific depth into the cable, d_{jk}, which is expressed as the number of wires from the surface wire, which is assigned the depth of 1. The number of wires in the ring containing wire jk is given by

$$n_{jk} = \frac{2x_{jk}(N-1)}{X(X-1)} \qquad (4.3.2\text{-}1)$$

in which

$$x_{jk} = X + 1 - d_{jk} \qquad (4.3.2\text{-}2)$$

where

x_{jk} = number of rings from the center of the

are not equally spaced, each sector still extends from a line midway between wedges on one side to a line midway between wedges on the other. In this case, each observed wire is assumed to represent half the wires in a ring in the sector rather than the wires on one side of the wedge. Both half-sectors are assumed to be of equal size in any given sector, but not all sectors are the same size.

C4.3.2

The most convenient way to calculate the fraction of the cable in each stage of corrosion is with a spreadsheet. The spreadsheet is constructed to calculate quantities of wires in each corrosion stage. The sum of the number of wires in each ring in each corrosion stage should equal the total number of wires in the cable. A sample spreadsheet is shown in Figure 4.3.2-1, which assumes that 8 rows of wedges have been observed.

The spreadsheet contains one row for each ring of wires from the surface to the center of the cable, with two columns for each wedge line inspected. The rings are numbered, starting with 1 for the outer ring, to fill out the first column of the spreadsheet. The shaded areas are filled in for each inspected panel with corrosion stage entered as an integer. Columns on the right are filled in automatically with spreadsheet formulas.

The center wire of the cable lies at $x = 0$, and $n_0 = 1$. The number, n_0, is not calculated by Equation 4.3.1.2-1, because the wire does not stand for a ring of wires. The value of d_{jk} for the wire is X+1.

The number of wires in each ring is shown in the second column of the spreadsheet. The corrosion stage of each ring of wires on each side of the wedged opening in each sector is entered on the spreadsheet in the appropriate column. For each observed wire, the worst corrosion stage found anywhere in the length of the panel is entered on the spreadsheet.

cable to the center of observed wire *jk*

n_{jk} = number of wires in the ring that contains observed wire *jk*

X = number of rings of wires in the cable not including the center wire

N = actual number of wires in the cable

d_{jk} = distance from the center of the surface wire (of cable) to center of observed wire *jk* expressed in the number of wires with $d_{jk} = 1$ for a surface wire

k = corrosion stage of wires (k=1 ,2, 3 and 4)

jk = identification number of an observed wire in Stage *k* (jk = 1 to J_k)

The number of wires in the cable represented by observed wire *jk* is

$$N_{jk} = n_{jk} \cdot a_{jk} \qquad (4.3.2\text{-}3)$$

where

N_{jk} = number of wires in cable represented by observed wire *jk*

a_{jk} = fraction of a circle corresponding to the width of the half-sector that contains observed wire *jk*; whenever all half-sectors are of equal size, a_{jk} is a constant.

and the total number of Stage *k* wires in the cable is

$$N_{sk} = \sum_{jk=1}^{J_k} N_{jk} = \sum_{jk=1}^{J_k} n_{jk} \cdot a_{jk} \qquad (4.3.2\text{-}4)$$

where

J_k = total number of observed wires in Stage *k*

N_{sk} = number of Stage *k* wires in the cable

The sum of all values of N_{sk} must equal the total number of wires in the cable. The fraction of the wires in the cable in each stage of corrosion is determined by

$$p_{sk} = N_{sk}/N \qquad (4.3.2\text{-}5)$$

where

p_{sk} = fraction of the wires in the cable represented by Stage *k*

N = total number of wires in the cable

4.3.3 Number of Broken Wires

The method of estimating the number of broken wires in a panel depends on their location. When they are found beyond the first few surface layers, each broken wire at a given depth in the cable is assumed to represent all wires at the same radius from the center of the cable in that half-sector (half-octant or half-quadrant, etc.). In Figure 4.3-1, the wires represented by the observed broken wires at depth d_L and d_R are indicated by the solid areas. This method of counting the wires is described in Article 4.3.3.1.

Whenever broken wires are found only on the outer surface and in the first few layers of the cable, they should be counted using the method described in Article 4.3.3.2.

A combination of the two counting methods is recommended whenever broken wires are found both on the surface and inside the cable The investigator should determine the depth to which each method is applied (see Article 4.3.3.3).

4.3.3.1 BROKEN WIRES IN CABLE INTERIOR

The number of broken wires is estimated in a manner similar to the one described for determining corrosion stages in Article 4.3.2. Interior broken wires are subdivided into two groups, those broken at the surface of the wedged opening, and those broken beneath the surface (a broken wire end is protruding). Broken wires in each sector, m, are counted separately. The equations for counting are:

$$n_{bm} = \sum_{j=1}^{J_{bm}} 0.5 \cdot n_j \cdot a_j \qquad (4.3.3.1\text{-}1)$$

where

n_{bm} = unfactored estimate of the number of broken wires in sector m

j = identification number of an observed broken wire in sector m

m = sector number

J_{bm} = total number of observed wires in sector m

n_j = number of wires in the ring that contains broken wire j (see Equation 4.3.2-1)

a_j = fraction of a circle corresponding to the width of sector m that contains broken

C4.3.3.1

Using a spreadsheet is also convenient for estimating the number of broken wires in a panel, as shown in Figure 4.3.3.1-1.

The shaded areas are filled in with the number of broken wires on both sides of the wedge at each depth. The last column is filled in automatically by spreadsheet formulas. The spreadsheet should contain a numbered row for each ring of wires from the surface to the center of the cable, and two columns for each inspected sector. The number of broken wires observed on the surface of the wedged opening is entered in one of the columns. If a wire is observed to be broken on each side of the wedged opening at the same depth, the number 2 is entered at the appropriate ring. If it is observed broken only on one side, the number 1 is entered. Broken wires observed in the layer directly beneath the surface layer are entered the same way in the right column.

Whenever broken wires at the surface (subscript “s”) and broken wires beneath the surface (subscript “u”) are found in a wedged opening, consideration must be given to the fact that more than one layer of wires has been observed. If the number of “s” and “u” wires is equal, then 2 layers have been observed. The observation of wires at the surface is always more dependable than the observation of wires beneath the wire j

A weighting factor, USF (Under Surface Factor), is applied to the number of broken wires, to account for the number of surfaces observed. It is calculated for each sector, making up for the fact that more wires have been sampled than the number of wires in contact with the wedges, protruding broken wires underneath the exposed layer in particular.

$$USF_m = \frac{B_{sm}}{(B_{sm} + B_{um})} \geq 0.5 \qquad (4.3.3.1\text{-}2)$$

where

USF_m = weighting factor to adjust estimated number of broken wires for the number of layers observed in sector m

B_{sm} = number of broken wires observed on the surfaces of the sector m wedged opening

B_{um} = number of broken wires observed below the wedged surface layers of sector m

The estimated total number of broken wires in a panel, i, is then

$$n_{bi} = \sum_{m=1}^{M} USF_m \cdot n_{bm} \qquad (4.3.3.1\text{-}3)$$

where

n_{bi} = estimated total number of broken wires in cable panel i

i = panel number

M = total number of sectors (4 for quadrants, 8 for octants, etc.)

4.3.3.2 BROKEN WIRES AT THE SURFACE

If broken wires are found only near the surface of the cable, then the depth at which broken wires are no longer found, d_0, can be determined by observing the wedged openings.

The inspector should use additional wedges to ascertain the depth at which no broken wires are found. The wedges should be located near surface broken wires, and driven at least 2 inches beyond the depth of Stage 4 wires.

Depth d_0 is expressed in number of wires from the cable surface, with the surface wire being number 1. The number of broken wires in each ring is conservatively

surface.

The USF, applied to the total number of wires estimated to be broken in each sector, is always greater than or equal to 0.5. If only “s” wires are observed, then USF = 1.0. If an equal number of “s” and “u” wires are observed, then USF = 0.50 (i.e., 2 layers of wires have been observed, each layer corresponds to half the number of wires at the corresponding radius from the center of the cable). If more “u” wires are observed than “s” wires, then the number of layers observed is still 2. USF remains 0.50, because the surface of the wedged opening is actually seen, and the lower layer is only assumed to be seen by noting the broken wires that protrude.

C4.3.3.2

In some cables, broken wires are found only at or near the outer surface of the cable. To count only wires found broken at the wedges would distort the assumed number of broken wires.

When broken wires are observed only in the outer layer, d_0 will be 2, because no broken wires are found in the second layer. The number of broken wires using Equation 4.3.3.2-1 is then equal to $n_{b1,i}$.

assumed to decrease in a linear manner from the surface to zero at the depth d_0. The total number of broken wires is calculated as the number of broken wires at the surface of the cable in ring 1 multiplied by $d_0/2$,

$$n_{bi} = n_{b1,i} \cdot d_0 / 2 \qquad (4.3.3.2\text{-}1)$$

where

d_0 = depth into cable at which no broken wires are found

$n_{b1,i}$ = number of broken wires in the outer ring of the cable in panel i

4.3.3.3 BROKEN WIRES AT BOTH LOCATIONS

Whenever broken wires are found at the surface and inside the cable, the investigator should determine whether broken wires can be observed in one or two layers from the surface, and then estimate the number of additional interior broken wires beyond those layers, using Article 4.3.3.1. The total number of broken wires, n_{bi}, is the sum of the observed broken wires in the outer one or two layers and the estimated interior broken wires.

Additional wedges should be driven between the recommended wedges halfway to the center of the cable for a more accurate estimate of the number of broken wires inside the cable.

4.4 WIRE PROPERTIES

4.4.1 General

The properties of a single cable wire can vary from those of other wires; they can also vary along the length of that wire. The investigator should obtain the lowest values of these properties in a panel length for each wire, as well as the variation among all the wires in the cable.

As a first step in this process, the laboratory test data for the sample wires are sorted into these groups:

Group 1	samples exhibiting Stage 1 corrosion, if determined by the investigator to be needed
Group 2	samples exhibiting Stage 1 or Stage 2 corrosion
Group 3	samples exhibiting Stage 3 corrosion that are not cracked
Group 4	samples exhibiting Stage 4 corrosion that are not cracked

C4.3.3.3

When a full panel length is unwrapped, the number of broken wires in the outer ring between cable bands can be known with certainty. If an outer wire is broken under the cable band, it will usually be loose in the exposed length. Broken wires in the second layer can often be detected with some prying of the outer layer of wires.

C4.4.1

In general, the properties of Stage 1 and Stage 2 wires are alike, or vary so little that they are considered to form a single group, called Group 2. Should the investigator find significant variations between the two stages, they should be divided into Group 1 and Group 2, respectively.

Wires that are not cracked but that exhibit corrosion pitting to any depth are assigned to Stage 3 and Stage 4.

Very few Stage 3 samples are expected to contain cracks, so that statistical data for the strength or elongation of any Stage 3 cracked samples should not be used in estimating cable strength. Cracks usually occur in Stage 3 wires that are close to being Stage 4, and therefore, Stage 3 and Stage 4 cracked wire data can be combined into a single group, called Group 5. It is more conservative, however, to use only the

Group 5 samples exhibiting Stage 3 or Stage 4 corrosion that contain one or more cracks

4.4.2 Cracked Wires as a Separate Group

A sample wire is cracked if any of the specimens cut from that sample contains a preexisting crack. The fraction of cracked wires in each stage of corrosion is given by

$$p_{c,k} = \frac{\text{number of cracked Stage } k \text{ sample wires}}{\text{total number of Stage } k \text{ sample wires}} \tag{4.4.2-1}$$

where

$p_{c,k}$ = fraction of Stage *k* wires that are cracked

For Stage 3 wires,

$$p_{c,3} = \frac{0.33 \cdot \text{number of cracked Stage 3 sample wires}}{\text{total number of Stage 3 sample wires}} \tag{4.4.2-2}$$

where

$p_{c,3}$ = fraction of Stage 3 wires that are cracked

4.4.3 Individual Wires

4.4.3.1 MEAN PROPERTIES

The sample mean and sample standard deviation of the tensile strengths, and the ultimate elongations of the specimens cut from each sample, are determined as follows

$$\mu_{sj} = \frac{1}{n_j} \cdot \sum_{i=1}^{n_j} x_{ij} \tag{4.4.3.1-1}$$

$$\sigma_{sj}^2 = \left(\frac{1}{(n_j - 1)} \cdot \sum_{i=1}^{n_j} x_{ij}^2 \right) - \mu_{sj}^2 \tag{4.4.3.1-2}$$

where

μ_{sj} = sample mean of the property *x* for sample *j*

σ_{sj} = sample standard deviation of the property *x* for sample *j*

x = property of a wire (i.e., tensile strength or

properties of Stage 4 cracked wires to represent all the cracked wires, a practice that is recommended.

The investigator must decide whether to introduce an additional group whenever 25% or 8 Stage 3 samples are found to have cracks. If so, all cracked wires should form a single group, and the property distributions for the two stages of cracked wires should be combined (see Article 5.3.3.1.1).

C4.4.2

The detection of a crack in a specimen is described in Article 3.2.5. If cracks are found in Stage 3 samples, they are usually in the outermost layers, with Stage 4 wires close by. The factor, 0.33, adjusts for the fact that Stage 3 wires found deeper inside the cable rarely exhibit cracks. If they do, the factor should be increased accordingly.

C4.4.3.1

The symbols μ and σ refer to the mean and standard deviation of a property of the entire population of wires in the cable. The mean and standard deviation used in cable strength models are the sample mean and sample deviation determined from laboratory tests made on a selection of cable wires removed during inspection. They are designated by μ_s and σ_s.

ultimate strain)

x_{ij} = property of specimen i cut from sample j

s = tensile strength of wire specimens, (replaces x in Equations 4.4.3.1-1 and 4.4.3.1-2)

e = ultimate strain of wire specimens (replaces x in Equations 4.4.3.1-1 and 4.4.3.1-2)

n_j = number of specimens tested from sample j

i = number of a specimen

j = number of a sample

4.4.3.2 MINIMUM PROPERTIES IN A PANEL LENGTH

It is necessary to estimate the weakest point of the wire between cable bands. To estimate the probable minimum tensile strength of each sample in a length equal to the cable band spacing, L, the following equation is used

$$x_{1,j} = \mu_{sj} + \Phi^{-1}\left(\frac{L_0}{L}\right) \cdot \sigma_{sj} \qquad (4.4.3.2\text{-}1)$$

where

$x_{1,j}$ = probable minimum value of x_j in a length L of the wire from which sample j is removed

$\Phi^{-1}(L_0/L)$ = inverse of the standard normal cumulative distribution for the probability L_0/L

L_0 = length of the test specimen between grips of the testing machine

L = length of a wire between centers of cable bands

The value of the term $\Phi^{-1}(L_0/L)$ is given in Figure 4.4.3.2-1.

If a negative minimum value of a property results, zero should be substituted for the minimum value.

C4.4.3.2

A wire will fail at its weakest point within a given panel. Thus, the estimated minimum strength or ultimate strain of a wire in a length of panel is required for estimating total cable strength.

The method for estimating the strength of the weakest link of a chain of n links is used to find this minimum.

The specimens used to determine the properties in tensile tests should measure 12 inches between the jaws of the testing machine. The properties of a specimen are, by definition, the minimum in this length, defined as L_0.

The probability of any 12-inch length of wire in a total length, L, being the weakest (or having the minimum ultimate strain) is $1/n$, with n being the number of lengths of wire in the length, L, or $n = L/L_0$. The properties of a single wire will vary according to a distribution function. The Normal distribution is often used for this purpose.

A substitution of the Standard Normal distribution for the Normal distribution is helpful. If the variant z, in terms of the number of standard deviations, is used, then the mean will be zero. The function, $\Phi(z)$, gives the probability of an event; thus the inverse, Φ^{-1}, will give the number of standard deviations for a given probability. The function can be expressed as the single curve shown in Figure 4.3.3.2-1, which is a function of $L/L_0 = n$. The value of Φ^{-1} is used in Equation 1 to determine the minimum value of the tensile strength. The appropriate number of standard deviations is subtracted from the mean tensile strength. The plus sign in the equation is correct, because Φ^{-1} is a negative value. The inverse of the Standard Normal distribution is included in some spreadsheet programs.

In some extreme cases, especially for ultimate strain, the Normal distribution may predict a negative value for the minimum value of a property when the coefficient of variation, *V*, is large. In these instances, zero is sufficient for the minimum value of the property. A more exact value can be calculated using the Gamma distribution, which is discussed in Appendix A to the final report for NCHRP Project 10-57, on the accompanying CD.

4.4.4 Means and Standard Deviations for Each Group

For each group of samples, calculate the sample mean and sample standard deviation of the minimum estimated properties using the following equations:

$$\mu_{sk} = \frac{1}{n_k} \cdot \sum_{j=1}^{n_k} x_{1,j} \tag{4.4.4-1}$$

$$\sigma_{sk}^2 = \left(\frac{1}{(n_k - 1)} \cdot \sum_{j=1}^{n_k} x_{1,j}^2 \right) - \mu_{sk}^2 \tag{4.4.4-2}$$

where

μ_{sk} = sample mean of property *x* of Group *k* wires

σ_{sk} = sample standard deviation of property *x* of Group *k* wires

n_k = number of samples in Group *k*

j = number of a sample

k = corrosion stage of a group of wires (k = 2, 3, 4 and 5)

$x_{1,j}$ = probable minimum value of x_j in a length *L* of the wire from which sample *j* is removed

x = property of a wire (i.e., tensile strength or ultimate strain)

C4.4.4

In calculating the sample standard deviation, the number of samples, (*n*), is usually decreased by 1 as a conservative measure, especially for small numbers of samples. The resulting increase in the standard deviation diminishes as the number of samples increases. This reduction in *n* is applied twice in these Guidelines, first to the individual samples, and again in calculating the standard deviation of the groups.

4.5 WIRE REDEVELOPMENT

A broken wire does not become inactive over the entire cable length. It redevelops its force as the distance from the break increases, caused by friction at the cable bands.

The force in a wire developed at a cable band is estimated using the measured gap between the ends of a broken wire, or a wire after the first cut is made for the purpose of removing a sample.

Wire failure separations used to estimate redevelopment capacity should come from an area near the evaluated panel.

Investigators should take measurements of as many failed wire separations as possible in the area under study. Refer to Section 2.4.3.4 for further discussion.

C4.5

Wire wrapping has also been found to reduce slippage in broken wires. The effect is ignored, because it is unquantifiable and is lost when the cable is unwrapped, although it is reestablished upon rewrapping. Whenever a single panel is unwrapped, the wrapping in adjacent panels remains effective, and the redevelopment coefficient allows for its effect.

Taking wire failure separations in the area under study is particularly important on the steeper slopes of the cable, where the bands are large and exhibit as much as 2.5 to 3 times the clamping force as at the center of the span. A smaller value of L_e may be found at these locations, which would increase cable strength. If data from shorter bands elsewhere on the cable were to be used instead, the redevelopment capacity could be underestimated.

Wire failure separations predict whether the band can redevelop dead load plus live load only at the time of observation. They cannot be used to determine whether the bands may develop more capacity in the future (e.g., if the cable band bolts are retightened).

4.5.1 Wire Force at a Cable Band

The effective development length is determined for each panel from which sample wires are removed, or in which broken wires are found. In the panels on each side of the one with the broken wire, the force in that wire is less than the service tension in an unbroken wire (Figure 4.5.1-1), The number of these panels is

$$N_T = (d_w/d_e) - 1,\ \text{rounded to the next higher integer} \tag{4.5.1-1}$$

in which

$$d_e = TL / a_w E \tag{4.5.1-2}$$

where

a_w = nominal area of one wire, used in lab analysis

d_e = elastic deformation in length L due to force T

d_w = average of measured gaps between the ends of a wire broken or cut in the cable in a panel or group of panels with the same length cable bands

E = Young’s modulus of wire

C4.5.1

Whenever a wire breaks or is cut inside the cable, the ends of the wire separate for a short distance. If the wires were perfectly clamped at the adjacent cable bands and could not slip relative to each other at those points, then the gap would be exactly equivalent to the elastic stretch in the wire between cable bands under the action of the cable loads. This is often the case, and then $N_T = 0$ in Equation 4.5.1-1. One cable band is able to develop at least the working tension in the wire, conservatively assumed to be exactly the working tension and no more.

If the solution of Equation 4.5.1-1 is an integer, including 0, then it is not rounded up to the next higher integer.

If the gap is greater than d_e, then it is necessary to determine the fraction of the working tension in the wires that one cable band can develop. It is assumed that the behavior is symmetrical, that the wire tension in all panels is the same, and that the force redeveloped in a wire is the same at all the bands near the wire break.

Bands at the steepest slope will be longer, have more bolts, and clamp the wires tighter. The number of locations for which the effective development length is

L = length of a wire between centers of cable bands

N_T = number of panels on one side of a wire break in which the wire tension is less than T

T = tension in wire under service loads

4.5.2 Effective Development Length and Redevelopment Coefficient

As shown in Figure 4.5.2-1, the effective development length is expressed as the number of cable panels, always odd, that is twice the number of panels in which the wire is redeveloped plus the panel in which the wire is evaluated, or twice the number of cable bands required to redevelop the wire minus 1, or

$$L_e = 2N_B - 1 \qquad (4.5.2\text{-}1)$$

in which

$$N_B = \frac{0.95 \cdot \mu_{s2} \cdot a_w}{T} \cdot \frac{N_T \cdot (N_T + 1)}{\left(2N_T + 1 - \dfrac{d_w}{d_e}\right)},$$

rounded to the next higher integer (4.5.2-2)

and where

L_e = effective development length

N_B = number of cable bands required to redevelop the wire

μ_{s2} = sample mean tensile strength of Group 2 wires

When $d_w = d_e$

$$N_B = \frac{0.95 \cdot \mu_{s2} \cdot a_w}{T},$$

rounded to the next higher integer (4.5.2-3)

The redevelopment coefficient is the fraction of 95% of the mean strength of Group 2 wires developed by friction at each cable band through which the wire passes, assuming that each cable band in the effective development length, including the end band, develops the same force in the wire.

$$C_d = \frac{1}{N_B} = \frac{2}{L_e - 1} \qquad (4.5.2\text{-}4)$$

where

calculated can be reduced by grouping panels that have cable bands of equal length. Then, d_w is determined by averaging the measured gaps at wire cuts in all the panels in the group.

C4.5.2

Both effective development length, L_e, and the redevelopment coefficient, C_d, are required for calculating cable strength. Beyond the effective development length, a broken wire will have no effect on the calculated panel strength at the center of that length. The effective development length is a function of the stress at which the cable reaches its strength, calculated with one of the various strength models. Cable efficiency, defined as the cable strength divided by the mean wire strength multiplied by the number of wires in the cable, is about 95% for an undeteriorated cable. Thus, to develop full cable strength, only 95% or less of the mean wire strength needs to be redeveloped in the broken wire.

Whenever $d_w = d_e$, Equation 4.5.2-2 contains the expression $N_T/N_T = 0/0$ and is indeterminate, use Equation 4.5.2-3 instead.

The redevelopment coefficient is needed to calculate the force of a wire in the evaluated panel that is broken in a nearby panel.

Whenever the value of L_e varies by more than two panels between areas with short and long cable bands, the investigator should determine whether different values for C_d and L_e are warranted in cable strength calculations. If the value varies by only two panels, the value of C_d and L_e calculated from the average of all the measured gaps at cut and broken wires may be used for the entire cable.

C_d = redevelopment factor (fraction of 95% of the mean tensile strength of Group 2 wires that is developed in a broken wire at each cable band)

The wire force, *F*, developed by friction at each cable band is then

$$F = C_d \cdot 0.95 \cdot \mu_{s2} \cdot a_w \qquad (4.5.2\text{-}5)$$

where

F = wire force developed at each cable band

4.6 FIGURES FOR SECTION 4

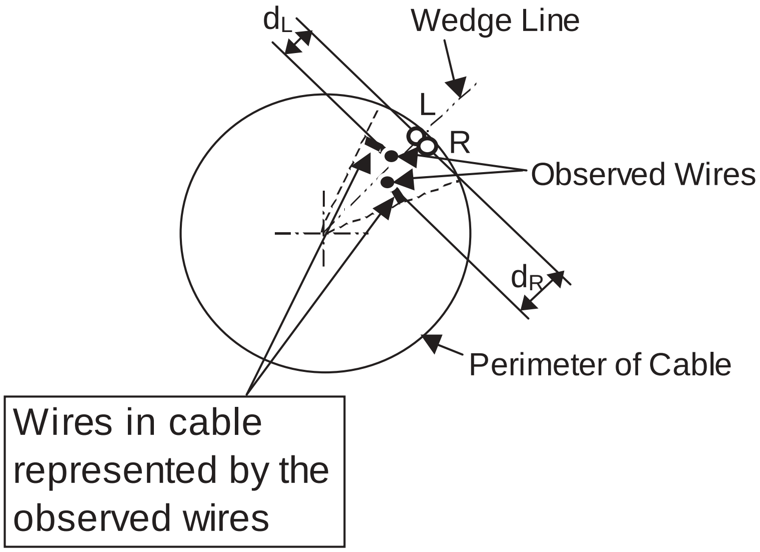


Figure 4.3.-1. Counting wires in half-sectors.

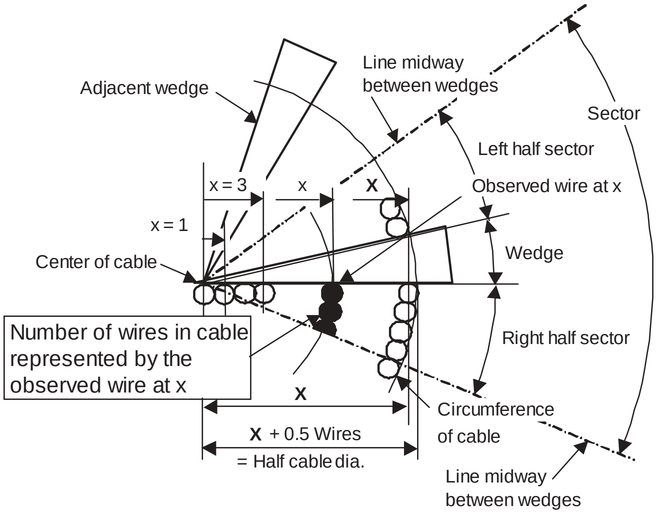


Figure 4.3.1-1. Counting wires.

EXAMPLE CALCULATION
PROJECT: **CENTENNIAL BRIDGE**
NUMBER OF ROWS OF WIRES IN CABLE **& NUMBER OF WIRES IN EACH ROW**

NO OF WIRES PER STRAND =	**270**
NO OF STRANDS IN CABLE =	**37**
TOTAL NO OF WIRES IN CABLE = *N* =	**9990**

$X = \sqrt{N\pi} + 0.5$ ROUNDED TO NEXT HIGHER INTEGER

$$n_x = \frac{2x(N-1)}{X(X+1)}$$

X = ROUNDUP(SQRT(N/π)+0.5,0) 57

	RING NO FROM OUTSIDE **d**	DIST FROM CTR OF CABLE **x**	NO OF WIRES IN RING **n**
OUTER LAYER OF WIRES	1	57	344.4
	2	56	338.4
	3	55	332.4
	4	54	326.3
	5	53	320.3
	6	52	314.2
	7	51	308.2
	8	50	302.1
	9	49	296.1
	10	48	290.1
	11	47	284.0
	12	46	278.0
	13	45	271.9
	14	44	265.9
	15	43	259.8
	16	42	253.8
	17	41	247.8
	18	40	241.7
	19	39	235.7
	20	38	229.6
	21	37	223.6
	22	36	217.5
	23	35	211.5
	24	34	205.5
	25	33	199.4
	26	32	193.4
	27	31	187.3
	28	30	181.3
	29	29	175.2
	30	28	169.2
	31	27	163.2
	32	26	157.1
	33	25	151.1
	34	24	145.0
	35	23	139.0
	36	22	132.9
	37	21	126.9
	38	20	120.9
	39	19	114.8
	40	18	108.8
	41	17	102.7
	42	16	96.7
	43	15	90.6
	44	14	84.6
	45	13	78.6
	46	12	72.5
	47	11	66.5
	48	10	60.4
	49	9	54.4
	50	8	48.3
	51	7	42.3
	52	6	36.3
	53	5	30.2
	54	4	24.2
	55	3	18.1
	56	2	12.1
	57	1	6.0
CENTER OF CABLE	58	0	1.0
	TOTAL		9990.0

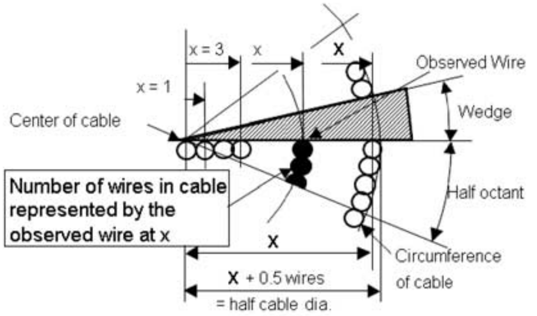
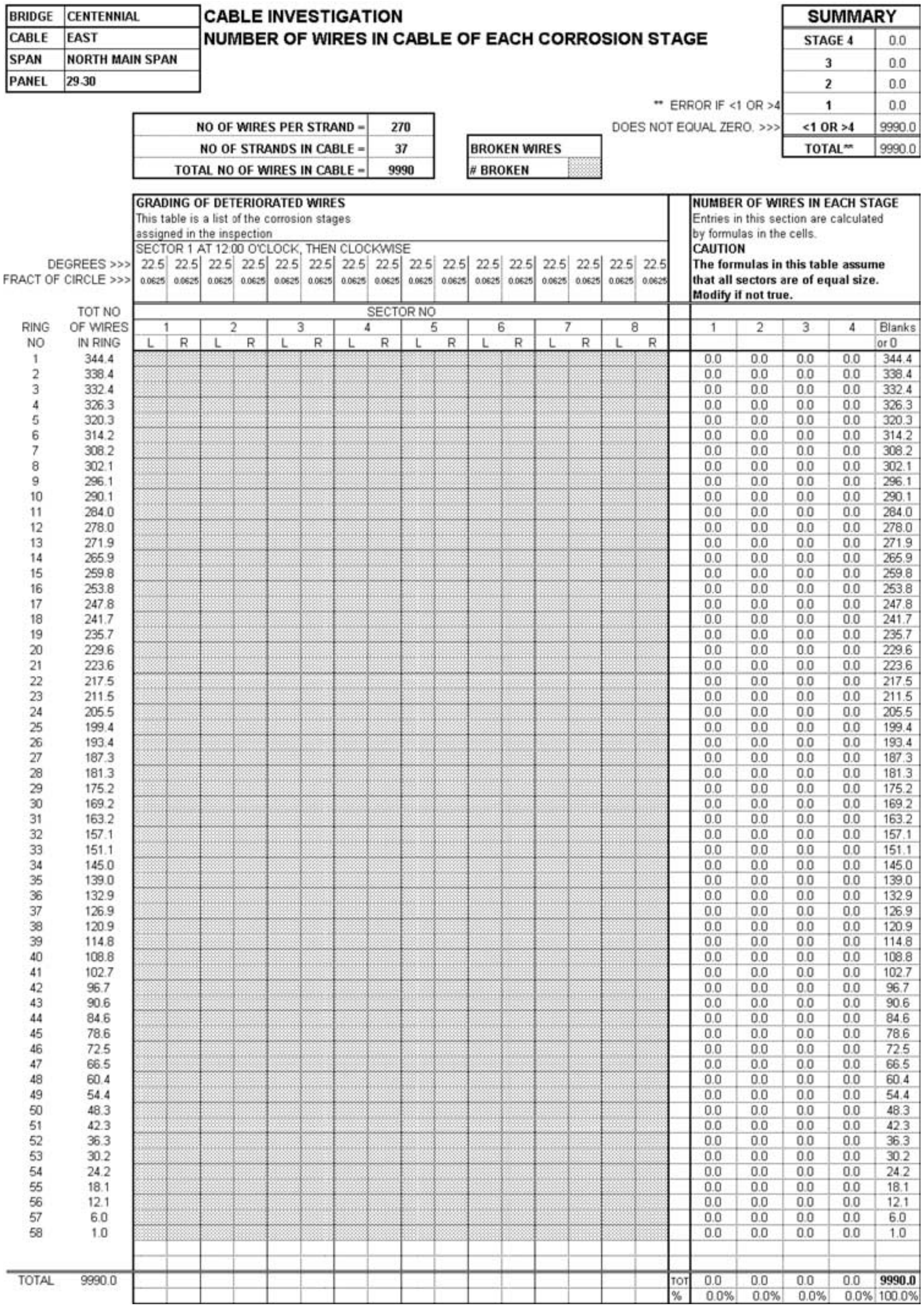


Figure 4.3.1.2-1. Calculation of number of rings and wires in each ring.



BRIDGE	CENTENNIAL
CABLE	EAST
SPAN	NORTH MAIN SPAN
PANEL	29-30

CABLE INVESTIGATION

NUMBER OF WIRES IN CABLE OF EACH CORROSION STAGE

SUMMARY	
STAGE 4	0.0
3	0.0
2	0.0
1	0.0
<1 OR >4	9990.0
TOTAL**	9990.0

** ERROR IF <1 OR >4 DOES NOT EQUAL ZERO. >>>

NO OF WIRES PER STRAND =	270
NO OF STRANDS IN CABLE =	37
TOTAL NO OF WIRES IN CABLE =	9990

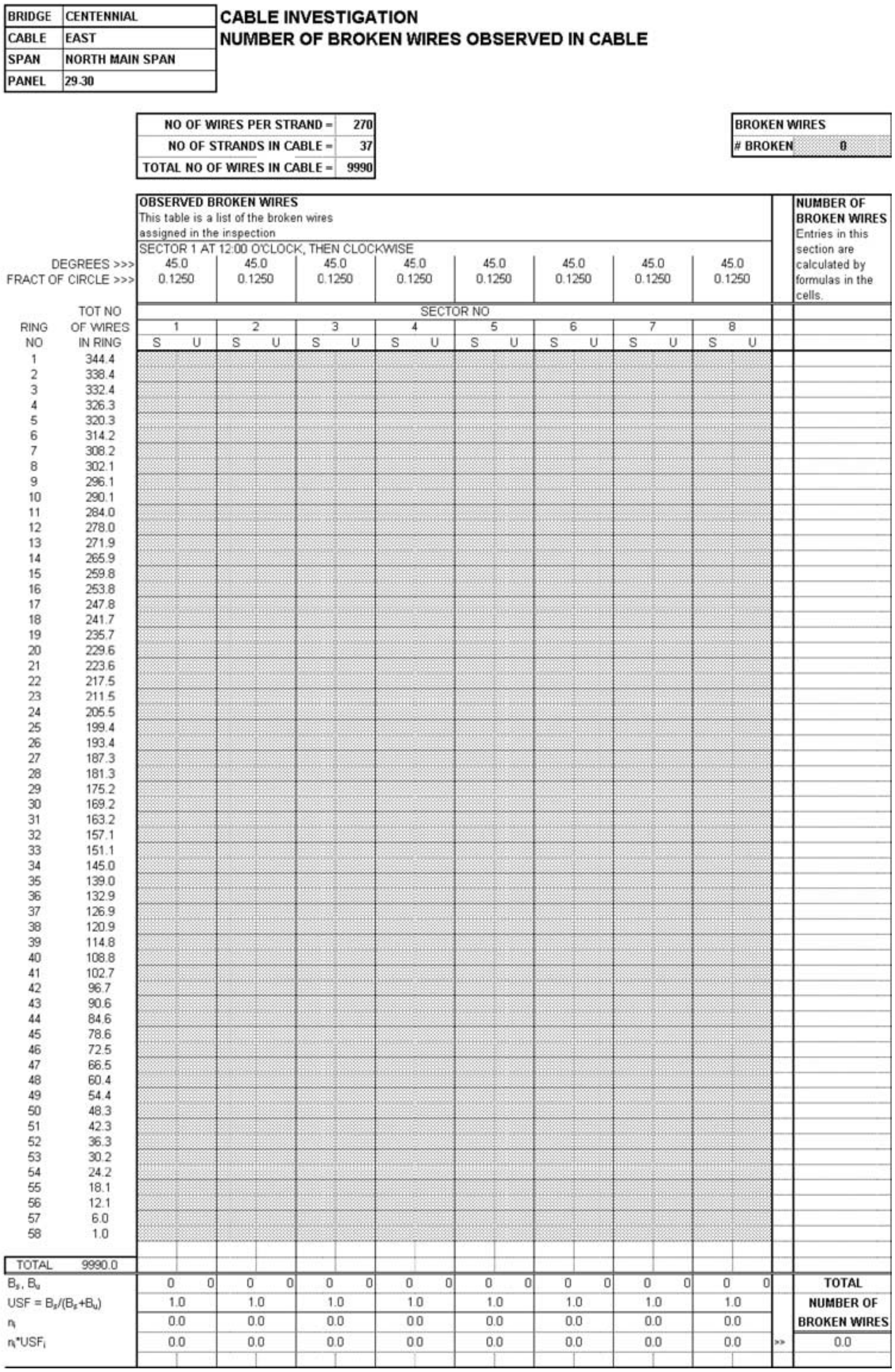
BROKEN WIRES	
# BROKEN	

GRADING OF DETERIORATED WIRES
This table is a list of the corrosion stages assigned in the inspection
SECTOR 1 AT 12:00 O'CLOCK, THEN CLOCKWISE

NUMBER OF WIRES IN EACH STAGE
Entries in this section are calculated by formulas in the cells.
CAUTION
The formulas in this table assume that all sectors are of equal size. Modify if not true.

RING NO	TOT NO OF WIRES IN RING	SECTOR NO 1		2		3		4		5		6		7		8			1	2	3	4	Blanks or 0
DEGREES >>>		22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5						
FRACT OF CIRCLE >>>		0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625						
		L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R						
1	344.4																		0.0	0.0	0.0	0.0	344.4
2	338.4																		0.0	0.0	0.0	0.0	338.4
3	332.4																		0.0	0.0	0.0	0.0	332.4
4	326.3																		0.0	0.0	0.0	0.0	326.3
5	320.3																		0.0	0.0	0.0	0.0	320.3
6	314.2																		0.0	0.0	0.0	0.0	314.2
7	308.2																		0.0	0.0	0.0	0.0	308.2
8	302.1																		0.0	0.0	0.0	0.0	302.1
9	296.1																		0.0	0.0	0.0	0.0	296.1
10	290.1																		0.0	0.0	0.0	0.0	290.1
11	284.0																		0.0	0.0	0.0	0.0	284.0
12	278.0																		0.0	0.0	0.0	0.0	278.0
13	271.9																		0.0	0.0	0.0	0.0	271.9
14	265.9																		0.0	0.0	0.0	0.0	265.9
15	259.8																		0.0	0.0	0.0	0.0	259.8
16	253.8																		0.0	0.0	0.0	0.0	253.8
17	247.8																		0.0	0.0	0.0	0.0	247.8
18	241.7																		0.0	0.0	0.0	0.0	241.7
19	235.7																		0.0	0.0	0.0	0.0	235.7
20	229.6																		0.0	0.0	0.0	0.0	229.6
21	223.6																		0.0	0.0	0.0	0.0	223.6
22	217.5																		0.0	0.0	0.0	0.0	217.5
23	211.5																		0.0	0.0	0.0	0.0	211.5
24	205.5																		0.0	0.0	0.0	0.0	205.5
25	199.4																		0.0	0.0	0.0	0.0	199.4
26	193.4																		0.0	0.0	0.0	0.0	193.4
27	187.3																		0.0	0.0	0.0	0.0	187.3
28	181.3																		0.0	0.0	0.0	0.0	181.3
29	175.2																		0.0	0.0	0.0	0.0	175.2
30	169.2																		0.0	0.0	0.0	0.0	169.2
31	163.2																		0.0	0.0	0.0	0.0	163.2
32	157.1																		0.0	0.0	0.0	0.0	157.1
33	151.1																		0.0	0.0	0.0	0.0	151.1
34	145.0																		0.0	0.0	0.0	0.0	145.0
35	139.0																		0.0	0.0	0.0	0.0	139.0
36	132.9																		0.0	0.0	0.0	0.0	132.9
37	126.9																		0.0	0.0	0.0	0.0	126.9
38	120.9																		0.0	0.0	0.0	0.0	120.9
39	114.8																		0.0	0.0	0.0	0.0	114.8
40	108.8																		0.0	0.0	0.0	0.0	108.8
41	102.7																		0.0	0.0	0.0	0.0	102.7
42	96.7																		0.0	0.0	0.0	0.0	96.7
43	90.6																		0.0	0.0	0.0	0.0	90.6
44	84.6																		0.0	0.0	0.0	0.0	84.6
45	78.6																		0.0	0.0	0.0	0.0	78.6
46	72.5																		0.0	0.0	0.0	0.0	72.5
47	66.5																		0.0	0.0	0.0	0.0	66.5
48	60.4																		0.0	0.0	0.0	0.0	60.4
49	54.4																		0.0	0.0	0.0	0.0	54.4
50	48.3																		0.0	0.0	0.0	0.0	48.3
51	42.3																		0.0	0.0	0.0	0.0	42.3
52	36.3																		0.0	0.0	0.0	0.0	36.3
53	30.2																		0.0	0.0	0.0	0.0	30.2
54	24.2																		0.0	0.0	0.0	0.0	24.2
55	18.1																		0.0	0.0	0.0	0.0	18.1
56	12.1																		0.0	0.0	0.0	0.0	12.1
57	6.0																		0.0	0.0	0.0	0.0	6.0
58	1.0																		0.0	0.0	0.0	0.0	1.0
TOTAL	9990.0																	TOT	0.0	0.0	0.0	0.0	**9990.0**
																		%	0.0%	0.0%	0.0%	0.0%	100.0%

Figure 4.3.2-1. Spreadsheet for reporting corrosion stages.



BRIDGE	CENTENNIAL
CABLE	EAST
SPAN	NORTH MAIN SPAN
PANEL	29-30

CABLE INVESTIGATION
NUMBER OF BROKEN WIRES OBSERVED IN CABLE

NO OF WIRES PER STRAND =	270
NO OF STRANDS IN CABLE =	37
TOTAL NO OF WIRES IN CABLE =	9990

BROKEN WIRES	
# BROKEN	0

OBSERVED BROKEN WIRES
This table is a list of the broken wires assigned in the inspection
SECTOR 1 AT 12:00 O'CLOCK, THEN CLOCKWISE

NUMBER OF BROKEN WIRES
Entries in this section are calculated by formulas in the cells.

	DEGREES >>>	45.0		45.0		45.0		45.0		45.0		45.0		45.0		45.0			
	FRACT OF CIRCLE >>>	0.1250		0.1250		0.1250		0.1250		0.1250		0.1250		0.1250		0.1250			
	TOT NO	SECTOR NO																	
RING	OF WIRES	1		2		3		4		5		6		7		8			
NO	IN RING	S	U	S	U	S	U	S	U	S	U	S	U	S	U	S	U		
1	344.4																		
2	338.4																		
3	332.4																		
4	326.3																		
5	320.3																		
6	314.2																		
7	308.2																		
8	302.1																		
9	296.1																		
10	290.1																		
11	284.0																		
12	278.0																		
13	271.9																		
14	265.9																		
15	259.8																		
16	253.8																		
17	247.8																		
18	241.7																		
19	235.7																		
20	229.6																		
21	223.6																		
22	217.5																		
23	211.5																		
24	205.5																		
25	199.4																		
26	193.4																		
27	187.3																		
28	181.3																		
29	175.2																		
30	169.2																		
31	163.2																		
32	157.1																		
33	151.1																		
34	145.0																		
35	139.0																		
36	132.9																		
37	126.9																		
38	120.9																		
39	114.8																		
40	108.8																		
41	102.7																		
42	96.7																		
43	90.6																		
44	84.6																		
45	78.6																		
46	72.5																		
47	66.5																		
48	60.4																		
49	54.4																		
50	48.3																		
51	42.3																		
52	36.3																		
53	30.2																		
54	24.2																		
55	18.1																		
56	12.1																		
57	6.0																		
58	1.0																		
TOTAL	9990.0																		
B_s, B_u		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		TOTAL
$USF = B_s/(B_s+B_u)$		1.0		1.0		1.0		1.0		1.0		1.0		1.0		1.0			NUMBER OF
n_i		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0			BROKEN WIRES
n_i*USF_i		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		>>	0.0

Figure 4.3.3.1-1. Spreadsheet for reporting broken wires.

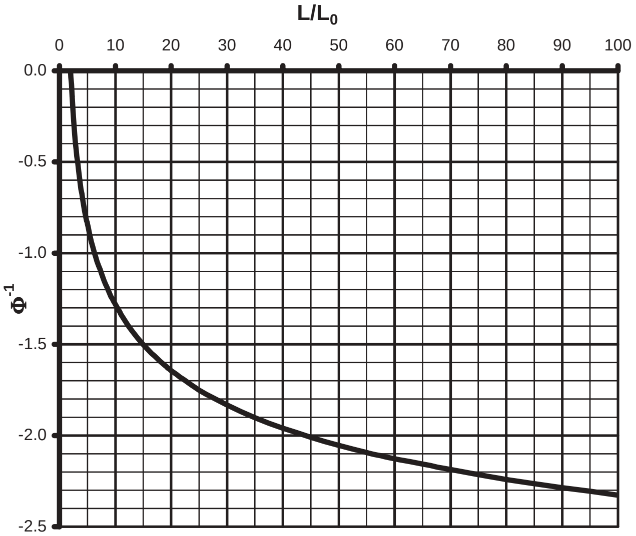


Figure 4.4.3.2-1. Inverse of standard Normal cumulative distribution.

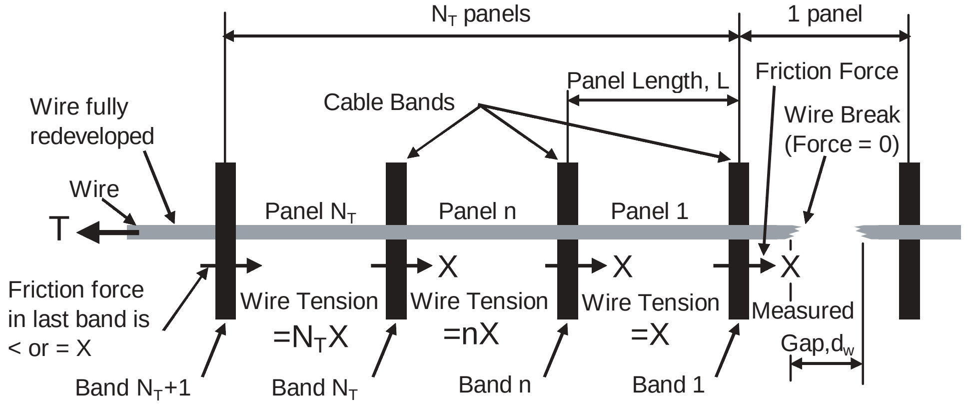


Figure 4.5.1-1. Redevelopment of wire tension through friction at the cable bands.

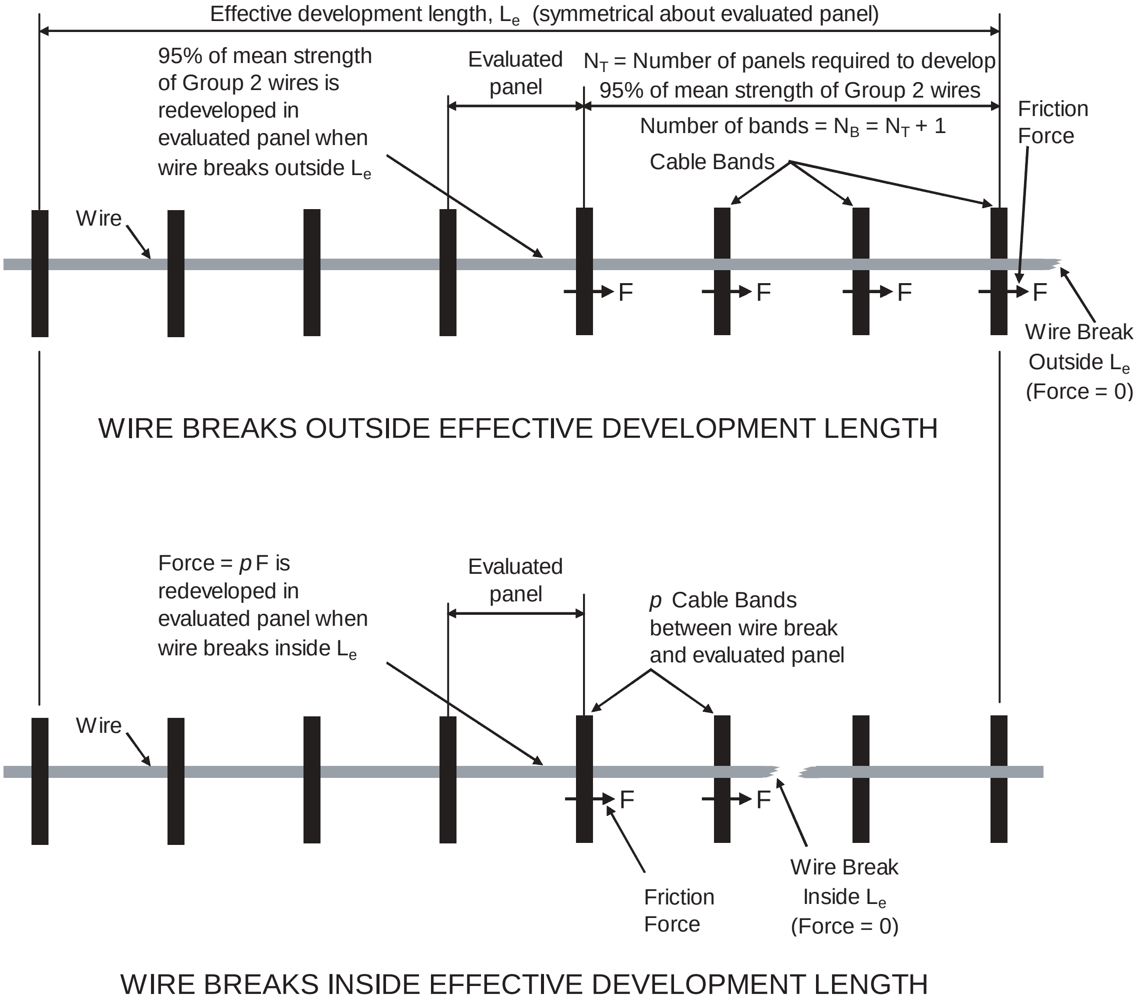


Figure 4.5.2-1. Effective development length.

CONTENTS

FIGURES

5.1 INTRODUCTION

The Equations for estimating the current strength of the cable are presented in this section. Three strength models of increasing complexity are included, along with a graph that aids in the calculation of the simplest model.

The section also includes information about separating the wires into groups that are in a similar state of deterioration, or that contain cracks or are broken. Grouping wires is required for applying the strength models.

The strength is calculated at a specific inspected location along the cable, called the evaluated panel. The concept of effective development length, covered previously in Article 4.5.2, is crucial for counting the number of broken and cracked wires and calculating their contribution to cable strength.

5.2 NOTATION

a_w = nominal area of one wire used in lab analysis (5.3.3.1.2) (5.3.3.2.2) (5.3.3.3.2) (5.3.7.3.3) (5.3.4)

C_d = fraction of 95% of the mean tensile strength of Group 2 wires that is developed in a broken wire at each cable band (5.3.4)

C_{di} = wire redevelopment factor for Panel i = C_d multiplied by the number of cable bands between Panel i and the evaluated panel (5.3.2.4.2)

e = strain in the unbroken wires of the cable (5.3.3.3.1)

$F3_5(e)$ = fraction of cracked wires that are broken at strain e = Weibull cumulative distribution of ultimate strain of Group 5 (cracked) wires at strain e (5.3.3.3.3)

$F3_5(s)$ = fraction of cracked wires that are broken at stress s = Weibull cumulative distribution of tensile strength of Group 5 (cracked) wires at stress s (5.3.3.2.3)

$F3_k(e)$ = Weibull cumulative distribution of ultimate strain of Group k wires (5.3.3.3.1)

$F3_k(s)$ = Weibull cumulative distribution of tensile strength of Group k wires (5.3.3.2.1) (5.3.3.2.2)

$F_c(e)$ = compound cumulative distribution of ultimate strain (5.3.3.3.1) (5.3.3.3.2)

$F_c(s)$ = compound cumulative distribution of tensile strength (5.3.3.2.1) (5.3.3.2.2)

i = number of a panel (5.3.2.1) (5.3.2.4.1) (5.3.2.4.2) (5.3.4)

K = reduction factor (given in Figure 5.3.3.1.2-1 as a function of the coefficient of variation, σ_s/μ_s) (5.3.3.1.2)

k = corrosion stage of wires (k = 1, 2, 3 and 4) (5.3.2.3) (5.3.2.4.1)

k = corrosion stage of a group of wires (k = 2, 3, 4 and 5) (5.3.2.5) (5.3.2.6) (5.3.3.2.1) (5.3.3.3.1); (k=2,3,&4) (5.3.3.1.1)

K = reduction factor (given in Figure 5.3.3.1.2-1 as a function of the coefficient of variation, σ_s/μ_s) (5.3.3.1.2)

L_e = number of panels in effective development length (5.3.2.1) (5.3.2.4.1) (5.3.2.4.2) (5.3.4)

max = maximum value of the expression inside the brackets (5.3.3.2.4) (5.3.3.3.4)

N_{0k} = number of unbroken Stage k wires in the evaluated panel (5.3.2.3) (5.3.2.4.1) (5.3.2.4.2) (5.3.2.5)

N_5 = number of discrete cracked wires in the effective development length (5.3.2.5) (5.3.3.1.1) (5.3.3.1.2)

N_b = number of broken wires in the effective development length (5.3.2.1) (5.3.2.3)

n_{b1} = number of broken wires in the evaluated panel (5.3.2.1) (5.3.4)

n_{bi} = number of broken wires in panel i (5.3.2.1) (5.3.4)

$N_{c,k}$ = total number of discrete cracked wires in the effective development length that are Stage k in the evaluated panel (5.3.2.4.1) (5.3.2.5)

N_{cr} = effective number of redeveloped cracked wires in the effective development length (5.3.2.4.2) (5.3.3.2.3) (5.3.3.3.3)

$N_{cr,k}$ = effective number of broken cracked wires that are Stage k in the evaluated panel and can be redeveloped (5.3.2.4.2)

N_{eff} = effective number of unbroken wires in the evaluated panel (5.3.2.5) (5.3.2.6) (5.3.3.1.1) (5.3.3.1.2) (5.3.3.2.2) (5.3.3.3.2)

N_k = number of Group k wires in the evaluated panel (5.3.2.5) (5.3.2.6) (5.3.3.1.1)

N_r = number of broken wires that are repaired in the effective development length (5.3.2.2) (5.3.2.3)

n_{r1} = number of broken wires that are repaired in the evaluated panel (i=1) (5.3.2.2)

n_{ri} = number of broken wires in panel i that are repaired (5.3.2.2) (5.3.4)

N_{sk} = number of Stage k wires in the evaluated panel (5.3.2.3)

p_i = number of cable bands between the evaluated panel and a wire break in panel i (5.3.4)

$p_{c,k}$ = fraction of Stage k wires that are cracked (5.3.2.4.1) (5.3.2.4.2)

p_k = fraction of unbroken wires in the evaluated panel represented by Group k (5.3.2.6) (5.3.3.2.1) (5.3.3.3.1)

p_{uk} = fraction of unbroken and uncracked wires in the cable represented by Group k (5.3.3.1.1)

R = estimated cable strength (5.3.3.1.2) (5.3.5)

R_b = cable strength attributable to broken wires in adjacent panels (5.3.4) (5.3.5)

R_u = cable strength attributable to unbroken wires (5.3.3.2.4) (5.3.3.3.4) (5.3.5)

s = stress in unbroken wires of the cable (5.3.3.2.1) (5.3.3.2.2); stress in wires corresponding to the estimated cable strength calculated in Article 5.3.3 (5.3.4)

$s(e)$ = stress in wires determined from the average stress-strain curve for all wires at strain e (5.3.3.3.2)

s_d = redeveloped stress in the evaluated panel for a broken wire in an adjacent panel (5.3.4)

$T_{cr}(e)$ = maximum force in broken cracked wires that can be redeveloped in the evaluated panel at strain e (5.3.3.3.3)

$T_{cr}(s)$ = maximum force in broken cracked wires that can be redeveloped in the evaluated panel at stress s (5.3.3.2.3)

$T_u(e)$ = force in unbroken wires in the evaluated panel at strain e (5.3.3.3.2)

$T_u(s)$ = force in unbroken wires in the evaluated panel at stress s (5.3.3.2.2)

μ_s = sample mean tensile strength of the combined groups of wires excluding cracked wires (5.3.3.1.1)

μ_{s2} = sample mean tensile strength of Group 2 wires (5.3.3.2.3) (5.3.3.3.3) (5.3.4)

μ_{sk} = sample mean tensile strength of Group k wires (5.3.3.1.1)

σ_s = sample standard deviation of tensile strength of the combined groups of wires excluding cracked wires (5.3.3.1.1)

σ_{sk} = sample standard deviation of the tensile strength of Group k wires (5.3.3.1.1)

5.3 ESTIMATED CABLE STRENGTH

5.3.1 General

The strength of a cable at the evaluated panel is the sum of the strengths of wires in three categories:

- all wires in the evaluated panel minus broken wires in that panel and nearby panels
- wires that are cracked in nearby panels, affecting the strength of the same wires in the evaluated panel
- wires that are broken in nearby panels, affecting the strength of the same wires in the evaluated panel

Methods for evaluating each of the three categories are described below in Articles 5.3.3 and 5.3.4.

5.3.2 Wire Groupings

The wires are assigned to groups that are numbered 2 to 5, corresponding to the corrosion stages they derive from. Stage 1 and Stage 2 wires are added together to form Group 2, because their properties are virtually identical. Stage 3 and Stage 4 wires become Group 3 and Group 4 respectively. All the discrete cracked wires are subtracted from their corresponding groups and added together to form Group 5. The number of discrete cracked wires in the effective development length is N_5. Broken wires are treated separately.

5.3.2.1 BROKEN WIRES IN EFFECTIVE DEVELOPMENT LENGTH

The total number of broken wires in the effective development length is

$$N_b = \sum_{i=1}^{L_e} n_{bi} \qquad (5.3.2.1\text{-}1)$$

where

N_b = number of broken wires in the effective development length

n_{bi} = number of broken wires in panel i

L_e = number of panels in the effective development length (see Article 4.5.2)

i = number of a panel

If the evaluated panel is the only panel that has been

C5.3.2.1

Wires that are broken in panels other than the panel being evaluated may affect the cable strength in the evaluated panel. The force that such a wire can sustain increases as the wire passes through one or more cable bands, until the wire is fully redeveloped. The increase in strength comes from the friction among the wires, caused by the clamping action of the cable bands and the cable wrapping.

inspected, then it is assumed that all panels in the effective development length are alike, and that all values of n_{bi} are equal to n_{b1}, and that

$$N_b = L_e \cdot n_{b1} \qquad (5.3.2.1\text{-}2)$$

where

n_{b1} = number of broken wires in the evaluated panel

5.3.2.2 REPAIRED WIRES IN EFFECTIVE DEVELOPMENT LENGTH

The total number of repaired wires in the effective development length is

$$N_r = \sum_{i=1}^{L_e} n_{ri} \qquad (5.3.2.2\text{-}1)$$

where

N_r = number of broken wires that are repaired in the effective development length

n_{ri} = number of broken wires that are repaired in panel *i*

If the evaluated panel is the only panel that has been inspected, then broken wires in that panel are the only ones to have been repaired,

$$N_r = n_{r1} \qquad (5.3.2.2\text{-}2)$$

where

n_{r1} = number of broken wires that are repaired in the evaluated panel (i=1)

5.3.2.3 UNBROKEN WIRES IN EACH CORROSION STAGE

The number of unbroken wires in each stage of corrosion is determined by subtracting the unrepaired broken wires in the effective development length from Stage 4 wires in the evaluated panel, and when there are none remaining, from Stage 3 wires in the panel, as follows:

when $N_b - N_r \le N_{s4}$

$$N_{04} = N_{s4} - N_b + N_r \qquad (5.3.2.3\text{-}1)$$

$$N_{03} = N_{s3} \qquad (5.3.2.3\text{-}2)$$

C5.3.2.2

If the evaluated panel is the only panel that has been inspected, numbering the order of the panels in the effective development length is not critical.

If adjacent panels have been inspected, and if the methods specified in Article 5.3.4 and Appendix B are used to evaluate the cable, then the panels should be numbered according to the instructions in Appendix B, Article B.4.1.

GUIDELINES **COMMENTARY**

$$N_{02} = N_{s2} + N_{s1} \qquad (5.3.2.3\text{-}3)$$

when $N_b - N_r > N_{s4}$

$$N_{04} = 0 \qquad (5.3.2.3\text{-}4)$$

$$N_{03} = N_{s3} + N_{s4} - N_b + N_r \qquad (5.3.2.3\text{-}5)$$

$$N_{02} = N_{s2} + N_{s1} \qquad (5.3.2.3\text{-}6)$$

where

N_{0k} = number of unbroken Stage *k* wires in the evaluated panel

N_{sk} = number of Stage *k* wires in the evaluated panel (Article 4.3.2)

N_b = number of broken wires in the effective development length

N_r = number of broken wires that are repaired in the effective development length

k = corrosion stage of wires (k=1, 2, 3 and 4)

5.3.2.4 CRACKED WIRES

The formulas in the following articles apply to situations in which only the evaluated panel has been inspected, and are based on the conservative assumption that all panels in the effective development length are in the same condition as the evaluated panel.

Of all the cracked wires in the cable, these calculations are applied to discrete cracked wires only. A discrete cracked wire is a wire that is cracked in panel *i* but is not cracked in all the panels nearer than *i* to the evaluated panel.

The effective number of discrete cracked wires that are assumed to be redeveloped in the evaluated panel due to friction at the cable bands is also required for the calculation.

5.3.2.4.1 Discrete Cracked Wires in Effective Development Length

The number of discrete wires in the effective development length is calculated separately for each corrosion stage. The number of discrete cracked wires in any stage, *k*, is given by the equation

C5.3.2.4

If all panels in the effective development length have been inspected, the technique presented in Appendix B should be used. The technique is limited in its application because it is complex and the data are usually not available. It is recommended for severely deteriorated panels, in which case additional adjacent panels must be opened to obtain these data.

$$N_{c,k} = N_{0k} \cdot \sum_{i=1}^{L_e} p_{c,k} \cdot \left(1 - p_{c,k}\right)^{i-1} \qquad (5.3.2.4.1\text{-}1)$$

where

$N_{c,k}$ = total number of discrete cracked wires in the effective development length that are Stage *k* in the evaluated panel

N_{0k} = number of unbroken Stage *k* wires in the evaluated panel

$p_{c,k}$ = fraction of Stage *k* wires that are cracked

i = number of a panel

L_e = number of panels in the effective development length

k = corrosion stage of wires (k = 1,2,3 and 4)

As stated above, this calculation is made separately for each stage. Usually, $p_{c,1}$ and $p_{c,2}$ will be zero; and $p_{c,3}$ may be zero.

The value of the expression

$$\sum_{i=1}^{L_e} p_{c,k} \cdot \left(1 - p_{c,k}\right)^{i-1} \qquad (5.3.2.4.1\text{-}2)$$

in Equation 1 represents the fraction of discrete cracked wires in each stage in the effective development length. Values of this expression as a function of the fraction of cracked wires in each stage are shown graphically in Figure 5.3.2.4.1-1. The expression is called $N_{c,k}/N_{0k}$.

5.3.2.4.2 Redevelopment of Cracked Wires That Fail

Cracked wires that are assumed to fail as the cable stress is increased may redevelop part of their strength in the evaluated panel. Assuming all of the cracked wires are broken, redeveloped wires for each stage, *k*, are

$$N_{cr,k} = N_{0k} \cdot \sum_{i=1}^{L_e} p_{c,k} \cdot \left(1 - p_{c,k}\right)^{i-1} \cdot C_{di} \qquad (5.3.2.4.2\text{-}1)$$

where

$N_{cr,k}$ = effective number of broken cracked wires that are Stage *k* in the evaluated panel and can be redeveloped

C_{di} = wire redevelopment factor for Panel *i* =

C_d multiplied by the number of cable bands between Panel *i* and the evaluated panel

The total effective number of redeveloped wires is

$$N_{cr} = N_{cr,2} + N_{cr,3} + N_{cr,4} \qquad (5.3.2.4.2\text{-}2)$$

where

N_{cr} = effective number of redeveloped cracked wires in the effective development length

The value of the expression

$$\sum_{i=1}^{L_e} p_{c,k} \cdot \left(1 - p_{c,k}\right)^{i-1} \cdot C_{di} \qquad (5.3.2.4.2\text{-}3)$$

in Equation 1 represents the effective fraction of cracked wires that are Stage *k* in the evaluated panel but are redeveloped because they are broken at stress, *s*. Figure 5.3.2.4.2-1 gives the effective fraction of cracked wires that will redevelop in the evaluated panel if they break, to be used in Equation 1. This expression is called $N_{cr,k}/N_{0k}$. Each stage, *k*, is treated separately, and then combined using Equation 2.

5.3.2.5 EFFECTIVE NUMBER OF UNBROKEN WIRES

The effective number of unbroken wires in the cable is

$$N_{eff} = \sum_{k=2}^{5} N_k \qquad (5.3.2.5\text{-}1)$$

in which

$$N_k = N_{0k} - N_{c,k} \ \ (k = 2, 3, 4) \qquad (5.3.2.5\text{-}2)$$

and

$$N_5 = \sum_{k=2}^{4} N_{c,k} \qquad (5.3.2.5\text{-}3)$$

where

N_{eff} = effective number of unbroken wires in the evaluated panel

N_k = number of Group *k* wires in the evaluated panel

N_5 = number of discrete cracked wires in the effective development length

N_{0k} = number of unbroken Stage *k* wires in the evaluated panel

$N_{c,k}$ = total number of discrete cracked wires in the effective development length that are Stage *k* in the evaluated panel

k = corrosion stage of group of wires ($k = 2, 3, 4$ and 5)

5.3.2.6 FRACTION OF THE CABLE REPRESENTED BY EACH GROUP OF WIRES

The unbroken wires in the cable are separated into four groups for the purpose of calculating cable strength. Each group has a different set of tensile strengths and/or ultimate strain properties. The values of N_k are used to calculate the fraction of the cable represented by each group of wires, *k*,

$$p_k = \frac{N_k}{N_{eff}} \qquad (5.3.2.6\text{-}1)$$

where

p_k = fraction of unbroken wires in the evaluated panel represented by Group *k*

N_k = number of Group *k* wires in the evaluated panel

N_{eff} = effective number of unbroken wires in the evaluated panel

k = corrosion stage of a group of wires (k =2,3,4 and 5)

C5.3.2.6

The calculation of the number of wires in each group is difficult to visualize and is summarized in Figure 5.3.2.6-1.

5.3.3 Strength of Unbroken Wires

The strength of the unbroken wires in the cable should be estimated using one of three strength models. The Limited Ductility Model is the most rigorous; the others are special cases of this model, using simplified assumptions. All three recommended models are further described in Appendix A.

The choice of model depends on the extent of the deterioration found in the cable:

- Use the Simplified Model for cables with no Stage 4 or cracked wires

C5.3.3

The Limited Ductility and Brittle-Wire models are used to estimate the strength of a cable composed of many wires that are subjected to the same strain. The Simplified Model, which is based on the Brittle-Wire Model, subtracts all cracked and broken wires and uses a single distribution curve for the tensile strength of the remaining unbroken, uncracked wires.

In the Limited Ductility Model, the cable is subjected to an incremental increase in strain The force in the cable at any strain is the sum of the forces in the individual wires at that strain. The wire forces vary in relation to the individual stress-strain diagrams.

GUIDELINES

- Use the Simplified Model (at the discretion of the owner or investigator) for cables in which cracked Stage 3 and Stage 4 wires account for up to 10% of the total wires. It is understood that the result in cable strength may be up to 10% less than the result using the Brittle Wire Model.
- Use the Brittle-Wire Model if cracks are present in more than 10% of all the wires in the cable.
- Use the Limited Ductility Model if the wires display unusual variations in tensile strength (sometimes due to varying carbon content), which are reflected in stress-strain curves that are also unusually varied.

COMMENTARY

Individual wires share in carrying the cable tension until one reaches its ultimate strain, at which point it breaks and no longer resists any force. The total force in the cable is reduced accordingly by the previous force carried by the wire. Increasing the strain further causes the cable force to increase again, until the next wire breaks. The process continues until the cable force reaches a maximum value, after which wires break more rapidly than the force increases in the individual wires, resulting in decreased cable force with increased strain. The maximum cable force achieved is the cable strength.

The Brittle-Wire Model is a special case of the Limited Ductility Model. In contrast to its parent model, it is assumed that all the wires are subjected to the same tensile stress at any given strain; thus, it is convenient to substitute an increasing stress in the calculation instead of an increasing strain. Any individual wire shares in carrying the tension in the cable until the stress in that wire exceeds its tensile strength and the wire fails, no longer participating in the cable force. As with the more general model, the cable force increases with increasing stress until a maximum value is reached, which is equivalent to the cable strength.

The Limited Ductility Model requires determining the ultimate strain of each wire specimen and developing a full stress-strain diagram for each wire sample. The ultimate strain corresponds to the tensile strength of the wire (see Appendix A). It is also the strain at failure when there is no reduction of area, for instance from a crack.

The percentage of elongation in a 10-inch gage length, determined in accordance with ASTM A370, cannot be used as the ultimate strain for the Limited Ductility Model, because it is measured only after necking down and does not include the elastic component of the strain.

The Brittle-Wire Model requires knowing only the tensile strength of each specimen, which can be obtained by testing in accordance with ASTM A370.

If a cable force vs. strain diagram is wanted by the investigator, then average stress-strain diagrams of the cable wires should be developed for each of the models. Several such diagrams are already needed for the Limited Ductility Model, whereas the Brittle-Wire Model requires only one.

5.3.3.1 SIMPLIFIED STRENGTH MODEL

The Simplified Model should be applied to cables that have very few cracked wires. The upper limit is no more than 10% of the total wire population.. The Brittle-Wire Model is used whenever this limit is exceeded. The Simplified Model is based on the Brittle-Wire Model; the estimated number of cracked wires (Group 5) and broken wires are omitted from the calculation, and the total number of wires in the cable is reduced accordingly.

Although the strength may be underestimated by up to 20%, the Simplified Model is useful in locating the most severely deteriorated panel among those inspected. Then the more complex models can be applied to that panel for a more realistic strength estimate.

5.3.3.1.1 Mean Tensile Strength of Uncracked Wires

The fraction of the cable represented by Groups 2, 3 and 4 is combined with the sample mean values of minimum tensile strength of the representative specimens of each group to determine the sample mean tensile strength and standard deviation of the entire unbroken and uncracked wire population, using the equations

$$\mu_s = \sum_{k=2}^{4} (p_{uk} \cdot \mu_{sk}) \qquad (5.3.3.1.1\text{-}1)$$

$$\sigma_s = \sqrt{\left(\sum_{k=2}^{4} p_{uk} \left(\sigma_{sk}^2 + \mu_{sk}^2 \right) \right) - \mu_s^2} \qquad (5.3.3.1.1\text{-}2)$$

in which

$$p_{uk} = \frac{N_k}{N_{eff} - N_5} \qquad (5.3.3.1.1\text{-}3)$$

where

μ_s = sample mean tensile strength of the combined groups of wires, excluding cracked wires

μ_{sk} = sample mean tensile strength of Group k wires

σ_s = sample standard deviation of the tensile strength of the combined groups of wires,

C5.3.3.1

A single Weibull distribution that combines Groups 2, 3 and 4 is used in the Simplified Model. It combines the tensile strength distributions of the individual wire groups, with the relative size of each group taken into account.

In order to minimize the computational effort required by the model, a factor is applied to the mean tensile strength, which is multiplied by the effective cable area.

C5.3.3.1.1

The symbols μ and σ refer to the mean and standard deviation of a property of the entire population of wires in the cable. The mean and standard deviation used in cable strength models are determined from laboratory tests on a selection of wires removed from the cable during inspection and are called the sample mean and sample standard deviation, designated by μ_s and σ_s.

excluding cracked wires

σ_{sk} = sample standard deviation of the tensile strength of Group *k* wires

p_{uk} = fraction of unbroken and uncracked wires in the cable represented by Group *k*

k = corrosion stage of a group of wires (k = 2, 3 and 4)

N_{eff} = effective number of unbroken wires in the evaluated panel

N_5 = number of discrete cracked wires in the effective development length

N_k = number of Group *k* wires in the evaluated panel

5.3.3.1.2 Cable Strength Using the Simplified Model

The cable strength is calculated from the equation

$$R = (N_{eff} - N_5) \cdot a_w \cdot \mu_s \cdot K \qquad (5.3.3.1.2\text{-}1)$$

in which

K = reduction factor (given in Figure 5.3.3.1.2-1 as a function of the coefficient of variation, σ_s/μ_s)

where

R = estimated cable strength

a_w = nominal area of one wire used in lab analysis

5.3.3.2 BRITTLE-WIRE MODEL

The tensile strength of each test specimen is used to determine the minimum tensile strength of each wire sample. The minima are used to determine the sample means and standard deviations for each group of wires, which are combined to construct a compound tensile strength distribution curve.

Whenever a cable force vs. strain diagram is required, the test laboratory determines the stress-strain curve up to the ultimate strain for at least one specimen from each sample wire. These curves are used to develop an average stress-strain curve for the entire cable.

5.3.3.2.1 Compound Tensile Strength Distribution Curve

The fraction of the cable represented by each of the groups (calculated in Article 5.3.2.6) and the Weibull distribution curves for tensile strength of the specimens

C5.3.3.1.2

The strength reduction factor, *K*, is the brittle-wire strength of the combined groups of uncracked wires, divided by the product of mean tensile strength of the combined groups of uncracked wires and total area of uncracked wires. The derivation of *K* is given in Appendix A.

C5.3.3.2

The Brittle-Wire Model is recommended with few exceptions for determining the strength of the cable. The distribution of the tensile strength of the entire population of unbroken wires is a compound distribution curve developed from the distributions of the individual wire groups, with the relative size of each group taken into account. The Weibull distribution is used in the analysis, with the lower limit of tensile strength, s_0, assumed to be zero (no wire can have a negative tensile strength).

C5.3.3.2.1

The Weibull distribution is a Type 3 extreme value distribution function. The function extends from a minimum value, x_0, to infinity. The cumulative distribution function is referred to as $F3(x)$ in the that represent each of the groups are combined to determine the compound distribution curve for the entire unbroken wire population. The equations used in the calculation are

$$F_C(s) = \sum_{k=2}^{5} p_k \cdot F3_k(s) \qquad (5.3.3.2.1\text{-}1)$$

where

$F_C(s)$ = compound cumulative distribution of the tensile strength

s = stress in unbroken wires of the cable

p_k = fraction of unbroken wires in the evaluated panel represented by Group k

k = corrosion stage of a group of wires (k = 2, 3, 4 and 5)

$F3_k(s)$ = Weibull cumulative distribution of tensile strength of Group k wires

5.3.3.2.2 Cable Force at Stress *s*

The total force in the unbroken wires at any value of cable stress, s, is given by

$$T_u(s) = N_{eff} \cdot a_w \cdot \left(s \cdot \left(1 - F_C\left(s\right)\right)\right) \qquad (5.3.3.2.2\text{-}1)$$

where

$T_u(s)$ = force in the unbroken wires in the evaluated panel at stress s

N_{eff} = effective number of unbroken wires in the evaluated panel

a_w = nominal area of one wire used in lab analysis

5.3.3.2.3 Force in Cracked Wires That Break in Adjacent Panels

The total force in the evaluated panel at cable stress, s, in wires that are cracked in other panels within the effective development length and that have a tensile strength less than that stress is given by

$$T_{cr}(s) = N_{cr} \cdot a_w \cdot \left(0.95\mu_{s2}\right) \cdot F3_5(s) \qquad (5.3.3.2.3\text{-}1)$$

where

$T_{cr}(s)$ = maximum force in the broken cracked wires that can be redeveloped in the evaluated panel at stress s

Guidelines. The equations for this function, as well as a method for determining the parameters of the function, are presented in Appendix A. The term x is the variable of the distribution and is replaced by s for tensile strength and by e for ultimate strain.

C5.3.3.2.2

In Equation 1, the wires with tensile strength less than s are assumed to have zero force. This is accomplished mathematically, using the Survivor Function, (1-$F_C(s)$).

$F3_5(s)$ = fraction of cracked wires that are broken at stress s = Weibull cumulative distribution of tensile strength of Group 5 (cracked) wires at stress s

N_{cr} = effective number of redeveloped cracked wires in the effective development length

μ_{s2} = sample mean tensile strength of Group 2 wires

5.3.3.2.4 Strength of Unbroken Wires in the Cable

The strength of the unbroken wires in the cable is given by

$$R_u = \max\left(T_u(s) + T_{cr}(s)\right) \qquad (5.3.3.2.4\text{-}1)$$

where

R_u = cable strength attributable to unbroken wires

max = maximum value of the expression inside the brackets

C5.3.3.2.4

$R_u = \max\left(T_u(s) - T_{cr}(s)\right)$ is determined by calculating the values of the expression for several values of s at suitably small increments (2 ksi) and seeking the maximum value. The entire calculation is best done on a computer spreadsheet program that incorporates the Weibull distribution functions. Alternatively, the expression can be evaluated for a single value of s, and an iterative program can then be used to determine the value of s that produces the maximum expression. Should a cable force vs. strain diagram be required, only the first technique provides the data to plot it.

5.3.3.3 LIMITED DUCTILITY MODEL

The Limited Ductility Model requires the ultimate strain of each test specimen based on laboratory results, as well as a stress-strain curve up to the ultimate strain for each specimen tested. The data are used to determine the minimum value of the ultimate strain and the stress-strain curve of each sample wire. Whenever the stress-strain curves for the sample wires are essentially the same, an average curve for all the samples is constructed, and the method given below of estimating the cable strength is followed. Whenever the individual stress-strain curves for the sample wires vary from one another, the general form of the Limited Ductility Model, given in Appendix A, must be used.

C5.3.3.3

In the Limited Ductility Model, the ultimate strain of the wires is used as the variable in the distribution functions. In the simple form of this model, presented in the articles below, the distribution of the ultimate strain for the entire population of unbroken wires is a compound distribution curve developed from the distributions of the individual wire groups, with the relative size of each group taken into account. The Weibull distribution is used in the analysis, with the lower limit of ultimate strain, e_0, assumed to be zero (no wire can have a negative ultimate strain).

5.3.3.3.1 Compound Ultimate Strain Distribution Curve

The fraction of the cable represented by each of the groups, (calculated in Article 5.3.2.6), and the Weibull distribution curves for ultimate strain of the specimens that represent each of the groups, are combined to determine the compound distribution curve for the entire unbroken wire population. The equation used for the calculation is

$$F_C(e) = \sum_{k=2}^{5} p_k \cdot F3_k(e) \qquad (5.3.3.3.1\text{-}1)$$

where

$F_C(e)$ = compound cumulative distribution of the ultimate strain

e = strain in the unbroken wires of the cable

p_k = fraction of the unbroken wires in the evaluated panel represented by Group k

k = corrosion stage of a group of wires (k = 2, 3, 4 and 5)

$F3_k(e)$ = Weibull cumulative distribution of ultimate strain of Group k wires

5.3.3.3.2 Force in Unbroken Wires at Strain *e*

If it can be shown that the average stress-strain curves for all the groups of wires are alike, then the following equation is used to estimate the force in unbroken wires in the cable at strain e:

$$T_u(e) = N_{eff} \cdot a_w \cdot \left(s(e) \cdot \left(1 - F_C(e)\right)\right) \qquad (5.3.3.3.2\text{-}1)$$

where

$s(e)$ = stress in wires determined from the average stress-strain curve for all wires at strain e

$T_u(e)$ = force in unbroken wires in the evaluated panel in strain e

N_{eff} = effective number of unbroken wires in the evaluated panel

a_w = nominal area of one wire, used in lab analysis

5.3.3.3.3 Force in Cracked Wires That Break in Adjacent Panels

C5.3.3.3.1

The compound distribution curve is the sum of several independent Weibull distributions but is not itself a Weibull distribution. While there are no explicit equations for the distribution, it can be described by Equation 1. The compound distribution curve is used only when all the groups of wires have the same stress-strain curve and the cable force in unbroken wires is calculated by Equation 5.3.3.3.2-1.

The total force in the evaluated panel at cable strain, e, in wires that are cracked in other panels in the effective development length and that have an ultimate strain smaller than e is given by

$$T_{cr}(e) = N_{cr} \cdot a_w \cdot (0.95\mu_{s2}) \cdot F3_5(e) \qquad (5.3.3.3.3\text{-}1)$$

in which

$T_{cr}(e)$ = maximum force in broken cracked wires that can be redeveloped in the evaluated panel at strain e

$F3_5(e)$ = fraction of cracked wires that are broken at strain e = Weibull cumulative distribution of ultimate strain of Group 5 (cracked) wires at strain e

N_{cr} = effective number of redeveloped cracked wires in the effective development length

μ_{s2} = mean sample tensile strength of Group 2 wires

5.3.3.3.4 Strength of Unbroken Wires in the Cable

The strength of the unbroken wires in the cable is given by

$$R_u = \max(T_u(e) + T_{cr}(e)) \qquad (5.3.3.3.4\text{-}1)$$

where

max = maximum value of the expression inside the brackets

R_u = cable strength attributable to unbroken wires

5.3.4 Redevelopment of Broken Wires

Wires that are broken in panels adjacent to the evaluated panel share in the cable tension because of the friction that develops at the intervening cable bands. If the tension in a wire exceeds the friction in the cable band adjacent to that panel, the wire will slip, but it will continue to carry a constant tension as the cable tension increases. The stress redeveloped in a broken wire is given by

$$s_d = p_i \cdot C_d \cdot (0.95 \cdot \mu_{s2}),\ s_d \le s \qquad (5.3.4\text{-}1)$$

where

s_d = redeveloped stress in the evaluated panel

C5.3.3.3.4

The value of the term

$$\max(T_u(e) + T_{cr}(e))$$

is determined by calculating the values of the expression for several values of e at suitably small increments (0.001 inch/inch) and seeking the maximum value. The entire calculation is best done on a computer spreadsheet program that incorporates the Weibull distribution functions.

C5.3.4

The stress in a broken wire that can be redeveloped is the number of cable bands between the break and the panel being evaluated multiplied by the stress redeveloped at each band. This redeveloped stress is, however, limited to the stress in the unbroken wires that corresponds to the cable strength calculated by the equations in Article 5.3.3. Generally, the stress in the unbroken wires will be more than 90% of the mean tensile strength of the Group 2 wires and the limitation can be disregarded, because the redeveloped stress with L_e = 9 is not greater than 76% of the mean tensile strength of Group 2.

for a broken wire in an adjacent panel

p_i = number of cable bands between the evaluated panel and a wire break in panel *i*

i = number of a panel

C_d = the fraction of 95% of the mean tensile strength of Group 2 wires that is developed in a broken wire at each cable band

μ_{s2} = sample mean tensile strength of Group 2 wires

s = stress in the wires corresponding to the estimated cable strength calculated in Article 5.3.3

The contribution of the broken wires to the cable strength is given by

$$R_b = a_w \cdot (0.95 \cdot \mu_{s2}) \cdot \sum_{i=2}^{L_e} p_i \cdot (n_{bi} - n_{ri}) \cdot C_d \qquad (5.3.4\text{-}2)$$

where

R_b = cable strength attributable to broken wires in adjacent panels

a_w = nominal area of one wire used in lab analysis

L_e = number of panels in effective development length

n_{bi} = number of broken wires in panel *i*

n_{ri} = number of broken wires in panel *i* that are repaired

If the evaluated panel is the only panel that has been inspected, then the contribution of the broken wires to the cable strength can be taken as

$$R_b = a_w \cdot (0.95 \cdot \mu_{s2}) \cdot n_{b1} \cdot 0.5 \cdot (L_e - 1) \qquad (5.3.4\text{-}3)$$

where

n_{b1} = number of broken wires in evaluated panel

5.3.5 Cable Strength

The strength of the cable using either the Brittle-Wire Model or the Limited Ductility Model in the evaluated panel is given by

$$R = R_u + R_b \qquad (5.3.5\text{-}1)$$

R = estimated cable strength

R_u = cable strength attributable to unbroken wires

R_b = cable strength attributable to broken wires in adjacent panels

5.4 FIGURES FOR SECTION 5

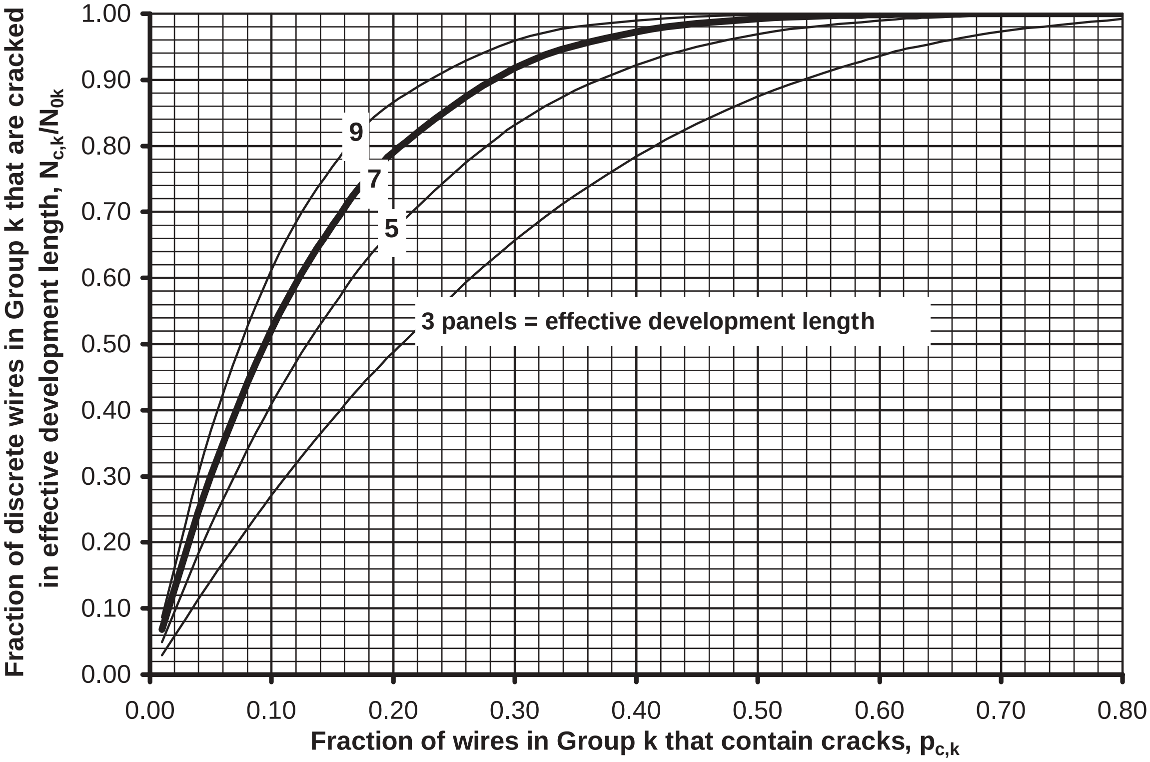


Figure 5.3.2.4.1-1. Fraction of discrete cracked wires in Stage k.

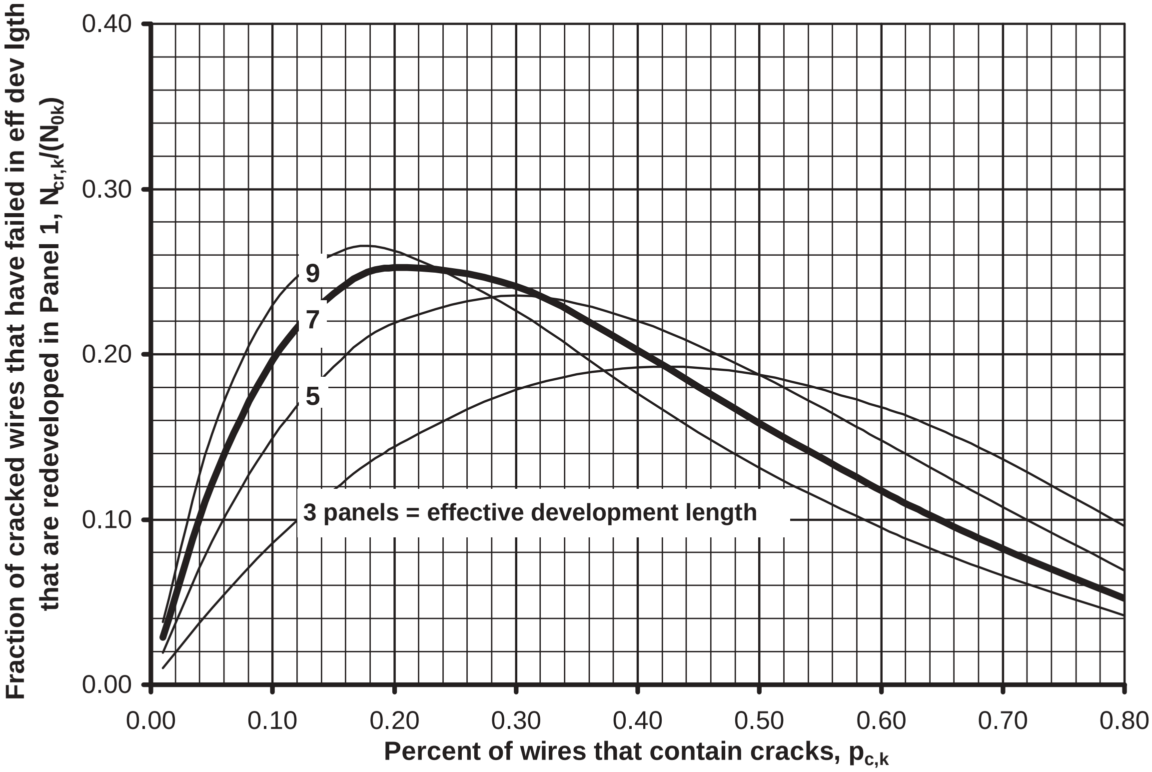


Figure 5.3.2.4.2-1. Fraction of cracked wires in Stage k that are redeveloped.

Type of wires	Notation						Remarks
	Stage					Total	
Number of:	k	1	2	3	4		
Wires in each stage from inspection	N_{sk}	N_{s1}	N_{s2}	N_{s3}	N_{s4}	N	Art 4.3.2
Broken wires in the effective development length	N_b				N_b	N_b	Eq 5.3.2.1-1 or 2
Repaired wires in the effective development length	N_r				N_r	N_r	Eq 5.3.2.2-1 or 2
Unbroken wires in each stage	N_{0k}	N_{01}	N_{02}	N_{03}	N_{04}	N_{eff}	Eq 5.3.2.3-1 to 6 ($N_{0k}=N_{sk}-N_b+N_r$)
Discrete cracked wires in effective development length	$N_{c,k}$	$N_{c,1}$	$N_{c,2}$	$N_{c,3}$	$N_{c,4}$	N_5	Eq 5.3.2.4.1-1 & Figure 5.3.2.4.1-1 & Eq. 5.3.2.5-3

	Groups						
	k	2	3	4	5	Total	
Effective number of unbroken wires in each group	N_k	N_2 Stages 1 and 2 combined	N_3	N_4	N_5	N_{eff}	Eq 5.3.2.5-1 to 3 ($N_k=N_{0k}-N_{c,k}$; $N_5=\Sigma N_{c,k}$)
Fraction of unbroken wires in cable represented by each group	p_k	p_2	p_3	p_4	p_5	1.00	Eq 5.3.2.6-1 $p_k=N_k/N_{eff}$

Figure 5.3.2.6-1. Summary of calculations for number of wires in each group.

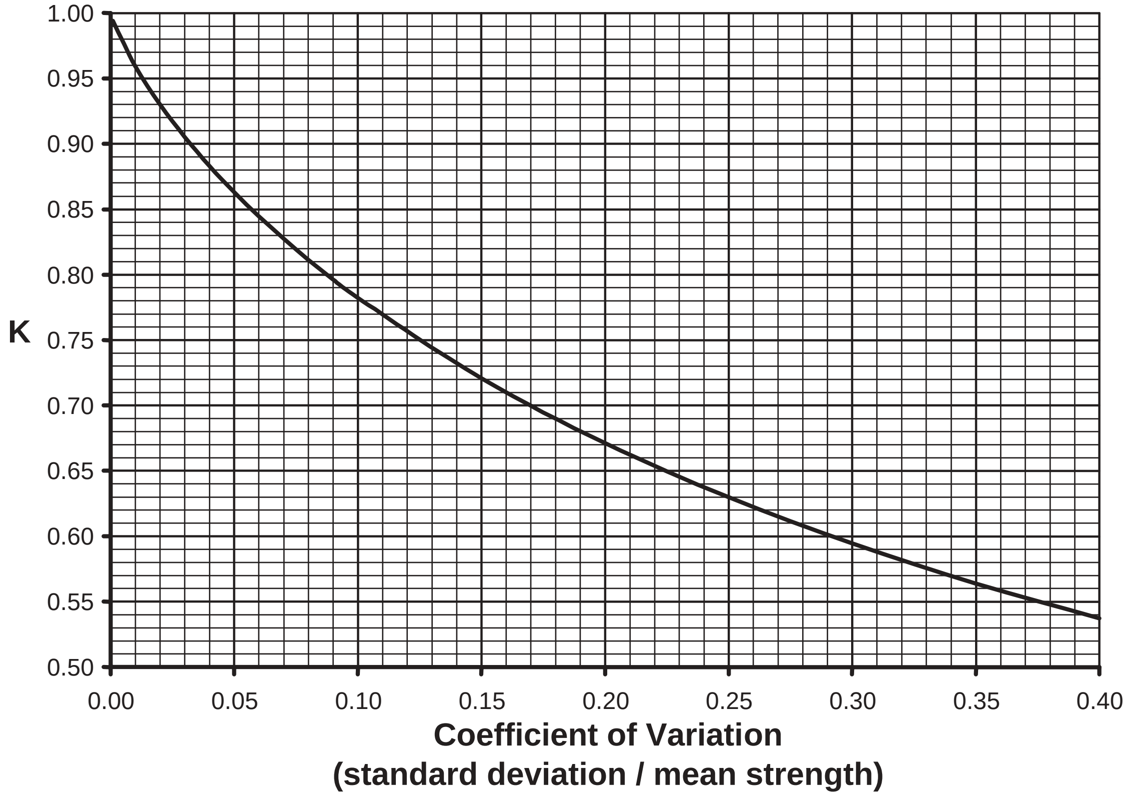


Figure 5.3.3.1.2-1. Strength reduction factor, K.

CONTENTS

6.1 INTRODUCTION

A report is required for each inspection performed. Over time, the reports form a historical record of the condition of the cable and help the bridge owner make informed decisions about maintenance schedules and budgets.

6.2 MAINTENANCE PERSONNEL INSPECTION

A report shall be prepared for each periodic inspection preformed by maintenance personnel. This report shall include at minimum:

1. date of inspection
2. weather and temperature
3. cable portion inspected (e.g., west main span, south anchorage, tower saddles and cable housings)
4. list of deficiencies, identified by panel number
5. one-page account of each deficiency with
    - verbal description (e.g., peeling paint, rust stains, broken wrapping)
    - color photograph
    - recommended action
6. list of recommended actions in order of priority

6.2.1 Follow-up report

A follow-up report shall be prepared for each action taken, with a description of the action and a photograph of the completed work.

6.3 BIENNIAL INSPECTION

The basic report for a biennial inspection is described in specifications provided by the state departments of transportation; they are not repeated here. The report should also contain the following information about the cables and suspension system:

1. separate listings of the ratings applied to each component (e.g., wrapping, hand ropes, etc.) in each inspected panel (see Figures 2.2.3.1-2 and 2.2.3.1-3)
2. photographs of deficiencies
3. reasons for ratings lower than 5 (on a scale of 1 to 7)

4. recommendations for action
5. reasons for recommending an internal inspection, if applicable

6.4 INTERNAL INSPECTION

The report for an internal inspection shall include all of the following:

1. executive summary providing a brief synopsis of the findings of the inspection that incorporates
    - number of locations opened for inspection
    - general description of conditions found (e.g., severe corrosion with 15 broken wires)
    - strength of each panel investigated
    - safety factor of each panel investigated
    - safety factor using the panel with lowest strength and maximum cable tension (usually adjacent to the tower)
    - recommendations for remedial action
    - recommendation for date of next inspection
2. table of contents
3. summary addressing executive summary items in greater detail
4. findings from preliminary cable walk and reasons for selecting investigated panels
5. plan and elevation of cables showing location of panels investigated
6. description and photographs of the means of access to the cable
7. detailed descriptions of each panel opened; cable cross-sections showing wedge locations, distribution of stages of corrosion and location of broken wires
8. summary of laboratory test results; cable cross-sections showing locations of sample wires
9. verbal description of method used to calculate cable strength; table of calculated strengths
10. table of cable tensions due to dead load, live load and temperature; table of cable safety factors
11. investigator's estimate of the accuracy of estimated cable strength

C6.4

The safety factor for an inspected panel is the cable strength in that panel divided by the cable tension in that panel, due to dead load, live load, and temperature effects.

The safety factor of the cable when it is inspected in its entirety is the lowest value found above.

The safety factor of the cable when only a portion of it has been inspected is determined by using the minimum cable strength and the maximum cable tension, which occurs in the panel with the maximum slope, usually adjacent to the tower.

The probable error in the strength of a specific panel (when adjacent panels have been inspected) is approximately 7% to 8%. The usual safety factors can accommodate this level of error.

This level of error is reasonably accurate but it applies only to inspected panels; therefore, it applies to the entire cable only when all the panels have been inspected. In all other cases, the error can be greater.

The additional error comes from lack of knowledge about the uninspected panels. When the results of a full-length inspection were compared with the results of a hypothetical inspection of 20% of the panels of the same cable, the error in the strength estimate of the hypothetical was 8% (See the final report for NCHRP Project 10-57, on the accompanying CD). Whenever fewer panels are inspected, the overestimation is greater, the inverse is also true.

Historically, cables have been designed for a safety factor of 4; more recently, safety factors of 2.7 (1939) and 2.4 (1990) have been used. The safety factor that results from assessing a deteriorated cable will be lower than the one used in designing the cable. Safety factors and live loading are not included in the scope of this project. Nevertheless, whenever the safety factor falls below 2.15%, it is recommended that:

- reductions in traffic be considered
- an acoustic monitoring system be installed to record future wire breaks
- a more intensive inspection, of the entire cable

GUIDELINES

cable strength

12. conclusions
    - discussion of cable strengths, safety factors and possible errors
    - discussion of probable causes of deterioration
13. recommendations
    - plan for continued operation of the bridge if the safety factor is low
    - general plan for maintenance and repairs
    - specific plan for time of next inspection and number of panels to be inspected (The exact panels should be selected during the preparatory period for the next inspection, unless follow-up inspections of specific panels are recommended.)
14. appendices
    - laboratory reports for
        - wire properties from tests; means and standard deviations of corrosion groups
        - Weight or Zinc Coating Test and Preece Test
        - chemical testing of metal and corrosion products
        - metallurgical examinations, including photographs
    - sample strength calculations
    - selected photographs showing condition of cable exterior (from the cable walk) and cable interior (from wedging)
    - selected photographs of inspection and rewrapping operations

COMMENTARY

if possible, be scheduled

- application of corrosion inhibitors be considered

CONTENTS

A.1 INTRODUCTION

A parallel wire cable on a suspension bridge can be defined as a bundle of parallel structural elements in tension. A statistical approach to the problem of estimating the strength of a parallel element system is described in Rao [1] He presents two models based on different assumptions, either that the elements are ductile (they continue to carry load after reaching maximum capacity) or that they are brittle (they break when they reach maximum capacity). Engineers currently depend on several variations of these models to estimate the strength of the unbroken wires in a cable that has experienced deterioration. In practice, the models that include all the wires in a cable are more complex than Rao's models would suggest. The series of tasks required for a proper assessment includes:

- developing stress-strain diagrams for the wires
- finding the minimum strength of a given length of wire
- calculating distribution functions to describe how the wires vary
- determining the effectiveness of the cable bands in redeveloping the strength of a wire broken at some distance from the point at which the strength is being determined
- estimating the effect on the cable of deterioration in panels near the one being evaluated
- estimating the strength of the cable in a given panel based on this data

The following pages describe the basic models found in the literature for parallel systems and their application to estimating cable strength.

The text includes the results of tensile strength tests on corroded wires that were removed from three bridges, a description of the behavior of a single bridge wire, and the statistical equations required for evaluating the models. An additional source of information is the simulated ten-wire cable demonstration calculations that appear in the final report for NCHRP Project 10-57, on the accompanying CD.

A.2 NOTATION

a_w = nominal area of one wire, used in lab analysis (A.5.1.1) (A.5.1.2) (A.5.2) (A.5.3.2)

e = specific value of strain (A.5.1.1)

exp(x) = e (2.7183) to the power (x), the "exponential" of (x) (A.4.2)

$F3_k(e)$ = Weibull cumulative distribution for ultimate strain of Group k wires (A.5.1.1) (A.5.1.2)

$F3_k(s)$ = Weibull cumulative distribution for tensile strength of Group k wires (A.5.2.)

$f3_{X1}(x)$ = Type III extreme value probability density distribution for the smallest values of random variable X (A.4.2.)

$F3_{X1}(x)$ = Weibull extreme value cumulative distribution for the smallest values of random variable X (A.4.2)

$F3(s)$ = single Weibull distribution of the tensile strength representing all of Group 2 to 4 wires (without cracked wires), based on the sample mean and sample standard deviation of the combined groups.(A.5.3.2)

$F3(s')$ = single Weibull distribution of the tensile strength representing all the Group 2 to 4 wires, based on a mean tensile strength of 1.0 and a standard deviation of the combined groups, divided by μ_s(A.5.3.2)

$F_C(e)$ = compound cumulative distribution of ultimate strain (A.5.1.2)

$F_C(s)$ = compound cumulative distribution of tensile strength (A.5.2)

k = corrosion stage of a group of wires (k = 2, 3, 4 and 5) (A.5.1.1)

k = corrosion stage of a group of wires (k = 2, 3, and 4) (A.5.3.1)

km = subgroup of Stage k wires that follow stress-strain curve m (A.5.1.1)

$\boldsymbol{K}$ **=** reduction factor from Chart 5.2.3.3.2-1 as a function of the coefficient of variation, σ_s/μ_s. (A.5.3.2)

max = maximum value of the expression inside the brackets (A.5.1.1) (A.5.1.2) (A.5.3.2)

m = parameter of the Type III extreme value distribution for minimum values (A.4.2)

m = number of a discrete stress-strain curve (A.5.1.1)

M = number of different stress-strain curves considered (A.5.1.1)

N_{eff} = effective number of unbroken wires in the cable (A.5.1.1) (A.5.1.2) (A.5.2)

N_{eff} = effective number of unbroken wires and uncracked wires in the cable (A.5.3.2)

p_k = fraction of unbroken wires represented by Group k wires (A.5.1.2) (A.5.2)

p_k = fraction of unbroken wires and uncracked wires in the cable represented by Group k wires (A.5.3.1)

p_{km} = fraction of cable represented by Subgroup km wires (A.5.1.1)

R_u = cable strength attributable wires in the cable that are not broken (A.5.1.1) (A.5.1.2) (A.5.2) (A.5.3.2)

s = stress in the unbroken wires of the cable (A.5.2) (A.5.3.2)

s^1 = s/μ_s (A.5.3.2)

$s(e)$ = stress in wires determined from average stress-strain curve for all wires (A.5.1.2)

$S_k(e)$ = survivor function, or that fraction of the wires in Group k that has an ultimate elongation greater than e (A.5.1.1)

$s_m(e)$ = stress at strain e in wires that follow stress-strain curve m (A.5.1.1)

T_{km} = force in Subgroup km wires (A.5.1.1)

$T_u(s)$ = tensile force in unbroken wires in the cable at stress s (A.5.2)

x = value of random variable X *or* X_1 (A.4.2)

x_0 = minimum value of x for which the Type III distribution is valid (A..4.2)

X_1 = random variable representing the smallest values of property x of each wire (A.4.2)

$\Gamma(\ )$ = Gamma function of the expression inside the brackets (A.4.2)

μ_s = sample mean tensile strength of the combined groups of wires, excluding cracked wires (A.5.3.1) (A.5.3.2)

μ_{sk} = sample mean tensile strength of Group k wires (A.5.3.1)

μ_{sx} = sample mean of property x (A.2.3.1) (A.2.3.2)

μ_{sX1} = sample mean of the extreme value distribution of x (A.4.2)

υ = parameter of the Type III extreme value distribution for minimum values (A.4.2)

σ_s = sample standard deviation of the tensile strength of the combined groups of wires, excluding cracked wires (A.5.2.1)

σ_{sk} = sample standard deviation of tensile strength of Group k wires (A.5.3.1)

σ_{sx} = sample standard deviation of property x (A.2.3.1) (A.2.3.2)

σ_{sX1} = sample standard deviation of the extreme value distribution of x, (A.4.2)

A.3 STRENGTH MODELS

A.3.1 Behavior of a Single Bridge Wire

The modern method of manufacturing bridge wire is to cold draw a carbon steel rod through successively smaller dies until the specified diameter and tensile strength are reached. The process imparts strength to the wire, along with an elongated grain structure.

The typical stress-strain curve for new bridge wire is shown in Figure A.3.1-1. The data were taken from Roebling [2] and represent the average results of tests on 126 wires from the Bear Mountain Bridge. Failure occurs almost immediately after the ultimate strain is reached. New, corroded and cracked wires all follow the same curve.

Any bridge wire subjected to a tensile test stretches elastically to the proportional limit. It doesn’t exhibit a true yield point as the strain increases, but enters a strain-hardening range instead, immediately after the transition from elastic behavior. The stress continues to increase with the strain until the tensile strength is reached, at which point the wire necks down and fails, resulting in a reduction of area and a cup-and-cone fracture surface. There is no yield plateau as with milder steel materials. The strain at the tensile strength is the ultimate strain.

Failure occurs almost immediately after the tensile strength and the ultimate strain are reached.

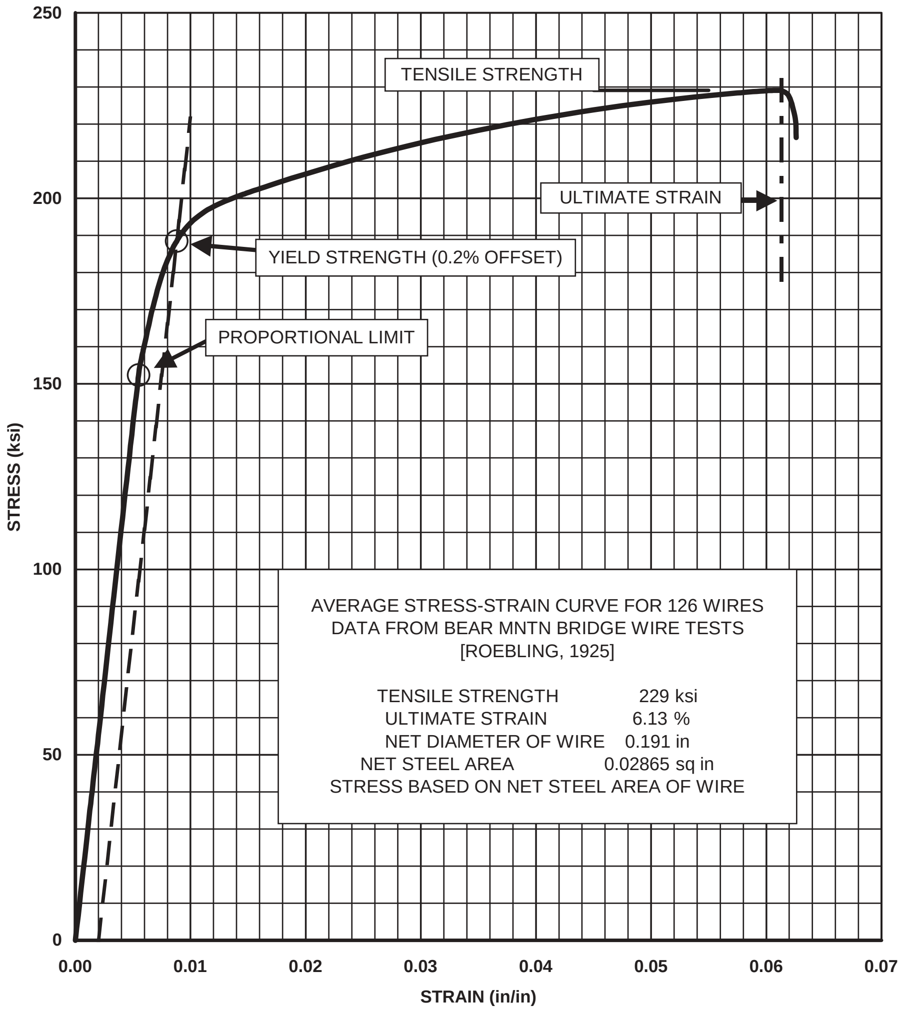


Figure A.3.1-1. Typical stress-strain curve for bridge wire. **[2]**

New wires have a tensile strength that varies little (the coefficient of variation is about 1.5% to 2%). Corroded wires that exhibit ductile fractures have a more variable tensile strength than new wires. Wires that are cracked to any degree have reduced and highly variable tensile strength. They exhibit brittle fracture surfaces with no reduction in area, often referred to as “square breaks.” The mean tensile strength and the coefficient of variation of wires removed from several suspension bridges are shown in Table A.3.1-1 for various stages of corrosion. Tensile strength in this table is based on the net steel area (the area not including the zinc coating).

Table A.3.1-1 Mean tensile strength and coefficient of variation for wires from several suspension bridges

Bridge	Corrosion Stage	Mean Tensile Strength of New Wire (ksi)	Number of Samples	Mean Tensile Strength (Fraction of New Wire)	Coefficient of Variation
X	New Wire	240	2	1.00	0.004
	1-2		30	0.99	0.018
	3		18	0.98	0.024
	4		10	0.94	0.038
	Cracked		14	0.84	0.131
Y	New Wire	231	0	1.00	N/A
	1-2		19	1.00	0.089
	3		12	0.97	0.119
	4		7	0.89	0.085
	Cracked		15	0.68	0.210
Z	New Wire	236	20	1.00	0.020
	1-2		29	0.98	0.031
	3		29	0.95	0.038
	4		33	0.94	0.041
	Cracked		7	0.75	0.260

A.3.2 Strength Models for Wire Bundles

Perry [3] describes 3 models that can be used to estimate the strength of a parallel wire cable. They are presented below, starting with the least conservative. One is for ductile wires, another is for brittle wires based on strain and the third, a subset of the second, is for brittle wires based on tensile strength.

In studies of cables, which are bundles of filaments or wires, it is assumed that all the filaments are held together firmly at the ends and subjected to equal strain. Internal cable inspections of the Williamsburg Bridge [4] and Mid-Hudson Bridge [5] can be cited as evidence that the gap in a broken cable wire is equal to or slightly greater than the elastic elongation of the wire between cable bands under the dead load tension of the cable. The conclusion is that all the wires are effectively clamped at the cable bands, at least for normal working stresses.

A.3.2.1 DUCTILE-WIRE MODEL

In the Ductile-Wire Model, it is assumed that all of the wires in the cable share in the cable force until the entire cable breaks as a single unit. In other words, all of the wires are assumed to break simultaneously. For this to happen, the wires need not have equal strength, but they must be ductile (able to stretch under a constant load). Each wire elongates elastically and then plastically to the same degree as all of the other wires. The cable strength is the sum of the individual wire strengths, which is equal to the average wire strength multiplied by the number of wires in the cable. This model should not be applied to bridge cables, because there are always some cable wires that break before the entire cable does, and the efficiency of a cable of parallel wires has been found to vary between 94% and 96% [2, 6]. Efficiency is defined in these references as the actual breaking strength divided by the calculated strength of the Ductile-Wire Model.

A.3.2.2 BRITTLE-WIRE MODELS

The term *brittle* in the context of the Brittle-Wire Model is used to describe the behavior of an individual wire. It does not mean that the material in the wire is brittle, but that the wire fails suddenly when the strain or the stress in the wire reaches a certain level and no longer shares in the tensile force of the cable. Perry [3]describes two separate models under this name. The first is a general model that is referred to as the Limited Ductility Model in these Guidelines. The second is a specific case of the Limited Ductility Model, which is used by Perry and others to calculate cable strength under the general name, Brittle-Wire Model. It is also called the Brittle-Wire Model in these Guidelines.

A.3.2.2.1 Limited Ductility Model

In the Limited Ductility Model, a wire is assumed to fail suddenly when the strain in the wire reaches a certain level. Each wire in the cable can elongate only to its individual limit, which is called the ultimate strain of the wire. A specific wire that reaches this elongation will fail by definition. The limit is different for each wire, and so is the strength. The small amount of strain that occurs at reduced stress after the tensile strength is reached, as shown in Figure A 3.1-1, is ignored in the analysis. For any specific value of strain, it is assumed that each intact wire is subject to a tensile stress that corresponds to the strain in the stress-strain diagram for that wire. Whenever a wire breaks, the force carried by the wire is distributed to all of the unbroken wires in the cable in the same proportion as before the wire failed. The wires are assumed to break sequentially as each wire reaches its maximum elongation, and the cable strength is attained only after some of the wires break.

To determine the cable strength, the cable strain is increased incrementally and then the number of wires that have reached their elongation limit and failed are calculated at each increment**.** For each subsequent calculation, the number of newly failed wires is subtracted from the number of still intact wires to determine the number of unbroken wires that remain. All of the wires in the cable are subjected to the same strain. The cable force is calculated as the sum of the forces in the intact wires at that strain. Wires will fail faster than the cable force can increase at some value of elongation. The maximum force attained is the cable strength. This technique uses a statistical method called “ordered statistics.” The strength can be estimated either by sorting the wires in order of ultimate elongation or by using the statistical distribution curve of this property.

A.3.2.2.2 Brittle-Wire Model (A Special Case)

In a special case of the Limited Ductility Model, it is assumed that all of the wires follow the same stress-strain diagram, and that the stress in all of the intact wires is the same at any specific value of strain. The model may be simplified by assuming that a wire fails suddenly when the stress in the wire reaches a certain level. In the Brittle-Wire Model that results, each wire in the cable can resist a stress only up to its specific limit, equivalent to its tensile strength. A specific wire that reaches this stress will fail by definition. The limit is different for each intact wire, which is assumed to carry the same tension as all of the other wires; hence, the model is also called the Load-Sharing Model. After a wire breaks, the force carried by the wire is distributed equally to all of the other unbroken wires in the cable. The wires are assumed to break sequentially as each wire reaches its tensile strength, and the cable strength is attained only after some of the wires have broken.

Determining the cable strength requires increasing the cable stress in steps and calculating the number of wires that fail at each increment as they reach their tensile strength. The number of newly failed wires is subtracted from the number of previously intact wires to determine the number of unbroken wires. The cable force is calculated as the area of unbroken wires at a given level of stress multiplied by the wire stress. At some level of stress, wires will fail faster than the wire force can increase. The maximum force attained is the cable strength. This technique uses the same “ordered statistics” method as the Limited Ductility Model. The strength is estimated either by sorting the wires in order of tensile strength, or by using a statistical distribution curve of this property.

A.3.2.3 BRITTLE-DUCTILE MODEL

The Brittle-Ductile Model [7] takes into account the cable wires that fail at very low strains, which are subtracted from the total number of wires in the cable. The model assumes that the remaining wires in the cable are ductile. The strength calculation is then the same as for the Ductile Model, except that the number of wires is reduced.

A.3.2.4 SIMPLIFIED MODEL

In a variation of the Brittle-Ductile Model, cracked and broken wires are subtracted from the total wires in the cable, and the Brittle-Wire Model is applied to the remaining intact wires. This alternative to the Brittle-Wire Model is called the Simplified Model in these Guidelines.

A.4 STATISTICS FOR CABLE STRENGTH ANALYSIS

Sample wires are removed from the cables and tested to provide the data required for estimation of cable strength.

In the calculation of cable strength using sample statistics, data are used to develop statistical distribution curves that represent the spectrum of wire strengths or ultimate strains present in the cable. The curves are described below, before presenting their use in estimating cable strength.

The equations that follow employ the results of physical tests performed on a selection of wires removed from an actual cable. The mean and standard deviations resulting from these tests are called sample means and sample standard deviations to differentiate them from the population means and population standard deviations that represent all of the wires in the cables. The terms μ (mean) and σ (standard deviation) apply to the entire population, while μ_s and σ_s apply to the samples.

Two types of distribution curves are discussed in the following text. The first is the probability density distribution curve shown in Figure A.4-1. This curve describes the fraction of the entire population that has a specific value of x. It is commonly known as the “Bell Curve” for a distribution that is Normal or Gaussian. The area under the curve is always unity, describing 100% of the population. The area under the curve to the left of a specific value of x is the fraction of th population that has a value less than or equal to that value of x. When this area is plotted against x, it becomes the cumulative probability curve (Figure A.4-2), and varies between 0 and 1. The area to the right of a specific value of x in Figure A.4-1 is the fraction of the population that has a value greater than the value of x.

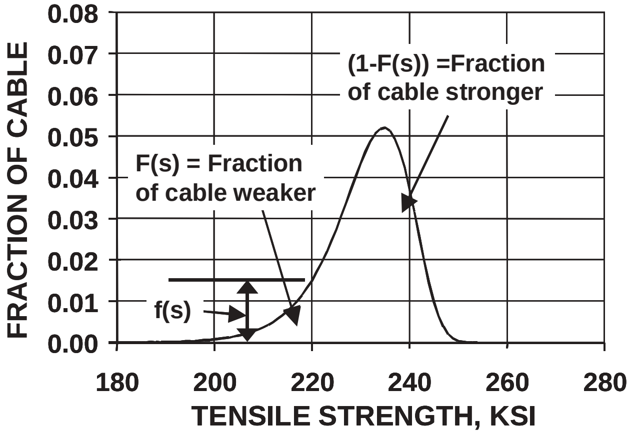


Figure A.4-1. Typical probability density distribution curve

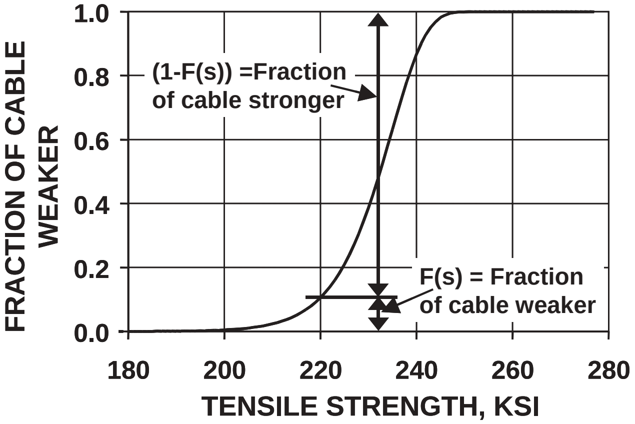


Figure A.4-2. Typical cumulative probability curve

The first of the distribution curves is represented by the expression *f*(*x*), while the second is represented by *F*(*x*). In these Guidelines, the expressions *f*3(*x*) and *F*3(*x*) are used to denote the recommended Weibull distribution.

The value that is derived from these distributions is the fraction of the population that has a value of *x* (i.e., tensile strength or ultimate strain) greater than a specific value of *x*. It is also known as the Survivor Function and is given as (1-*F* (*x*)). It is equivalent to the area to the right of *x* on the probability density distribution. The term *s* is substituted for *x* for the distribution of tensile strength in these Guidelines, and *e* is substituted for *x* for ultimate strain.

A.4.1 Extreme Value Distributions

The distribution of the minimum tensile strengths of the wires must be obtained to determine the strength of the cable in any panel of length L. The extreme value distributions are very useful for this purpose. In the discussions and equations that follow, the general variable, *X*, represents either the tensile strength or the ultimate elongation in the strength models described previously.

The derivation of the extreme value distributions is given in various references [1, 7-9] and will not be repeated here. The Type I and Type III extreme value distributions are useful in describing the minimum strength of wires. Type I (also known as the Gumbel) extends from -∞ to +∞, as does the Normal distribution.

Type III, extending from a minimum value of x_0 to a maximum of +∞, corresponds to a material with a lower limit of tensile strength or ultimate elongation. Rao [1]states that the parent function of this extreme value distribution is a Gamma distribution. The Gamma distribution is valued for $x > x_0$, as is the Weibull distribution, and for very small standard deviations is virtually the same as a Normal distribution. The value of x_0 is assumed to be zero, because the tensile strength and ultimate elongation of materials cannot be less than zero.

The Type III extreme value distribution is a Weibull distribution, which is discussed in many references, among them Rao and Weibull. [1, 9] The parameters of the distribution are not implicit, but it is relatively simple to find a solution through trial-and-error using a spreadsheet. An alternative method is to use Weibull graph paper. [1] Perry [3]argues that the Weibull distribution is the only correct distribution in this instance**.** The Weibull distribution is used in these Guidelines because it allows limiting the minimum value of the variable, which is of particular importance for the Limited Ductility Model. Ultimate strains less than zero could result from the use of other distribution functions.

A.4.2 Weibull Distribution

The Type III extreme value distribution is the Weibull distribution. As stated above, it extends from a minimum value, x_0, to +∞. This distribution is given in Rao [1] as

$$F3_{X_1}(x) = 1 - \exp\left[-\left(\frac{x - x_0}{\upsilon - x_0}\right)^m\right] \qquad \text{(A.4.2-1)}$$

$$f3_{X_1}(x) = \frac{m}{\upsilon - x_0} \cdot \left(\frac{x - x_0}{\upsilon - x_0}\right)^{m-1} \cdot \exp\left[-\left(\frac{x - x_0}{\upsilon - x_0}\right)^m\right] \qquad \text{(A.4.2-2)}$$

where

$f3_{X1}(x)$ = Type III extreme value probability density distribution for the smallest values of random variable *X*

$F3_{X1}(x)$ = Weibull extreme value cumulative distribution for the smallest values of random variable *X*

exp(*x*) = *e* (2.7183) to the power (*x*), the “exponential” of (*x*)

x = a value of random variable X_1

x_0 = minimum value of x for which the Type III distribution is valid. It is taken as 0 in these Guidelines.

X_1 = random variable representing the smallest values of property x of each wire

m = parameter of the Type III extreme value distribution for minimum values

υ = parameter of the Type III extreme value distribution for minimum values

The function $F3_{X1}(x)$ is the cumulative probability distribution. Its value at any value of x is the probable fraction of the entire population of wires for which the property represented by the general variable X_1 is smaller than the specific value x.

The probability density distribution $f3_{X1}(x)$ represents the fraction of the population for which one unit of property represented by X_1 is equal to x. The unit of x is the basic unit of the property, e.g., ksi or inches/inch. The cumulative distribution is the integral of the density distribution between x_0 and x.

In these equations and the ones that follow, the term X_1 represents the smallest values of X in a specific length of wire determined from tests on specimens cut from sample wires.

The mode, mean and variance are given as

$$\text{mode} = x_0 + (\upsilon - x_0)\cdot\left(\frac{m-1}{m}\right)^{1/m} \qquad \text{(A.4.2-3)}$$

$$\text{mean} = \mu_{X_1} = x_0 + (\upsilon - x_0)\cdot\Gamma\left(1+\frac{1}{m}\right) \qquad \text{(A.4.2-4)}$$

$$\text{variance} = \sigma_{X_1}^2 = (\upsilon - x_0)^2\cdot\left[\Gamma\left(1+\frac{2}{m}\right) - \Gamma^2\left(1+\frac{1}{m}\right)\right] \qquad \text{(A.4.2-5)}$$

In these equations, x_0 is the lower limit of the tensile strength or ultimate strain of the wire (usually taken as zero) and υ and m are parameters of the distribution. If the sample mean and standard deviation for the smallest values of x for each wire sample are given, μ_{X1} becomes μ_{sX1} and σ_{X1} becomes σ_{sX1}.

Eliminating the variable $(\upsilon - x_0)$ in Equation 4 and Equation 5 results in the following equation, given by Castillo [10] that can be solved for m by successive approximation, illustrated in Figure A.4.2-1 (use the“Solver”function of a spreadsheet program such as Microsoft Excel for this purpose)

$$\left[\Gamma\left(1+\frac{2}{m}\right)\Big/\Gamma^2\left(1+\frac{1}{m}\right) - 1\right] = \sigma_{sX_1}^2\Big/(\mu_{sX1} - x_0)^2 \qquad \text{(A.4.2-6)}$$

where

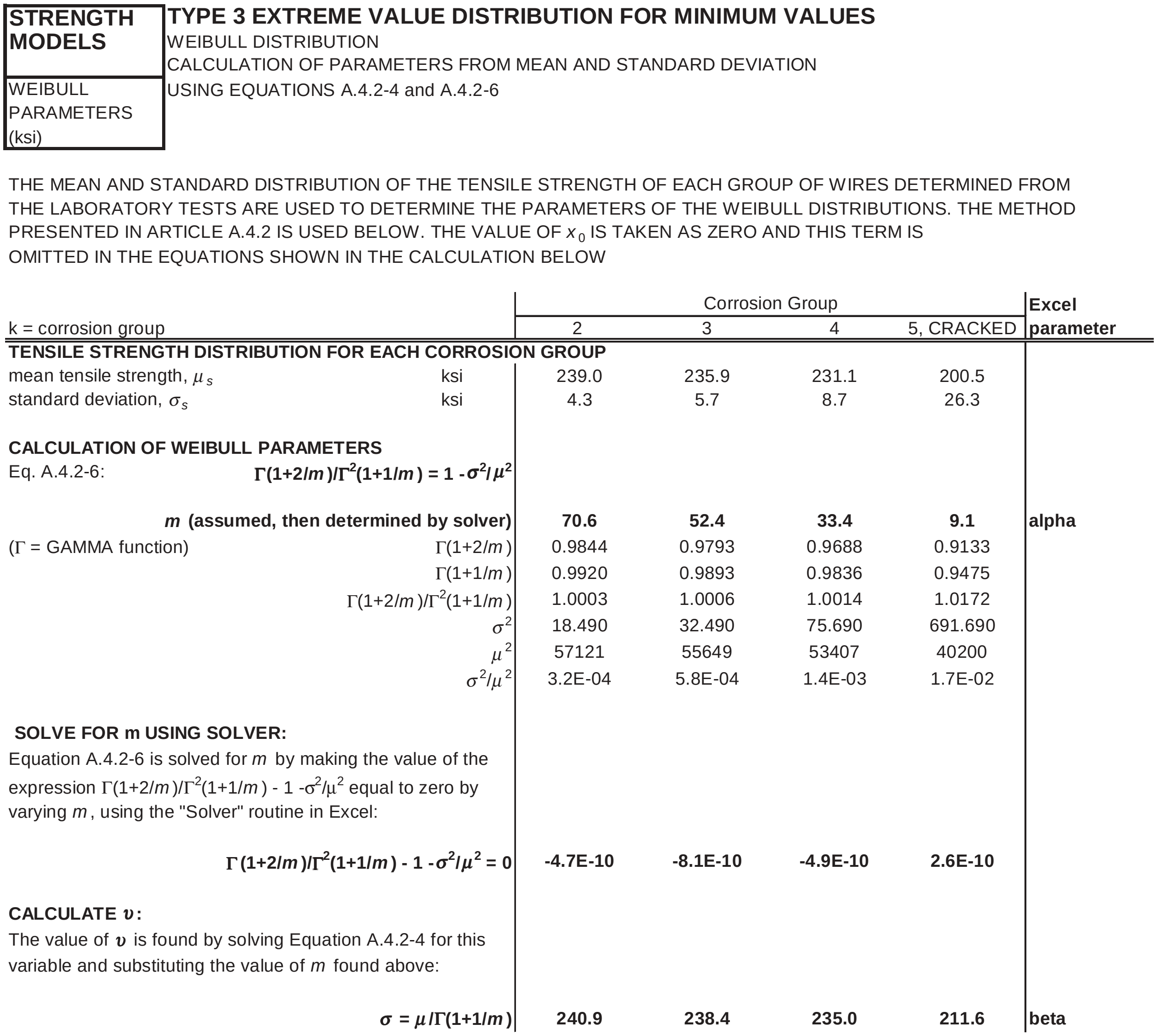
μ_{sX1} = sample mean of the extreme value distribution of X_1

σ_{sX1} = sample standard deviation of the extreme value distribution of X_1

$\Gamma(\,)$ = Gamma function of the expression inside the brackets

The Weibull function is one of the functions included in the Microsoft Excel spreadsheet program, which makes it relatively simple to use once the parameters have been determined. The parameters υ and m are called beta and alpha, respectively, in Excel. The Weibull function in Excel uses $x_0 = 0$. If another value is used, $(x - x_0)$ must be substituted for x, and $(\upsilon - x_0)$ substituted for beta, in the Excel function.

The recommended value of x_0 in these Guidelines is zero. It can be argued that this value should be the dead load stress in the cable because the wires have been "tested" in service at this stress and the tensile strength cannot be smaller, but comparative calculations using the dead load stress for x_0 in one case and zero in the other show that the difference in cable strength is very small, and Equations 1 to 6 can be simplified by omitting the term x_0.



STRENGTH MODELS	TYPE 3 EXTREME VALUE DISTRIBUTION FOR MINIMUM VALUES
WEIBULL PARAMETERS (ksi)	WEIBULL DISTRIBUTION CALCULATION OF PARAMETERS FROM MEAN AND STANDARD DEVIATION USING EQUATIONS A.4.2-4 and A.4.2-6

THE MEAN AND STANDARD DISTRIBUTION OF THE TENSILE STRENGTH OF EACH GROUP OF WIRES DETERMINED FROM THE LABORATORY TESTS ARE USED TO DETERMINE THE PARAMETERS OF THE WEIBULL DISTRIBUTIONS. THE METHOD PRESENTED IN ARTICLE A.4.2 IS USED BELOW. THE VALUE OF x_0 IS TAKEN AS ZERO AND THIS TERM IS OMITTED IN THE EQUATIONS SHOWN IN THE CALCULATION BELOW

		Corrosion Group				**Excel**
k = corrosion group		2	3	4	5, CRACKED	**parameter**
TENSILE STRENGTH DISTRIBUTION FOR EACH CORROSION GROUP						
mean tensile strength, μ_s	ksi	239.0	235.9	231.1	200.5	
standard deviation, σ_s	ksi	4.3	5.7	8.7	26.3	
CALCULATION OF WEIBULL PARAMETERS						
Eq. A.4.2-6:	$\boldsymbol{\Gamma(1+2/m)/\Gamma^2(1+1/m) = 1 - \sigma^2/\mu^2}$					
	***m* (assumed, then determined by solver)**	**70.6**	**52.4**	**33.4**	**9.1**	**alpha**
(Γ = GAMMA function)	$\Gamma(1+2/m)$	0.9844	0.9793	0.9688	0.9133	
	$\Gamma(1+1/m)$	0.9920	0.9893	0.9836	0.9475	
	$\Gamma(1+2/m)/\Gamma^2(1+1/m)$	1.0003	1.0006	1.0014	1.0172	
	σ^2	18.490	32.490	75.690	691.690	
	μ^2	57121	55649	53407	40200	
	σ^2/μ^2	3.2E-04	5.8E-04	1.4E-03	1.7E-02	

SOLVE FOR m USING SOLVER:

Equation A.4.2-6 is solved for m by making the value of the expression $\Gamma(1+2/m)/\Gamma^2(1+1/m) - 1 - \sigma^2/\mu^2$ equal to zero by varying m, using the "Solver" routine in Excel:

	2	3	4	5, CRACKED	
$\boldsymbol{\Gamma(1+2/m)/\Gamma^2(1+1/m) - 1 - \sigma^2/\mu^2 = 0}$	**-4.7E-10**	**-8.1E-10**	**-4.9E-10**	**2.6E-10**	

CALCULATE $\boldsymbol{\upsilon}$:

The value of υ is found by solving Equation A.4.2-4 for this variable and substituting the value of m found above:

	2	3	4	5, CRACKED	
$\boldsymbol{\sigma = \mu/\Gamma(1+1/m)}$	**240.9**	**238.4**	**235.0**	**211.6**	**beta**

Figure A.4.2-1. Calculation of parameters of Weibull distribution by iteration.

A.5 EQUATIONS FOR ESTIMATING CABLE STRENGTH USING THE WEIBULL DISTRIBUITON

For both the Limited Ductility and Brittle-Wire Models, the Weibull distribution curve is used to estimate cable strength. The use of the expression $(1-F3(x))$ is equivalent to making the force equal to zero in wires that break as strain or stress is increased**.**

A.5.1 Limited Ductility Model Equations

A.5.1.1 DIFFERENT STRESS-STRAIN CURVES AVAILABLE FOR WIRES

The general form of the Limited Ductility Model is used whenever the stress-strain curves for wires vary significantly. This can occur when the carbon content of the wires varies from wire to wire because of poor manufacturing quality control or multiple suppliers. The stress-strain curves should be reduced to a limited number, *M*, of average curves, and each group of wires subdivided and assigned to the various *M* curves proportionally. This requires a map of the cable cross-section in each evaluated panel showing the distribution for each stress-strain curve. Additional samples must be taken to obtain the data to prepare these maps; a sampling pattern is suggested in the final report for NCHRP Project 10-57, on the accompanying CD. These additional samples may also be added to the random samples for the purpose of determining the tensile properties of the wires. It is recommended that a statistician be added to the investigation team when this procedure is followed.

The separation of test samples into these subgroups would necessitate the removal of many more sample wires from the cable, and is not recommended. Thus, all wires in a specific group are assumed to follow the same distribution of the ultimate strain. At any value of strain, the fraction of unbroken wires in each subgroup of wires is represented by the survivor function,

$$S_k(e) = \left(1 - F3_k(e)\right) \tag{A.5.1.1-1}$$

where

$S_k(e)$ = survivor function; or that fraction of the wires in Group *k* that has an ultimate elongation greater than *e*

e = specific value of strain

$F3_k(e)$ = Weibull cumulative distribution function for ultimate strain of Group *k* wires

k = corrosion stage of a group of wires (k = 2, 3, 4 and 5)

The total force in the wires of Subgroup *km* at strain *e* is

$$T_{km} = N_{eff} \cdot a_w \cdot p_{km} \cdot s_m(e) \cdot \left(1 - F3_k(e)\right) \tag{A.5.1.1-2}$$

where

T_{km} = force in Subgroup *km* wires

N_{eff} = effective number of unbroken wires in the cable

a_w = nominal area of one wire, used in lab analysis

p_{km} = fraction of cable represented by Subgroup *km* wires

$s_m(e)$ = stress at strain *e* in wires that follow stress-strain curve *m*

m = number of a discrete stress-strain curve

km = subgroup of Stage *k* wires that follow stress-strain curve *m*

The total cable force is the sum of the forces in the subgroups of wires, and the cable strength is the maximum force attained

$$R_u = N_{eff} \cdot a_w \cdot \max\left(\sum_{m=1}^{M} \sum_{k=2}^{5} p_{km} \cdot s_m(e) \cdot \left(1 - F3_k(e)\right)\right) \tag{A.5.1.1-3}$$

where

R_u = cable strength attributable to wires in the cable that are not broken

M = number of different stress-strain curves considered

This strength model requires M times as many calculations as when only a single average stress curve can be used for all wires, as in the following article.

A.5.1.2 ALL GROUPS OF WIRES HAVE THE SAME STRESS-STRAIN CURVE

Where all groups of wires have the same stress-strain curve, the term $s_m(e)$ becomes the same for all groups at any specific strain, e. The individual cumulative distributions may be combined into a single compound distribution (not a Weibull distribution) and Equation A.5.1.1-3 simplifies to

$$R_u = N_{eff} \cdot a_w \cdot \max\left(s(e) \cdot \left(1 - F_C\left(e\right)\right)\right) \tag{A.5.1.2-1}$$

in which

$$F_C(e) = \sum_{k=2}^{5} p_k \cdot F3_k(e) \tag{A.5.1.2-2}$$

where

$F_C(e)$ = compound cumulative distribution of the ultimate strain

p_k = fraction of unbroken wires represented by Group k wires

$s(e)$ = stress in wires determined from average stress-strain curve for all wires

A.5.2 Brittle-Wire Model Equations

The compound tensile strength distribution is used in the Brittle-Wire Model (again, not a Weibull distribution). A single average stress-strain curve is used to represent the entire cable. The fraction of the cable that is essentially unbroken at any specific stress level s is given by the expression.

$$\left(1 - F_C\left(s\right)\right) \tag{A.5.2-1}$$

in which

$$F_C\left(s\right) = \sum_{k=2}^{5} p_k \cdot F3_k\left(s\right) \tag{A.5.2-2}$$

where

$F_C(s)$ = compound cumulative distribution of tensile strength

$F3_k(s)$ = Weibull cumulative distribution function for tensile stress of Group k wires

s = stress in the unbroken wires of the cable

The force in the cable is

$$T_u(s) = N_{eff} \cdot a_w \cdot \left[s \cdot (1 - F_C(s)) \right] \qquad \text{(A.5.2-3)}$$

where

$T_u(s)$ = tensile force in unbroken wires in the cable at stress s

and the cable strength is the maximum value that $T_u(s)$ attains,

$$R_u = N_{eff} \cdot a_w \cdot max\left(s \cdot (1 - F_C(s)) \right) \qquad \text{(A.5.2-4)}$$

This equation can be solved by trial-and-error using “Solver” in the Microsoft Excel spreadsheet program, as shown in Appendix C. If a cable force vs. strain diagram is required, the cable force must be calculated at selected increments of strain.

A.5.3 Simplified Model Equations

Using the simplified model requires:

- Calculation of the effective number of wires, obtained by subtracting the unrepaired broken wires plus the estimated number of wires in Stages 3 and Stage 4 that contain cracks from the total number of wires in the cable (there will be no Group 5, because cracked wires are omitted from this calculation)
- Calculation of the combined mean and standard deviation of the tensile strengths of the remaining wires that comprise Groups 2, 3, and 4, using Equation A-5.3.1-1 and Equation A-5.3.1-2)
- Applying the Brittle-Wire Model to the wires, using the single distribution curve

A.5.3.1 SINGLE DISTRIBUTION CURVE FOR TENSILE STRENGTH

The fraction of the cable represented by Groups 2, 3 and 4 is combined with the sample mean and standard deviation values for the minimum tensile strength of the representative specimens of each group. The result is used to determine the sample mean tensile strength and standard deviation of the entire unbroken and uncracked wire population as follows:

$$\mu_s = \sum_{k=2}^{4} (p_k \cdot \mu_{sk}) \qquad \text{(A.5.3.1-1)}$$

$$\sigma_s = \sqrt{\left(\sum_{k=2}^{4} p_k \left(\sigma_{sk}^2 + \mu_{sk}^2 \right) \right) - \mu_s^2} \qquad \text{(A.5.3.1-2)}$$

where

μ_s = sample mean tensile strength of the combined groups of wires excluding cracked wires

μ_{sk} = sample mean tensile strength of Group k wires

σ_s = sample standard deviation of the tensile strength of the combined groups of wires, excluding cracked wires

σ_{sk} = sample standard deviation of the tensile strength of Group *k* wires

p_k = fraction of the unbroken and uncracked wires in the cable represented by Group *k* wires

k = corrosion stage of a group of wires (k = 2, 3 and 4)

A.5.3.2 CABLE STRENGTH USING THE SIMPLIFIED MODEL

The estimated cable strength calculated according to the Brittle-Wire Model is given by Equation A-5.2-4. In the Simplified Model, which uses a single tensile strength distribution, the compound distribution $F_C(s)$ is replaced by the single Weibull distribution $F3(s)$, resulting in

$$R_u = N_{eff} \cdot a_w \cdot max\left(s \cdot \left(1 - F3(s)\right)\right) \qquad \text{(A.5.3.2-1)}$$

where

$F3(s)$ = single Weibull distribution of the tensile strength representing all of the Group 2 to 4 wires (without cracked wires), based on the sample mean and sample standard deviation of the combined groups, calculated using equations A.5.3.1-1 and A.5.3.1-2

s = stress in the unbroken wires of the cable

The sample mean tensile strength μ_s can be factored out of the expression in brackets in Equation A-5.3.2-2 to result in

$$R_u = N_{eff} \cdot a_w \cdot \mu_s \cdot max\left(s' \cdot \left(1 - F3(s')\right)\right) \qquad \text{(A.5.3.2-2)}$$

in which

s' = s/μ_s

$F3(s')$ = single Weibull distribution of the tensile strength representing all the Group 2 to 4 wires, based on a mean tensile strength of 1.0 and a standard deviation of the combined groups, calculated using Equations A.5.3.1-1 and A.5.3.1-2, divided by μ_s

Referring to Equation A.4.2-1, $F3_{x1}(x)$ does not change if the terms x, x_0 and υ on the right-hand side of the equation are all divided by μ_s. The value of the distribution functions $F3(s)$ and $F3(s')$ are identical for any specific value of s, if the distribution $F3(s')$ is based on $\mu_s' = 1$ and $\sigma_s' = \sigma_s/\mu_s$. The value of the term $K = max(s' \cdot (1 - F3(s')))$ can be determined as a function of the coefficient of variation, σ_s/μ_s. The calculation results in the curve of K vs. σ_s/μ_s shown in Figure 5.3.3.1.2-1, where K is the reduction factor to be applied in the equation

$$R_u = N_{eff} \cdot a_w \cdot \mu_s \cdot K \qquad \text{(A.5.3.2-3)}$$

where

K = reduction factor from Figure 5.3.3.1.2-1 as a function of the coefficient of variation, σ_s/μ_s.

A.6 REFERENCES

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CONTENTS

B.1 INTRODUCTION

The equations for cable strength given in the Guidelines are based on the assumption that only wires in the specific panel being evaluated have been inspected and that, wire for wire, all other panels within the effective development length are at the same stage of corrosion. Of course, this is not usually the case. The physical strength of a wire may vary in adjacent panels, the wire may have cracks, or it may be at a different corrosion stage, but there is no way to know for sure without inspecting all the panels in the effective development length. In Article B.4.1 all the panels are assumed to have been inspected. In Article B.4.2, only one panel is inspected, and the equations presented in Section 5 are derived.

A wire that is deteriorated or cracked in the evaluated panel as well as in adjacent panels may fail in an adjacent panel rather than in the evaluated panel. Part of the wire's capacity will be redeveloped in the evaluated panel, because of the friction that is developed in the cable bands between the break location and the investigated panel.

The issue of wires that are broken in service in the cable was addressed in Section 5. The broken wires, which are treated separately from intact wires, are also partially redeveloped as they pass through the cable bands, but this Appendix addresses only cracked wires.

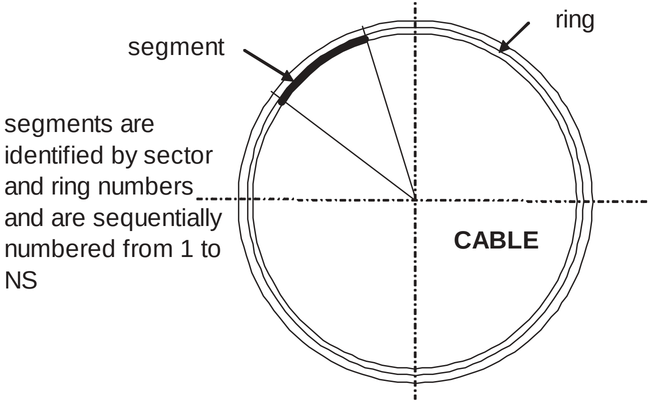
The calculation of the effect of adjacent panels becomes manageable once certain assumptions are made. The cable cross-section is divided into segments. Each segment extends over the arc of a sector of the cable and is composed of wires that are equidistant from the center of the cable (see Figure B.1-1). All wires in a segment are assumed to be at the same corrosion stage in any one panel, but not in adjacent panels (e.g., a segment may contain Stage 3 wires in one panel and Stage 4 wires in another panel).

Cracked wires are the major factor in determining cable strength. As an example, the calculated strength for one bridge cable was reached at a wire stress of 213 ksi. 14.2% of the wires had a tensile strength lower than this stress and were assumed to have failed. Wires with cracks accounted for 13.8% of this total, uncracked Stage 3 and Stage 4 wires for only 0.4%. No "good" (Stage 1 and Stage 2) wires were broken at this stress level.

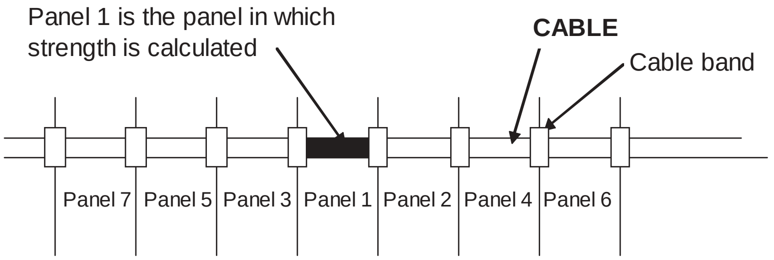
A fractured wire regains a constant fraction of its tensile strength at each cable band, equal to the redevelopment coefficient, C_d, multiplied by 95% of the mean tensile strength of Group 2 wires. Wires that break in adjacent panels are redeveloped in the evaluated panel to the extent made possible by cable band friction, and the redevelopment force is added to the cable strength. It is assumed that these wires will not break again in the effective development length.

Usually, the stress in the cable at failure will be greater than the stress that can be redeveloped in a wire that breaks within the effective development length. The use of a constant for the maximum force that can be redeveloped will not affect the contribution to cable strength of cracked wires that fail, because the maximum redeveloped stress is generally smaller than the stress in the cable at failure. The calculated cable force at stresses lower than the stress at which the cable fails may be slightly too high, but the cable strength will not be affected.

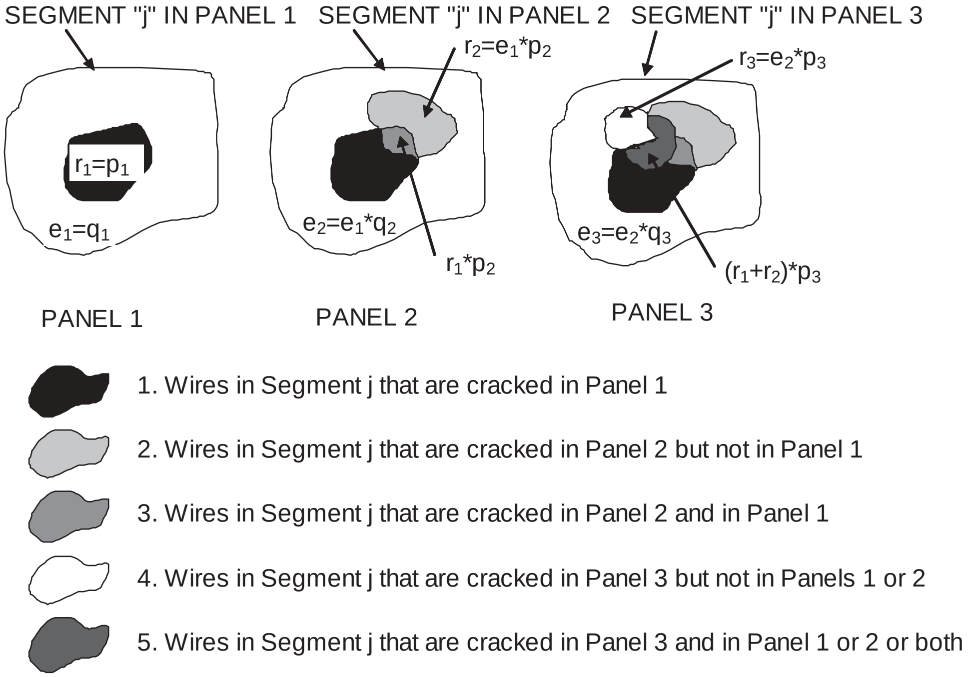
The cable force and wire stress are assumed to be the same in all the panels. Whenever a wire breaks in one panel, the redistribution of wire force makes an infinitesimal change in the stress in the remaining wires in the other panels, but this change in stress can be ignored.



CROSS SECTION OF CABLE



ELEVATION OF CABLE



1, 2 & 4 are "discrete cracked wires"

DIAGRAMS OF SEGMENT "j" IN THREE ADJACENT PANELS

Figure B.1-1. Definitions of segments, panels and discrete cracked wires.

B.2 NOTATION

a_w = nominal area of one wire, used in lab analysis

C_d = redevelopment factor, (fraction of 95% of the mean tensile strength of Group 2 wires that is developed in a broken wire at each cable band)

C_{di} = wire re-development factor for panel i = C_d multiplied by the number of cable bands between panel i and Panel 1

e_{ij} = fraction of uncracked wires in segment j, panel i, not cracked in panels less than i

$F3_5(s)$ = fraction of cracked wires that are broken at stress s = Weibull cumulative distribution of tensile strength for Group 5 (cracked) wires at stress s

i = number of a cable panel

j = number of a cable segment

jk = a segment j that contains Stage k wires in Panel 1

k = corrosion stage of a group of wires

k_{ij} = corrosion stage of wires in segment j, panel i

L_e = effective development length (number of panels)

N = total number of wires in the cable

N_{0k} = number of unbroken Stage k wires in the evaluated panel

N_5 = number of discrete cracked wires in the effective development length

$n_{c,j}$ = number of discrete cracked wires in segment j for the effective development length

$n_{c,jk}$ = number of discrete cracked wires in a segment, j, that contains Group k wires in Panel 1, in the effective development length

N_{cr} = total number of cracked wires in the effective development length that are redeveloped in Panel 1 after breaking

$N_{cr,k}$ = effective number of broken cracked wires that are Stage k in Panel 1 and can be redeveloped

$N_{c,k}$ = total number of discrete cracked wires in the effective development length in segments that are Group k in Panel 1

N_{eff} = effective number of unbroken wires in the evaluated panel

NS = total number of segments in the cross-section of the cable

n_j = number of wires in segment j

p_5 = fraction of unbroken wires in the evaluated panel represented by Group 5

$p_{c,ij}$ = fraction of wires cracked in segment j, panel i

$p_{c,k}$ = fraction of Stage k wires that are cracked

p_k = fraction of Stage k wires in the cable

$p_{cr}(s)$ = fraction of cracked wires that have broken at stress level s and are redeveloped in Panel 1

q_{ij} = fraction of uncracked wires in segment j, panel i

R_b = cable strength attributable to broken wires in adjacent panels.

r_{ij} = fraction of wires in segment j that are cracked in panel i but that are not cracked in panels less than i

r_{ki} = fraction of wires cracked in panel i in all segments that are Group k in Panel 1

R_u = cable strength attributable to unbroken wires

s = stress in the unbroken wires of the cable

$T_{cr}(s)$ = maximum force in the broken cracked wires that can be redeveloped in the evaluated panel at stress s

μ_{s2} = sample mean tensile strength of Group 2 wires

Note: $p_{c,ij}$, q_{ij}, r_{ij} and e_{ij} are also called p_i, q_i, r_i and e_i respectively in the derivation in Article B.4.1.1

B.3 ORDER OF FAILURE OF CRACKED WIRES

It is assumed that wires in a given stage in Panel 1 will break before wires at the same stage or better in an adjacent panel, and equally that a wire in an adjacent panel will break before a better stage wire in Panel 1. Cracks have not been found in Stage 1 or Stage 2 wires, and therefore only Stage 3 and Stage 4 cracked wires are considered in this analysis, and they are assumed to share a common tensile strength distribution curve. If the cracked wires in the two stages have different curves, they should be treated separately. A determination must be made about where they will break first. It is suggested that a single tensile strength distribution curve be calculated for the combined groups of wires, thus simplifying the calculation. The net effect is that a wire with cracks along its length will break as near to Panel 1 as possible.

B.4 NUMBER OF DISCRETE CRACKED WIRES AND THEIR REDEVELOPMENT

B.4.1 All Panels in Effective Development Length Inspected

The segments in the cable cross-section are numbered from 1 to NS, the total number of segments. The integer j is used to identify the segments.

Cable panels are numbered from 1 to L_e , where L_e is the number of panels in the effective development length. The panel numbers begin at Panel 1, which is the panel under evaluation, located at the center of the effective development length. Panel numbers increase as the distance from Panel 1 increases on both sides, as shown in Figure B.1-1. The integer i is used to identify the panels.

When all panels within the effective development length are inspected, the corrosion stage and thus the wire group observed in each segment of the cable should be known.

In the following derivation, some shorthand notation is used. The subscript j is omitted because the derivation is for a single segment, j, of the cable, and the subscript c is omitted for cracked wires.

p_i = $p_{c,ij}$ = fraction of wires in segment j in panel i that are cracked

q_i = $1\text{-}p_i$ = fraction of wires in segment j in panel i that are not cracked

e_i = e_{ij} = fraction of wires in segment j in panel i that are not cracked and are also not cracked in panels less than i

r_i = r_{ij} = fraction of wires in segment j that are cracked in panel i but that are not cracked in panels less than i

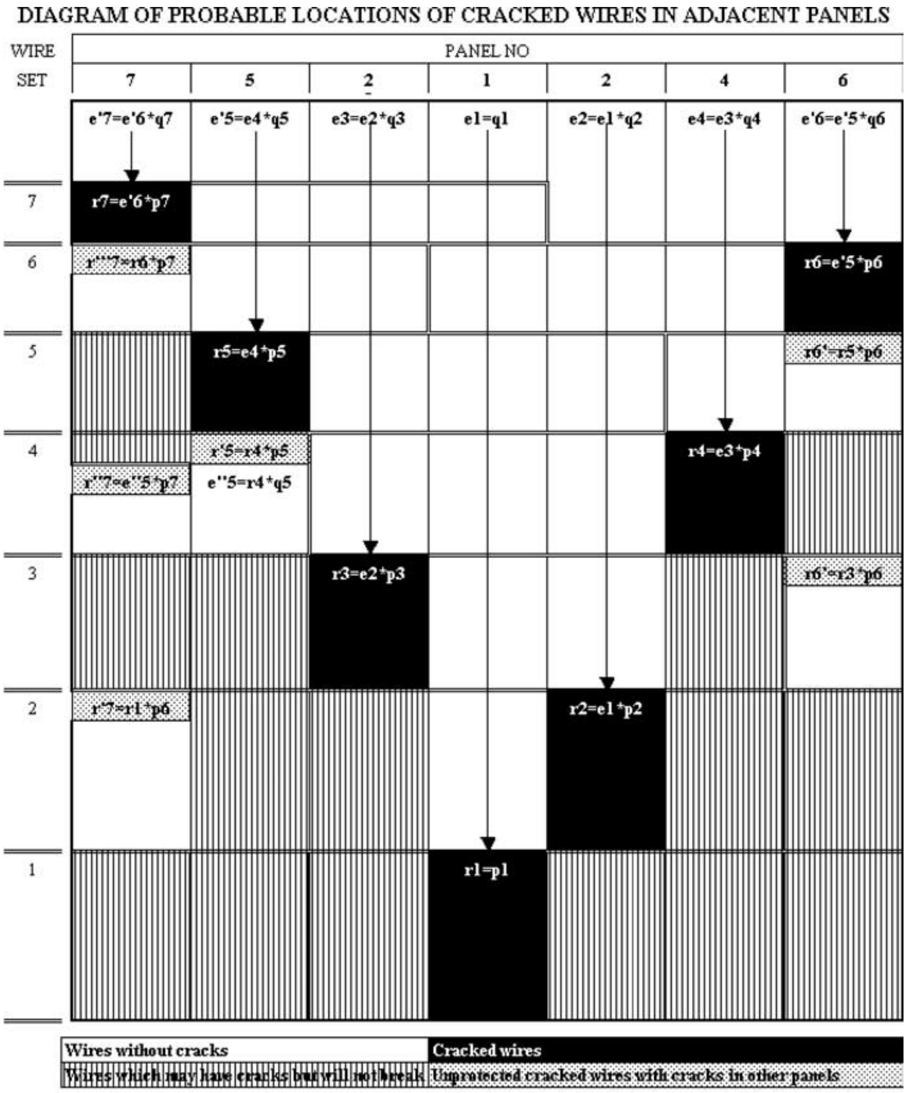
To account for the effect of deteriorated wires in adjacent panels, the number of wires in each corrosion stage in Panel 1 is reduced by the effective number of cracked wires in that stage in all panels in the effective development length. The number of discrete cracked wires is the total number of cracked wires that have an impact on Panel 1when they break in the effective development length, and is equal to the number of cracked wires in each panel that are not cracked in lower numbered panels (the black areas in Figure B.4.1.1-1). A wire that is cracked in Panel i and also cracked in a panel less than i will break in that other panel and is already counted there. It is not counted again in Panel i.

The reduction is calculated for each group of wires, k. The fraction of discrete cracked wires, r_i, in each panel is then multiplied by the appropriate factor to arrive at the effective number of cracked wires that fail in the calculation of strength, and that are redeveloped in Panel 1. This factor is zero for Panel 1; C_d for panels 2 and 3, $2C_d$ for Panels 4 and 5, etc., where C_d is the fraction of 95% of the mean tensile strength of Group 2 wires that is developed through friction at each cable band.

B.4.1.1 DISCRETE CRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH

The separation of Stage 3 and Stage 4 wires into uncracked and cracked sets in each segment in each panel is illustrated in Figure 1, and is made as follows. In Panel 1, there is a set of cracked wires, $r_1 = p_1$, and a set of uncracked wires, $e_1 = q_1 = (1 – p_1)$. In Panel 2, the first adjacent panel, a fraction of the cracked wires will probably be the same wires as wires in each of these Panel 1 sets, in proportion to p_2. Thus, $p_2 \; x \; p_1$ wires will correspond one-for-one with cracked wires in Panel 1 and will break in Panel 1. These wires will not break again until they are fully redeveloped, and they will not affect the strength of Panel 1. In this same Panel (Panel 2), however, there will be $r_2 = p_2 \; x \; e_1$ cracked wires that do not correspond to cracked wires in Panel 1 and will break in Panel 2. They must be subtracted from Panel 1 wires of the appropriate stage in the calculation of uncracked, unbroken wires in Panel 1.

The calculations for the fraction of discrete cracked wires in each panel are tabulated in Table B.4.1.1-1. The values of e_i and r_i are calculated in numerical panel order, starting from Panel 1. The table assumes an effective development length of 7 panels and must be expanded or contracted for other values of the effective development length. Note that panels separated by more than four cable bands are calculated as if no wires could be redeveloped. Wires can obviously break in another panel more than 4 cable bands away from a break, but because they correspond one-for-one with broke wires closer to Panel 1 that have already been considered, they can be ignored.



Each wire set consists of the same wires throughout the seven cable panels.

EXAMPLES:

1. There are n wires in segment "j". Wire set 1 contains p1*n wires with cracks in panel 1. All these cracked wires are assumed to break in panel 1. Since the wires will be redeveloped at the rate of 0.25 x the wire strength at each cable band it passes through, another cracked wire in the vertically shaded areas will not break because the force in the wires is less than 0.75 x the wire strength. Wires which break in panels outside those shown will be fully redeveloped in panel 1.
2. Wire set 4 contains cracks which, if broken, will be redeveloped inside the seven cable panels under consideration. This is indicated by the double vertical line between the third and fourth panels from the broken wires. Thus, additional wires can break in panel 5, as well as in panel 7. These wires are shown in grey, and are not considered in the analysis of panel 1, since, if they break, they will be redeveloped to a further degree than those broken in panel 4, and will not reduce the strength of the cable in panel 1.

Figure B.4.1.1-1. Probable location of cracked wires in adjacent panels.

Table B.4.1.1-1 Calculation of discrete cracked wires

	Panel Number, i						
	7	5	3	1	2	4	6
Corrosion Stage	g_7	g_5	g_3	g_1	g_2	g_4	g_6
Fraction Cracked, p_i	p_7	p_5	p_3	p_1	p_2	p_4	p_6
Fraction Not Cracked, qi	$1\text{-}p_7$	$1\text{-}p_5$	$1\text{-}p_3$	$1\text{-}p_1$	$1\text{-}p_2$	$1\text{-}p_4$	$1\text{-}p_6$
Net Not Cracked, ei Note that redevelopment at cable bands is not considered in this value	$q_1*q_2*q_3*q_4*q_5*q_6*q_7$	$q_1*q_2*q_3*q_4*q_5$	$q_1*q_2*q_3$	$e_1 = q_1$	q_1*q_2	$q_1*q_2*q_3*q_4$	$q_1*q_2*q_3*q_4*q_5*q_6$
Additional cracked wires in segment, ri	p_7*e_6	p_5*e_4	p_3*e_2		p_2*e_1	p_4*e_3	p_6*e_5

The calculation of discrete cracked wires is made for each of the *NS* segments in the cable cross-section. For each group of wires, *k*, in Panel 1, the total number of discrete cracked wires is required in the effective development length. The number of discrete wires, regardless of group in Panel 1, that are cracked in a segment *j* is calculated by adding the fraction of discrete cracked wires in that segment, r_{ij}, for all panels in the effective development length, and multiplying by the number of wires in segment *j*.

$$n_{c,j} = \sum_{i=1}^{L_e} n_j \cdot r_{ij} \qquad \text{(B.4.1.1-1)}$$

where

$n_{c,j}$ = number of discrete cracked wires in segment *j* in the effective development length

L_e = number of panels included in the effective development length

n_j = number of wires in segment *j*

r_{ij} = fraction of wires in segment *j* that are cracked in panel *i* but that are not cracked in panels less than *i*

i = number of a cable panel

j = number of a cable segment

The total number of discrete cracked wires corresponding to Stage *k* wires in Panel 1 is found by adding $N_{c,jk}$ for all segments that contain Stage *k* wires in Panel 1.

$$N_{c,k} = \sum_{jk=1}^{NS} n_{c,jk} \qquad \text{(B.4.1.1-2)}$$

where

$N_{c,k}$ = total number of discrete cracked wires in the effective development length in segments that are Group k in Panel 1

$n_{c,jk}$ = number of discrete cracked wires in a segment, j, that contains Group k wires in Panel 1, in the effective development length

NS = total number of segments in the cross-section of the cable

jk = a segment j that contains Stage k wires in Panel 1

k = corrosion stage of a group of wires

The cracked wires, $N_{c,k}$, are subtracted from the wires in the appropriate stages in the strength calculation for Panel 1. There may be cracked wires that correspond to Group 2 in Panel 1, $N_{c,2}$, because a higher stage is present in a segment in an adjacent panel that is Group 2 in Panel 1. The number of cracked Stage 4 wires in adjacent panels must be adjusted for broken wires, because the number of cracked wires is calculated based on the entire cable. The adjustment is made in proportion to the number of Stage 4 unbroken wires in Panel 1, N_{04}, divided by the total number of Stage 4 wires in Panel 1, N_{s4}.

B.4.1.2 EFFECTIVE NUMBER OF CRACKED WIRES THAT CAN BE REDEVELOPED

Also required in the calculation is the effective number of cracked wires that are redeveloped in Panel 1 when all the cracked wires fail. This is the sum of discrete cracked wires in each segment in each panel multiplied by the appropriate redevelopment factor, C_{di}, for the panel

$$N_{cr} = \sum_{j=1}^{NS} \sum_{i=1}^{L_e} n_j \cdot r_{ij} \cdot C_{di} \qquad \text{(B.4.1.2-1)}$$

where

N_{cr} = total number of cracked wires in the effective development length that can be redeveloped in Panel 1 after breaking, if all cracked wires break

C_{di} = wire redevelopment factor for panel $i = C_d$, multiplied by the number of cable bands between panel i and Panel 1

This number, N_{cr}, is independent of the corrosion stage or group.

The number of redeveloped cracked wires, which includes both Stage 3 and Stage 4 wires, must also be adjusted for broken wires in the cable. This single adjustment is the ratio of all unbroken wires in Panel 1, N_{eff}, to the total number of wires in the cable, N.

The fraction of broken cracked wires that is developed in Panel 1 is calculated as the effective number of redeveloped cracked wires divided by the total number of discrete cracked wires.

The calculation of cable strength then follows the method given in the Limited Ductility Model or the Brittle-Wire Model, with all cracked wires treated as another group (Group 5). At each value of the stress, the redeveloped force in Panel 1 in broken cracked wires is added to the cable force, in the same manner as the redeveloped force in the in-service broken wires was added. As before, the maximum cable force reached is the cable strength.

B.4.2 Only Panel 1 Inspected

When only selected panels are opened for inspection, and no observations are made in adjacent panels in the effective development length, it is conservative to assume that the condition of all panels in that length is the same as that of the evaluated panel. In this case, the calculation is considerably simplified. Only segments with Group 3 and Group 4 wires need be considered, and each of these groups can be combined into a single segment, which is continuous in the effective development length.

B.4.2.1 DISCRETE CRACKED WIRES WITHIN EFFECTIVE DEVELOPMENT LENGTH

For a segment that is Group *k* in Panel 1, the value of $p_{c,k}$ is the same in all panels in the effective development length. Table B.4.1.1-1 shows that the fraction of discrete cracked wires in panel *i* is equal to the fraction of uncracked wires in panel *i*-1, multiplied by the fraction of cracked wires in panel *i*. The fraction of uncracked wires in panel *i*-1 is equal to the fraction of uncracked wires in Panel *i*-2, multiplied by one minus the fraction of cracked wires in panel *i*-1, etc. The number of discrete cracked wires in panel *i* can be expressed as

$$r_{ki} = p_{c,k}(1 - p_{c,k})^{i-1} \qquad \text{(B.4.2.1-1)}$$

where

r_{ki} = fraction of wires cracked in panel *i* in all segments that are Group *k* in Panel 1

$p_{c,k}$ = fraction of Stage *k* wires that are cracked

The number of discrete cracked wires in the effective development length in segments that are Group *k* in Panel 1 is

$$N_{c,k} = N_{0k} \cdot \sum_{i=1}^{L_e} p_{c,k} \cdot (1 - p_{c,k})^{i-1} \qquad \text{(B.4.2.1-2)}$$

where

N_{0k} = number of unbroken Stage *k* wires in the evaluated panel

All the cracked wires are treated as a separate group, Group 5

$$N_5 = \sum_{k=2}^{4} N_{c,k} \qquad \text{(B.4.2.1-3)}$$

where

N_5 = number of discrete cracked wires in the effective development length

B.4.2.2 REDEVELOPMENT OF BROKEN CRACKED WIRES

Cracked wires that fail as the cable stress is increased in the calculation of cable strength can redevelop a part of their strength in Panel 1. Assuming all the cracked wires are broken, redeveloped wires for each Stage *k* are

$$N_{cr,k} = N_{0k} \cdot \sum_{i=1}^{L_e} p_{c,k} \cdot (1 - p_{c,k})^{i-1} \cdot C_{di} \qquad \text{(B.4.2.2-1)}$$

where

$N_{cr,k}$ = effective number of broken cracked wires that are Stage *k* in Panel 1 that can be redeveloped after breaking, if all cracked Stage *k* wires break

C_{di} = wire redevelopment factor for Panel $i = C_d$, multiplied by the number of cable bands between panel *i* and Panel 1

The total effective number of redeveloped wires is

$$N_{cr} = \sum_{k=2}^{4} N_{cr,k} \qquad \text{(B.4.2.1-2)}$$

The broken wires are subtracted in determining N_{0k}, and hence the corrections for broken wires given in Articles B.4.1.1. and B.4.1.2 are not required in this case.

B.5 MAXIMUM CABLE TENSION THAT CAN BE DEVELOPED IN CRACKED WIRES

The effective fraction of cracked wires that will be redeveloped in Panel 1 is N_{cr}/N_5. This fraction is applied to the fraction of cracked wires that have failed at a stress, *s*, to arrive at the fraction of cracked wires that have broken and are redeveloped in Panel 1 at stress level *s*.

$$p_{cr}(s) = \frac{N_{cr}}{N_5} \cdot F3_5(s) \qquad \text{(B.5-1)}$$

where

$p_{cr}(s)$ = fraction of cracked wires that have broken at stress level *s* and are redeveloped in Panel 1.

N_{cr} = total number of cracked wires in the effective development length that can be redeveloped in Panel 1 after breaking

N_5 = number of discrete cracked wires in the effective development length

$F3_5(s)$ = fraction of cracked wires that are broken at stress *s* = Weibull cumulative distribution of tensile strength for Group 5 (cracked) wires at stress *s*

s = stress in the unbroken wires of the cable

This is an effective fraction, based on 95% of the mean tensile strength of Stage 2 wire; hence, the maximum force that can be redeveloped in these wires is

$$T_{cr}(s) = p_5 \cdot N_{eff} \cdot a_w \cdot 0.95 \cdot \mu_{s2} \cdot p_{cr}(s) \qquad \text{(B.5-2)}$$

where

$T_{cr}(s)$ = maximum force in the broken cracked wires that can be redeveloped in the evaluated panel at stress *s*

p_5 = fraction of unbroken wires in the evaluated panel represented by Group 5

N_{eff} = effective number of unbroken wires in the evaluated panel

a_w = nominal area of one wire, used in lab analysis

μ_{s2} = sample mean tensile strength of Group 2 wires

Substituting Equation B.5-1 into Equation B.5-2, and noting that p_5 multiplied by $N_{eff} = N_5$, results in

$$T_{cr}(s) = N_{cr} \cdot a_w \cdot \left(0.95\mu_{s2}\right) \cdot F3_5(s) \qquad \text{(B.5-3)}$$

This equation is given in Article 5.3.3.2.3 as Equation 5.3.3.2.3-1.

B.6 CABLE STRENGTH

The force redeveloped in broken cracked wires at stress *s* is added to the cable force at stress *s* calculated for unbroken wires, and the maximum value of the sum plus the redeveloped strength of the in-service broken wires is the cable strength.

$$R = N_{eff} \cdot a_w \cdot \max\left[s \cdot \left(1 - F_c(s)\right) + p_5 \cdot 0.95 \cdot \mu_{s2} \cdot p_{cr}(s)\right] + R_b \qquad \text{(B.5-4)}$$

in which

R = cable strength

R_b = cable strength attributable to broken wires in adjacent panels.

N_5 = number of discrete cracked wires in the effective development length

$F3_5(s)$ = fraction of cracked wires that are broken at stress *s*

= Weibull cumulative distribution of tensile strength for Group 5 cracked wires at stress *s*

CONTENTS

C.1 INTRODUCTION

Three different calculations for estimating the strength of a cable panel on the Centennial Bridge are presented in Appendix C. The bridge and the data are entirely fictional, although the same level of deterioration has been found in some real inspections. The events are reported as if they had actually occurred (e.g., so many samples taken, so much deterioration found, etc.). The number of samples was deliberately reduced to limit the size of the tables, but obtaining less than the recommended number of samples can be defended as reasonable, considering that this is only the first internal inspection.

Three locations on each cable were selected for inspection, following the recommendations in Article 2.2.5.1. Ten Stage 1 and 15 Stage 2 wires were sampled. After a significant number of Stage 4 wires were found in two of the panels, 20 Stage 3 and 30 Stage 4 wires were also sampled. Table 24.3.5.1-1 requires even more samples: 35 Stage 3 and 60 Stage 4, but opening only 6 panels reduced the number of samples that could be removed. It is expected that more samples will be obtained during the next scheduled inspection, when more panels are opened.

The strength of each opened panel was calculated using the Simplified Model presented in Article 5.3.3.1, which excludes broken and cracked wires. It was determined from these calculations that the lowest cable strength occurred at the low point of the south cable in Panel 77-78. In the third sample calculation, it is assumed that the owner was concerned enough about the apparent low strength of this panel to open up additional panels for inspection. The other two examples are based on the original plan of 6 locations. Calculations for the estimated strength of this panel are presented as follows:

- Example 1: Simplified Model, with all panels in the effective development length assumed alike, since adjacent panels were not inspected (Article 5.3.3.1)
- Example 2: Brittle-Wire Model, with same assumptions (Articles 5.3.3.2, 5.3.4 and 5.3.2.4)
- Example 3: Brittle-Wire Model, with all panels in the effective development length inspected, using a more elaborate method for determining the effects of deterioration in adjacent panels (Articles 5.3.3.2, 5.3.4 and Appendix B).

In all three examples, the results are often given to more significant figures than is necessary, implying an accuracy that does not exist. For instance, the mean tensile strength of wires is shown to 1 decimal place, while the nearest integer is sufficient for the calculation. This is also true of the standard deviation. The cable strength is shown to the nearest integer, implying that it is known to 5 significant figures, whereas 3 figures, or the nearest 1%, are sufficient.

Various methods for checking the accuracy of the calculations are part of the reason for retaining significant figures beyond their apparent effectualness. For example:

- The number of wires in each ring, when added together, should result in exactly the total number of wires in the cable. This is a check on the formulas entered into the cells of the spreadsheet. If the total is not exact, the error should be found. This is one of the reasons that the number of wires in each ring is not rounded.
- On Page EX1-12, the number of wires that are less than Stage 1 or greater than Stage 4 must be exactly zero, or the data are incorrect.
- The total number of wires in each stage must add up exactly to the number of wires in the cable, or there is an error.

It is primarily for these checks that the calculations are shown with so much seeming accuracy. The results should be rounded in the final summary. As stated above, 1% is close enough.

C.2 EXAMPLE 1 SIMPLIFIED MODEL

Each cable of the Centennial Bridge is composed of 9,990 galvanized steel parallel wires.

Each wire is 0.196 inches in diameter, including the zinc coating. The nominal diameter of the wire before galvanizing is 0.192 inches. Three panels on each cable were selected for inspection, as shown in the Inspection Location Diagram on Page EX1-02. The condition of the wires in Panel 77-78 was found to be severe enough to warrant removal of the cable band at panel point 77 to facilitate inspection of the entire cable cross-section. The steps required for this representative inspection (prefixed I), data reduction and testing (prefixed D), and calculation of cable strength (prefixed SS) are described on the following pages, and then illustrated. The page numbers in the follow paragraphs refer to the calculation page numbers that can be found in the upper right corner of the calculation sheets, e.g., EX1-02.

Step I-1 Prepare inspection forms. Prior to the preparation of inspection forms, the number of rings of wire in the cable and the number of wires in each ring were estimated. This calculation is shown on Page EX1-03. The relevant forms are shown in the next step, on Pages EX1-04 and EX1-05.

Step I-2 Record the inspection observations. The condition of the wires at one of the inspected locations along the length of Panel 77-78, inside wedged opening No. 5 (at 6:00), was recorded on the Field Inspection Sheet shown on Page EX1-04; the conditions at other locations were similarly recorded, but are not shown in the example.

Step I-3 Remove sample wires for testing and measure retraction of the cut ends. The separations of the ends of four wires, at the location of the first cut for removal of samples, were measured and recorded on another field inspection form showing the cable cross-section, along with the location of the sample wires and wires found broken in the cable. This inspection form is shown on Page EX1-05.

Step D-1 Calculate the redevelopment coefficient and the effective development length. The effective development length is calculated on Pages EX1-06 and EX1-07, using the measurements of wire retraction made during the inspection.

Step D-2 Test the sample wires and calculate the tensile strength distribution (mean and standard deviation) of each group of wires. Many sample wires were removed from the cable for testing. Ten Stage 1 and 15 Stage 2 wires were selected, as well as 18 Stage 3 and 30 Stage 4 wires. Although the deterioration of the cable was observed to be severe in Panel 77-78, the limited number of panels opened in this inspection was insufficient for a larger sampling of the wires. The condition of this panel shows that a more intense investigation is needed at the next internal inspection, during which at least 35 Stage 3 and 60 Stage 4 wires should be sampled.

The results of tensile tests on these samples are shown on Pages EX1-08 to EX1-11; the test results on an individual specimen from one sample are shown on Page EX1-08, along with the calculation of the estimated minimum tensile strength in one panel length, or 41 feet. When a crack is present in one or more specimens, the calculation of the estimated minimum strength using Equation 4.4.3.2-1 is not valid, and the lowest strength found for a cracked specimen is used instead, as shown on Page EX1-09. These values are calculated for each sample, and the results carried to Pages EX1-10 and EX1-11, where the sample means and sample standard deviations of the tensile strengths for each stage of corrosion are calculated.

The fraction of samples in each corrosion stage that contain one or more cracks is calculated on Page EX1-11.

Step D-3 Determine the number of wires in each corrosion stage. The corrosion stage of each wire in the wedged openings is tabulated on Page EX1-12. Upon reviewing all inspection records for wedge line 5, in Panel 77-78, Stage3 and Stage 4 were found to extend one to two wires deeper into the cable at another panel segment than at the middle panel for which the example on Page EX1-04 is shown, and this is reflected in the data on Page EX1-12. There is one line on this spreadsheet for each ring in the cable, and the estimated number of wires is entered for each ring. Two columns represent each wedge, one for the left-hand side and one for the right-hand side of the opening formed by the wedge. The fraction of the circle corresponding to the arc subtended by each half-sector is given at the top of each column. The number of wires in each stage in each ring is calculated by formulas in the appropriate cells, and the totals for the entire cable given at the bottom of the spreadsheet.

These numbers are carried to Pages EX1-14 and EX1-16. Page EX1-13 presents a corrosion map of the cable cross-section in the inspected panel.

All data up to this calculation on Page EX1-14 are the same for all the examples, and these pages will not be repeated for Example 2 and Example 3.

Step D-4 Determine the number of broken wires in the effective development length and the effective number of unbroken wires in the cable. In this inspection, broken wires were found only on the periphery of the cable, up to 6 wires from the surface. The spreadsheet for broken wires is therefore not needed.

The number of broken wires and the number of unbroken wires in the cable are estimated directly on Page EX1-14. Equation 4.3.3.2-1 is used to estimate the number of broken wires, because no wires were found broken beyond the sixth ring. The depth at which no broken wires are found is 7 wires (i.e., broken wires were found 6 layers into the cable), and d_0 equals 7. Of the 8 broken wires found, 6 were repaired.

The number of broken wires in all the panels in the effective development length is assumed to be the same as in the inspected panel, because only that panel was inspected. It follows that only wires in the inspected panel were repaired.

Step D-5 Determine the number of discrete cracked wires in the effective development length. The total fraction (and total number) of wires in each stage that are cracked in the effective development length is found using the graph in Figure 5.3.2.4.1-1. These calculations are shown on Pages EX1-15. This information is added to the summary sheet shown on Page EX1-16.

Step SS-1 Determine the fraction of the cable in each group of wires. The fraction of the cable in each stage of corrosion, and the fraction represented by each group of wires, is calculated on Page EX1-16. The testing laboratory reported that 50% of Stage 4 wires and 5% of Stage 3 wires contained preexisting cracks (i.e., they were observed to be cracked before testing). The cracked wires represented by these fractions are subtracted from the total number of wires in the appropriate stages to determine the net number of wires per stage that are not broken or cracked. The cracked wires are added together to form Group 5. In the Simplified Model, broken and cracked wires are ignored, and thus Group 5 has no wires.

Steps SS-2 (Weibull parameters) and SS-3 (Strength of broken wires) are not used in the Simplified Model.

Step SS-4 Determine the combined distribution of the tensile strength of unbroken and uncracked wires. The mean and standard deviation of the tensile strength of the combined groups of wires are calculated on Page EX1-17 using Equation 5.3.3.1.1-1 and Equation 5.3.3.1.1-2; the coefficient of variation (standard deviation divided by the mean) is also calculated.

Step SS-5 Estimate the cable strength. On Page EX1-18, the strength reduction factor for use in Equation 5.3.3.1.2-1 is found from Figure 5.3.3.1.2-1, and the cable strength is calculated as 38,968 kips. The result is rounded to 3 significant figures, or 39,000 kips.

C.2.1 Simplified model assuming that adjacent panels are perfect

The Simplified Model can be used to quickly and easily identify the worst of the inspected panels for more detailed analysis, by assuming that only the inspected panel is deteriorated and all other panels are perfect. This calculation is shown on Page EX1-19. Only broken and cracked wires in the evaluated panel are considered; the entire calculation can be made on a single sheet. The effective development length is taken to be 1 panel because there are no broken wires outside this panel to be redeveloped. The number of cracked wires in each corrosion stage is the fraction cracked multiplied by the number if wires in that stage. The calculations on Pages EX1-14, 16, 17 and 18 are shown on Page EX1-19; Calculation Page EX1-15 is not required.

C.3 EXAMPLE 2 BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

In Example 2, the investigator seeks to estimate the lower bound of the cable strength by including the effect of adjacent panels. The condition in adjacent panels is assumed conservatively to be the same as in the inspected panel, because only the latter has been inspected. Pages EX1-02 to EX1-14 also apply to this example, and are not repeated. The example starts with **Step D-4**.

Step D-4 Determine the number of broken wires in the effective development length and the effective number of unbroken wires in the cable. The number of broken wires and the number of unbroken wires in the cable are estimated directly on Page EX2-02. Equation 4.3.3.2-1 is used to estimate the number of broken wires, because no wires were found at a depth greater than 6 rings. This page is the same as Page EX1-15, but is included here because some of the data calculated on this page are required on the following pages. This information is added to the summary sheet shown on Page EX2-04. Of the 8 broken wires found, 7 were repaired.

Step D-5 Determine the number of discrete cracked wires in the effective development length. The number of discrete cracked wires is calculated on Page EX1-15, as described previously. This information is added to the summary sheet shown on Page EX2-04.

Step D-6 Determine the number of discrete cracked wires that can be redeveloped in the evaluated panel when they break in an adjacent panel. The effective fraction of discrete cracked wires that will be redeveloped in the evaluated panel if they break is found by using Figure 5.3.2.4.2-1, and their effective number is calculated for each corrosion stage. The total fraction of wires that can be redeveloped is calculated on Page EX2-03. This fraction is used in the calculation of the cable tension at a given stress, found on Page EX2-08, and in the calculation of the cable strength on Page EX2-09.

Step BS-1 Determine the fraction of the cable in each group of wires. The fraction of the cable in each stage of corrosion and the number of wires represented by each group are calculated on Page EX2-04. The number of cracked wires is subtracted from the total wires one stage at a time to determine the net number of wires per stage that are not broken or cracked. Unlike the Simplified Model, broken and cracked wires are included in the calculation, and are used to form Group 5.

Step BS-2 Determine the Weibull coefficients. Coefficients for the Weibull distribution of each Group of wires are calculated on Page EX2-05, using the method given in Article A.4.2, Appendix A. The Microsoft Excel Spreadsheet Program is used for this purpose, and the tool, “Solver,” is used to determine the values of the parameters.

Step BS-3 Determine the force that can be redeveloped in wires found broken in adjacent panels. The maximum force that wires found broken in the effective development length can sustain in the evaluated panel because of friction among wires developed at the cable bands is calculated on Page EX2-06, using Equation 5.3.4-3.

Step BS-4 Determine the cable force at a specific value of stress. This calculation is shown on two pages, and is divided into two steps as follows.

Step BS-4A Develop the cumulative compound distribution of the tensile strength. The Weibull parameters calculated on Page EX2-05, along with the fractions for each group of wires, are applied on Page EX2-07, using Equation 5.3.3.2.1-1 to evaluate the cumulative compound distribution curve for the entire cable at a specific stress. The calculation on this page is for the value of the distribution at a stress of 220 ksi.

Step BS-4B Determine the cable force at a specific value of stress. The cumulative distribution is calculated on Page EX2-07 (the calculations are shown again in condensed form). The capacity of redeveloped wires found broken in the cable from Page EX2-06 and the fraction of Stage 5 wires that have failed at Stress s ($F3_5(s)$) from Page EX2-07 are used on Page EX2-08 to determine the force in the cable when the stress is 220 ksi.

Step BS-5 Determine the estimated cable strength. The estimated cable strength is calculated on Page EX2-09. The “Solver” function is used to maximize the cable force by varying the wire stress. The cable strength is found to be 50,824 kips, which rounds to 50,800 kips.

C.4 EXAMPLE 2A (EXAMPLE 2 - CONDENSED FORMAT)

On Pages EX2A-01 to EX2A-09, the calculations detailed in Example 2 are given in condensed form on spreadsheets.

Steps D-4, D-5, D-6, BS-1 and BS-2. Page EX2A-02 shows the data from the inspection and calculated values (from Pages EX2-02 to EX2-05) for use in the spreadsheets that follow.

Steps BS-3 to 5. Page EX2A-03 is a calculation of cable strength using the technique on Pages EX2-07 to EX2-09, while Pages EX2A-04 to EX2A-07 illustrate the steps required to develop both the cable strength and cable force vs. strain curve. On these 4 pages, each line of the spreadsheet calculates the cable tension at one value of the stress, the same as on Page EX2A-03. The calculation of redeveloped cracked wires that break as the stress is increased uses Equation B.5-1 and Equation B.5-2, instead of Equation 5.3.3.2.3-1, for convenience.

The stress-strain curve of the wires and tensile strength distribution curves are shown on Page EX2A-08; Page EX2A-09 includes curves for cable force vs. stress and strain.

C.5 EXAMPLE 3 BRITTLE WIRE MODEL, ENTIRE EFFECTIVE LENGTH INSPECTED

When all the panels in the effective development length have been inspected, it is possible to estimate cable strength more accurately than in Example 2, using the method in Appendix B. The example applies whenever the entire length of the cable is opened for inspection, for instance during a maintenance operation. In this instance, the panels adjacent to the worst panel were opened after a low strength estimate was found in one of the panels.

The initial calculations on Pages EX1-02 to EX1-14 are the same, and are not repeated here. The effective development length, calculated on Page EX1-07, is 7 panels.

Step D-4 Determine the number of broken wires in the effective development length and the effective number of unbroken wires in the cable. In this example, since all panels in the effective development length are inspected, the number of broken wires found in each panel is entered into the summary sheet on Page EX3-02. The number of broken wires in each panel is estimated separately, and the number of repaired wires is entered for each panel. Then, the number of unbroken wires in the cable is calculated, taking into account the number of broken wires that were repaired in each panel.

Step D-5 Determine the number of discrete cracked wires in the effective development length, and

Step D-6 Determine the number of discrete cracked wires that can be redeveloped in the evaluated panel when they break in an adjacent panel. The number of discrete cracked wires in the effective development length is calculated on the large spreadsheet shown on Pages EX3-08 to EX3-23. Each line of this spreadsheet compares the corrosion stages of a single cable segment along the entire effective development length, L_e, determines where cracks are likely, assumes the location of a crack, and calculates the probable number of discrete cracks in that segment and how many will redevelop in the evaluated panel. Totals are made on the last page. A detailed calculation of a single line of the spreadsheet is shown on Pages EX3-05 to EX3-07.

The number of discrete cracked wires, given at the bottom of Page EX3-23, is used to divide the wires into groups on Page EX3-24; the effective number of cracked wires that can be redeveloped in the evaluated panel, also calculated on Page EX3-23, is used on Page EX3-28 to calculate the fraction of wires that are redeveloped at a given stress level.

Step BS(adj)-1 Determine the fraction of the cable in each group of wires. The fraction of the cable in each stage of corrosion and the number of wires represented by each fraction are calculated on Page EX3-24. The number of cracked wires is subtracted from the total wires in each stage to determine the net number of wires per stage that are not broken or cracked. Unlike the Simplified Model, broken and cracked wires are included in the calculation; cracked wires are used to form Group 5.

Step BS(adj)-2 Determine the Weibull coefficients. The calculation of the parameters of the Weibull distribution is the same as in Example 2, repeated here on Page EX3-25. These parameters are used on Page EX3-27, along with the fraction of wires in each group, to develop the compound cumulative distribution of the tensile strength of the wires in the cable at a stress of 220 ksi.

Step BS(adj)-3 Determine the force that can be redeveloped in wires found broken in adjacent panels. The force that can be resisted in the evaluated panel by the broken wires is calculated using Equation 5.3.4-2 on Page EX3-26.

Step BS(adj)-4A Develop the cumulative compound distribution of the tensile strength. The Weibull parameters calculated on Page EX3-25, along with the fractions for each group of wires, are applied on Page EX3-27, using Equation 5.3.3.2.1-1 to evaluate the cumulative compound distribution curve for the entire cable at a specific stress. The example calculation on this page is for the distribution at a stress of 220 ksi.

Steps BS(adj)-4B and 5 Determine the cable force at a specific value of stress and calculate the estimated cable strength. The cable tension at a stress of 220 ksi is calculated on Page EX3-28; the estimated cable strength is calculated on Page EX3-29 by varying the cable stress until a maximum cable tension is reached, resulting in a cable strength of 53,092 kips (which should be rounded to 53,100 kips).

C.6 EXAMPLE 3A (EXAMPLE 3 - CONDENSED FORMAT)

A condensed form of Example 3, using spreadsheets, is given on Pages EX3A-02 to EX3A-07. This is in the same form as Example 2A. The calculation for the effect of cracked wires in adjacent panels is the same as in Example 3 (***Steps D(adj) 5 and 6***, Pages EX3-08 to EX3-23) and is not repeated here.

Steps D(adj)-4, BS(adj)-1 and BS(adj)-2. Page EX3A-02 shows the data from the inspection and calculated values (from Pages EX3-02 and EX3-24 to EX3-26) for use in the spreadsheets that follow.

Steps BS-3 to 5. Page EX3A-03 is a calculation of cable strength using the technique on Pages EX3-27 to EX3-29, while Pages EX3A-04 to EX3A-07 illustrate the steps required to develop both the cable strength and cable force vs. strain curve. On these 4 pages, each line of the spreadsheet calculates the cable tension at one value of the stress, the same as on Page EX3-29.

The stress-strain curve of the wires and tensile strength distribution curves are shown on Page EX3A-08; Page EX3A-09 includes curves of cable force vs. stress and strain.

C.7 SUMMARY

The initial strength of a new cable can be estimated using the Simplified Model by assuming that only Group 2 wires are present. This calculation, which is not shown, results in a cable strength of 66,400 kips, for the cable in these examples.

A severely corroded condition was assumed in the examples to demonstrate more clearly the differences in the three calculations.

The Simplified Model, as expected, results in very low cable strength, 39,000 kips. This is the result of assuming that all cracked and broken wires in the effective development length do not contribute to the cable strength; redevelopment of force in these wires is assumed to be zero.

When the conservative assumption of all panels alike is made in Example 2, the predicted cable strength is 50,800 kips. The assumption that all panels are alike is reasonable, especially when the entire cable is not inspected and such a severe condition is found. The difference between the cable strengths predicted by Examples 1 and 2 would be smaller in a less deteriorated cable. Nevertheless, the Simplified Model is useful as a quick way of finding the worst inspected panel.

Estimating the strength when all panels in the effective length have been inspected is far more complex, but it results in a higher strength of 53,100 kips. The conditions assumed for this example approximate those that were found in an actual cable; the evaluated panel was known to be the worst in the entire cable.

As a quick and easy way to identify the weakest panel of those inspected, the adjacent panels can be assumed to be perfect in the Simplified Model, resulting in a strength of 53,600 kips. The similarity between this strength and that found using the Brittle-Wire Model when all panels in the effective development length are inspected (Example 3), is coincidental. Use of the Simplified Model (i.e., assuming adjacent panels are perfect), however, can provide a quick indication of the weakest inspected panel. Example 3, which is complex, should be reserved for the worst panel, and then it is only worth the effort when the cable strength is marginal. All other panels inspected can be evaluated using the method shown in Example 2, or when the cable is less deteriorated, by the Simplified Model shown in Example 1.

When only a few panels are inspected, as in these examples, it is important to remember that it cannot be known whether there is a panel in worse condition elsewhere in the cable.

C.8 EXPLANATION OF STEP NUMBERING

The steps required in the evaluation of a cable are numbered in these examples sequentially. The letters indicate the phase of the investigation, the numbers indicate the order of the steps in the phase. Only those actions required for evaluating the strength of the cable are included.

C.8.1 Inspection (*I*)

Step I-1 ***Prepare inspection forms***

Step I-2 ***Record the inspection observations***

Step I-3 ***Remove sample wires for testing and measure retraction of the cut ends***

C.8.2 Data Reduction (*D*)

In this phase, sample wires are tested and the data obtained are reduced for use in estimating cable strength. Other information obtained in the field is also reduced so that it is in the form required by the calculations. Whenever all panels in the effective development length are inspected, the suffix ***(adj)*** is added (e.g., ***D(adj)-5***), signifying that the techniques given in Appendix B are used.

Step D-1 ***Calculate the redevelopment coefficient and the effective development length***

Step D-2 ***Test the sample wires and calculate the tensile strength distribution (mean and standard deviation) of each group of wires***

Step D-3 ***Determine the number of wires in each corrosion stage***

Step D-4 ***Determine the number of broken wires in the effective development length and the effective number of unbroken wires in the cable***

Step D-5 ***Determine the number of discrete cracked wires in the effective development length***

Step D-6 ***Determine the number of discrete cracked wires that can be redeveloped in the evaluated panel when they break in an adjacent panel***

C.8.3 Estimation of Cable Strength (*S*)

In this phase, the data obtained in Steps ***D-1 to 6*** are used to estimate the strength of the cable. The steps are prefixed and suffixed by a letter indicating the model that is used in the analysis. The prefixes used are ***S*** for the Simplified Model and ***B*** for the Brittle-Wire Model. When all panels in the effective development length are inspected, the suffix ***(adj)*** is added (e.g., ***BS(adj)-1***), signifying that the techniques given in Appendix B are used.

C.8.3.1 SIMPLIFIED MODEL (STEPS 2 AND 3 NOT USED)

Step SS-1 ***Determine the fraction of the cable in each group of wires***

Step SS-4 ***Determine the combined distribution of the tensile strength of unbroken and uncracked wires***

Step SS-5 ***Estimate the cable strength***

C.8.3.2 BRITTLE-WIRE MODEL

Step BS-1 ***Determine the fraction of the cable in each group of wires***

Step BS-2 ***Determine the Weibull coefficients***

Step BS-3 ***Determine the force that can be redeveloped in wires found broken in adjacent panels***

Step BS-4A ***Develop the cumulative compound distribution of the tensile strength***

Step BS-4B ***Determine the cable force at a specific value of stress***

Step BS-5 ***Determine the estimated cable strength***

EXAMPLE CALCULATION NO 1
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

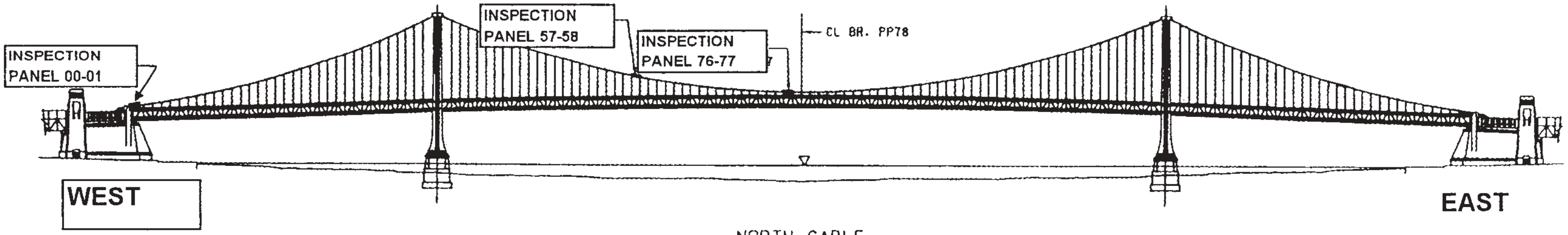
EXAMPLE CALCULATION NO 1

SIMPLIFIED MODEL

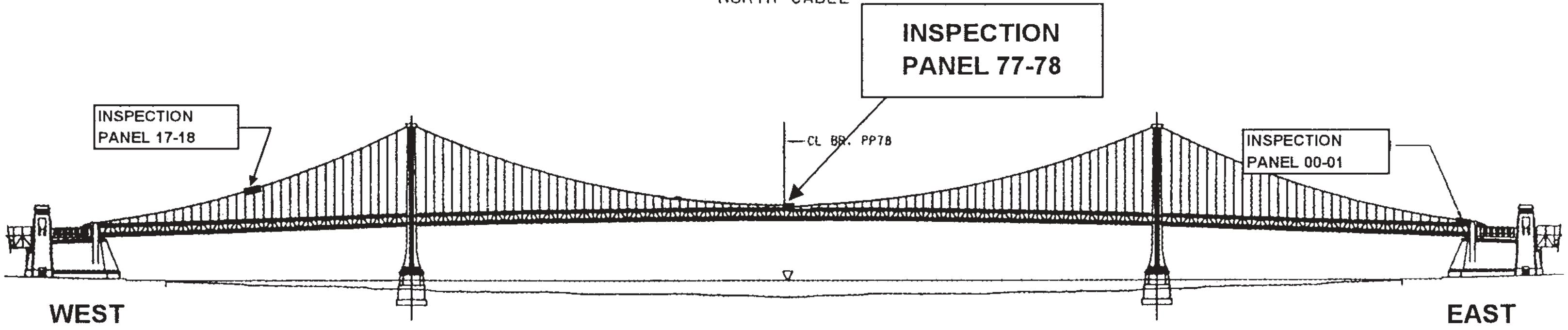
TABLE OF CONTENTS

CENTENNIAL BRIDGE

INSPECTION YEAR 2000



NORTH CABLE



SOUTH CABLE

DIAGRAM OF INSPECTION LOCATIONS

EXAMPLE CALCULATION **STEP I-1** **CALCULATION PAGE EX1-03**

PROJECT:
CENTENNIAL BRIDGE

INFORMATION FOR INSPECTION FORMS

NUMBER OF ROWS OF WIRES IN CABLE
& NUMBER OF WIRES IN EACH ROW

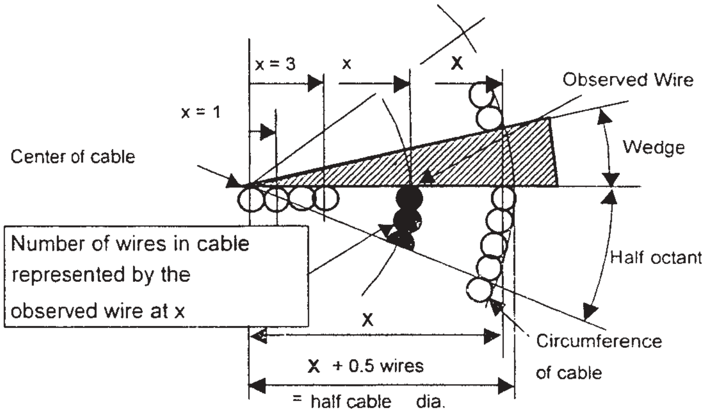
$$X=\sqrt{N/\pi}+0.5$$ ROUNDED TO NEXT HIGHER INTEGER

$$n_x = \frac{2x(N-1)}{X(X+1)}$$

X = ROUNDUP(SQRT(N/π)+0.5,0) = 57

NO OF WIRES PER STRAND = 270
NO OF STRANDS IN CABLE = 37
TOTAL NO OF WIRES IN CABLE = *N* = 9990

	RING NO FROM OUTSIDE d	DIST FROM CTR OF CABLE x	NO OF WIRES IN RING n
OUTER LAYER OF WIRES	1	57	344.4
	2	56	338.4
	3	55	332.4
	4	54	326.3
	5	53	320.3
	6	52	314.2
	7	51	308.2
	8	50	302.1
	9	49	296.1
	10	48	290.1
	11	47	284.0
	12	46	278.0
	13	45	271.9
	14	44	265.9
	15	43	259.8
	16	42	253.8
	17	41	247.8
	18	40	241.7
	19	39	235.7
	20	38	229.6
	21	37	223.6
	22	36	217.5
	23	35	211.5
	24	34	205.5
	25	33	199.4
	26	32	193.4
	27	31	187.3
	28	30	181.3
	29	29	175.2
	30	28	169.2
	31	27	163.2
	32	26	157.1
	33	25	151.1
	34	24	145.0
	35	23	139.0
	36	22	132.9
	37	21	126.9
	38	20	120.9
	39	19	114.8
	40	18	108.8
	41	17	102.7
	42	16	96.7
	43	15	90.6
	44	14	84.6
	45	13	78.6
	46	12	72.5
	47	11	66.5
	48	10	60.4
	49	9	54.4
	50	8	48.3
	51	7	42.3
	52	6	36.3
	53	5	30.2
	54	4	24.2
	55	3	18.1
	56	2	12.1
	57	1	6.0
CENTER OF CABLE	58	0	1.0
	TOTAL		9990.0



BRIDGE NAME: CENTENNIAL BRIDGE PREPARED BY: JS

SOUTH CABLE EAST MAIN SPAN

DATE 5/9/2000

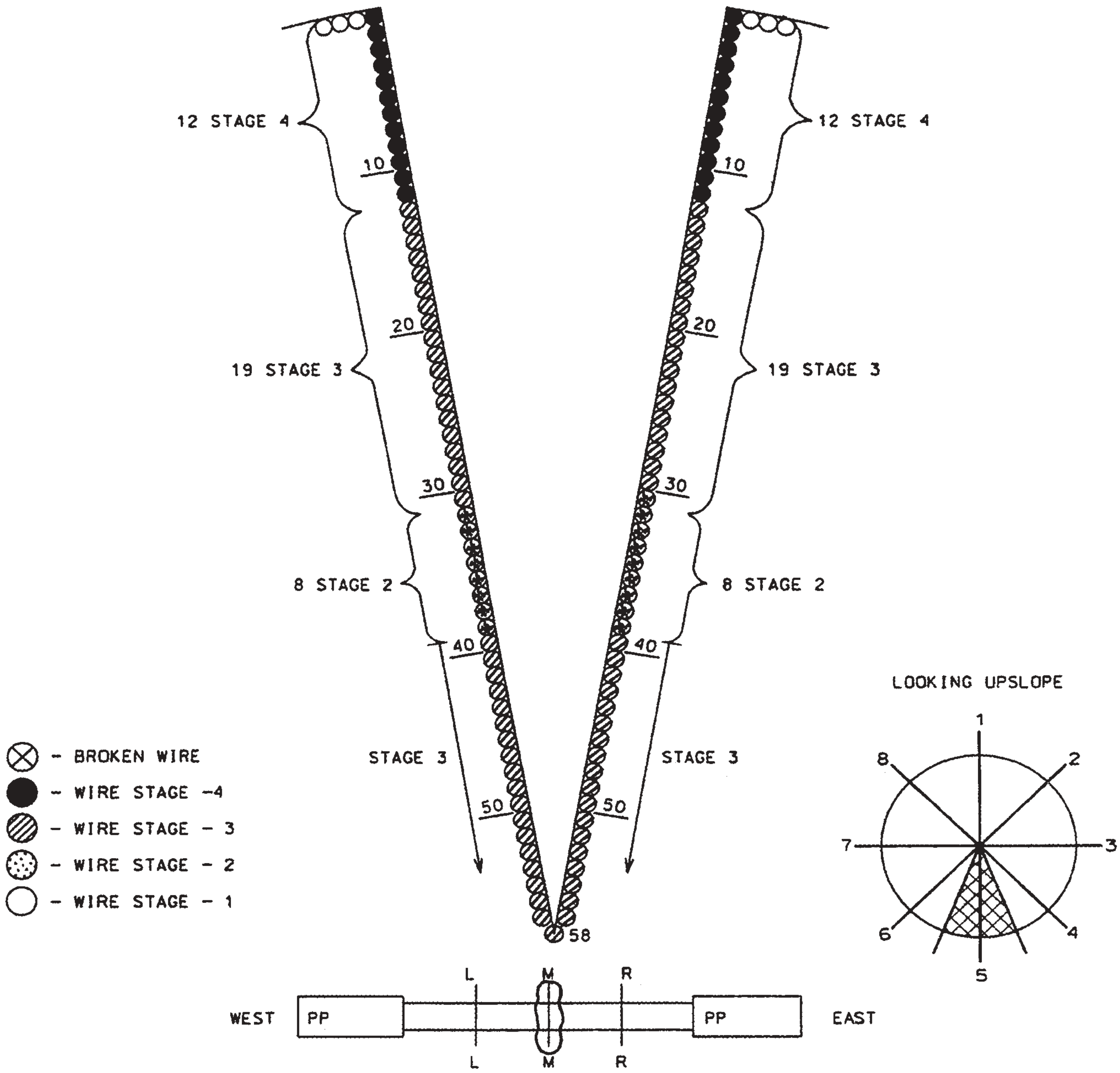
PANEL 77-78

CALCULATION PAGE EX1-04

DEPTH OF CABLE INSPECTED 11"

STEP I-2

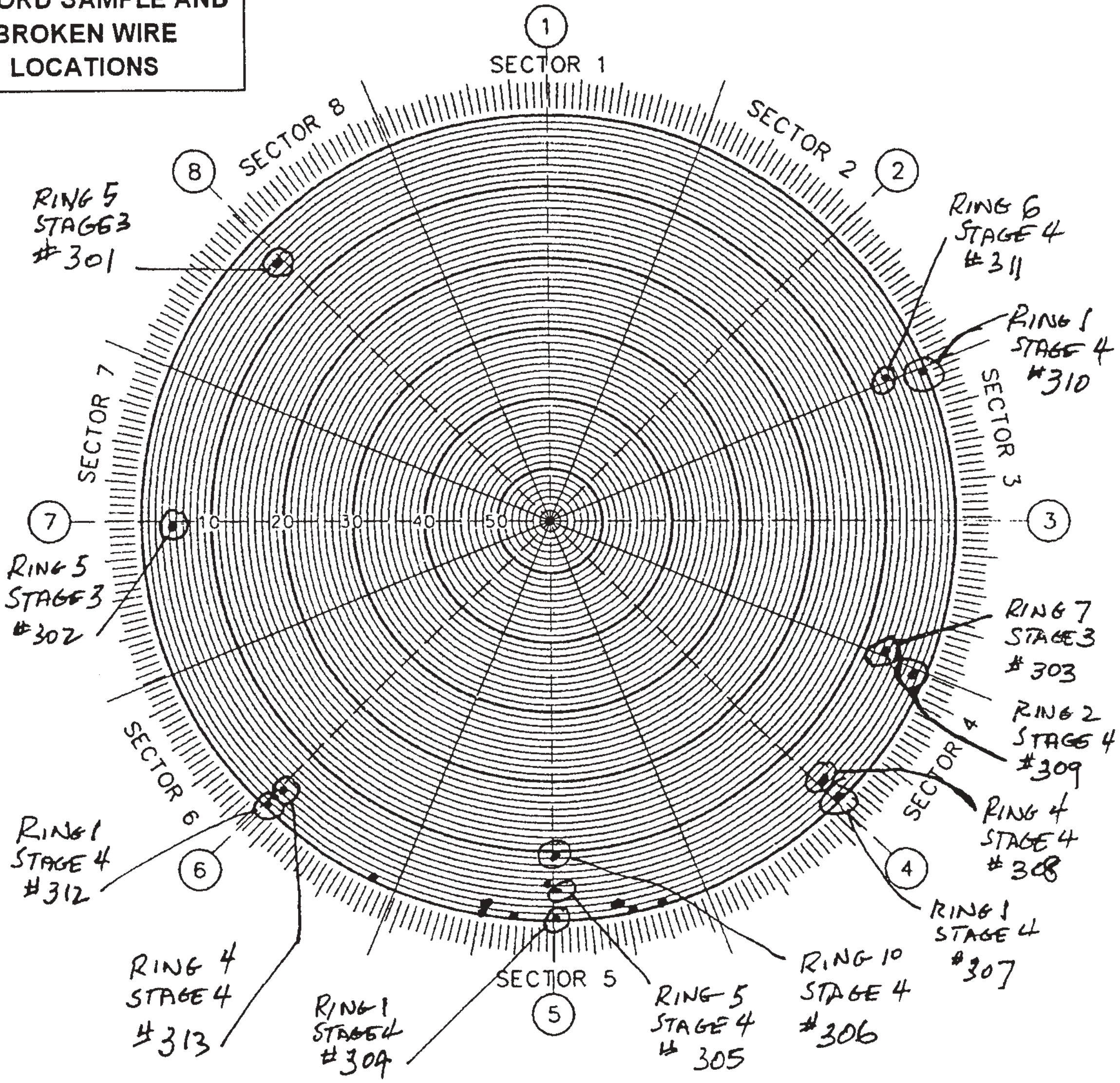
RECORD INSPECTION OBSERVATIONS



STEP I-3

RECORD SAMPLE AND BROKEN WIRE LOCATIONS

SOUTH



CABLE CROSS SECTION

BRIDGE **CENTENNIAL**
SOUTH CABLE, LOOKING EAST (UPSLOPE)
SPAN EAST MAIN
PANEL 77-78

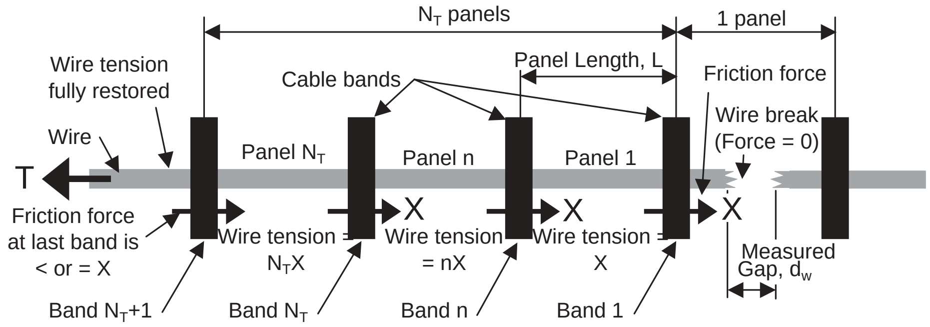
LEGEND

- ● BROKEN WIRE NO. -8
- (8) WEDGE LOCATION
- ● SAMPLE FOR TESTING

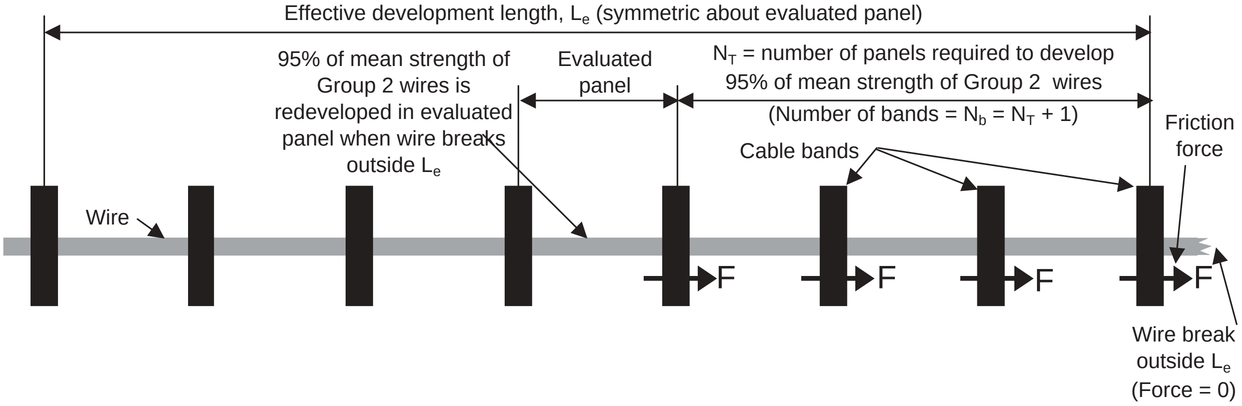
GAPS BETWEEN ENDS OF WIRES CUT FOR TESING

#304	1 - 7/8"
#308	2"
#310	1 - 15/16"
#313	2 - 1/8"

EXAMPLE CALCULATION NO 1		**STEP D-1**
PROJECT: **CENTENNIAL BRIDGE**		**REDEVELOPMENT COEFFICIENT** **EFFECTIVE DEVELOPMENT LENGTH**
CABLE	**SOUTH**	**ARTICLES 4.5.1 AND 4.5.2**
SPAN	**EAST MAIN SPAN**	
PANEL	**77-78**	



CALCULATION OF REDEVELOPMENT COEFFICIENT



WIRE BREAKS OUTSIDE EFFECTIVE DEVELOPMENT LENGTH

CALCULATION OF EFFECTIVE DEVELOPMENT LENGTH

REDEVELOPMENT OF WIRE TENSION THROUGH FRICTION AT CABLE BANDS

EXAMPLE CALCULATION NO 1		**STEP D-1**
PROJECT: CENTENNIAL BRIDGE		REDEVELOPMENT COEFFICIENT EFFECTIVE DEVELOPMENT LENGTH
CABLE	SOUTH	ARTICLES 4.5.1 AND 4.5.2
SPAN	EAST MAIN SPAN	
PANEL	77-78	

ONLY THE EVALUATED PANEL 77-78 HAS BEEN INSPECTED. FOUR GAPS IN THE WIRES THAT WERE FOUND BROKEN OR THAT WERE CUT FOR SAMPLES FOR TESTING IN THIS PANEL WERE MEASURED. THESES GAPS ARE:

1-7/8" =	1.875	INCHES
2" =	2.000	
1-15/16" =	1.938	
2-1/8" =	2.125	
AVERAGE = d_w =	1.985	

THE CABLE DATA NEEDED TO DETERMINE THE FORCE THAT CAN BE DEVELOPED AT ONE CABLE BAND ARE:

NOMINAL AREA OF ONE WIRE	a_w	0.0290	SQ IN
LENGTH OF A WIRE BETWEEN CTRS OF BANDS	L	41	FEET
YOUNG'S MODULUS	E	29,000	KSI
WIRE TENSION	T	2.3	KIPS
MEAN TENSILE STRENGTH OF GROUP 2 WIRES	μ_{s2}	239	KSI

THE ELASTIC DEFORMATION IN LENGTH L DUE TO FORCE T IS GIVEN BY EQUATION 4.5.1-2:

$d_e = TL/a_wE = 2.3 * 41 * 12 / (0.0290 * 29,000)$ $\quad d_e =$ 1.346 INCHES

THE NUMBER OF PANELS ON ONE SIDE OF A WIRE BREAK IN WHICH THE WIRE TENSION IS LESS THAN T IS CALCULATED USING EQUATION 4.5.1-1:

$N_T = [(d_w/d_e)-1]$, ROUNDED UP TO THE NEXT INTEGER
$= (1.985/1.346)-1$, ROUNDED UP $\quad N_T =$ 1 PANEL

THIS VALUE OF N_T IS USED IN EQUATION 4.5.2-2 TO DETERMINE THE NUMBER OF CABLE BANDS REQUIRED TO REDEVELOP A WIRE

$N_B = 0.95 * \mu_{s2} * a_w * N_T(N_T + 1) / (T * (2N_T + 1 - d_w / d_e))$, ROUNDED UP
$= 0.95 * 239 * 0.029 * 1(1+1) / (2.3 * (2 * 1 + 1 - 1.985/1.346))$, $\quad$ NB = 4 BANDS
ROUNDED UP

EFFECTIVE DEVELOPMENT LENGTH
EQUATION 4.5.2-1 IS NOW USED TO DETERMINE THE EFFECTIVE DEVELOPMENT LENGTH:

$L_e = 2 * N_B - 1 = 2 * 4 - 1 =$ $\quad L_e =$ 7 PANELS

FINALLY, EQUATION 4.5.2-4 IS USED TO CALCULATE THE REDEVELOPMENT COEFFICIENT:

$C_d = 2 / (Le + 1) = 2 / (7 + 1)$ $\quad C_d =$ 0.25

EXAMPLE CALCULATION NO 1	
PROJECT: **CENTENNIAL BRIDGE**	
CABLE	**NORTH**
SPAN	**WEST MAIN SPAN**
PANEL	**76-77**

STEP D-2

RESULTS OF TESTS ON WIRES REMOVED FROM CABLE
TESTS ON SPECIMENS FROM A SINGLE SAMPLE WIRE

ALL STRESSES BASED ON 0.192 INCH DIA, AREA = 0.0289529 SQ IN

CABLE & PANEL DESIGNATIONS

W = WEST	M = MAIN
E = EAST	S = SIDE
N = NORTH CABLE	2123 = PANEL 21-23
S = SOUTH CABLE	ANCH = ANCHORAGE

LEGEND

X	NUMBER OF SAMPLE WIRE
X.01	SPECIMEN NO 1 FROM WIRE X
X.02	SPECIMEN NO 2 FROM WIRE X
X.91	LONG SPECMN FROM WIRE X

YEAR	CABLE AND PANEL	WIRE SAMPLE NO	SPECMN NO	CORR STAGE	MAX LOAD (LBS)	YIELD STRGTH (KSI)	TENSILE STRGTH (KSI)	ELONG IN 10" PCT	REDUCT IN AREA PCT	REMARKS	FRACT TYPE
2000	NWM7677	609	609.01	3	6918	200.0	238.9	5.0	29.00	note 2,L	B
			609.02	3	6938	201.0	239.6	4.5	35.50	note 2,L	B
			609.03	3	6934	200.0	239.5	5.0	27.00	note 2,H	B
			609.04	3	6938	200.0	239.6	5.5	35.50	note 2,M	B
			609.05	3	6930	200.0	239.4	6.0	39.00	note 2,M	B
			609.06	3	6930	200.0	239.4	5.0	29.50	note 2,L	B
			609.07	3	6950	200.0	240.0	5.0	37.50	note 2,L	B
			609.08	3	6962	201.0	240.5	5.0	37.50	note 2,L	B
			609.09	3	6962	201.0	240.5	5.5	39.00	note 2,L	B
			609.10	3	6958	202.0	240.3	5.0	37.50	note 2,L	B
			609.11	3	6954	200.0	240.2	6.0	31.50	note 2,M	B
# OF SMPLS/SPEC		1	11								
MEAN					6943		239.8	5.2	34.41		
STD DEV					15		0.5	0.5	4.36		
MAX							240.5				
MIN							238.9				
STD DEVIATION * Φ^{-1}(L0/L) =							-1.0				
PROBABLE MIN TENSILE STRENGTH IN LENGTH L					6914		**238.8**				

FRACTURE TYPES

CUP & CONE	DUCTILE	A
CUP & CONE WITH SHEAR LIPS ALTERNATING ABOVE & BELOW FRACTURE PLANE	DUCTILE	B
RAGGED WITH PARTIAL SHEAR LIPS AND REDUCED REDUCTION IN AREA	SEMI - DUCTILE	B-C
RAGGED WITH MINIMAL OR NO REDUCTION IN AREA	BRITTLE	C
FRACTURE WITH PARTIAL CRACK	BRITTLE W/ CRACK	D

MINIMUM TENSILE STRENGTH OF A WIRE IN A PANEL LENGTH

PANEL LENGTH	$L =$	41	FEET
SPECIMEN LENGTH BETWEEN JAWS OF TEST MACHINE	$L_0 =$	12	IN
	$L/L_0 =$	41	
FROM Figure 4.4.3.2-1	$\Phi^{-1}(L_0/L) = -1.97$		

EQUATION 4.4.3.2-1 GIVES PROBABLE MIN TENSILE STRENGTH = $x_{1,i} = \mu_{si} + \Phi^{-1}(L_0/L) * \sigma_{si}$

NOTE 1: SURFACE OF WIRE COVERED WITH A GUMMY MATERIAL, POSSIBLY DRIED LINSEED OIL

NOTE 2: SURFACE CORROSION IS PRESENT AT THE FRACTURE LOCATION, WHICH IS THE PROBABLE INITITIATION POINT OF THE FRACTURE

L = LOCAL
O = OVERALL
M = MODERATE
H = HEAVY
S = SEVERE

EXAMPLE CALCULATION NO 1	
PROJECT: CENTENNIAL BRIDGE	
CABLE	NORTH
SPAN	WEST MAIN SPAN
PANEL	76-77

STEP D-2

RESULTS OF TESTS ON WIRES REMOVED FROM CABLE
TESTS ON SPECIMENS FROM A SINGLE SAMPLE WIRE

ALL STRESSES BASED ON 0.192 INCH DIA, AREA = 0.0289529 SQ IN

CABLE & PANEL DESIGNATIONS	
W = WEST	M = MAIN
E = EAST	S = SIDE
N = NORTH CABLE	2123 = PANEL 21-23
S = SOUTH CABLE	ANCH = ANCHORAGE

LEGEND	
X	NUMBER OF SAMPLE WIRE
X.01	SPECIMEN NO 1 FROM WIRE X
X.02	SPECIMEN NO 2 FROM WIRE X
X.91	LONG SPECMN FROM WIRE X

YEAR	CABLE AND PANEL	WIRE SAMPLE NO	SPECMN NO	CORR STAGE	MAX LOAD (LBS)	YIELD STRGTH (KSI)	TENSILE STRGTH (KSI)	ELONG IN 10" PCT	REDUCT IN AREA PCT	REMARKS		FRACT TYPE
2000	NWM7677	613	613.01	4	6044	198.0	208.8	0.5	2.00	CRACK 1/6D	note 2,L	D
			613.02	4	6974	199.0	240.9	4.0	24.50		note 2,M	B
			613.03	4	7003	199.0	241.9	4.0	26.00		note 2,H	B
			613.04	4	6113	202.0	211.1	0.5	2.00	CRACK 1/8D	note 2,M	D
			613.05	4	7017	201.0	242.4	4.5	20.00		note 2,H	B-C
			613.06	4	7005	203.0	241.9	4.0	20.00		note 2,H	B
			613.07	4	6906	200.0	238.5	5.0	21.50		note 2,H	B-C
			613.08	4	7051	202.0	243.5	3.5	24.50		note 2,M	B-C
			613.09	4	6970	201.0	240.7	3.0	20.00		note 2,H	B-C
			613.10	4	6998	201.0	241.7	4.5	29.50		note 2,M	B
			613.11	4	7012	203.0	242.2	3.5	20.00		note 2,H	B-C

			MAX LOAD (LBS)	TENSILE STRGTH (KSI)	ELONG IN 10" PCT	REDUCT IN AREA PCT
# OF SMPLS/SPEC	1	11				
MEAN			6827	235.8	3.4	19.09
STD DEV			372	12.8	1.5	8.99
MAX				243.5		
MIN				208.8		

~~STD DEVIATION * Φ^{-1}(L0/L) =~~ ~~-25.3~~

~~PROBABLE MIN TENSILE STRENGTH IN LENGTH L~~ ~~210.5~~

MINIMUM TENSILE STRENGTH OF CRACKED SPECIMENS **208.8** <<<

THE CALCULATION OF THE MINIMUM STRENGTH IN LENGTH L GIVEN IN ARTICLE 4.3.1.3 CANNOT BE APPLIED WHEN SOME SPECIMENS CONTAIN PRE-EXISTING CRACKS BECAUSE THE CRACKED AND UNCRACKED SPECIMENS BELONG TO TWO DISTINCT POPULATIONS. THE MINIMUM TENSILE STRENGTH FOUND FOR THE CRACKED SPECIMENS IS USED INSTEAD.

FRACTURE TYPES

CUP & CONE	DUCTILE	A
CUP & CONE WITH SHEAR LIPS ALTERNATING ABOVE & BELOW FRACTURE PLANE	DUCTILE	B
RAGGED WITH PARTIAL SHEAR LIPS AND REDUCED REDUCTION IN AREA	SEMI - DUCTILE	B-C
RAGGED WITH MINIMAL OR NO REDUCTION IN AREA	BRITTLE	C
FRACTURE WITH PARTIAL CRACK	BRITTLE W/ CRACK	D

MINIMUM TENSILE STRENGTH OF A WIRE IN A PANEL LENGTH

PANEL LENGTH	$L =$	41	FEET
SPECIMEN LENGTH BETWEEN JAWS OF TEST MACHINE	$L_0 =$	12	IN
	$L/L_0 =$	41	
FROM Figure 4.4.3.2-1	$\Phi^{-1}(L_0/L) = -1.97$		

EQUATION 4.4.3.2-1 GIVES PROBABLE MIN
TENSILE STRENGTH = $x_{1,i} = \mu_{si} + \Phi^{-1}(L_0/L) * \sigma_{si}$

NOTE 1: SURFACE OF WIRE COVERED WITH A GUMMY MATERIAL, POSSIBLY DRIED LINSEED OIL.

NOTE 2: SURFACE CORROSION IS PRESENT AT THE FRACTURE LOCATION, WHICH IS THE PROBABLE INITITIATION POINT OF THE FRACTURE.

L = LOCAL
O = OVERALL
M = MODERATE
H = HEAVY
S = SEVERE

EXAMPLE CALCULATION NO 1 **STEP D-2**

PROJECT:

CENTENNIAL BRIDGE

RESULTS OF TESTS ON WIRES REMOVED FROM CABLE

SUMMARY OF ALL TENSILE TESTS

CABLE	**BOTH**
SPAN	**ALL SPANS**
PANEL	**ALL PANELS**

ALL STRESSES BASED ON 0.192 INCH DIA, AREA = 0.028953 SQ IN

CABLE & PANEL DESIGNATIONS

W = WEST	M = MAIN
E = EAST	S = SIDE
N = NORTH CABLE	2123 = PANEL 21-23
S = SOUTH CABLE	ANCH = ANCHORAGE

				MINIMUM IN 41 FEET					STRENGTH BY GROUP				
YEAR	CABLE AND PANEL	WIRE SAMPLE NO	CORR STAGE	WIRE GROUP	MAX LOAD (LBS)	TENSILE STRGTH (KSI)	REMARKS	FRACT TYPE	1	2	3	4	5
2000	SES0001	101	1	1	6885	237.8		B	237.8				
2000	SES0001	102	1	1	6920	239.0		A	239.0				
2000	SWS1718	201	1	1	6450	222.8		B	222.8				
2000	SWS1718	202	1	1	6821	235.6		B	235.6				
2000	NWS0001	401	1	1	6955	240.2		B	240.2				
2000	NWS0001	402	1	1	6833	236.0		A	236.0				
2000	NWM5758	501	1	1	6865	237.1		B	237.1				
2000	NWM5758	502	1	1	6891	238.0		A	238.0				
2000	NWM7677	601	1	1	6914	238.8		B	238.8				
2000	NWM7677	602	1	1	6926	239.2		A	239.2				
2000	SES0001	103	2	2	6865	237.1		B		237.1			
2000	SES0001	104	2	2	6876	237.5		A		237.5			
2000	SES0001	105	2	2	6824	235.7		A		235.7			
2000	SWS1718	203	2	2	6969	240.7		A		240.7			
2000	SWS1718	204	2	2	6983	241.2		A		241.2			
2000	SWS1718	205	2	2	7091	244.9		A		244.9			
2000	NWS0001	403	2	2	6954	240.2		A		240.2			
2000	NWS0001	404	2	2	6946	239.9		B		239.9			
2000	NWS0001	405	2	2	6914	238.8		B-C		238.8			
2000	NWM5758	503	2	2	6940	239.7		B		239.7			
2000	NWM5758	504	2	2	7004	241.9		B		241.9			
2000	NWM5758	505	2	2	7001	241.8		B		241.8			
2000	NWM7677	603	2	2	7001	241.8		B		241.8			
2000	NWM7677	604	2	2	7004	241.9		B		241.9			
2000	NWM7677	605	2	2	7148	246.9		A		246.9			
2000	SES0001	106	3	3	6471	223.5		B-C			223.5		
2000	SES0001	107	3	3	7029	242.8					242.8		
2000	SES0001	108	3	3	6923	239.1		B			239.1		
2000	SWS1718	206	3	3	6740	232.8		B			232.8		
2000	SWS1718	207	3	3	6847	236.5		B			236.5		
2000	SWS1718	208	3	3	6998	241.7		B			241.7		
2000	SEM7778	301	3	3	6891	238.0		A			238.0		
2000	SEM7778	302	3	3	6700	231.4		B			231.4		
2000	NWM5758	506	3	3	6752	233.2		B-C			233.2		
2000	NWM5758	507	3	3	6630	229.0		B			229.0		
2000	NWM5758	508	3	3	6986	241.3		B			241.3		
2000	NWM5758	510	3	3	6883	237.7		B			237.7		
2000	NWM7677	606	3	3	6662	230.1		B			230.1		
2000	NWM7677	608	3	3	7027	242.7		B			242.7		
2000	NWM7677	609	3	3	6914	238.8		B			238.8		
2000	NWM7677	617	3	3	6991	241.5		B			241.5		
2000	NWM7677	618	3	3	6659	230.0		B			230.0		
2000	SES0001	109	4	4	6346	219.2		B-C				219.2	
2000	SES0001	111	4	4	6907	238.6						238.6	
2000	SES0001	112	4	4	6764	233.6		B				233.6	
2000	SEM7778	305	4	4	6775	234.0		B				234.0	
2000	SEM7778	307	4	4	6754	233.3		B				233.3	
2000	SEM7778	309	4	4	6868	237.2		B				237.2	
2000	SEM7778	310	4	4	6280	216.9		C				216.9	
2000	NWM5758	511	4	4	6483	223.9		C				223.9	
2000	NWM5758	514	4	4	6859	236.9		B				236.9	
2000	NWM5758	516	4	4	6920	239.0		B-C				239.0	
2000	NWM5758	518	4	4	6931	239.4		B				239.4	
2000	NWM7677	610	4	4	6862	237.0		B-C				237.0	
2000	NWM7677	611	4	4	6920	239.0		B-C				239.0	
2000	NWM7677	614	4	4	6370	220.0		C				220.0	
2000	NWM7677	615	4	4	6320	218.3		A				218.3	

EXAMPLE CALCULATION NO 1

STEP D-2

PROJECT:

CENTENNIAL BRIDGE

RESULTS OF TESTS ON WIRES REMOVED FROM CABLE

SUMMARY OF ALL TENSILE TESTS

CABLE	BOTH
SPAN	ALL SPANS
PANEL	ALL PANELS

ALL STRESSES BASED ON 0.192 INCH DIA, AREA = 0.028953 SQ IN

CABLE & PANEL DESIGNATIONS

W = WEST	M = MAIN
E = EAST	S = SIDE
N = NORTH CABLE	2123 = PANEL 21-23
S = SOUTH CABLE	ANCH = ANCHORAGE

YEAR	CABLE AND PANEL	WIRE SAMPLE NO	CORR STAGE	MINIMUM IN 41 FEET WIRE GROUP	MAX LOAD (LBS)	TENSILE STRGTH (KSI)	REMARKS	FRACT TYPE	STRENGTH BY GROUP 1	2	3	4	5
2000	SES0001	110	4	5	6749	233.1	CRACK 0.05DIAMETER	C					233.1
2000	SES0001	113	4	5	6502	224.6	CRACK <0.1D	D					224.6
2000	SEM7778	304	4	5	5620	194.1	CRACK 0.2D	D					194.1
2000	SEM7778	306	4	5	5450	188.2	CRACK 0.25D	D					188.2
2000	SEM7778	308	4	5	6211	214.5	CRACK 0.1D	D					214.5
2000	SEM7778	311	4	5	5539	191.3	CRACK 0.2D	D					191.3
2000	SEM7778	312	4	5	4100	141.6	CRACK 0.25D	D					141.6
2000	SEM7778	313	4	5	6610	228.3	CRACK 0.08D	B-C					228.3
2000	NWM5758	512	4	5	6509	224.8	CRACK 0.1D	B					224.8
2000	NWM5758	513	4	5	4551	157.2	CRACK 0.2D	D					157.2
2000	NWM5758	515	4	5	5220	180.3	CRACK 0.15D	D					180.3
2000	NWM5758	517	4	5	5671	195.9	CRACK 1/8D	B-C					195.9
2000	NWM7677	612	4	5	6323	218.4	CRACK 0.05D	B					218.4
2000	NWM7677	613	4	5	6045	208.8	CRACK 1/6D	C					208.8
2000	NWM7677	616	4	5	5981	206.6	CRACK .05D	B-C					206.6
2000	SEM7778	303	3	NOT USED	6671	230.4	CRACK 0.15D	B					
2000	NWM5758	509	3	NOT USED	6480	223.8	CRACK 0.2D	D					
2000	NWM7677	607	3	NOT USED	5892	203.5	CRACK 0.15D	D					

# OF SAMPLES	75		
	group or stage	#samples per stage	#samples per group
	1	10	
	2	15	25
	3	20	76
	4	30	15
	5		15
CRACKED STAGE 3 NOT USED*			3
	TOTAL	75	134

	1	2	3	4	5
MEAN	236.5	240.7	235.9	231.1	200.5
STD DEV	5.0	2.9	5.7	8.7	26.3
MEAN GROUP	239.0		235.9	231.1	200.5
STD DEV GROUP	4.3		5.7	8.7	26.3

FRACTURE TYPES

CUP & CONE	DUCTILE	A
CUP & CONE WITH SHEAR LIPS ALTERNATING ABOVE & BELOW FRACTURE PLAN	DUCTILE	B
RAGGED WITH PARTIAL SHEAR LIPS AND REDUCED REDUCTION IN AREA	SEMI - DUCTILE	B-C
RAGGED WITH MINIMAL OR NO REDUCTION IN AREA	BRITTLE	C
FRACTURE WITH PARTIAL CRACK	BRITTLE W/ CRACK	D

* STAGE 3 CRACKED WIRES NOT INCLUDED IN CALCULATION OF MEAN AND STANDARD DEVIATION OF WIRE GROUP 5 (CRACKED WIRES)

FRACTION OF WIRES CRACKED

STAGE 3 (EQUATION 4.4.2-2)

TOTAL NUMBER OF STAGE 3 SAMPLES		20
NUMBER OF STAGE 3 SAMPLES WITH CRACKS		3
FRACTION OF STAGE 3 SAMPLES WITH CRACKS = 3 / 20		0.15
FRACTION OF STAGE 3 WIRES CRACKED = FRACTION OF STAGE 3 SAMPLES CRACKED * 0.33	p_{c3} =	0.050

STAGE 4 (EQUATION 4.4.2-1)

TOTAL NUMBER OF STAGE 4 SAMPLES		30
NUMBER OF STAGE 4 SAMPLES WITH CRACKS		15
FRACTION OF STAGE 4 WIRES CRACKED = 15/30	p_{c4} =	0.500

EXAMPLE CALCULATION NO 1	**STEP D-3**
PROJECT: CENTENNIAL BRIDGE	NUMBER OF WIRES IN CABLE OF EACH CORROSION STAGE
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

	NO OF WIRES PER STRAND =	270
	NO OF STRANDS IN CABLE =	37
TOTAL NO OF WIRES IN CABLE =		9990

SUMMARY	
STAGE 4	2175.5
3	5540.9
2	2273.7
1	0.0
<1 OR >4	0.0
TOTAL**	9990.0

** ERROR IF <1 OR >4 DOES NOT EQUAL ZERO. >>>

GRADING OF DETERIORATED WIRES
This table is a list of the corrosion stages (k) assigned in the inspection

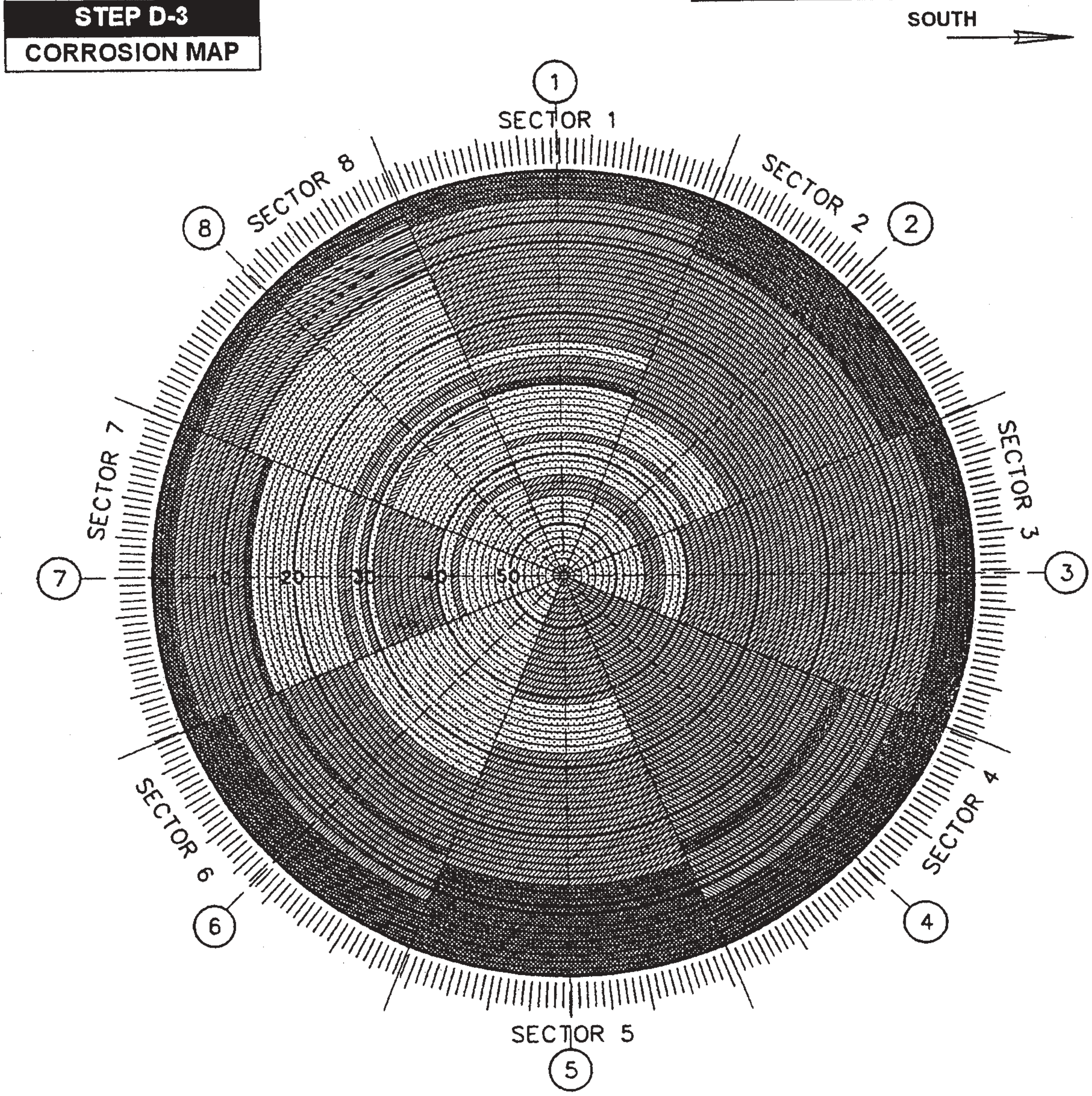
SECTOR 1 AT 12:00 O'CLOCK, THEN CLOCKWISE

NUMBER OF WIRES IN EACH STAGE, N_{sk}
Entries in this section are calculated by formulas in the cells.

CAUTION
The formulas in this table assume that all sectors are of equal size. Modify if not true.

RING NO, d (p EX1-04)	TOT NO OF WIRES IN RING, n (p EX1-04)	SECTOR NO 1 L	1 R	2 L	2 R	3 L	3 R	4 L	4 R	5 L	5 R	6 L	6 R	7 L	7 R	8 L	8 R	CORROSION STAGE, k 1	2	3	4	k<1 or k>4
	DEGREES >>>	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5					
	FRACT OF CIRCLE >>>	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625					
1	344.4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0.0	0.0	0.0	344.4	0.0
2	338.4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0.0	0.0	0.0	338.4	0.0
3	332.4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0.0	0.0	0.0	332.4	0.0
4	326.3	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	0.0	0.0	81.6	244.7	0.0
5	320.3	3	3	4	4	4	4	4	4	4	4	4	4	3	3	3	3	0.0	0.0	120.1	200.2	0.0
6	314.2	3	3	4	4	3	3	4	4	4	4	4	4	3	3	3	3	0.0	0.0	157.1	157.1	0.0
7	308.2	3	3	4	4	3	3	4	4	4	4	4	4	3	3	3	3	0.0	0.0	154.1	154.1	0.0
8	302.1	3	3	4	4	3	3	3	3	4	4	3	3	3	3	3	3	0.0	0.0	226.6	75.5	0.0
9	296.1	3	3	3	3	3	3	3	3	4	4	3	3	3	3	3	3	0.0	0.0	259.1	37.0	0.0
10	290.1	3	3	3	3	3	3	3	3	4	4	3	3	3	3	3	3	0.0	0.0	253.8	36.3	0.0
11	284.0	3	3	3	3	3	3	3	3	4	4	3	3	3	3	3	3	0.0	0.0	248.5	35.5	0.0
12	278.0	3	3	3	3	3	3	3	3	4	4	3	3	3	3	2	2	0.0	34.7	208.5	34.7	0.0
13	271.9	3	3	3	3	3	3	3	3	4	4	3	3	3	3	2	2	0.0	34.0	204.0	34.0	0.0
14	265.9	3	3	3	3	3	3	3	3	3	3	3	3	4	4	2	2	0.0	33.2	199.4	33.2	0.0
15	259.8	3	3	3	3	3	3	4	4	3	3	4	4	2	2	2	2	0.0	65.0	129.9	65.0	0.0
16	253.8	3	3	3	3	3	3	4	4	3	3	3	3	2	2	2	2	0.0	63.5	158.6	31.7	0.0
17	247.8	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	61.9	185.8	0.0	0.0
18	241.7	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	60.4	181.3	0.0	0.0
19	235.7	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	58.9	176.8	0.0	0.0
20	229.6	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	57.4	172.2	0.0	0.0
21	223.6	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	55.9	167.7	0.0	0.0
22	217.5	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	54.4	163.2	0.0	0.0
23	211.5	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	52.9	158.6	0.0	0.0
24	205.5	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	51.4	154.1	0.0	0.0
25	199.4	2	2	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	74.8	124.6	0.0	0.0
26	193.4	2	2	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0.0	72.5	120.9	0.0	0.0
27	187.3	3	3	3	3	3	3	3	3	3	3	2	2	3	3	3	3	0.0	23.4	163.9	0.0	0.0
28	181.3	3	3	3	3	3	3	3	3	3	3	2	2	3	3	3	3	0.0	22.7	158.6	0.0	0.0
29	175.2	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	0.0	65.7	109.5	0.0	0.0
30	169.2	4	4	3	3	3	3	3	3	3	3	2	2	3	3	3	3	0.0	21.2	126.9	21.2	0.0
31	163.2	2	2	3	3	3	3	3	3	3	3	2	2	2	2	2	2	0.0	81.6	81.6	0.0	0.0
32	157.1	2	2	3	3	3	3	3	3	3	3	2	2	3	3	3	3	0.0	39.3	117.8	0.0	0.0
33	151.1	2	2	2	2	3	3	3	3	2	2	2	2	3	3	2	2	0.0	94.4	56.7	0.0	0.0
34	145.0	2	2	2	2	3	3	3	3	2	2	2	2	3	3	2	2	0.0	90.6	54.4	0.0	0.0
35	139.0	2	2	2	2	3	3	3	3	2	2	2	2	3	3	2	2	0.0	86.9	52.1	0.0	0.0
36	132.9	2	2	2	2	3	3	3	3	2	2	2	2	3	3	2	2	0.0	83.1	49.9	0.0	0.0
37	126.9	2	2	2	2	3	3	3	3	2	2	2	2	3	3	2	2	0.0	79.3	47.6	0.0	0.0
38	120.9	3	3	3	3	3	3	3	3	2	2	2	2	3	3	2	2	0.0	45.3	75.5	0.0	0.0
39	114.8	2	2	2	2	3	3	3	3	2	2	2	2	3	3	2	2	0.0	71.8	43.1	0.0	0.0
40	108.8	2	2	2	2	3	3	3	3	3	3	2	2	3	3	2	2	0.0	54.4	54.4	0.0	0.0
41	102.7	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	77.0	25.7	0.0	0.0
42	96.7	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	72.5	24.2	0.0	0.0
43	90.6	2	2	2	2	2	2	3	3	3	3	2	2	3	3	3	3	0.0	45.3	45.3	0.0	0.0
44	84.6	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	0.0	31.7	52.9	0.0	0.0
45	78.6	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	0.0	29.5	49.1	0.0	0.0
46	72.5	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	0.0	27.2	45.3	0.0	0.0
47	66.5	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	49.9	16.6	0.0	0.0
48	60.4	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	45.3	15.1	0.0	0.0
49	54.4	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	40.8	13.6	0.0	0.0
50	48.3	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	36.3	12.1	0.0	0.0
51	42.3	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	31.7	10.6	0.0	0.0
52	36.3	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	27.2	9.1	0.0	0.0
53	30.2	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	22.7	7.6	0.0	0.0
54	24.2	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	18.1	6.0	0.0	0.0
55	18.1	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	13.6	4.5	0.0	0.0
56	12.1	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	9.1	3.0	0.0	0.0
57	6.0	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	4.5	1.5	0.0	0.0
58	1.0	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	0.0	0.8	0.3	0.0	0.0
check: $\Sigma n=N$	9990.0																TOTAL = N_{sk} =	0.0	2273.7	5540.9	2175.5	**0.0**
check: ΣN_{sk}	9990.0																N_{sk}/N =	0.0%	22.8%	55.5%	21.8%	0.0%

STEP D-3
CORROSION MAP



CABLE CROSS SECTION

BRIDGE: CENTENNIAL
SOUTH CABLE, LOOKING UPSLOPE (EAST)
SPAN EAST MAIN
PANEL 77-78

CORROSION STAGE	
□	1
▒	2
▨	3
■	4

LEGEND

● BROKEN WIRE NO.
⑧ WEDGE LOCATION

EXAMPLE CALCULATION NO 1	SIMPLIFIED MODEL, ONE PANEL INSPECTED
PROJECT:	**STEP D-4**
CENTENNIAL BRIDGE	DATA FROM INSPECTION - BROKEN WIRES

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BASIC CABLE INFORMATION	
NO OF WIRES PER STRAND	270
NO OF STRANDS IN CABLE	37
TOTAL NO OF WIRES IN CABLE	9990
NET WIRE DIAMETER (INCHES)	0.192
AREA OF ONE WIRE (SQ IN)	0.02895

ONLY THE EVALUATED PANEL 77-78 HAS BEEN INSPECTED. BROKEN WIRES WERE FOUND ONLY IN THE OUTER LAYERS, WITH NONE FOUND MORE THAN SIX LAYERS INTO THE CABLE. FIVE BROKEN WIRES WERE FOUND IN THE OUTER RING OF THE CABLE, AND A TOTAL OF SIX WIRES WERE REPAIRED. THE NUMBER OF BROKEN WIRES IN ALL PANELS WITHIN THE EFFECTIVE DEVELOPMENT LENGTH IS ASSUMED TO BE THE SAME AS IN THE INSPECTED PANEL.

THE ESTIMATED NUMBER OF BROKEN WIRES IN THE PANEL IS CALCULATED BY EQUATION 4.3.3.2-1, AND IS ROUNDED TO THE NEXT HIGHER INTEGER, AS THERE CANNOT BE FRACTIONAL BROKEN WIRES:

$n_{bi} = n_{b1,i} * d_0 / 2 = 5 * 7 / 2$ (for evaluated panel, i = 1) **$n_{b1} =$ 18 WIRES**

NUMBER OF BROKEN WIRES IN EFFECTIVE DEVELOPMENT LENGTH

effective development length = 7 panels panel number p		number of wires observed broken total	outer layer $n_{b1,i}$	depth at which no broken wires are found d_0	estimat'd number broken n_{bi}		number repaired n_{ri}	net number broken in effect dev lgth N_b-N_r
7					18			
5					18			
3					18			
1	inspected panel	8	5	7	18		6	
2					18			
4					18			
6					18			
	totals			N_b =	126	N_r =	6	120

THE NUMBER OF UNBROKEN WIRES IN EACH STAGE IS CALCULATED BY EQUATIONS 5.3.2.3-1 TO 6, AND THE EFFECTIVE NUMBER OF WIRES IN THE CABLE IS CALCULATED BY EQUATION 5.3.2.5-1. THE LATTER EQUATION CAN BE RESTATED BY ADDING THE NUMBER OF DISCRETE CRACKED WIRES BACK INTO THE INDIVIDUAL TERMS N_K AND OMITTING THE VALUE OF N_5 FROM THE SUMMATION, RESULTING IN:

$$N_{eff} = \sum_{k=2}^{5} N_k = N_5 + \sum_{k=2}^{4} \left(N_{0k} - N_{c,k}\right) = \sum_{k=2}^{4} N_{0k} \qquad \text{(Eq. 5.3.2.5-1)}$$

Source>	p EX1-12	above	calc
Corrosion Stage k	Number of Wires N_{sk}	Number. Broken N_b-N_r	Number Unbroken N_{0k}
1	0		
2	2274		2274
3	5541		5541
4	2175	120	2055
N =	9990	**Neff =**	**9870** **WIRES**

EXAMPLE CALCULATION NO 1		SIMPLIFIED MODEL, ONE PANEL INSPECTED
PROJECT:		**STEP D-5**
CENTENNIAL BRIDGE		EFFECT OF WIRES THAT ARE CRACKED
CABLE	SOUTH	IN ADJACENT PANELS
SPAN	EAST MAIN SPAN	ARTICLE 5.3.2.4.1
PANEL	77-78	FIGURE 5.3.2.4.1-1

ONLY THE EVALUATED PANEL 77-78 HAS BEEN INSPECTED. IT IS ASSUMED THAT ALL THE PANELS IN THE EFFECTIVE DEVELOPMENT LENGTH ARE IN THE SAME CONDITION AS PANEL 77-78. IN THIS EXAMPLE, CHART 5.3.2.4.1-1 IS USED TO DETERMINE THE NUMBER OF DISCRETE CRACKED WIRES THESE WIRES ARE TO BE SUBTRACTED FROM THE APPROPRIATE GROUP OF UNBROKEN WIRES IN CALCULATING THE CABLE STRENGTH.

THE DATA NEEDED ARE: **(RESULTS FROM THIS PAGE GO TO AND DATA COMES FROM P EX1-16)**

EFFECTIVE DEVELOPMENT LENGTH	L_{eff}	7	PANELS (p EX1-07)
EFFECTIVE NUMBER OF WIRES IN THE CABLE	N_{eff}	9,870	WIRES (p EX1-14)
NO OF UNBROKEN STAGE k WIRES IN THE EVALUATED PANEL	N_{03}	5541	WIRES (p EX1-14)
	N_{04}	2055	WIRES (p EX1-14)
FRACTION OF STAGE k WIRES THAT ARE CRACKED	$p_{c,3}$	0.05	(p EX1-11)
	$p_{c,4}$	0.50	(p EX1-11)

FIGURE 5.3.2.4.1-1 GIVES THE VALUE OF THE EXPRESSION $\Sigma p_{c.K}(1-p_{c.K})^{i-1}$ FOR EACH GROUP OF WIRES (THIS EXPRESSION FOR GROUP 2 IS ZERO, THERE ARE NO CRACKED WIRES IN THIS GROUP)

FROM FIGURE 5.3.2.4.1-1

$$N_{c.3}/N_{03} = \Sigma p_{c.3}(1-p_{c.3})^{i-1} = \mathbf{0.30}$$

$$N_{c.4}/N_{04} = \Sigma p_{c.4}(1-p_{c.4})^{i-1} = \mathbf{0.99}$$

EQUATION 5.3.2.4.1-1 GIVES THE NUMBER OF DISCRETE CRACKED WIRES IN EACH GROUP; THESE NUMBERS ARE ROUNDED TO THE NEXT HIGHER INTEGER:

$$N_{c.k} = N_{0k} * \Sigma p_{c.k}(1-p_{c.k})^{i-1} = 5541 * 0.30 \text{ (GROUP 3)} \qquad N_{c,3} = 1663 \text{ WIRES}$$

$$= 2055 * 0.99 \text{ (GROUP 4)} \qquad N_{c,4} = 2035 \text{ WIRES}$$

TOTAL NUMBER OF DISCRETE CRACKED WIRES = $N_{c,3} + N_{c,4}$ = N_5 = **3698 WIRES**

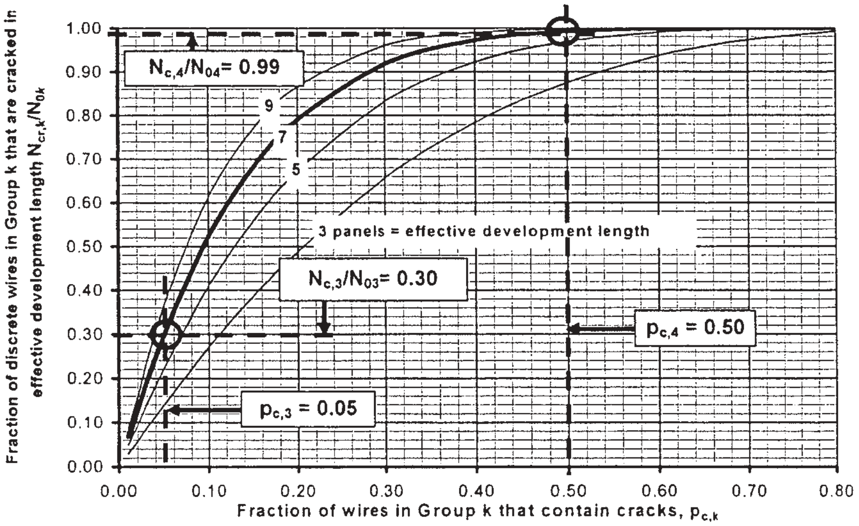


FIGURE 5.3.2.4.1-1 DISCRETE CRACKED WIRES

EXAMPLE CALCULATION NO 1	
PROJECT:	
CENTENNIAL BRIDGE	
CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

SIMPLIFIED MODEL, ONE PANEL INSPECTED

STEP SS-1

FRACTION OF CABLE IN EACH CORROSION STAGE

ADJUSTMENT FOR CRACKED WIRES

FRACTION OF CABLE IN EACH CORROSION STAGE

corrosion stage k	source >	number of wires in each stage N_{sk}	net number of broken wires N_b-N_r		number of unbroken wires N_{0k}	fraction unbroken in each stage p_{0k}	fraction of each stage cracked $p_{c,k}$
		p EX1-12	p EX1-14		calc	calc	p EX1-11
1		0			0	0.000	0.00
2		2274			2274	0.230	0.00
3		5541			5541	0.561	0.05
4		2175	120		2055	0.208	0.50
total	N =	9990	120	N_{eff} =	9870	1.000	

IN THIS TABLE:

N_{0k} IS CALCULATED BY EQUATIONS 5.3.2.3-1 to 3, $N_{0k} = N_{sk} - N_b + N_r$

p_{0k} IS CALCULATED AS N_{0k} / N_{eff}. THIS VALUE IS GIVEN FOR INFORMATION ONLY AND IS NOT USED IN FURTHER CALCULATIONS.

N_{eff} IS CALCULATED BY EQUATION 5.3.2.5-1

FRACTION OF CABLE REPRESENTED BY EACH GROUP OF WIRES

wire group k	source >	number of unbroken wires N_{0k}	cracked wires in evaluated panel $N_{c,k}$	number of wires in each group N_k	wires in each group w/o N_5 N_k	fraction of cable in each group p_{uk}
		above	p EX1-15	calc	calc	calc
2	stages 1 + 2 not cracked	2274	0	2274	2274	0.368
3	stage 3 not cracked	5541	1663	3878	3878	0.628
4	stage 4 not cracked	2055	2035	20	20	0.003
5	all cracked wires			3698		
totals		9870	3698	9870	6172 N_{eff}-N_5	1.000

IN THIS TABLE:

N_{0K} FOR WIRE GROUP 2 IS THE SUM OF THE VALUES OF N_{0k} FOR STAGES 1 & 2

$N_{c,k}$ IS CALCULATED BY EQUATION 5.3.2.4.1-1 = $N_{0k} * N_{c,k} / N_{0k}$

N_k IS CALCULATED BY EQUATION 5.3.2.5-2, $N_k = N_{0k} - N_{c,k}$

p_{uk} FOR USE IN EQUATIONS 5.3.3.1.1-1 & 2 IS THE FRACTION OF THE UNBROKEN AND UNCRACKED WIRES IN THE CABLE REPRESENTED BY EACH GROUP , $p_{uk} = N_k / (N_{eff} - N_5)$

FOR USE IN EQUATION 5.3.3.1.2-1, $N_{eff} - N_5$ = 9870 - 3688 **N_{eff}-N_5 = 6172 WIRES**

EXAMPLE CALCULATION NO 1		**SIMPLIFIED MODEL, ONE PANEL INSPECTED**
PROJECT:		**STEP SS-4**
CENTENNIAL BRIDGE		**MEAN AND STANDARD DEVIATION**
CABLE	**SOUTH**	**OF TENSILE STRENGTH, COMBINED GROUPS 2, 3 & 4**
SPAN	**EAST MAIN SPAN**	
PANEL	**77-78**	

THE CABLE STRENGTH IN THE SIMPLIFIED MODEL IS BASED ON ONLY THOSE WIRES THAT ARE NOT BROKEN IN THE EFFECTIVE REDEVELOPMENT LENGTH AND ARE ALSO NOT CRACKED (GROUP 5) IN THE EVALUATED PANEL.

THE MEAN AND STANDARD DEVIATION OF THE TENSILE STRENGTH OF EACH GROUP OF WIRES ARE COMBINED USING EQUATIONS 5.3.3.1.1-1 & 2. WIRES THAT ARE REPRESENTED BY EACH OF GROUPS 2 TO 4 ARE USED TO DETERMINE THE MEAN AND STANDARD DEVIATION OF THE TENSILE STRENGTH OF THE COMBINED WIRE GROUPS. WIRE GROUP 5 IS OMITTED FROM THIS CALCULATION BECAUSE IT CONSISTS OF THE ELIMINATED CRACKED WIRES.

THE DATA NEEDED ARE:

		source	wire group			
			good	fair	poor	cracked
k = corrosion stage of group			2	3	4	5
fraction of remaining wires	p_{uk}	p EX1-16	0.368	0.628	0.003	
mean tensile strength, ksi	μ_{sk}	p EX1-11	239.0	235.9	231.1	
standard deviation, ksi	σ_{sk}	p EX1-11	4.3	5.7	8.7	

remaining wires $N_{eff} - N_5 =$ 6172 wires

area of one wire $a_w =$ 0.03 sq in

CALCULATION OF MEAN AND STANDARD DEVIATION OF COMBINED GROUPS

THE MEAN TENSILE STRENGTH IS CALCULATED BY EQUATION 5.3.3.3.1-1

FRACTION OF WIRES IN GROUP 2 x MEAN OF GROUP 2 = 0.368 * 239.0 = 88.1

FRACTION OF WIRES IN GROUP 3 x MEAN OF GROUP 3 = 0.628 * 235.9 = 148.2

FRACTION OF WIRES IN GROUP 4 x MEAN OF GROUP 4 = 0.003 * 231.1 = 0.7

TOTAL = MEAN OF COMBINED GROUPS = $\Sigma p_k * \mu_{sk}$, k = 2 to 4 $\mu_s =$ **237.0 ksi**

EQUATION 5.3.3.1.1-2 IS USED TO CALCULATE THE STANDARD DEVIATION OF THE TENSILE STRENGTH FOR THE COMBINED GROUPS. IN THIS CALCULATION, THE VALUES OF THE FRACTION OF WIRES IN A GROUP x THE SUM OF THE MEAN OF THAT GROUP SQUARED PLUS THE STANDARD DEVIATION OF THAT GROUP SQUARED IS REQUIRED.

FOR GROUP 2 $p_2 * (\mu_{s2}^2 + \sigma_{s2}^2) = 0.368 * (239.0^2 + 4.3^2) =$ 21052.4

FOR GROUP 3 $p_3 * (\mu_{s3}^2 + \sigma_{s3}^2) = 0.628 * (235.9^2 + 5.7^2) =$ 34985.8

FOR GROUP 4 $p_4 * (\mu_{s4}^2 + \sigma_{s4}^2) = 0.003 * (231.1^2 + 8.7^2) =$ 173.308

TOTAL = 56211.4

$\mu_s^2 =$ 56181.6

$(\Sigma p_k * (\sigma_{sk}^2 + \mu_{sk}^2)) - \mu_s^2 =$ 29.8

STD DEV OF COMBINED GROUPS = SQRT(($\Sigma p_k * (\sigma_{sk}^2 + \mu_{sk}^2)) - \mu_s^2$) $\sigma_s =$ **5.5 ksi**

COEFFICIENT OF VARIATION, V = σ_s / μ_s, FOR USE IN FIGURE 5.3.3.1.2-1 $\sigma_s / \mu_s =$ **0.023**

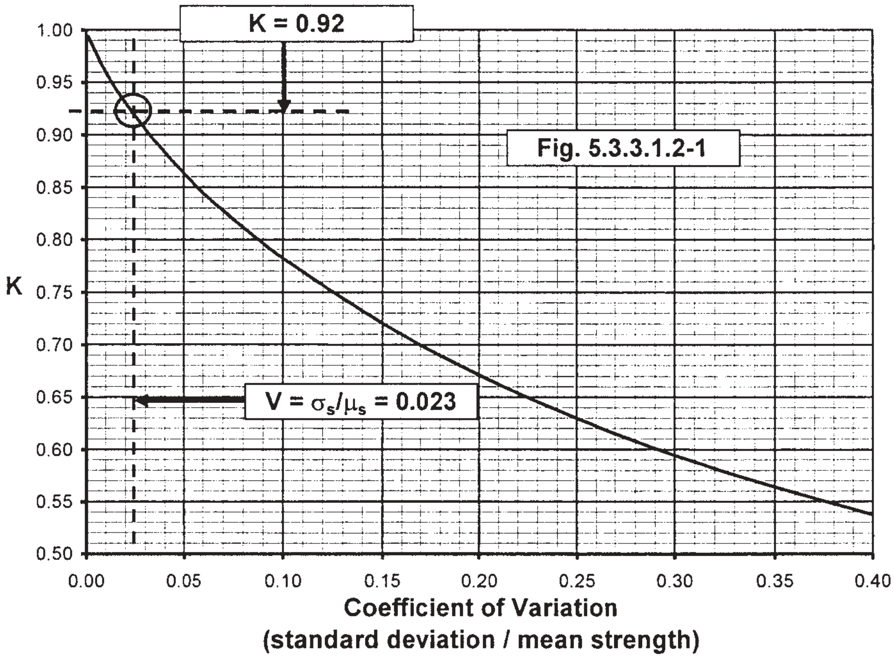
EXAMPLE CALCULATION NO 1	
PROJECT:	
CENTENNIAL BRIDGE	
CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

SIMPLIFIED MODEL, ONE PANEL INSPECTED

STEP SS-5

CALCULATION OF CABLE STRENGTH

THE VALUE OF THE REDUCTION FACTOR FOR USE IN EQUATION 5.3.3.1.2-1 , K, IS TAKEN FROM FIGURE 5.3.3.1.2-1:



THE DATA NEEDED TO CALCULATE THE CABLE STRENGTH ARE:

number of unbroken, uncracked wires in cable	N_{eff}-N_5 =	6172	wires
area of one wire	a_w =	0.0290	sq in
mean tensile strength of combined groups	μ_s =	237.0	ksi
Strength Reduction Factor	K =	0.92	

THE CABLE STRENGTH IS CALCULATED BY EQUATION 5.3.3.1.2-1:

$R_u = (N_{eff} - N_5) * a_w * \mu_s * K = 6172 * 0.0290 * 237.0 * 0.920$ **R_u = 38968 KIPS**

EXAMPLE CALCULATION NO 1	
PROJECT:	
CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

SIMPLIFIED MODEL, ADJACENT PANELS ASSUMED PERFECT

STEPS D-4, SS1.5 & 5

BASIC CABLE INFORMATION	
NO OF WIRES PER STRAND	270
NO OF STRANDS IN CABLE	37
TOTAL NO OF WIRES IN CABLE	9990
NET WIRE DIAMETER (INCHES)	0.192
AREA OF ONE WIRE (SQ IN)	0.028953

ONLY THE EVALUATED PANEL 77-78 HAS BEEN INSPECTED. BROKEN WIRES WERE FOUND ONLY IN THE OUTER LAYERS, WITH NONE FOUND MORE THAN SIX LAYERS INTO THE CABLE. FIVE BROKEN WIRES WERE FOUND IN THE OUTER RING OF THE CABLE, AND A TOTAL OF SIX WIRES WERE REPAIRED. ADJACENT PANELS ARE ASSUMED TO BE PERFECT IN ORDER TO LOCATE THE WORST PANEL BY A SIMPLIFIED TECHNIQUE.

THE ESTIMATED NUMBER OF BROKEN WIRES IN THE PANEL IS CALCULATED BY EQUATION 4.3.3.2-1, AND IS ROUNDED TO THE NEXT HIGHER INTEGER, AS THERE CANNOT BE FRACTIONAL BROKEN WIRES:

$n_{bi} = n_{b1,i} * d_0 / 2 = 5 * 7 / 2$ (for evaluated panel, $i = 1$) **$n_{b1} =$** **18 WIRES**

NUMBER OF BROKEN WIRES IN EFFECTIVE DEVELOPMENT LENGTH

effective development length = 1 panel

panel number p		number of wires observed broken: total	number of wires observed broken: outer layer $n_{b1,i}$	depth at which no broken wires are found d_0	estimat'd number broken n_{bi}		number repaired n_{ri}	net number broken in effect dev lgth N_b-N_r
1	inspected panel	8	5	7	18		6	↓
	totals			N_b =	18	N_r =	6	12

FRACTION OF CABLE IN EACH CORROSION STAGE

	source >	p EX1-12	above		calc	calc	p EX1-11	calc
corrosion stage k		number of wires in each stage N_{sk}	net number of broken wires N_b-N_r		number of unbroken wires N_{0k}	fraction unbroken in each stage p_{0k}	fraction of each stage cracked $p_{c,k}$	cracked wires in evaluated panel $N_{c,k}$
1		0			0	0.000	0.00	0
2		2274			2274	0.228	0.00	0
3		5541			5541	0.555	0.05	278
4		2175	12		2163	0.217	0.50	1082
total	N =	9990	12	N_{eff} =	9978	1.000		1360

FRACTION OF CABLE REPRESENTED BY EACH GROUP OF WIRES

	source >	calc	calc	calc	p EX1-11	p EX1-11		
wire group k		number of wires in each group N_k	wires in each group w/o N_5 N_k	fraction of cable in each group p_{uk}	mean μ_{sk}	standard deviation σ_{sk}	$p_{uk}{*}\mu_{sk}$	$p_{uk}{*}(\mu_{sk}^2+\sigma_{sk}^2)$
2	stages 1 + 2 not cracked	2274	2274	0.264	239.0	4.3	63.1	15077.2
3	stage 3 not cracked	5263	5263	0.611	235.9	5.7	144.1	34004.5
4	stage 4 not cracked	1081	1081	0.125	231.1	8.7	29.0	6708.6
5	all cracked wires	1360						
totals		9978		1.000			236.1	55790.3
		N_{eff}-N_5	8618		$(\Sigma p_k * (\sigma_{sk}^2 + \mu_{sk}^2)) - \mu_s^2$			39.6

TOTAL = MEAN OF COMBINED GROUPS = $\Sigma p_k * \mu_{sk}$, $k = 2$ to 4 $\mu_s =$ 236.1 ksi

STD DEV OF COMBINED GROUPS = $\text{SQRT}((\Sigma p_k * (\sigma_{sk}^2 + \mu_{sk}^2)) - \mu_s^2)$ $\sigma_s =$ 6.3 ksi

COEFFICIENT OF VARIATION, $V = \sigma_s / \mu_s$, FOR USE IN FIGURE 5.3.3.1.2-1 $\sigma_s / \mu_s =$ 0.027

STRENGTH REDUCTION FACTOR FROM FIGURE 5.3.3.1.2-1: K = 0.91

THE CABLE STRENGTH IS CALCULATED BY EQUATION 5.3.3.1.2-1:

$R_u = (N_{eff} - N_5) * a_w * \mu_s * K = 8618 * 0.0290 * 236.1 * 0.91$ **$R_u =$** **53612 KIPS**

EXAMPLE CALCULATION NO 2	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

EXAMPLE CALCULATION NO 2

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

TABLE OF CONTENTS

EXAMPLE CALCULATION NO 2	BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
PROJECT:	STEP D-4
CENTENNIAL BRIDGE	DATA FROM INSPECTION - BROKEN WIRES
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BASIC CABLE INFORMATION	
NO OF WIRES PER STRAND	270
NO OF STRANDS IN CABLE	37
TOTAL NO OF WIRES IN CABLE	9990
NET WIRE DIAMETER (INCHES)	0.192
AREA OF ONE WIRE (SQ IN)	0.02895

ONLY THE EVALUATED PANEL 77-78 HAS BEEN INSPECTED. BROKEN WIRES WERE FOUND ONLY IN THE OUTER LAYERS, WITH NONE FOUND MORE THAN SIX LAYERS INTO THE CABLE. FIVE BROKEN WIRES WERE FOUND IN THE OUTER RING OF THE CABLE, AND A TOTAL OF SIX WIRES WERE REPAIRED. THE NUMBER OF BROKEN WIRES IN ALL PANELS WITHIN THE EFFECTIVE DEVELOPMENT LENGTH IS ASSUMED TO BE THE SAME AS IN THE INSPECTED PANEL.

THE ESTIMATED NUMBER OF BROKEN WIRES IN THE PANEL IS CALCULATED BY EQUATION 4.3.3.2-1, AND IS ROUNDED TO THE NEXT HIGHER INTEGER, AS THERE CANNOT BE FRACTIONAL BROKEN WIRES:

$n_{bi} = n_{b1,i} * d_0 / 2 = 5 * 7 / 2$ (for evaluated panel, i = 1) **$n_{b1} =$ 18 WIRES**

NUMBER OF BROKEN WIRES IN EFFECTIVE DEVELOPMENT LENGTH

effective development length = 7 panels

panel number p		number of wires observed broken: total	number of wires observed broken: outer layer $n_{b1,i}$	depth at which no broken wires are found d_0	estimat'd number broken n_{bi}	number repaired n_{ri}	net number broken in effect dev lgth N_b-N_r
7					18		
5					18		
3					18		
1	inspected panel	8	5	7	18	6	
2					18		
4					18		
6					18		
	totals			N_b =	126	N_r = 6	120

THE NUMBER OF UNBROKEN WIRES IN EACH STAGE IS CALCULATED BY EQUATIONS 5.3.2.3-1 TO 6, AND THE EFFECTIVE NUMBER OF WIRES IN THE CABLE IS CALCULATED BY EQUATION 5.3.2.5-1. THE LATTER EQUATION CAN BE RESTATED BY ADDING THE NUMBER OF DISCRETE CRACKED WIRES BACK INTO THE INDIVIDUAL TERMS N_K AND OMITTING THE VALUE OF N_5 FROM THE SUMMATION, RESULTING IN:

$$N_{eff} = \sum_{k=2}^{5} N_k = N_5 + \sum_{k=2}^{4} \left(N_{0k} - N_{c,k} \right) = \sum_{k=2}^{4} N_{0k} \qquad \text{(Eq. 5.3.2.5-1)}$$

Source>	p EX1-12	above	calc
Corrosion Stage k	No of Wires N_{sk}	No. Broken N_b-N_r	No Unbroken N_{0k}
1	0		
2	2274		2274
3	5541		5541
4	2175	120	2055
N =	9990	**Neff =**	**9870**

WIRES

EXAMPLE CALCULATION NO 2		BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
PROJECT:		**STEPS D-5 & D-6**
CENTENNIAL BRIDGE		EFFECT OF WIRES THAT ARE CRACKED
CABLE	SOUTH	IN ADJACENT PANELS
SPAN	EAST MAIN SPAN	ARTICLE 5.3.2.4.2
PANEL	77-78	FIGURE 5.3.2.4-2

STEP D-5 THE NUMBER DISCRETE CRACKED WIRES WITHIN THE EFFECTIVE DEVELOPMENT LENGTH HAS BEEN CALCULATED ON PAGE EX1-15. THIS CALCULATION IS NOT REPEATED HERE.

STEP D-6 THE EFFECTIVE NUMBER OF CRACKED WIRES THAT BREAK IN ADJACENT PANELS AND THAT CAN BE REDEVELOPED IN PART IN THE EVALUATED PANEL IS REQUIRED IN THIS EXAMPLE, AND IS CALCULATED USING FIGURE 5.3.2.4.1-2 AND EQUATION 5.3.2.4.2-1.

THE VALUES OF N_{0k} CALCULATED ON PAGE EX1-14 ARE USED IN THIS CALCULATION.

NO OF UNBROKEN STAGE k WIRES IN THE EVALUATED PANEL	N_{03}	5541 WIRES (p EX1-14)
	N_{04}	2055 WIRES (p EX1-14)

FROM FIGURE 5.3.2.4-2

$N_{cr.3}/N_{03} = \Sigma(p_{c.3}(1-p_{c.3})^{i-1} * C_{di}) =$ **0.12**

$N_{cr.4}/N_{04} = \Sigma(p_{c.4}(1-p_{c.4})^{i-1} * C_{di}) =$ **0.16**

EQUATION 5.3.2.4.-2 GIVES THE EFFECTIVE NUMBER OF REDEVELOPED CRACKED WIRES (THESE ARE ROUNDED TO THE NEXT HIGHER INTEGERS)

$N_{cr.k} = N_{0k} * \Sigma(p_{c.k}(1-p_{c.k})^{i-1} * C_{di}) = 5541 * 0.12$ **(GROUP 3)** $N_{cr,3} =$ **665 WIRES**

$= 2055 * 0.16$ **(GROUP 4)** $N_{cr,4} =$ **329 WIRES**

TOTAL EFFECTIVE NO OF REDEVELOPED CRACKED WIRES $N_{cr} =$ **994 WIRES**

THE VALUE OF N_{cr} / N_5 IS USED WHEN THE STRENGTH CALCULATION IS MADE ON A SPREADSHEET AS ILLUSTRATED HEREAFTER:

N5 = 3698 WIRES (p EX1-15) $N_{cr}/N_5 =$ **0.269**

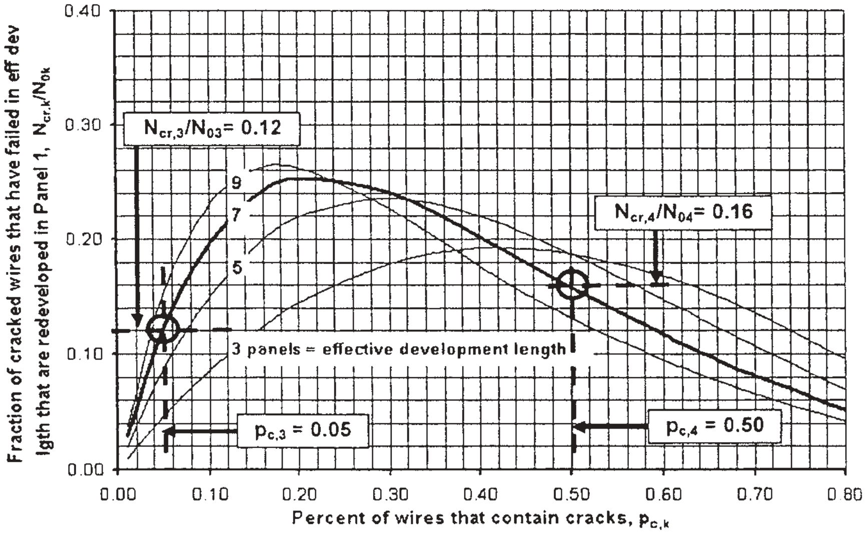


FIGURE 5.3.2.4.2-1 REDEVELOPED CRACKED WIRES

EXAMPLE CALCULATION NO 2
PROJECT:
CENTENNIAL BRIDGE

CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

STEP BS-1

DATA FROM INSPECTION
FRACTION OF CABLE IN EACH CORROSION STAGE
ADJUSTMENT FOR CRACKED WIRES

FRACTION OF CABLE IN EACH CORROSION STAGE

	source >	p EX1-12	p EX2-02		calc	calc	tests
corrosion stage k		number of wires in each stage N_{sk}	net number of broken wires N_b-N_r		number of unbroken wires N_{0k}	fraction unbroken in each stage p_{0k}	fraction of each stage cracked $p_{c,k}$
1		0			0	0.000	0.00
2		2274			2274	0.230	0.00
3		5541			5541	0.561	0.05
4		2175	120		2055	0.208	0.50
total	N =	9990	120	N_{eff} =	9870	1.000	

IN THIS TABLE:
N_{0k} IS CALCULATED BY EQUATIONS 5.3.2.3-1 to 3, $N_{0k} = N_{sk} - N_b + N_r$
p_{0k} IS CALCULATED AS N_{0k} / N_{eff}. THIS VALUE IS GIVEN FOR INFORMATION ONLY AND IS NOT USED IN FURTHER CALCULATIONS.
N_{eff} IS CALCULATED BY EQUATION 5.3.2.5-1

FRACTION OF CABLE REPRESENTED BY EACH GROUP OF WIRES

	source >	above	p EX1-15	calc	calc
wire group k		number of unbroken wires N_{0k}	cracked wires in eff dev length $N_{c,k}$	number of wires in each group N_k	fraction of cable in each group p_k
2	stages 1 + 2 not cracked	2274	0	2274	0.230
3	stage 3 not cracked	5541	1663	3878	0.393
4	stage 4 not cracked	2055	2035	20	0.002
5	all cracked wires			3698	0.375
totals		9870	3698	9870	1.000

IN THIS TABLE:
N_{0k} FOR GROUP 2 IS THE SUM OF THE VALUES OF N_{0k} FOR STAGES 1 & 2
N_k IS CALCULATED BY EQUATION 5.3.2.5-2, $N_k = N_{0k} - N_{c,k}$
p_k IS CALCULATED BY EQUATION 5.3.2.6-1, $p_k = N_k / N_{eff}$

EXAMPLE CALCULATION NO 2		BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
PROJECT: CENTENNIAL BRIDGE		**STEP BS-2** CALCULATION OF WEIBULL DISTRIBUTION PARAMETERS
CABLE	SOUTH	
SPAN	EAST MAIN SPAN	
PANEL	77-78	

THE MEAN AND STANDARD DISTRIBUTION OF THE TENSILE STRENGTH OF EACH GROUP OF WIRES DETERMINED FROM THE LABORATORY TESTS ARE USED TO DETERMINE THE PARAMETERS OF THE WEIBULL DISTRIBUTIONS. THE METHOD PRESENTED IN APPENDIX A, ARTICLE A.4.2 IS USED BELOW. THE VALUE OF x_0 IS TAKEN AS ZERO AND THIS TERM IS OMITTED IN THE EQUATIONS SHOWN IN THE CALCULATION BELOW

TENSILE STRENGTH DISTRIBUTION FOR EACH WIRE CLASS

		source	wire group			
			good	fair	poor	cracked
k = corrosion stage of group			2	3	4	5
mean tensile strength, μ_s	ksi	p EX1-11	239.0	235.9	231.1	200.5
standard deviation, σ_s	ksi	p EX1-11	4.3	5.7	8.7	26.3
ALPHA (shape parameter) = m			70.6	52.4	33.4	9.1
BETA (υ)			240.9	238.4	235.0	211.6
x_0	ksi		0.00	0.00	0.00	0.00

CALCULATION OF WEIBULL PARAMETERS

	wire group					Excel
k = corrosion stage of group	0	2	3	4	5	parameter
m (assumed, then determined by solver)	This column may be used to develop the Weibull parameters for new wire if desired	**70.6**	**52.4**	**33.4**	**9.1**	alpha
(Γ = GAMMA function) $\Gamma(1+2/m)$		0.9844	0.9793	0.9688	0.9133	
$\Gamma(1+1/m)$		0.9920	0.9893	0.9836	0.9475	
$\Gamma(1+2/m)/\Gamma^2(1+1/m)$		1.0003	1.0006	1.0014	1.0172	
σ^2		18.490	32.490	75.690	691.690	
μ^2		57121	55649	53407	40200	
σ^2/μ^2		3.2E-04	5.8E-04	1.4E-03	1.7E-02	
SOLVE FOR m USING SOLVER: Equation A.4.2-6 is solved for m by making the value of the expression $\Gamma(1+2/m)/\Gamma^2(1+1/m) - 1 - \sigma^2/\mu^2$ equal to zero by varying m, using the "Solver" routine in Excel:						
$\mathbf{\Gamma(1+2/m)/\Gamma^2(1+1/m) - 1 - \sigma^2/\mu^2 = 0}$		**-4.7E-10**	**-8.1E-10**	**-4.9E-10**	**2.6E-10**	
CALCULATE υ: The value of (υ) is found by solving Equation A.4.2-4 for this expression and substituting the value of m found above:						
$\mathbf{\upsilon = \mu/\Gamma(1+1/m)}$		**240.9**	**238.4**	**235.0**	**211.6**	**beta**

EXAMPLE CALCULATION NO 2	
PROJECT: **CENTENNIAL BRIDGE**	
CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

STEP BS-3

FORCE IN EVALUATED PANEL IN WIRES
THAT ARE BROKEN IN ADJACENT PANELS
ARTICLE 5.3.4, EQUATION 5.3.4-3

ONLY THE EVALUATED PANEL 77-78 HAS BEEN INSPECTED. IT IS ASSUMED THAT ALL THE PANELS IN THE EFFECTIVE DEVELOPMENT LENGTH ARE IN THE SAME CONDITION AS PANEL 77-78.
THE FORCE IN THE EVALUATED PANEL ATTRIBUTABLE TO WIRES THAT ARE BROKEN IN OTHER PANELS IS CALCULATED BY EQUATION 5.3.4-3 WHEN ONLY THE EVALUATED PANEL HAS BEEN INSPECTED. THIS EQUATION IS BASED ON THE ASSUMPTION THAT EACH ADJACENT PANEL CONTAINS THE SAME NUMBER OF BROKEN WIRES AS THE EVALUATED PANEL.

THE DATA NEEDED ARE:

EFFECTIVE DEVELOPMENT LENGTH	L_{eff}	7	PANELS
NOMINAL AREA OF ONE WIRE	a_w	0.0290	SQ IN
MEAN TENSILE STRENGTH OF GROUP 2 WIRES	μ_{s2}	239	KSI
EST NO OF WIRES BROKEN IN THE EVALUATED PANEL	N_{b1}	18	WIRES

NOTE THAT N_{b1} IS THE NUMBER OF WIRES BROKEN IN THE EVALUATED (I.E., INSPECTED) PANEL, AND IS NOT REDUCED BY THE NUMBER OF WIRES THAT ARE REPAIRED.

THE FORCE IN THE EVALUATED PANEL ATTRIBUTABLE TO WIRES THAT ARE BROKEN IN OTHER PANELS IS CALCULATED BY EQUATION 5.3.4-3.

$$R_b = a_w * (0.95 * \mu_{s2}) * n_{b1} * 0.5*(L_e-1) = 0.029 * (0.95 * 239) * 18 * 0.5*(7-1) \qquad R_b = 355 \text{ KIPS}$$

EXAMPLE CALCULATION NO 2	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

STEP BS-4A

COMPOUND CUMULATIVE DISTRIBUTION OF TENSILE STRENGTH

THE CABLE DATA NEEDED TO DEVELOP THE COMPOUND CUMULATIVE DISTRIBUTION OF THE TENSILE STRENGTH ARE THE FRACTION OF UNBROKEN WIRES IN THE CABLE REPRESENTED BY EACH GROUP OF WIRES AND THE WEIBULL PARAMETERS FOR EACH GROUP. THESE ARE:

wire group	k	2	3	4	5
fraction of cable	p_k	0.230	0.393	0.002	0.375
Weibull parameters	m	70.6	52.4	33.4	9.1
	υ	240.9	238.4	235.0	211.6

THE VALUE OF THE CUMULATIVE WEIBULL DISTRIBUTION FOR TENSILE STRENGTH AT A SPECIFIC STRESS, s, IS GIVEN BY EQUATION 5.3.3.2.1-1. THIS EQUATION REQUIRES THE SUMMING UP OF THE WEIBULL DISTRIBUTIONS FOR EACH GROUP OF WIRES MULTIPLIED BY THE FRACTION OF THE UNBROKEN WIRES IN THE CABLE REPRESENTED BY EACH GROUP. IN THE FOLLOWING CALCULATION, THE VALUE OF THE WEIBULL DISTRIBUTION FOR THE INDIVIDUAL GROUPS IS CALCULATED, THEN SUMMED. THE EXAMPLE CALCULATION IS MADE FOR s = **220** **KSI.**

$F_c(s) = \Sigma\, p_k * F3_k(s)$ EQUATION 5.3.3.2.1-1

CUMULATIVE WEIBULL DISTRIBUTIONS FOR TENSILE STRENGTH (EQUATION A.4.2-1):

$F3_k(s) = 1 - e\hat{}(-(s/\upsilon)\hat{}m) = 1 - e\hat{}(-(220/240.9)\hat{}70.6)$

$F3_2(220) =$ 0.0016
$F3_3(220) =$ 0.0147
$F3_4(220) =$ 0.1054
$F3_5(220) =$ 0.7599

CUMULATIVE DISTRIBUTIONS MULTIPLIED BY FRACTION REPRESENTED BY EACH GROUP:

$p_k * F3_k(s) = 0.230 * 0.0016$

$p_2{*}F3_2(220) =$ 0.0004
$p_3{*}F3_3(220) =$ 0.0058
$p_4{*}F3_4(220) =$ 0.0002
$p_5{*}F3_5(220) =$ 0.2847

$F_c(s) = \Sigma p_k * F3_k(s)$ $F_c(200) =$ 0.2910

EXAMPLE CALCULATION NO 2	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

STEP BS-4B

CALCULATION OF CABLE FORCE AT STRESS, s

THE DEVELOPMENT OF THE VALUE OF THE CUMULATIVE COMPOUND DISTRIBUTION AT A STRESS OF 220 KSI IS SUMMARIZED BELOW. THIS VALUE IS THEN USED TO CALCULATE THE CABLE TENSION AT A STRESS LEVEL OF 220 KSI. THE REDEVELOPED FORCE IN THE CRACKED WIRES THAT ARE BROKEN AT THIS STRESS AND THE REDEVELOPED FORCE IN THE WIRES FOUND BROKEN IN THE CABLE ARE THEN ADDED TO FIND THE TOTAL FORCE IN THE CABLE WHEN THE STRESS IN THE EVALUATED PANEL IS 220 KSI.

STRESS **$s =$ 220 KSI**

$p_2 * F3_2(s) =$ 0.0004
$p_3 * F3_3(s) =$ 0.0058
$p_4 * F3_4(s) =$ 0.0002
$p_5 * F3_5(s) =$ 0.2847

CUMULATIVE DISTRIBUTION OF TENSILE STRENGTH **$F_c(s) =$ 0.2910**

THE FORCE IN THE UNBROKEN WIRES AT STRESS s IS CALCULATED USING EQUATION 5.3.3.2.2-1:

NEEDED DATA: NUMBER OF UNBROKEN WIRES IN CABLE $N_{eff} =$ 9870 WIRES
NET STEEL AREA OF ONE WIRE $a_w =$ 0.0290 SQ IN

$T_u = N_{eff} * a_w * (s * (1 - F_c(s)) = 9870 * .0290 * 220 * (1 - .2910)$ **$T_u =$ 44571 KIPS**

THE FORCE THAT IS REDEVELOPED IN GROUP 5 (CRACKED) WIRES THAT ARE BROKEN AT STRESS s IS CALCULATED USING EQUATION 5.3.3.2.3-1.

EFFECTIVE NUMBER OF REDEVELOPED CRACKED WIRES IN ADJACENT PANELS WHEN ALL CRACKED WIRES BREAK $N_{cr} =$ 994 WIRES (p EX2-03)
MEAN TENSILE STRENGTH OF GROUP 2 WIRES $\mu_{s2} =$ 239 KSI
FRACTION OF STAGE 5 WIRES BROKEN AT STRESS s $F3_5(s)$ 0.7599 p EX2-07

$T_{cr}(s) = N_{cr} * a_w * (0.95 * \mu_{s2}) * F3_5(s)$
$= 994 * .0290 * 0.95 * 239 * 0.7599$ **$T_{cr}(s) =$ 4965 KIPS**

THE FORCE THAT CAN BE DEVELOPED IN THE EVALUATED PANEL THROUGH FRICTION AT CABLE BANDS IN THE WIRES THAT ARE FOUND BROKEN WITHIN THE EFFECTIVE DEVELOPMENT LENGTH IS GIVEN BY EQUATION 5.3.4-3 ON PAGE EX2-06

CAPACITY IN EVALUATED PANEL OF WIRES FOUND BROKEN **$R_b =$ 355 KIPS**

AT STRESSES LESS THAN ABOUT 75% OF THE MEAN TENSILE STRENGTH OF GROUP 2 WIRES, THE FORCE IN BROKEN WIRES AND IN BROKEN CRACKED WIRES MAY BE OVERSTATED, BUT THIS WILL NOT AFFECT THE CABLE STRENGTH, WHICH IS USUALLY DETERMINED AT A GREATER STRESS . THE TOTAL FORCE IN THE CABLE IN THE EVALUATED PANEL AT STRESS s IS:

TOTAL FORCE IN CABLE AT STRESS $s = T = T_u + T_{cr}(s) + R_b$ **$T =$ 49,891 KIPS**

EXAMPLE CALCULATION NO 2	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

STEP BS-5

CALCULATION OF CABLE STRENGTH

THE DEVELOPMENT OF THE FORCE, T, IN THE CABLE AT STRESS s IS ILLUSTRATED ON THE PREVIOUS PAGE, AND IS SUMMARIZED BELOW. THE CABLE STRENGTH IS FOUND BY VARYING THE STRESS s TO MAXIMIZE T USING "SOLVER" IN EXCEL. A VALUE OF s IS ASSUMED; THE VALUE OF s CORRESPONDING TO THE CABLE STRENGTH REPLACES THIS ASSUMED VALUE DURING ITERATION. THE CALCULATED FORCES, Tu AND Tcr, ON THIS PAGE ARE THE FORCES AFTER MAXIMIZING T.

STRESS $s =$ 202.2 KSI

$F3_2(s) =$ 0.00000 $p_2 * F3_2(s) =$ 0.00000
$F3_3(s) =$ 0.00018 $p_3 * F3_3(s) =$ 0.00007
$F3_4(s) =$ 0.00666 $p_4 * F3_4(s) =$ 0.00001
$F3_5(s) =$ 0.48364 $p_5 * F3_5(s) =$ 0.18120

CUMULATIVE DISTRIBUTION OF TENSILE STRENGTH $F_c(s) =$ 0.18129

EQUATION 5.3.3.2.2-1 GIVES THE CABLE FORCE IN THE UNBROKEN WIRES IN THE CABLE AT THE STRESS, s

$T_u = N_{eff} * a_w * (s * (1 - F_c(s)) = 9870 * .0290 * s * (1 - F_c(s))$ $T_u =$ 47309 KIPS

THE FORCE THAT IS REDEVELOPED IN GROUP 5 (CRACKED) WIRES THAT ARE BROKEN AT STRESS s IS CALCULATED USING EQUATION 5.3.3.2.3-1.

$T_{cr}(s) = N_{cr} * a_w * (0.95 * \mu_{s2}) * F3_5(s)$
$= 994 * .0290 * 0.95 * 239 * F3_5(s)$ $T_{cr}(s) =$ 3160 KIPS

THE FORCE THAT CAN BE DEVELOPED IN THE EVALUATED PANEL THROUGH FRICTION AT CABLE BANDS IN THE WIRES THAT ARE FOUND BROKEN WITHIN THE EFFECTIVE DEVELOPMENT LENGTH IS GIVEN BY EQUATION 5.3.4-3 (FROM PG EX2-06)

CAPACITY IN EVALUATED PANEL OF WIRES FOUND BROKEN $R_b =$ 355 KIPS

AT STRESSES LESS THAN ABOUT 75% OF THE MEAN TENSILE STRENGTH OF GROUP 2 WIRES, THE FORCE IN BROKEN WIRES AND IN BROKEN CRACKED WIRES MAY BE OVERSTATED, BUT THIS WILL NOT AFFECT THE CABLE STRENGTH, WHICH IS USUALLY DETERMINED AT A STRESS GREATER THAN THIS. THE TOTAL FORCE IN THE CABLE IN THE EVALUATED PANEL AT A STRESS s IS THE SUM OF T_u, $T_{cr}(s)$ AND R_b.

THE CABLE STRENGTH IS FOUND BY VARYING THE STRESS s TO MAXIMIZE THE TOTAL CABLE FORCE USING "SOLVER" IN THE EXCEL SPREADSHEET PROGRAM:

CABLE STRENGTH IS MAXIMUM FORCE ACHIEVED
$R = MAX\ T = MAX(T_u + T_{cr}(s) + R_b)$ $R =$ 50,824 KIPS

EXAMPLE CALCULATION NO 2A
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

EXAMPLE CALCULATION NO 2A
BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
(CONDENSED FORMAT)

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GRAPHS:

EXAMPLE CALCULATION NO 2A		**BRITTLE-WIRE MODEL, ONE PANEL INSPECTED**
PROJECT:		**STEPS D-4, D-5, D6, BS-1 AND BS-2**
CENTENNIAL BRIDGE		**CONDENSED FORMAT - SUMMARY OF CORROSION STAGES AND CABLE STRENGTH**
CABLE	**SOUTH**	
SPAN	**EAST MAIN SPAN**	
PANEL	**77-78**	

CABLE STRENGTH =	50,824	kips
@ STRESS =	202	ksi
WIRES REMAIN = 0.8187 x 9870 =	8,081	wires

NO OF WIRES PER STRAND =	270
NO OF STRANDS IN CABLE =	37
TOTAL NO OF WIRES IN CABLE =	9990
NET WIRE DIAMETER (INCHES) =	0.192
AREA OF ONE WIRE SQ IN) =	0.0290

NOTE: SHADED AREAS REQUIRE INPUT FOR EACH PANEL

NO OF BROKEN WIRES IN EFFECTIVE DEVELOPMENT LENGTH & EFFECTIVE NO OF UNBROKEN WIRES IN PANEL

effective development length = 7 panels

panel number p		number of wires observed broken: total	number of wires observed broken: outer layer n_{t1}	depth at which no broken wires are found d_0	estimat'd number broken n_{ti}	number repaired n_{ri}	0.5*(L_e-1)
7					18		
5					18		
3					18		
1	inspected panel	8	5	7	18	6	3
2					18		
4					18		
6					18		
			totals	N_b =	126	6	

NO OF BROKEN WIRES IN EFFECTIVE DEVELOPMENT LENGTH = N_b-N_r = 120

NO OF UNBROKEN WIRES = N - N_b + N_r = N_{eff} = 9870

EFFECTIVE NUMBER OF BROKEN WIRES THAT ARE REDEVELOPED = $n_{t,1}$* 0.5*(L_e-1) = 54

FRACTION OF CABLE IN EACH CORROSION STAGE

	source >	p EX1-12	above	calc	calc	p EX1-11	Fig 5.3.2.4.2-1	calc
corrosion stage k		number of wires in each stage N_{sk}	net number of broken wires N_b-N_r	number of unbroken wires N_{0k}	fraction unbroken in each stage p_{0k}	fraction of each stage cracked p_{ck}	fraction of cracked wires that are redeveloped $N_{cr\,k}/N_{0k}$	number of cracked wires that are redeveloped $(N_{cr\,k}/N_{0k})*N_{0k}$
1		0		0	0.000	0.00	0.00	0
2		2274		2274	0.230	0.00	0.00	0
3		5541		5541	0.561	0.05	0.12	665
4		2175	120	2055	0.208	0.50	0.16	329
total	N =	9990	120	9870	1.000	eff no redev cracked, N_{cr} =		994

FRACTION OF CABLE REPRESENTED BY EACH GROUP OF WIRES

	source >	above	Fig 5.3.2.4.1-1	calc	calc	calc	calc
wire group k		number of unbroken wires N_{0k}	fraction of discrete cracked wires N_{ck}/N_{0k}	cracked wires in eff dev length N_{ck}	number of wires in each group N_k	fraction of cable in each group p_k	fraction of Group 5 that are redeveloped N_{cr}/N_5
2	stages 1 + 2 not cracked	2274	0.00	0	2274	0.230	
3	stage 3 not cracked	5541	0.30	1663	3878	0.393	
4	stage 4 not cracked	2055	0.99	2035	20	0.002	
5	cracked wires, all stages				3698	0.375	0.269
totals		9870		3698	9870	1.000	

WIRE STRENGTH DISTRIBUTION FOR EACH GROUP OF WIRES

		source	wire group: new	good	fair	poor	cracked
k = corrosion stage of group			0	2	3	4	5
mean tensile strength, μ_s	ksi	p EX1-11		239.0	235.9	231.1	200.5
standard deviation, σ_s	ksi	p EX1-11		4.3	5.7	8.7	26.3
ALPHA (shape parameter) = m		calc		70.6	52.4	33.4	9.1
BETA (υ)		calc		240.9	238.4	235.0	211.6
x_0	ksi	assumed		0.0	0.0	0.0	0.0

CALCULATION OF WEIBULL PARAMETERS

			wire group					Excel
k = corrosion stage of group			0	2	3	4	5	parameter
	m (assumed, then determined by solver)		This column may be used to develop the Weibull parameters for new wire if desired	70.6	52.4	33.4	9.1	alpha
(Γ = GAMMA function)	$\Gamma(1+2/m)$			0.9844	0.9793	0.9688	0.9133	
	$\Gamma(1+1/m)$			0.9920	0.9893	0.9836	0.9475	
	$\Gamma(1+2/m)/\Gamma^2(1+1/m)$			1.0003	1.0006	1.0014	1.0172	
	σ^2			18.490	32.490	75.690	691.690	
SOLVE FOR m USING SOLVER BY	μ^2			57121	55649	53407	40200	
VARYING m TO MAKE THIS EQUATION	σ^2/μ^2			0.000324	0.000584	0.001417	0.017206	
EQUAL TO ZERO >>>	$\Gamma(1+2/m)/\Gamma^2(1+1/m) - 1 - \sigma^2/\mu^2 = 0$			-4.72E-10	-8.10E-10	-4.90E-10	2.60E-10	
CALCULATE υ:	$\upsilon = \mu/\Gamma(1+1/m)$			240.9	238.4	235.0	211.6	beta

EXAMPLE CALCULATION NO 2A	BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
PROJECT:	STEPS BS-3 TO BS-5
CENTENNIAL BRIDGE	CONDENSED FORMAT - STRENGTH CALCULATION (SHORT FORMAT)

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

CABLE STRENGTH = 50,824 kips
STRESS AT FAILURE = 202 ksi

number of unbroken wires in thecable	N_{eff} =	9870	wires
net steel area of one wire	a_w =	0.0290	sq in
effective number of broken wires that are redeveloped	$n_{b1}*C_{deff}$ =	54	
mean tensile strength of Group 2 wires	μ_{s2} =	239	ksi
fraction of Group 5 wires that are redeveloped	N_{cr}/N_5 =	0.269	

wire group	k	2	3	4	5
fraction of cable	p_k	0.230	0.393	0.002	0.375
weibull parameters: alpha	m	70.6	52.4	33.4	9.1
beta	υ	240.9	238.4	235.0	211.6

	wire group					
STRESS		s =	220		202.2	ksi
fraction of cable represented by each group multiplied by	2	$p_2*F3_2(s)$ =	0.0004		0.0000	
cumulative distribution of tensile strength for each group	3	$p_3*F3_3(s)$ =	0.0058		0.0001	
of wires = $p_k * F3_k(s) = p_k * (1 - EXP(- ((s/υ)^m)))$	4	$p_4*F3_4(s)$ =	0.0002		0.0000	
or, in Excel, = p_k * WEIBULL(s, alpha, beta, true)	5	$p_5*F3_5(s)$ =	0.2847		0.1812	
total = compound cumulative distribution = $F_c(s) = \Sigma p_k * F3_k(s)$		$F_c(s)$ =	0.2910	$F_c(s)$ =	0.1813	
FORCE IN UNBROKEN WIRES IN CABLE = $N_{eff} * a_w * (s * (1 - F_c(s))$		T_u =	**44571**	R_u =	**47309**	**kips**
fraction of cracked wires that are broken at stress s		$F3_5(s)$ =	0.7599	$F3_5(s)$ =	0.4836	
fraction of group 5 wires redeveloped at stress s = $F3_5(s)*N_{cr}/N_5$		$p_{cr}(s)$ =	0.204	$p_{cr}(s)$ =	0.130	
FORCE REDEV IN CRKD WIRES BROKEN AT STRESS s = $N_{eff}*a_w*p_5*p_{cr}(s)*(0.95*\mu_{s2})$		$T_{cr}(s)$ =	**4965**	$R_{cr}(s)$ =	**3160**	**kips**
CAPACITY IN EVAL PNL OF WIRES FOUND BROKEN = $N_{eff}*a_w*n_{b1}*0.5*(L_e-1)*(0,95*\mu_{s2})$		R_b =	**355**	R_b =	**355**	**kips**
FORCE IN CABLE		T =	**49891 kips**			
CABLE STRENGTH = MAXIMUM FORCE				R =	**50824**	**kips**

(cable strength is found by maximizing T by varying s, using Solver in the Excel spreadsheet program)

EXAMPLE CALCULATION NO 2A	
PROJECT:	
CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

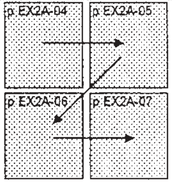
BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

STEPS BS-3 TO BS-5

CONDENSED FORMAT

STRENGTH CALCULATION (LONG FORMAT)

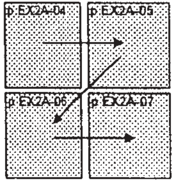
ARRANGEMENT OF PAGES >



BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER
120 BROKEN WIRES (N_b), **54** REDEVELOPED BROKEN WIRES ($n_{b1}*0.5*(L_e-1)$)
9990 TOTAL WIRES IN CABLE (N) AND **3698** DISCRETE CRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

	EVALUATED PANEL						**EVALUATED PANEL & ADJ PNLS**		
	Group 2 (Stages 1 & 2 without cracks)		**Group 3 (Stage 3 without cracks)**		**Group 4 (Stage 4 without cracks)**		**Group 5 (cracked wires, all stages)**		
p_k =	**0.2304**		**0.3929**		**0.0020**		**0.3747**		
mean =	239		235.9		231.1		200.5		
std dev =	4.3		5.7		8.7		26.3		
distr type=	WEIBULL		WEIBULL		WEIBULL		WEIBULL		fraction of
	alpha =	70.6	alpha =	52.4	alpha =	33.4	alpha =	9.1	failed redev
	beta =	240.9	beta =	238.4	beta =	235.0	beta =	211.6	N_{cr}/N_5 =
	x_0 =	0.0	x_0 =	0.0	x_0 =	0.0	x_0 =	0.0	0.269
	good		fair		poor		crkd		crkd redev
stress (s)	$p_2*f3_2(s)$	$p_2*(1-F3_2(s))$	$p_3*f3_3(s)$	$p_3*(1-F3_3(s))$	$p_4*f3_4(s)$	$p_4*(1-F3_4(s))$	$p_5*f3_5(s)$	$p_5*(1-F3_5(s))$	$p_5*p_{cr}(s)$
	eq A.4.2-2	see eq A.4.2-1	eq A.4.2-2	see eq A.4.2-1	eq A.4.2-2	see eq A.4.2-1	eq A.4.2-2	see eq A.4.2-1	p_5*eq B.5-1
(ksi)	fract wires	fraction	fract wires	fraction	fract wires	fraction	fract wires	fraction	=(p_5 -
incr =		of wires		of wires		of wires		of wires	$p_5*(1-F3_5(s))$)
2		remaining		remaining		remaining		remaining	* N_{cr}/N_5
100	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0000	0.3743	0.0001
102	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0000	0.3742	0.0001
104	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3741	0.0002
106	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3740	0.0002
108	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3739	0.0002
110	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3737	0.0003
112	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3735	0.0003
114	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3733	0.0004
116	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3731	0.0004
118	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3729	0.0005
120	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0002	0.3726	0.0006
122	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0002	0.3722	0.0007
124	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0002	0.3718	0.0008
126	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0002	0.3714	0.0009
128	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0003	0.3709	0.0010
130	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0003	0.3703	0.0012
132	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0003	0.3696	0.0014
134	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0004	0.3689	0.0015
136	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0004	0.3681	0.0018
138	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0005	0.3672	0.0020
140	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0006	0.3661	0.0023
142	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0006	0.3650	0.0026
144	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0007	0.3637	0.0030
146	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0008	0.3622	0.0034
148	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0009	0.3606	0.0038
150	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0009	0.3588	0.0043
152	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0010	0.3568	0.0048
154	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0012	0.3546	0.0054
156	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0013	0.3522	0.0061
158	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0014	0.3495	0.0068
160	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0015	0.3465	0.0076
162	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0017	0.3433	0.0084
164	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0018	0.3398	0.0094
166	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0020	0.3359	0.0104
168	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0022	0.3317	0.0116
170	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0024	0.3271	0.0128
172	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0026	0.3222	0.0141
174	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0028	0.3168	0.0156
176	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0030	0.3110	0.0171
178	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0032	0.3048	0.0188
180	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0035	0.2981	0.0206
182	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0037	0.2909	0.0225
184	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0039	0.2833	0.0246
186	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0042	0.2752	0.0267

EXAMPLE CALCULATION NO 2A		**BRITTLE-WIRE MODEL, ONE PANEL INSPECTED**
PROJECT:		**STEPS BS-3 TO BS-5**
CENTENNIAL BRIDGE		**CONDENSED FORMAT**
CABLE	**SOUTH**	**STRENGTH CALCULATION (LONG FORMAT)**
SPAN	**EAST MAIN SPAN**	**Cable strength = 50,824 kips**
PANEL	**77-78**	**Stress at failure = 202.2 ksi**



BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER ARRANGEMENT OF PAGES >
120 BROKEN WIRES (N_b), **54** REDEVELOPED BROKEN WIRES (n_{b1}*0.5*(L_e-1))
9990 TOTAL WIRES IN CABLE (N) AND **3698** DISCRETECRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

EVALUATED PANEL & ADJACENT PANELS

all wires

stress x remaining area

cable force

FORCE-STRAIN

data for force vs. strain diagram

p_k = **1.000**
mean =
std dev =
distr type= COMPOUND
compound distr curve

	panel 1	adj panels	
# crkd incl adj pnls, N_c		3698	strength of
# unbroken wires, N_{eff}	9870		redeveloped broken
area, one wire, a_w	0.0290	0.0290	wires (eq 5.3.4-3)
total area = N_{eff}*a_w	285.7653	107.0679	$R_b = n_{b1}*0.5*(Le-1)*a_w*s_2$
0.95*mean tens strgth Stage 2 = s_2 =		227.1	355 kips

stress (s) (ksi) incr = 2	all $f_c(s)$ =Σp_k*f3$_k$(s) k=2 to 5	1-$F_c(s)$ see eq A.5.2-2 =Σp_k*(1-F3$_k$(s)) k=2 to 5 =fract wires remaining	compound distr curve stress, s_1 =stress * fract wires remaining	$T_u(s)$ eq 5.3.3.2.2-1 =s_1*N_{eff}*a_w =cbl frce	$T_{cr}(s)$ eq B.5-2 = p_5*$p_{cr}(s)$ *s_2*N_{eff}*a_w	total force = $T_u(s)$ + $T_{cr}(s)$ + R_b	stress (s)	strain	force in cable
			0.0	0	0	0	0	0.0000	0
100	0.0000	0.9996	100.0	28565	7	28927	100	0.0035	28,927
102	0.0000	0.9995	102.0	29134	8	29497	102	0.0035	29,497
104	0.0001	0.9994	103.9	29703	10	30068	104	0.0036	30,068
106	0.0001	0.9993	105.9	30270	12	30637	106	0.0037	30,637
108	0.0001	0.9992	107.9	30838	14	31207	108	0.0037	31,207
110	0.0001	0.9990	109.9	31404	17	31776	110	0.0038	31,776
112	0.0001	0.9989	111.9	31970	20	32344	112	0.0039	32,344
114	0.0001	0.9987	113.8	32534	23	32912	114	0.0040	32,912
116	0.0001	0.9984	115.8	33097	27	33479	116	0.0040	33,479
118	0.0001	0.9982	117.8	33659	32	34046	118	0.0041	34,046
120	0.0002	0.9979	119.7	34219	37	34611	120	0.0042	34,611
122	0.0002	0.9975	121.7	34778	43	35176	122	0.0042	35,176
124	0.0002	0.9972	123.6	35334	50	35739	124	0.0043	35,739
126	0.0002	0.9967	125.6	35888	57	36300	126	0.0044	36,300
128	0.0003	0.9962	127.5	36439	66	36860	128	0.0044	36,860
130	0.0003	0.9956	129.4	36987	76	37418	130	0.0045	37,418
132	0.0003	0.9950	131.3	37532	88	37974	132	0.0046	37,974
134	0.0004	0.9942	133.2	38072	100	38528	134	0.0046	38,528
136	0.0004	0.9934	135.1	38608	115	39078	136	0.0047	39,078
138	0.0005	0.9925	137.0	39139	131	39625	138	0.0048	39,625
140	0.0006	0.9914	138.8	39665	149	40169	140	0.0049	40,169
142	0.0006	0.9903	140.6	40184	169	40709	142	0.0049	40,709
144	0.0007	0.9890	142.4	40697	192	41244	144	0.0050	41,244
146	0.0008	0.9875	144.2	41201	218	41774	146	0.0051	41,774
148	0.0009	0.9859	145.9	41697	246	42298	148	0.0052	42,298
150	0.0009	0.9841	147.6	42184	277	42816	150	0.0052	42,816
152	0.0010	0.9821	149.3	42660	312	43327	152	0.0053	43,327
154	0.0012	0.9799	150.9	43124	350	43829	154	0.0054	43,829
156	0.0013	0.9775	152.5	43576	393	44323	156	0.0055	44,323
158	0.0014	0.9748	154.0	44013	439	44808	158	0.0056	44,808
160	0.0015	0.9719	155.5	44436	491	45282	160	0.0057	45,282
162	0.0017	0.9686	156.9	44842	547	45744	162	0.0057	45,744
164	0.0018	0.9651	158.3	45230	609	46193	164	0.0058	46,193
166	0.0020	0.9612	159.6	45598	676	46629	166	0.0059	46,629
168	0.0022	0.9570	160.8	45945	750	47050	168	0.0060	47,050
170	0.0024	0.9524	161.9	46270	829	47454	170	0.0061	47,454
172	0.0026	0.9475	163.0	46570	916	47841	172	0.0062	47,841
174	0.0028	0.9421	163.9	46845	1009	48209	174	0.0063	48,209
176	0.0030	0.9363	164.8	47092	1110	48558	176	0.0064	48,558
178	0.0032	0.9301	165.6	47311	1219	48885	178	0.0065	48,885
180	0.0035	0.9234	166.2	47499	1336	49189	180	0.0067	49,189
182	0.0037	0.9163	166.8	47655	1460	49470	182	0.0068	49,470
184	0.0039	0.9087	167.2	47778	1593	49726	184	0.0069	49,726
186	0.0042	0.9006	167.5	47868	1734	49957	186	0.0070	49,957

CALCULATION PAGE EX2A-06

EXAMPLE CALCULATION NO 2A		
PROJECT:		
CENTENNIAL BRIDGE		
	CABLE	**SOUTH**
	SPAN	**EAST MAIN SPAN**
	PANEL	**77-78**

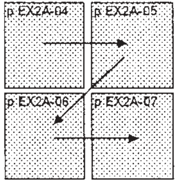
BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

STEPS BS-3 TO BS-5

CONDENSED FORMAT

STRENGTH CALCULATION (LONG FORMAT)

ARRANGEMENT OF PAGES >



BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER

120 BROKEN WIRES (N_b), **54** REDEVELOPED BROKEN WIRES (n_{b1}*0.5*(L_e-1))

9990 TOTAL WIRES IN CABLE (N) AND **3698** DISCRETE CRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

	EVALUATED PANEL						**EVALUATED PANEL & ADJ PNLS**		
	Group 2 (Stages 1 & 2 without cracks)		**Group 3 (Stage 3 without cracks)**		**Group 4 (Stage 4 without cracks)**		**Group 5 (cracked wires, all stages)**		
188	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0044	0.2667	0.0290
190	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0046	0.2576	0.0315
192	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0049	0.2482	0.0340
194	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0051	0.2382	0.0367
196	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0053	0.2279	0.0395
198	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0055	0.2171	0.0423
200	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0056	0.2061	0.0453
202	0.0000	0.2304	0.0000	0.3928	0.0000	0.0020	0.0058	0.1947	0.0484
204	0.0000	0.2304	0.0000	0.3928	0.0000	0.0020	0.0059	0.1830	0.0515
206	0.0000	0.2304	0.0000	0.3927	0.0000	0.0020	0.0059	0.1712	0.0547
208	0.0000	0.2304	0.0001	0.3926	0.0000	0.0020	0.0060	0.1593	0.0579
210	0.0000	0.2304	0.0001	0.3924	0.0000	0.0020	0.0060	0.1474	0.0611
212	0.0000	0.2304	0.0002	0.3921	0.0000	0.0020	0.0059	0.1355	0.0643
214	0.0000	0.2303	0.0003	0.3915	0.0000	0.0019	0.0058	0.1237	0.0675
216	0.0000	0.2303	0.0005	0.3907	0.0000	0.0019	0.0057	0.1121	0.0706
218	0.0001	0.2302	0.0009	0.3893	0.0000	0.0019	0.0055	0.1008	0.0736
220	0.0001	0.2300	0.0014	0.3871	0.0000	0.0018	0.0053	0.0900	0.0765
222	0.0002	0.2297	0.0021	0.3837	0.0000	0.0017	0.0051	0.0796	0.0793
224	0.0004	0.2290	0.0034	0.3783	0.0001	0.0017	0.0048	0.0697	0.0820
226	0.0008	0.2279	0.0052	0.3699	0.0001	0.0015	0.0045	0.0605	0.0844
228	0.0014	0.2257	0.0079	0.3570	0.0001	0.0014	0.0041	0.0519	0.0867
230	0.0026	0.2218	0.0116	0.3377	0.0001	0.0012	0.0037	0.0441	0.0889
232	0.0046	0.2149	0.0166	0.3096	0.0001	0.0011	0.0034	0.0370	0.0908
234	0.0078	0.2028	0.0226	0.2705	0.0001	0.0008	0.0030	0.0306	0.0925
236	0.0127	0.1825	0.0284	0.2193	0.0001	0.0006	0.0026	0.0250	0.0940
238	0.0189	0.1510	0.0317	0.1586	0.0001	0.0004	0.0023	0.0201	0.0953
240	0.0241	0.1075	0.0295	0.0963	0.0001	0.0003	0.0019	0.0160	0.0964
242	0.0234	0.0586	0.0211	0.0448	0.0001	0.0001	0.0016	0.0125	0.0974
244	0.0141	0.0199	0.0100	0.0139	0.0000	0.0001	0.0013	0.0096	0.0981
246	0.0037	0.0030	0.0026	0.0023	0.0000	0.0000	0.0011	0.0072	0.0988
248	0.0002	0.0001	0.0003	0.0002	0.0000	0.0000	0.0008	0.0053	0.0993
250	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0038	0.0997
252	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0027	0.1000
254	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0019	0.1002
256	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0013	0.1004
258	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0008	0.1005
260	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0005	0.1006
262	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.1006
264	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.1007
266	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.1007
268	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.1007
270	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
272	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
274	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
276	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
278	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
280	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
tot x incr	0.23040		0.3929		0.0020		0.3747		

FOR MAXIMUM CABLE FORCE = CABLE STRENGTH, USE SOLVER TO MAXIMIZE FIELD X121BY VARYING FIELD B121

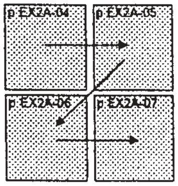
202.2	0.0000	0.2304	0.0000	0.3928	0.0000	0.0020	0.0058	0.1935	0.0487

EXAMPLE CALCULATION NO 2A
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
STEPS BS-3 TO BS-5
CONDENSED FORMAT
STRENGTH CALCULATION (LONG FORMAT)

Cable strength = 50,824 kips
Stress at failure = 202.2 ksi



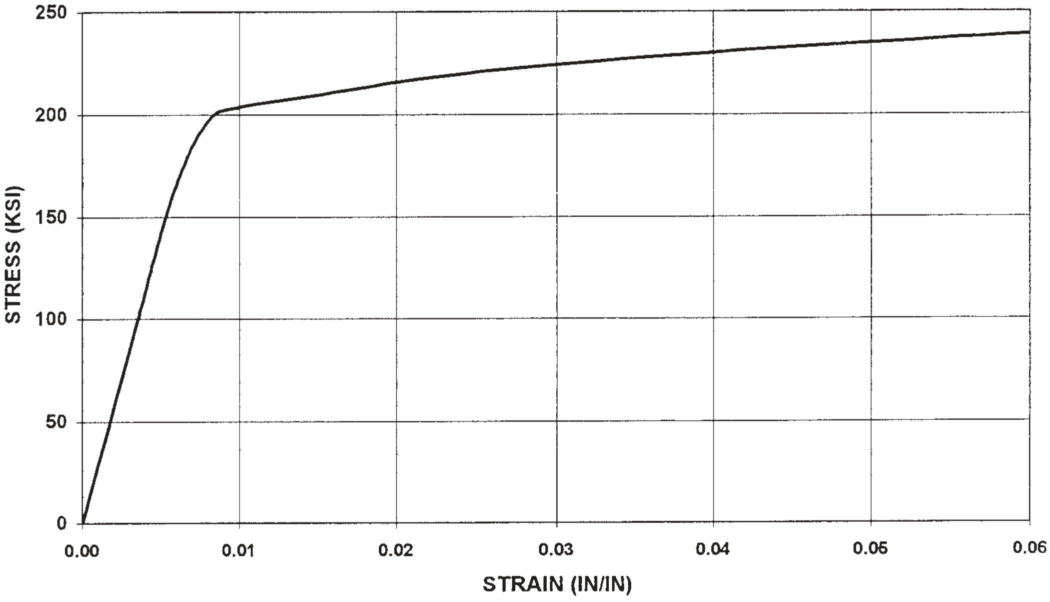
BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER ARRANGEMENT OF PAGES >
120 BROKEN WIRES (N_b), **54** REDEVELOPED BROKEN WIRES ($n_{b1}*0.5*(L_e-1)$)
9990 TOTAL WIRES IN CABLE (N) AND **3698** DISCRETECRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

	EVALUATED PANEL & ADJACENT PANELS							**FORCE-STRAIN**	
	all wires			**stress x remaining area**				**data for force vs. strain diagram**	
					cable force				
188	0.0044	0.8920	167.7	47922	1883	50161	188	0.0072	50,161
190	0.0046	0.8830	167.8	47941	2041	50337	190	0.0073	50,337
192	0.0049	0.8735	167.7	47925	2206	50487	192	0.0075	50,487
194	0.0051	0.8635	167.5	47873	2380	50608	194	0.0077	50,608
196	0.0053	0.8532	167.2	47787	2560	50702	196	0.0079	50,702
198	0.0055	0.8424	166.8	47666	2747	50769	198	0.0081	50,769
200	0.0056	0.8313	166.3	47513	2941	50809	200	0.0084	50,809
202	0.0058	0.8199	165.6	47330	3139	50824	202	0.0088	50,824
204	0.0059	0.8082	164.9	47118	3342	50815	204	0.0100	50,815
206	0.0060	0.7964	164.0	46880	3548	50782	206	0.0117	50,782
208	0.0061	0.7843	163.1	46618	3756	50729	208	0.0134	50,729
210	0.0061	0.7721	162.1	46336	3964	50655	210	0.0151	50,655
212	0.0062	0.7599	161.1	46034	4172	50561	212	0.0168	50,561
214	0.0062	0.7475	160.0	45712	4378	50445	214	0.0185	50,445
216	0.0063	0.7350	158.8	45368	4579	50302	216	0.0202	50,302
218	0.0065	0.7222	157.4	44993	4776	50124	218	0.0220	50,124
220	0.0068	0.7090	156.0	44571	4965	49891	220	0.0242	49,891
222	0.0075	0.6947	154.2	44072	5146	49573	222	0.0267	49,573
224	0.0086	0.6787	152.0	43446	5318	49119	224	0.0295	49,119
226	0.0105	0.6598	149.1	42612	5479	48446	226	0.0325	48,446
228	0.0135	0.6361	145.0	41444	5629	47427	228	0.0359	47,427
230	0.0180	0.6049	139.1	39756	5765	45876	230	0.0396	45,876
232	0.0247	0.5625	130.5	37294	5889	43539	232	0.0436	43,539
234	0.0335	0.5047	118.1	33749	6000	40104	234	0.0479	40,104
236	0.0438	0.4275	100.9	28830	6098	35283	236	0.0525	35,283
238	0.0529	0.3302	78.6	22458	6183	28996	238	0.0574	28,996
240	0.0556	0.2200	52.8	15091	6256	21701	240	0.0626	21,701
242	0.0461	0.1160	28.1	8021	6317	14693	242	0.0682	14,693
244	0.0254	0.0434	10.6	3029	6368	9752	244	0.0740	9,752
246	0.0073	0.0125	3.1	880	6409	7644	246	0.0801	7,644
248	0.0013	0.0056	1.4	395	6442	7192	248	0.0865	7,192
250	0.0007	0.0038	1.0	275	6467	7097	250	0.0932	7,097
252	0.0005	0.0027	0.7	196	6487	7038	252	0.1003	7,038
254	0.0004	0.0019	0.5	137	6501	6993	254	0.1076	6,993
256	0.0003	0.0013	0.3	93	6512	6960	256	0.1152	6,960
258	0.0002	0.0008	0.2	62	6520	6936	258	0.1232	6,936
260	0.0001	0.0005	0.1	40	6525	6920	260	0.1314	6,920
262	0.0001	0.0003	0.1	25	6528	6908	262	0.1400	6,908
264	0.0001	0.0002	0.1	15	6531	6901	264	0.1488	6,901
266	0.0000	0.0001	0.0	9	6532	6896	266	0.1580	6,896
268	0.0000	0.0001	0.0	5	6533	6893	268	0.1674	6,893
270	0.0000	0.0000	0.0	3	6534	6891	270	0.1772	6,891
272	0.0000	0.0000	0.0	1	6534	6890	272	0.1873	6,890
274	0.0000	0.0000	0.0	1	6534	6890	274	0.1976	6,890
276	0.0000	0.0000	0.0	0	6534	6890	276	0.2083	6,890
278	0.0000	0.0000	0.0	0	6534	6889	278	0.2193	6,889
280	0.0000	0.0000	0.0	0	6534	6889	280	0.2305	6,889
	1.0000								
202.2	0.0058	0.8187	165.6	47309	3160	**50824**	202.2		

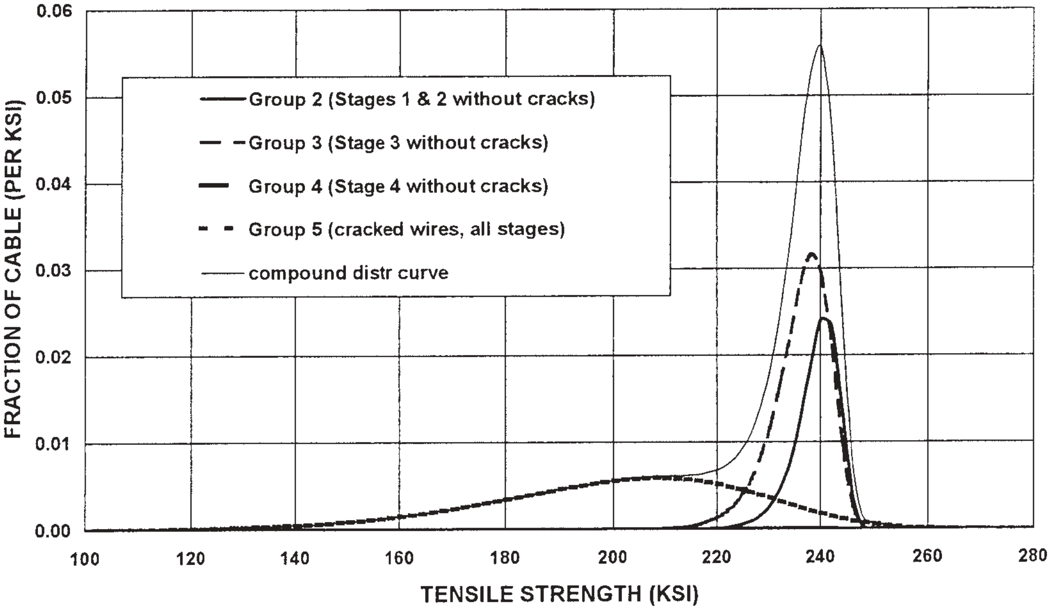
EXAMPLE CALCULATION NO 2A	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
CONDENSED FORMAT
STRENGTH CALCULATION (LONG FORMAT)
GRAPHS: STRESS - STRAIN
TENSILE STRENGTH DISTRIBUTIONS

STRESS - STRAIN CURVE



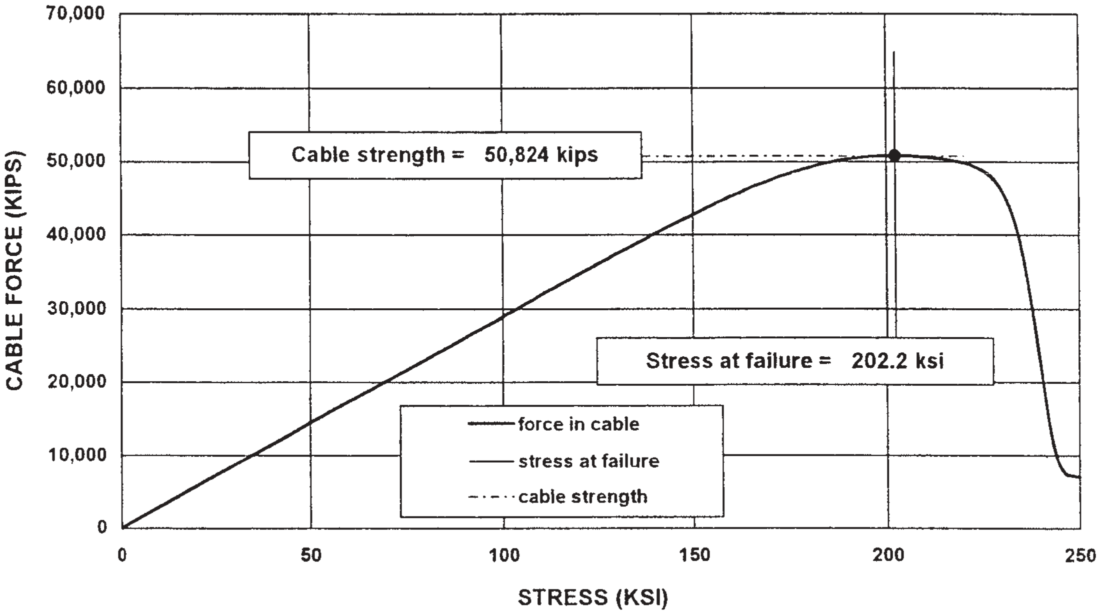
TENSILE STRENGTH DISTRIBUTION CURVES



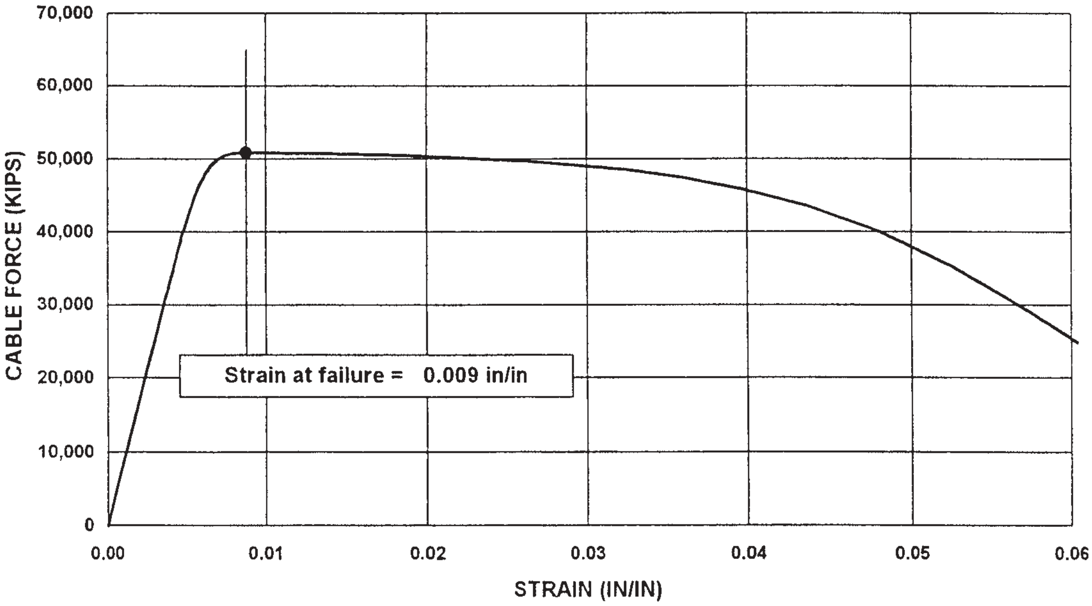
EXAMPLE CALCULATION NO 2A	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
CONDENSED FORMAT
STRENGTH CALCULATION (LONG FORMAT)
GRAPHS: FORCE VS STRESS
FORCE VS STRAIN

FORCE VS STRESS DIAGRAM



FORCE VS STRAIN DIAGRAM

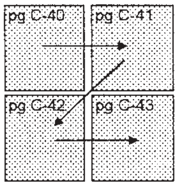


EXAMPLE CALCULATION NO 2A
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
STEPS BS-3 TO BS-5
CONDENSED FORMAT
STRENGTH CALCULATION (LONG FORMAT)

ARRANGEMENT OF PAGES >



BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER
120 BROKEN WIRES (N_b), **54** REDEVELOPED BROKEN WIRES (n_{b1}*0.5*(L_e-1))
9990 TOTAL WIRES IN CABLE (N) AND **3698** DISCRETE CRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

	EVALUATED PANEL						**EVALUATED PANEL & ADJ PNLS**		
	Group 2 (Stages 1 & 2 without cracks)		**Group 3 (Stage 3 without cracks)**		**Group 4 (Stage 4 without cracks)**		**Group 5 (cracked wires, all stages)**		
p_k =	**0.2304**		**0.3929**		**0.0020**		**0.3747**		
mean =	239		235.9		231.1		200.5		
std dev =	4.3		5.7		8.7		26.3		
distr type=	WEIBULL		WEIBULL		WEIBULL		WEIBULL		fraction of
	alpha =	70.6	alpha =	52.4	alpha =	33.4	alpha =	9.1	failed redev
	beta =	240.9	beta =	238.4	beta =	235.0	beta =	211.6	N_{cr}/N_5 =
	x_0 =	0.0	x_0 =	0.0	x_0 =	0.0	x_0 =	0.0	0.269
	good		fair		poor		crkd		crkd redev
stress (s) (ksi) incr = 2	$p_2*f3_2(s)$ eq A.5.2-2 fract wires	$p_2*(1-F3_2(s))$ see eq A.5.2-1 fraction of wires remaining	$p_3*f3_3(s)$ eq A.5.2-2 fract wires	$p_3*(1-F3_3(s))$ see eq A.5.2-1 fraction of wires remaining	$p_4*f3_4(s)$ eq A.5.2-2 fract wires	$p_4*(1-F3_4(s))$ see eq A.5.2-1 fraction of wires remaining	$p_5*f3_5(s)$ eq A.5.2-2 fract wires	$p_5*(1-F3_5(s))$ see eq A.5.2-1 fraction of wires remaining	$p_5*p_{cr}(s)$ p_5*eq B.5-1 $=(p_5 - p_5*(1-F3_5(s)))*N_{cr}/N_5$
100	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0000	0.3743	0.0001
102	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0000	0.3742	0.0001
104	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3741	0.0002
106	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3740	0.0002
108	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3739	0.0002
110	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3737	0.0003
112	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3735	0.0003
114	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3733	0.0004
116	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3731	0.0004
118	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0001	0.3729	0.0005
120	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0002	0.3726	0.0006
122	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0002	0.3722	0.0007
124	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0002	0.3718	0.0008
126	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0002	0.3714	0.0009
128	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0003	0.3709	0.0010
130	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0003	0.3703	0.0012
132	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0003	0.3696	0.0014
134	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0004	0.3689	0.0015
136	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0004	0.3681	0.0018
138	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0005	0.3672	0.0020
140	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0006	0.3661	0.0023
142	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0006	0.3650	0.0026
144	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0007	0.3637	0.0030
146	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0008	0.3622	0.0034
148	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0009	0.3606	0.0038
150	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0009	0.3588	0.0043
152	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0010	0.3568	0.0048
154	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0012	0.3546	0.0054
156	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0013	0.3522	0.0061
158	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0014	0.3495	0.0068
160	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0015	0.3465	0.0076
162	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0017	0.3433	0.0084
164	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0018	0.3398	0.0094
166	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0020	0.3359	0.0104
168	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0022	0.3317	0.0116
170	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0024	0.3271	0.0128
172	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0026	0.3222	0.0141
174	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0028	0.3168	0.0156
176	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0030	0.3110	0.0171
178	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0032	0.3048	0.0188
180	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0035	0.2981	0.0206
182	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0037	0.2909	0.0225
184	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0039	0.2833	0.0246
186	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0042	0.2752	0.0267

EXAMPLE CALCULATION NO 2A	
PROJECT: **CENTENNIAL BRIDGE**	
CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

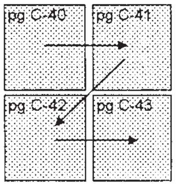
BRITTLE-WIRE MODEL, ONE PANEL INSPECTED

STEPS BS-3 TO BS-5

CONDENSED FORMAT

STRENGTH CALCULATION (LONG FORMAT)

Cable strength = 50,824 kips
Stress at failure = 202.2 ksi



BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER — ARRANGEMENT OF PAGES >
120 BROKEN WIRES (N_b), **54** REDEVELOPED BROKEN WIRES (n_{b1}*0.5*(L_e-1))
9990 TOTAL WIRES IN CABLE (N) AND **3698** DISCRETECRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

EVALUATED PANEL & ADJACENT PANELS

all wires — **stress x remaining area** — **cable force**

FORCE-STRAIN
data for force vs. strain diagram

p_k = **1.000**
mean =
std dev =
distr type= COMPOUND
compound distr curve

	panel 1	adj panels	
# crkd incl adj pnls, N_c		3698	strength of
# unbroken wires, N_{eff}	9870		redeveloped broken
area, one wire, a_w	0.0290	0.0290	wires (eq 5.3.4-3)
total area = N_{eff}*a_w	285.7653	107.0679	R_b = n_{b1}*0.5*(Le-1)*a_w*s_2
0.95*mean tens strgth Stage 2 = s_2 =		227.1	355 kips

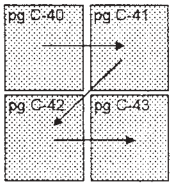
stress (s) (ksi) incr = 2	all $f_c(s)$ =Σp_k*f3$_k$(s) k=2 to 5	1-$F_c(s)$ see eq A.6.2-2 =Σp_k*(1-F3$_k$(s)) k=2 to 5 =fract wires remaining	compound distr curve stress, s_1 =stress * fract wires remaining	$T_u(s)$ eq 5.3.3.2.2-1 =s_1*N_{eff}*a_w =cbl frce	$T_{cr}(s)$ eq B.5-2 = p_5*$p_{cr}(s)$ *s_2*N_{eff}*a_w	total force = $T_u(s)$ + $T_{cr}(s)$ + R_b	stress (s)	strain	force in cable
			0.0	0	0	0	0	0.0000	0
100	0.0000	0.9996	100.0	28565	7	28927	100	0.0035	28,927
102	0.0000	0.9995	102.0	29134	8	29497	102	0.0035	29,497
104	0.0001	0.9994	103.9	29703	10	30068	104	0.0036	30,068
106	0.0001	0.9993	105.9	30270	12	30637	106	0.0037	30,637
108	0.0001	0.9992	107.9	30838	14	31207	108	0.0037	31,207
110	0.0001	0.9990	109.9	31404	17	31776	110	0.0038	31,776
112	0.0001	0.9989	111.9	31970	20	32344	112	0.0039	32,344
114	0.0001	0.9987	113.8	32534	23	32912	114	0.0040	32,912
116	0.0001	0.9984	115.8	33097	27	33479	116	0.0040	33,479
118	0.0001	0.9982	117.8	33659	32	34046	118	0.0041	34,046
120	0.0002	0.9979	119.7	34219	37	34611	120	0.0042	34,611
122	0.0002	0.9975	121.7	34778	43	35176	122	0.0042	35,176
124	0.0002	0.9972	123.6	35334	50	35739	124	0.0043	35,739
126	0.0002	0.9967	125.6	35888	57	36300	126	0.0044	36,300
128	0.0003	0.9962	127.5	36439	66	36860	128	0.0044	36,860
130	0.0003	0.9956	129.4	36987	76	37418	130	0.0045	37,418
132	0.0003	0.9950	131.3	37532	88	37974	132	0.0046	37,974
134	0.0004	0.9942	133.2	38072	100	38528	134	0.0046	38,528
136	0.0004	0.9934	135.1	38608	115	39078	136	0.0047	39,078
138	0.0005	0.9925	137.0	39139	131	39625	138	0.0048	39,625
140	0.0006	0.9914	138.8	39665	149	40169	140	0.0049	40,169
142	0.0006	0.9903	140.6	40184	169	40709	142	0.0049	40,709
144	0.0007	0.9890	142.4	40697	192	41244	144	0.0050	41,244
146	0.0008	0.9875	144.2	41201	218	41774	146	0.0051	41,774
148	0.0009	0.9859	145.9	41697	246	42298	148	0.0052	42,298
150	0.0009	0.9841	147.6	42184	277	42816	150	0.0052	42,816
152	0.0010	0.9821	149.3	42660	312	43327	152	0.0053	43,327
154	0.0012	0.9799	150.9	43124	350	43829	154	0.0054	43,829
156	0.0013	0.9775	152.5	43576	393	44323	156	0.0055	44,323
158	0.0014	0.9748	154.0	44013	439	44808	158	0.0056	44,808
160	0.0015	0.9719	155.5	44436	491	45282	160	0.0057	45,282
162	0.0017	0.9686	156.9	44842	547	45744	162	0.0057	45,744
164	0.0018	0.9651	158.3	45230	609	46193	164	0.0058	46,193
166	0.0020	0.9612	159.6	45598	676	46629	166	0.0059	46,629
168	0.0022	0.9570	160.8	45945	750	47050	168	0.0060	47,050
170	0.0024	0.9524	161.9	46270	829	47454	170	0.0061	47,454
172	0.0026	0.9475	163.0	46570	916	47841	172	0.0062	47,841
174	0.0028	0.9421	163.9	46845	1009	48209	174	0.0063	48,209
176	0.0030	0.9363	164.8	47092	1110	48558	176	0.0064	48,558
178	0.0032	0.9301	165.6	47311	1219	48885	178	0.0065	48,885
180	0.0035	0.9234	166.2	47499	1336	49189	180	0.0067	49,189
182	0.0037	0.9163	166.8	47655	1460	49470	182	0.0068	49,470
184	0.0039	0.9087	167.2	47778	1593	49726	184	0.0069	49,726
186	0.0042	0.9006	167.5	47868	1734	49957	186	0.0070	49,957

EXAMPLE CALCULATION NO 2A
PROJECT:
CENTENNIAL BRIDGE

CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

BRITTLE-WIRE MODEL, ONE PANEL INSPECTED
STEPS BS-3 TO BS-5
CONDENSED FORMAT
STRENGTH CALCULATION (LONG FORMAT)

ARRANGEMENT OF PAGES >



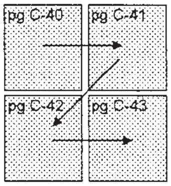
BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER
120 BROKEN WIRES (N_b), **54** REDEVELOPED BROKEN WIRES (n_{b1}*0.5*(L_e-1))
9990 TOTAL WIRES IN CABLE (N) AND **3698** DISCRETE CRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

	EVALUATED PANEL						**EVALUATED PANEL & ADJ PNLS**		
	Group 2 (Stages 1 & 2 without cracks)		**Group 3 (Stage 3 without cracks)**		**Group 4 (Stage 4 without cracks)**		**Group 5 (cracked wires, all stages)**		
188	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0044	0.2667	0.0290
190	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0046	0.2576	0.0315
192	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0049	0.2482	0.0340
194	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0051	0.2382	0.0367
196	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0053	0.2279	0.0395
198	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0055	0.2171	0.0423
200	0.0000	0.2304	0.0000	0.3929	0.0000	0.0020	0.0056	0.2061	0.0453
202	0.0000	0.2304	0.0000	0.3928	0.0000	0.0020	0.0058	0.1947	0.0484
204	0.0000	0.2304	0.0000	0.3928	0.0000	0.0020	0.0059	0.1830	0.0515
206	0.0000	0.2304	0.0000	0.3927	0.0000	0.0020	0.0059	0.1712	0.0547
208	0.0000	0.2304	0.0001	0.3926	0.0000	0.0020	0.0060	0.1593	0.0579
210	0.0000	0.2304	0.0001	0.3924	0.0000	0.0020	0.0060	0.1474	0.0611
212	0.0000	0.2304	0.0002	0.3921	0.0000	0.0020	0.0059	0.1355	0.0643
214	0.0000	0.2303	0.0003	0.3915	0.0000	0.0019	0.0058	0.1237	0.0675
216	0.0000	0.2303	0.0005	0.3907	0.0000	0.0019	0.0057	0.1121	0.0706
218	0.0001	0.2302	0.0009	0.3893	0.0000	0.0019	0.0055	0.1008	0.0736
220	0.0001	0.2300	0.0014	0.3871	0.0000	0.0018	0.0053	0.0900	0.0765
222	0.0002	0.2297	0.0021	0.3837	0.0000	0.0017	0.0051	0.0796	0.0793
224	0.0004	0.2290	0.0034	0.3783	0.0001	0.0017	0.0048	0.0697	0.0820
226	0.0008	0.2279	0.0052	0.3699	0.0001	0.0015	0.0045	0.0605	0.0844
228	0.0014	0.2257	0.0079	0.3570	0.0001	0.0014	0.0041	0.0519	0.0867
230	0.0026	0.2218	0.0116	0.3377	0.0001	0.0012	0.0037	0.0441	0.0889
232	0.0046	0.2149	0.0166	0.3096	0.0001	0.0011	0.0034	0.0370	0.0908
234	0.0078	0.2028	0.0226	0.2705	0.0001	0.0008	0.0030	0.0306	0.0925
236	0.0127	0.1825	0.0284	0.2193	0.0001	0.0006	0.0026	0.0250	0.0940
238	0.0189	0.1510	0.0317	0.1586	0.0001	0.0004	0.0023	0.0201	0.0953
240	0.0241	0.1075	0.0295	0.0963	0.0001	0.0003	0.0019	0.0160	0.0964
242	0.0234	0.0586	0.0211	0.0448	0.0001	0.0001	0.0016	0.0125	0.0974
244	0.0141	0.0199	0.0100	0.0139	0.0000	0.0001	0.0013	0.0096	0.0981
246	0.0037	0.0030	0.0026	0.0023	0.0000	0.0000	0.0011	0.0072	0.0988
248	0.0002	0.0001	0.0003	0.0002	0.0000	0.0000	0.0008	0.0053	0.0993
250	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0038	0.0997
252	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0027	0.1000
254	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0019	0.1002
256	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0013	0.1004
258	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0008	0.1005
260	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0005	0.1006
262	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.1006
264	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.1007
266	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.1007
268	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.1007
270	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
272	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
274	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
276	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
278	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
280	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1007
tot x incr	0.23040		0.3929		0.0020		0.3747		

FOR MAXIMUM CABLE FORCE = CABLE STRENGTH, USE SOLVER TO MAXIMIZE FIELD X121BY VARYING FIELD B121

202.2	0.0000	0.2304	0.0000	0.3928	0.0000	0.0020	0.0058	0.1935	0.0487

EXAMPLE CALCULATION NO 2A	**BRITTLE-WIRE MODEL, ONE PANEL INSPECTED**
PROJECT:	**STEPS BS-3 TO BS-5**
CENTENNIAL BRIDGE	**CONDENSED FORMAT**
CABLE / **SOUTH**	**STRENGTH CALCULATION (LONG FORMAT)**
SPAN / **EAST MAIN SPAN**	**Cable strength = 50,824 kips**
PANEL / **77-78**	**Stress at failure = 202.2 ksi**



BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER ARRANGEMENT OF PAGES >

120 BROKEN WIRES (N_b), **54** REDEVELOPED BROKEN WIRES (n_{b1}*0.5*(L_e-1))

9990 TOTAL WIRES IN CABLE (N) AND **3698** DISCRETECRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

	EVALUATED PANEL & ADJACENT PANELS							**FORCE-STRAIN**	
	all wires			**stress x remaining area**				**data for force vs. strain diagram**	
					cable force				
188	0.0044	0.8920	167.7	47922	1883	50161	188	0.0072	50,161
190	0.0046	0.8830	167.8	47941	2041	50337	190	0.0073	50,337
192	0.0049	0.8735	167.7	47925	2206	50487	192	0.0075	50,487
194	0.0051	0.8635	167.5	47873	2380	50608	194	0.0077	50,608
196	0.0053	0.8532	167.2	47787	2560	50702	196	0.0079	50,702
198	0.0055	0.8424	166.8	47666	2747	50769	198	0.0081	50,769
200	0.0056	0.8313	166.3	47513	2941	50809	200	0.0084	50,809
202	0.0058	0.8199	165.6	47330	3139	50824	202	0.0088	50,824
204	0.0059	0.8082	164.9	47118	3342	50815	204	0.0100	50,815
206	0.0060	0.7964	164.0	46880	3548	50782	206	0.0117	50,782
208	0.0061	0.7843	163.1	46618	3756	50729	208	0.0134	50,729
210	0.0061	0.7721	162.1	46336	3964	50655	210	0.0151	50,655
212	0.0062	0.7599	161.1	46034	4172	50561	212	0.0168	50,561
214	0.0062	0.7475	160.0	45712	4378	50445	214	0.0185	50,445
216	0.0063	0.7350	158.8	45368	4579	50302	216	0.0202	50,302
218	0.0065	0.7222	157.4	44993	4776	50124	218	0.0220	50,124
220	0.0068	0.7090	156.0	44571	4965	49891	220	0.0242	49,891
222	0.0075	0.6947	154.2	44072	5146	49573	222	0.0267	49,573
224	0.0086	0.6787	152.0	43446	5318	49119	224	0.0295	49,119
226	0.0105	0.6598	149.1	42612	5479	48446	226	0.0325	48,446
228	0.0135	0.6361	145.0	41444	5629	47427	228	0.0359	47,427
230	0.0180	0.6049	139.1	39756	5765	45876	230	0.0396	45,876
232	0.0247	0.5625	130.5	37294	5889	43539	232	0.0436	43,539
234	0.0335	0.5047	118.1	33749	6000	40104	234	0.0479	40,104
236	0.0438	0.4275	100.9	28830	6098	35283	236	0.0525	35,283
238	0.0529	0.3302	78.6	22458	6183	28996	238	0.0574	28,996
240	0.0556	0.2200	52.8	15091	6256	21701	240	0.0626	21,701
242	0.0461	0.1160	28.1	8021	6317	14693	242	0.0682	14,693
244	0.0254	0.0434	10.6	3029	6368	9752	244	0.0740	9,752
246	0.0073	0.0125	3.1	880	6409	7644	246	0.0801	7,644
248	0.0013	0.0056	1.4	395	6442	7192	248	0.0865	7,192
250	0.0007	0.0038	1.0	275	6467	7097	250	0.0932	7,097
252	0.0005	0.0027	0.7	196	6487	7038	252	0.1003	7,038
254	0.0004	0.0019	0.5	137	6501	6993	254	0.1076	6,993
256	0.0003	0.0013	0.3	93	6512	6960	256	0.1152	6,960
258	0.0002	0.0008	0.2	62	6520	6936	258	0.1232	6,936
260	0.0001	0.0005	0.1	40	6525	6920	260	0.1314	6,920
262	0.0001	0.0003	0.1	25	6528	6908	262	0.1400	6,908
264	0.0001	0.0002	0.1	15	6531	6901	264	0.1488	6,901
266	0.0000	0.0001	0.0	9	6532	6896	266	0.1580	6,896
268	0.0000	0.0001	0.0	5	6533	6893	268	0.1674	6,893
270	0.0000	0.0000	0.0	3	6534	6891	270	0.1772	6,891
272	0.0000	0.0000	0.0	1	6534	6890	272	0.1873	6,890
274	0.0000	0.0000	0.0	1	6534	6890	274	0.1976	6,890
276	0.0000	0.0000	0.0	0	6534	6890	276	0.2083	6,890
278	0.0000	0.0000	0.0	0	6534	6889	278	0.2193	6,889
280	0.0000	0.0000	0.0	0	6534	6889	280	0.2305	6,889
	1.0000								
202.2	0.0058	0.8187	165.6	47309	3160	**50824**	202.2		

EXAMPLE CALCULATION NO 3	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

CALCULATION PAGE EX3-01

EXAMPLE CALCULATION NO 3

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LENGTH INSPECTED

TABLE OF CONTENTS

CALCULATION PAGE EX3-02

EXAMPLE CALCULATION NO 3	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED

STEP D(adj)-4

DATA FROM INSPECTION - BROKEN WIRES

BASIC CABLE INFORMATION	
NO OF WIRES PER STRAND	270
NO OF STRANDS IN CABLE	37
TOTAL NO OF WIRES IN CABLE	9990
NET WIRE DIAMETER (INCHES)	0.192
AREA OF ONE WIRE (SQ IN)	0.02895

ALL OF THE PANELS IN THE EFFECTIVE DEVELOPMENT LENGTH CENTERED AROUND PANEL 77-78 HAVE BEEN INSPECTED. BROKEN WIRES WERE FOUND ONLY IN THE OUTER LAYERS, WITH NONE FOUND MORE THAN SEVEN LAYERS INTO THE CABLE. THE NUMBER OF BROKEN WIRES OBSERVED, ALONG WITH THE NUMBER OF WIRES REPAIRED, ARE ENTERED INTO THE TABLE BELOW. THE ESTIMATED NUMBER OF BROKEN WIRES IN EACH PANEL IS CALCULATED BY EQUATION 4.3.3.2-1, AND IS ROUNDED TO THE NEXT HIGHER INTEGER, AS THERE CANNOT BE FRACTIONAL BROKEN WIRES. AN EXAMPLE OF THIS CALCULATION IS GIVEN FOR PANEL 1:

e.g., in panel 1, $n_{bi} = n_{b1,i} * d_0 / 2 = 5 * 7 / 2$ (i = 1) **n_{b1} = 18 WIRES**

NUMBER OF BROKEN WIRES IN EFFECTIVE DEVELOPMENT LENGTH

effective development length L_e = 7 panels panel number p		number of wires observed broken total	 outer layer $n_{b1,i}$	depth at which no broken wires are found d_0	estimat'd number broken n_{bi}	number repaired n_{ri}	net number broken n_{bi}-n_{ri}
7		4	4	7	14	3	11
5		15	6	7	21	15	6
3		22	19	7	67	21	46
1	inspected panel	8	5	7	18	6	12
2		20	9	7	32	20	12
4		1	1	7	4	1	3
6		12	8	7	28	12	16
				totals	184	78	106

THE NUMBER OF UNBROKEN WIRES IN EACH STAGE IS CALCULATED BY EQUATIONS 5.3.2.3-1 TO 6, AND THE EFFECTIVE NUMBER OF WIRES IN THE CABLE IS CALCULATED BY EQUATION 5.3.2.5-1. THE LATTER EQUATION CAN BE RESTATED BY ADDING THE NUMBER OF DISCRETE CRACKED WIRES BACK INTO THE INDIVIDUAL TERMS N_K AND OMITTING THE VALUE OF N_5 FROM THE SUMMATION, RESULTING IN:

$$N_{eff}=\sum_{k=2}^{5}N_k = N_5+\sum_{k=2}^{4}\left(N_{0k}-N_{c,k}\right)=\sum_{k=2}^{4}N_{0k} \qquad \text{(Eq. 5.3.2.5-1)}$$

Source>	p EX1-12	above	calc
Corrosion Stage k	No of Wires N_{sk}	No. Broken N_b-N_r	No Unbroken N_{0k}
1	0		
2	2274		2274
3	5541		5541
4	2175	106	2069
N =	9990	**Neff =**	**9884** **WIRES**

EXAMPLE CALCULATION NO 3	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

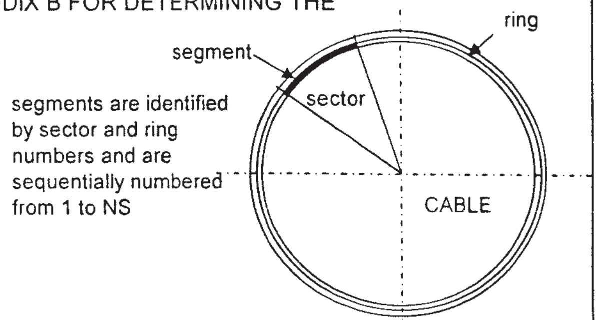
BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED

STEPS D(adj)-5 & 6

EFFECT OF WIRES THAT ARE CRACKED
IN ADJACENT PANELS
APPENDIX B, ARTICLE B.4.1

WHEN ALL THE PANELS IN THE EFFECTIVE DEVELOPMENT LENGTH AROUND THE EVALUATED PANEL HAVE BEEN INSPECTED, THE METHOD GIVEN IN APPENDIX B FOR DETERMINING THE EFFECT OF CRACKED WIRES IN ADJACENT PANELS MAY BE USED. THIS REQUIRES THE USE OF THE VERY LARGE SPREADSHEET THAT IS SHOWN ON PAGES EX3-08 to EX3-23

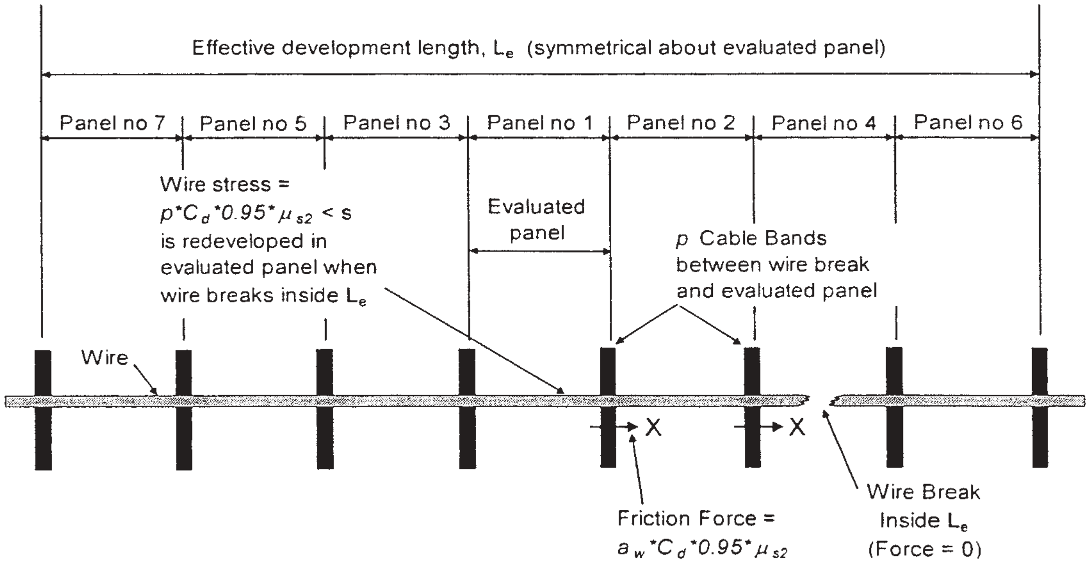
EACH SEGMENT OF THE CABLE CROSS SECTION IS LISTED SEQUENTIALLY ON A SEPARATE ROW ON THIS SPREADSHEET. A SEGMENT IS DEFINED AS THAT PART OF A RING OF CABLE WIRES THAT LIES WITHIN A SECTOR OF THE CABLE.



SEPARATE RANGES OF THE SPREADSHEET, EACH OF WHICH CONTAINS ONE COLUMN FOR EACH CABLE PANEL, ARE USED TO LIST:

RANGE 1	CORROSION STAGE OF WIRES IN EACH PANEL IN EACH SEGMENT	k
RANGE 2	FRACTION OF WIRES CRACKED IN EACH PANEL IN EACH SEGMENT	$p_{c.ij}$
RANGE 3	FRACTION OF WIRES NOT CRACKED	q_{ij}
RANGE 4	FRACT OF DISCRETE CRACKED WIRES THAT ARE NOT CRACKED IN LOWER NUMBERED PANELS	e_{ij}
RANGE 5	FRACT OF WIRES NOT CRACKED THAT ARE ALSO NOT CRACKED IN LOWER NUMBERED PANELS	r_{ij}
RANGE 6	FRACT OF EFFECTIVE CRACKED WIRES THAT WILL BE REDEVELOPED IF THEY BREAK	$n_{r,ij}$

THE CABLE PANELS ARE NUMBERED BEGINNING WITH 1 FOR THE EVALUATED PANEL, AND INCREASING WITH INCREASING DISTANCE FROM THIS PANEL ALTERNATING ON EACH SIDE OF THE EVALUATED PANEL, CONSISTENT WITH TABLE B.4.1-1.



WIRE BREAKS INSIDE EFFECTIVE DEVELOPMENT LENGTH

EXAMPLE CALCULATION NO 3	
PROJECT:	
CENTENNIAL BRIDGE	
CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
STEPS D(adj)-5 & 6
EFFECT OF WIRES THAT ARE CRACKED
IN ADJACENT PANELS
APPENDIX B, ARTICLE B.4.1

THE VALUES OF $p_{c,ij}$ ARE THE VALUES OF $p_{c,k}$ CORRESPONDING TO THE CORROSION STAGE, k, OF THE WIRES DETERMINED IN THE LABORATORY TESTS. OTHER VALUES ARE CALCULATED IN EACH RANGE AS FOLLOWS:

RANGE 3	$q_{ij} = 1 - p_{c,ij}$
RANGE 4	$e_{ij} = q_{ij} * q_{(i-1)j} * \dots * q_{1j} = q_{ij} * e_{(i-1)j}$, with $e_{1j} = q_{1j}$
RANGE 5	$r_{ij} = p_{c,ij} * e_{(i-1)j}$
RANGE 6	$n_{r,ij} = n_j * r_{ij} * C_{di}$

IN THE FINAL COLUMN OF RANGE 5, THE NUMBER OF DISCRETE CRACKED WIRES FOR EACH SEGMENT, j, IS CALCULATED BY EQUATION B.4.1.1-1.

$n_{c,j} = \Sigma\, n_i * r_{ij}$; THE SUMMATION IS FOR ALL PANELS IN THE EFFECTIVE LENGTH

THESE NUMBERS ARE ADDED TO DETERMINE THE TOTAL NUMBER OF DISCRETE CRACKED WIRES IN THE EFFECTIVE DEVELOPMENT LENGTH. THIS SUMMATION IS MADE SEPARATELY FOR EACH CORROSION STAGE PRESENT IN THE EVALUATED PANEL, BY EQUATION B.4.1.1-2, AND THE RESULTS ARE SHOWN AT THE BOTTOM OF RANGE 5.

$N_{c,k} = \Sigma\, n_{c,jk}$; THE SUMMATION IS FOR ALL SEGMENTS THAT ARE STAGE k IN PANEL 1.

IF ALL THE CRACKED WIRES IN THE EFFECTIVE LENGTH BREAK, THESE BROKEN WIRES WILL STILL BE ABLE TO RESIST A FORCE IN THE EVALUATED PANEL. THIS IS EXPRESSED AS THE EFFECTIVE NUMBER OF WIRES THAT, WHEN STRESSED TO THE 95% OF THE MEAN TENSILE STRENGTH OF GROUP 2 WIRES, RESULT IN THE FORCE THAT THESE WIRES CAN RESIST. THIS EFFECTIVE NUMBER OF REDEVELOPED WIRES IS GIVEN BY EQUATION B.4.1.2-1, AND THE VALUE IS GIVEN AT THE BOTTOM OF RANGE 6.

$N_{cr} = \Sigma\Sigma\, n_i * r_{ij} * C_{di}$; THE SUMMATION IS FOR ALL PANELS IN THE EFFECTIVE DEVELOPMENT LENGTH AND ALL SEGMENTS IN THE CROSS-SECTION

IN THIS EQUATION, THE VALUE OF C_{di} IS THE REDEVELOPMENT COEFFICIENT MULTIPLIED BY THE NUMBER OF CABLE BANDS BETWEEN PANEL i AND THE EVALUATED PANEL SHOWN AT THE TOP OF THE SPREADSHEET AND ALSO AT THE TOP OF EACH COLUMN IN RANGE 6.

THE VALUES OF $N_{c,k}$ AND N_{cr} ARE CARRIED TO PAGE EX3-24 FOR THE CALCULATION OF p_k AND N_{cr}/N_5.

EXAMPLE CALCULATION NO 3	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED

STEP D(adj)-5

EFFECT OF WIRES THAT ARE CRACKED
IN ADJACENT PANELS
APPENDIX B, ARTICLE B.3.1

THE EXAMPLES OF THE CALCULATION OF THE EFFECTS OF CRACKED WIRES IN ADJACENT PANELS SHOWN ON THESE PAGES ARE FOR THE CABLE SEGMENT IN SECTOR 1, RING 3, AND CAN BE FOLLOWED ON THE OVERALL SPEADSHEET CALCULATION ON PAGES EX3-08 and EX3-09, ROW 18. THIS SEGMENT IS CHOSEN AS AN EXAMPLE BECAUSE IT HAS A VARIETY OF CORROSION STAGES PRESENT IN THE DIFFERENT PANELS.

BASIC DATA REQUIRED IN CALCULATION

fraction crkd, p_k		fraction uncrkd, q_k		redevelopment factor, C_{di} (C_d = 0.25)				
p_2 =	0.00	q_2 =	1.00	panel	1	2 & 3	4 & 5	6 & 7
p_3 =	0.05	q_3 =	0.95	Cdi	0.00	0.25	0.50	0.75
p_4 =	0.50	q_4 =	0.50					

THE FIRST RANGE OF THE SPREADSHEET CONTAINS THE CORROSION STAGE OF EACH SEGMENT IN EACH PANEL. THIS DATA IS OBTAINED FROM THE INSPECTION DATA:

SEGMENT		TOTAL WIRES IN RING	NO. WIRES IN SECT. n_j	k = CORROSION STAGE						
				(<<WEST) PANEL, i (EAST >>)						
SECTOR NO	ROW NO			75-76 7	76-77 5	77-78 3	**77-78** **1** **CTR**	76-77 2	75-76 4	74-75 6
1	3	327.0	40.9	2	3	2	**4**	4	2	2

RANGE 2 LISTS THE FRACTION OF CRACKED WIRES IN EACH PANEL FOR THIS SEGMENT. THIS IS A FUNCTION OF THE CORROSION STAGE PRESENT IN EACH PANEL, AS GIVEN IN THE DATA, ABOVE.

$p_{c,ij}$ = FRACTION WIRES CRACKED IN PANEL i						
(<<WEST) PANEL, i (EAST >>)						
75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6
0.00	0.05	0.00	0.50	0.50	0.00	0.00

THE THIRD RANGE LISTS THE FRACTION OF THE WIRES IN THE SEGMENT THAT ARE NOT CRACKED IN EACH PANEL.

	q_{ij} = FRACTION WIRES NOT CRACKED IN PANEL i						
	(<<WEST) PANEL (EAST >>)						
	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6
NOTE: SUBSCRIPTS j ARE OMITTED	1.00	0.95	1.00	0.50	0.50	1.00	1.00
FROM FORMULAS >>>	$q_7=1-p_{c,7}$ =1-0.00	$q_5=1-p_{c,5}$ =1-0.05	$q_3=1-p_{c,3}$ =1-0.00	$q_1=1-p_{c,1}$ =1-0.50	$q_2=1-p_{c,2}$ =1-0.50	$q_4=1-p_{c,4}$ =1-0.00	$q_6=1-p_{c,6}$ =1-0.00

EXAMPLE CALCULATION NO 3	**BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED**
PROJECT:	**STEPS D(adj)-5 & 6**
CENTENNIAL BRIDGE	**EFFECT OF WIRES THAT ARE CRACKED**
CABLE **SOUTH**	**IN ADJACENT PANELS**
SPAN **EAST MAIN SPAN**	**APPENDIX B, ARTICLE B.4.1**
PANEL **77-78**	

IN THE FOURTH RANGE, THE FRACTION OF WIRES THAT ARE NOT CRACKED IN A PANEL AND THAT ARE ALSO NOT CRACKED IN SMALLER NUMBERED PANELS IS CALCULATED. THIS CALCULATION USES THE FORMULA $e_{ij} = q_{ij} * q_{(i-1)j}$, WITH THE VALUE OF $e_{1j} = q_{1j}$.

	e_{ij} = FRACTION OF WIRES NOT CRACKED IN PANEL i THAT ARE ALSO NOT CRACKED IN PANELS < i						
	(<<WEST) PANEL, i (EAST >>)						
	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6
NOTE: SUBSCRIPTS j ARE OMITTED	0.238	0.238	0.250	0.500	0.250	0.250	0.238
FROM FORMULAS >>>	$=q_7*e_6$	$=q_5*e_4$	$=q_3*e_2$	$=q_1$	$=q_2*e_1$	$=q_4*e_3$	$=q_6*e_5$
	=1.00*0.238	=0.95*0.250	=1.00*0.250	=0.500	=0.50*0.500	=1.00*0.250	=1.00*0.238

THE FRACTION OF DISCRETE CRACKED WIRES IN EACH PANEL IS CALCULATED IN RANGE 5. THESE ARE NOT CRACKED IN SMALLER NUMBERED PANELS. THE FRACTION OF WIRES THAT ARE CRACKED IN ANY PANEL IS $p_{c,ij}$, AND THUS THE FRACTION OF WIRES THAT ARE CRACKED IN PANEL i, BUT NOT CRACKED IN LOWER NUMBERED PANELS, IS $r_{ij} = p_{c,ij} * e_{(i-1)j}$.

	NO. WIRES IN SECT. n_j	r_{ij} = FRACTION OF DISCREET CRACKED WIRES IN PANEL i THAT ARE NOT CRACKED IN PANELS < i							NUMBER # OF WIRES CRACKED, $n_{c,j} = \Sigma n_i * r_{ij}$, i = 1 to 7
		(<<WEST) PANEL, i (EAST >>)							
		75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6	
	41.5	0.000	0.013	0.000	0.500	0.250	0.000	0.000	31.678
NOTE: SUBSCRIPTS j ARE OMITTED		$=p_{c,7}*e_6$	$=p_{c,5}*e_4$	$=e_{c,3}*e_2$	$=p_{c,1}$	$=p_{c,2}*e_1$	$=p_{c,4}*e_3$	$=p_{c,6}*e_5$	
FROM FORMULAS >>>		=0.00*0.238	=0.05*0.250	=0.00*0.250	=0.500	=0.500*0.500	=0.00*0.250	=0.00*0.238	

IN RANGE 6, THE EFFECTIVE NUMBER OF REDEVELOPED CRACKED WIRES IS CALCULATED. WHEN A CRACKED WIRE BREAKS IN A PANEL WITHIN THE EFFECTIVE DEVELOPMENT LENGTH AS THE STRESS IS INCREASED DURING THE MATHEMATICAL STRENGTH CALCULATION, THE FORCE THAT CAN BE SUSTAINED BY THIS WIRE IN THE EVALUATED PANEL DEPENDS ON THE NUMBER OF CABLE BANDS BETWEEN THE LOCATION OF THE BREAK AND THE EVALUATED PANEL. IN THIS CALCULATION, IT IS ASSUMED THAT ALL THE DISCRETE CRACKED WIRES IN THE CABLE BREAK. THE EFFECTIVE NUMBER OF REDEVELOPED WIRES IN EACH PANEL IS $n_{r,ij} = n_j * r_{ij} * C_{di}$.

	NUMBER OF EFFECTIVE CRACKED WIRES, $n_{r,ij} = n_j * r_{ij} * C_{di}$							CRKD REDEV IN PANEL 1, $n_{r,j} = \Sigma_{nr,ij}$ i = 1 to 7
	(<<WEST) PANEL, i (EAST >>)							
	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6	
C_{di} >>>	0.75	0.50	0.25	**0**	0.25	0.50	0.75	
NOTE: SUBSCRIPTS j ARE OMITTED	0.00	0.26	0.00	0.00	2.60	0.00	0.00	2.86
FROM FORMULAS >>>	$=n*r_7*C_{d7}$	$=n*r_6*C_{d6}$	ETC >>		$=n*r_2*C_{d2}$			
	=40.9*0.000*0.75		ETC >>		=40.9*0.250*0.25			

EXAMPLE CALCULATION NO 3	BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
PROJECT:	**STEPS D(adj)-5 & 6**
CENTENNIAL BRIDGE	EFFECT OF WIRES THAT ARE CRACKED
CABLE: SOUTH	IN ADJACENT PANELS
SPAN: EAST MAIN SPAN	APPENDIX B, ARTICLE B.3.1
PANEL: 77-78	

THE VALUES OF Ncj ARE ADDED FOR ALL SEGMENTS THAT ARE IN THE SAME CORROSION STAGE IN THE EVALUATED PANEL TO DETERMINE THE VALUES OF $N_{c,k}$. THIS IS ACHIEVED ON PAGE EX3-23 AT THE BOTTOM OF RANGE 5, USING THE EXCEL FUNCTION "DSUM", WHICH IS A CONDITIONAL SUMMATION MADE FROM A TABLE. THE CONDITION USED IS THE VALUE OF k IN PANEL 1, WHICH IS THE EVALUATED PANEL. THE RESULTS OF THIS CALCULATION ARE:

# of cracked wires, $N_{c,k}$, by stage		Adjustm't	$N_{c,k}$ Without Broken Wires * by group	
stage or group	$N_{c,k} = \Sigma(n_{c,jk})$	Factor	$N_{c,k}$	
1	0.0	1.000		
2	25.3	1.000	25	the values of $N_{c,k}$ are
3	738.8	1.000	739	rounded to the nearest
4	1656.3	0.951	1576	integer
total	2420.4		2340	

TABLES FROM PAGE EX3-23

THE RAW VALUE OF $N_{c,k}$ IS ADJUSTED FOR BROKEN WIRES THAT ARE SUBTRACTED FROM EACH CORROSION STAGE IN CALCULATING N_{eff}. IN THIS EXAMPLE, THE WIRES FOUND BROKEN IN THE CABLE ARE ALL SUBTRACTED FROM STAGE 4 WIRES, AND ONLY $N_{c,4}$ NEED BE ADJUSTED. THE ADJUSTMENT FACTOR IS

total stage 4 wires	N_{s4} =	2175
broken wires	N_b =	184
repaired wires	N_r =	78
total group 4 without broken wires = N_{0k}; $N_{04} = N_{s4} - N_b + N_r$	N_{04} =	2069

adjustment factor for broken wires	
Total Group 4	2175
Group 4 w/o Broken	2069
Factor	0.951

TABLE FROM PAGE EX3-23

THE VALUES OF n_{rj} ARE ALSO ADDED FOR ALL SEGMENTS TO ARRIVE AT N_r ON PAGE EX3-23, BELOW RANGE 6. THIS VALUE, WHICH APPLIES TO THE ENTIRE CABLE, IS SIMILARLY ADJUSTED BY A FACTOR EQUAL TO THE TOTAL NUMBER OF UNBROKEN WIRES IN THE CABLE DIVIDED BY THE TOTAL NUMBER OF WIRES IN THE CABLE.

$\Sigma n_{r,ij} = N_{cr}$: 380.8

TABLE FROM PAGE EX3-23

Adjustment of eff # redev crkd for broken wires		
factor = $(N-N_b+N_r)/N$		0.989
where N =	9842	CARRIED
N_b-N_r =	106	TO STRGTH
		CALC
adjusted eff # redev crkd, N_{cr} = 0.989 * 380.8 =		377

EXAMPLE CALCULATION NO 3

PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

fract crkd, p_k		fract uncr, q_k		redevelopment factor, C_d					broken wires		fraction of circle	
p_2 =	0.00	q_2 =	1.00	panel	1	2 & 3	4 & 5	6 & 7	Total Group 4	2175	all sectors	0.125
p_3 =	0.05	q_3 =	0.95	C_d	0.00	0.25	0.50	0.75	Group 4 w/o Broken	2069		
p_4 =	0.50	q_4 =	0.50						Factor	0.951		

SEGMENT		TOTAL WIRES IN RING	NO WIRES IN SEGM n_i	RANGE 1							RANGE 2							RANGE 3						
				k = CORROSION STAGE IN PANEL i							p_{ij} = FRACTION WIRES CRACKED IN PANEL i							q_{ij} = FRACTION WIRES NOT CRACKED IN PANEL						
				(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)						
SECTOR	RING			75-76 7	76-77 5	77-78 3	**77-78** 1 EVAL	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6
1	1	344.4	43.1	2	4	2	**4**	4	2	2	0	0.5	0	0.5	0.5	0	0	1	0.5	1	0.5	0.5	1	1
	2	338.4	42.3	2	4	2	**4**	4	2	2	0	0.5	0	0.5	0.5	0	0	1	0.5	1	0.5	0.5	1	1
	3	332.4	41.5	2	3	2	**4**	4	2	2	0	0.05	0	0.5	0.5	0	0	1	0.95	1	0.5	0.5	1	1
	4	326.3	40.8	2	3	2	**4**	3	2	2	0	0.05	0	0.5	0.05	0	0	1	0.95	1	0.5	0.95	1	1
	5	320.3	40.0	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	6	314.2	39.3	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	7	308.2	38.5	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	8	302.1	37.8	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	9	296.1	37.0	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	10	290.1	36.3	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	11	284.0	35.5	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	12	278.0	34.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	13	271.9	34.0	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	14	265.9	33.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	15	259.8	32.5	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	16	253.8	31.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	17	247.8	31.0	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	18	241.7	30.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	19	235.7	29.5	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	20	229.6	28.7	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	21	223.6	27.9	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	22	217.5	27.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	23	211.5	26.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	24	205.5	25.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	25	199.4	24.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	26	193.4	24.2	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	27	187.3	23.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	28	181.3	22.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	29	175.2	21.9	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	30	169.2	21.2	2	2	2	**4**	2	2	2	0	0	0	0.5	0	0	0	1	1	1	0.5	1	1	1
	31	163.2	20.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	32	157.1	19.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	33	151.1	18.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	34	145.0	18.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	35	139.0	17.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	36	132.9	16.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	37	126.9	15.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	38	120.9	15.1	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	39	114.8	14.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	40	108.8	13.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	41	102.7	12.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	42	96.7	12.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	43	90.6	11.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	44	84.6	10.6	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	45	78.6	9.8	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	46	72.5	9.1	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	47	66.5	8.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	48	60.4	7.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	49	54.4	6.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	50	48.3	6.0	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	51	42.3	5.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	52	36.3	4.5	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	53	30.2	3.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	54	24.2	3.0	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	55	18.1	2.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	56	12.1	1.5	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	57	6.0	0.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	58	1.0	0.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1

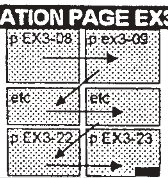
EXAMPLE CALCULATION NO 3	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED

CRACKED WIRES IN ADJACENT PANELS

RESULTS OF THIS SPREADSHEET CALCULATION THAT ARE USED IN STRENGTH CALCULATION ARE SHOWN IN FIELDS ON LAST PAGE OF SPREADSHEET WITH ASTERISKS (*)

ARRANGEMENT OF PAGES >



SEGMENT		RANGE 4							RANGE 5								RANGE 6							
		e_{ij} = FRACTION WIRES NOT CRACKED IN PANEL THAT ARE ALSO NOT CRACKED IN PANELS < i							r_{ij} = FRACT DISCRETE CRCKD WIRES IN PANEL i THAT ARE NOT CRACKED IN PANELS < i							# OF WIRES CRACKED, $n_{c,i} = \Sigma n_i * r_{ij}$, i = 1 thru 7	$n_{r,ij}$ = # OF EFFECTIVE CRACKED WIRES IN PANEL i = $n_i * r_{ij} * C_{di}$							# CRKD WIRES REDEVELOPED IN PANEL 1, $n_{r,i} = \Sigma n_{r,ij}$ i = 1 thru 7
		(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)								(<<WEST) PANEL, i (EAST >>)							
SECTOR	RING	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6		75-76 7 0.75	76-77 5 0.5	77-78 3 0.25	**77-78** 1 **0**	76-77 2 0.25	75-76 4 0.5	74-75 6 0.75	
1	1	0.125	0.125	0.250	0.500	0.250	0.250	0.125	0.000	0.125	0.000	0.500	0.250	0.000	0.000	37.078	0.00	2.65	0.00	0.00	2.65	0.00	0.00	5.30
	2	0.125	0.125	0.250	0.500	0.250	0.250	0.125	0.000	0.125	0.000	0.500	0.250	0.000	0.000	36.422	0.00	2.60	0.00	0.00	2.60	0.00	0.00	5.20
	3	0.238	0.238	0.250	0.500	0.250	0.250	0.238	0.000	0.013	0.000	0.500	0.250	0.000	0.000	31.167	0.00	0.26	0.00	0.00	2.55	0.00	0.00	2.81
	4	0.451	0.451	0.475	0.500	0.475	0.475	0.451	0.000	0.024	0.000	0.500	0.025	0.000	0.000	22.019	0.00	0.48	0.00	0.00	0.25	0.00	0.00	0.73
	5	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.634	0.00	0.89	0.00	0.00	0.47	0.00	0.00	1.36
	6	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.527	0.00	0.87	0.00	0.00	0.46	0.00	0.00	1.33
	7	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.420	0.00	0.86	0.00	0.00	0.45	0.00	0.00	1.31
	8	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.313	0.00	0.84	0.00	0.00	0.44	0.00	0.00	1.28
	9	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.206	0.00	0.82	0.00	0.00	0.43	0.00	0.00	1.26
	10	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.788	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.750	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.713	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.675	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.638	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	3.120	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.38
	16	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.563	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.525	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.488	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	19	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	2.754	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.67
	21	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.375	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	22	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.338	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	23	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.263	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	25	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	27	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.156	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.119	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.081	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.000	0.000	0.000	0.500	0.000	0.000	0.000	10.438	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	31	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	35	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	37	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.744	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	41	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	42	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	43	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	44	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.519	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	45	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.481	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	46	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.444	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	47	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	48	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	49	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	51	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	52	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	53	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	54	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	55	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	56	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	57	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	58	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXAMPLE CALCULATION NO 3

PROJECT:

CENTENNIAL BRIDGE

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED

CRACKED WIRES IN ADJACENT PANELS

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

fract crkd, p_k		fract uncr, q_k		redevelopment factor, C_d					broken wires		fraction of circle	
p_2 =	0.00	q_2 =	1.00	panel	1	2 & 3	4 & 5	6 & 7	Total Group 4	2175	all sectors	0.125
p_3 =	0.05	q_3 =	0.95	C_d	0.00	0.25	0.50	0.75	Group 4 w/o Broken	2069		
p_4 =	0.50	q_4 =	0.50						Factor	0.951		

SEGMENT		TOTAL WIRES IN RING	NO WIRES IN SEGM	RANGE 1							RANGE 2							RANGE 3						
				k = CORROSION STAGE IN PANEL i							p_{ij} = FRACTION WIRES CRACKED IN PANEL i							q_{ij} = FRACTION WIRES NOT CRACKED IN PANEL						
				(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)						
SECTOR	RING		n_i	75-76 7	76-77 5	77-78 3	**77-78** 1 EVAL	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6
2	1	344.4	43.1	2	4	2	**4**	4	2	2	0	0.5	0	0.5	0.5	0	0	1	0.5	1	0.5	0.5	1	1
	2	338.4	42.3	2	3	3	**4**	3	2	2	0	0.05	0.05	0.5	0.05	0	0	1	0.95	0.95	0.5	0.95	1	1
	3	332.4	41.5	2	3	4	**4**	3	2	2	0	0.05	0.5	0.5	0.05	0	0	1	0.95	0.5	0.5	0.95	1	1
	4	326.3	40.8	2	3	4	**4**	3	2	2	0	0.05	0.5	0.5	0.05	0	0	1	0.95	0.5	0.5	0.95	1	1
	5	320.3	40.0	3	3	3	**4**	3	2	2	0.05	0.05	0.05	0.5	0.05	0	0	0.95	0.95	0.95	0.5	0.95	1	1
	6	314.2	39.3	2	3	3	**4**	3	2	2	0	0.05	0.05	0.5	0.05	0	0	1	0.95	0.95	0.5	0.95	1	1
	7	308.2	38.5	2	3	3	**4**	3	2	2	0	0.05	0.05	0.5	0.05	0	0	1	0.95	0.95	0.5	0.95	1	1
	8	302.1	37.8	2	3	2	**4**	3	2	2	0	0.05	0	0.5	0.05	0	0	1	0.95	1	0.5	0.95	1	1
	9	296.1	37.0	2	3	2	**3**	4	2	2	0	0.05	0	0.05	0.5	0	0	1	0.95	1	0.95	0.5	1	1
	10	290.1	36.3	2	3	2	**3**	4	2	2	0	0.05	0	0.05	0.5	0	0	1	0.95	1	0.95	0.5	1	1
	11	284.0	35.5	2	3	2	**3**	4	2	2	0	0.05	0	0.05	0.5	0	0	1	0.95	1	0.95	0.5	1	1
	12	278.0	34.7	2	3	2	**3**	4	2	2	0	0.05	0	0.05	0.5	0	0	1	0.95	1	0.95	0.5	1	1
	13	271.9	34.0	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	14	265.9	33.2	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	15	259.8	32.5	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	16	253.8	31.7	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	17	247.8	31.0	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	18	241.7	30.2	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	19	235.7	29.5	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	20	229.6	28.7	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	21	223.6	27.9	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	22	217.5	27.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	23	211.5	26.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	24	205.5	25.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	25	199.4	24.9	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	26	193.4	24.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	27	187.3	23.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	28	181.3	22.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	29	175.2	21.9	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	30	169.2	21.2	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	31	163.2	20.4	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	32	157.1	19.6	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	33	151.1	18.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	34	145.0	18.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	35	139.0	17.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	36	132.9	16.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	37	126.9	15.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	38	120.9	15.1	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	39	114.8	14.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	40	108.8	13.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	41	102.7	12.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	42	96.7	12.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	43	90.6	11.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	44	84.6	10.6	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	45	78.6	9.8	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	46	72.5	9.1	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	47	66.5	8.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	48	60.4	7.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	49	54.4	6.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	50	48.3	6.0	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	51	42.3	5.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	52	36.3	4.5	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	53	30.2	3.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	54	24.2	3.0	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	55	18.1	2.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	56	12.1	1.5	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	57	6.0	0.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	58	1.0	0.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1

CALCULATION PAGE EX3-11

EXAMPLE CALCULATION NO 3

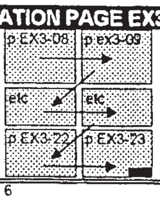
PROJECT:
CENTENNIAL BRIDGE

CABLE SOUTH
SPAN EAST MAIN SPAN
PANEL 77-78

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

RESULTS OF THIS SPREADSHEET CALCULATION THAT ARE
USED IN STRENGTH CALCULATION ARE SHOWN IN FIELDS
ON LAST PAGE OF SPREADSHEET WITH ASTERISKS (*)

ARRANGEMENT OF PAGES >



SEGMENT		RANGE 4							RANGE 5								RANGE 6							
		e_{ij} = FRACTION WIRES NOT CRACKED IN PANEL i THAT ARE ALSO NOT CRACKED IN PANELS < i							r_{ij} = FRACT DISCRETE CRCKD WIRES IN PANEL i THAT ARE NOT CRACKED IN PANELS < i							# OF WIRES CRACKED, $n_{c,J}$ $= \Sigma n_i * r_{iJ}$ i = 1 thru 7	$n_{r,ij}$ = # OF EFFECTIVE CRACKED WIRES IN PANEL i = $n_j * r_{ij} * C_{di}$							# CRKD WIRES REDEVELOPED IN PANEL 1, $n_{r,J}$ $= \Sigma n_{r,iJ}$ i = 1 thru 7
		(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)								(<<WEST) PANEL, i (EAST >>)							
SECTOR	RING	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6		75-76 7 0.75	76-77 5 0.5	77-78 3 0.25	**77-78** 1 0	76-77 2 0.25	75-76 4 0.5	74-75 6 0.75	
2	1	0.125	0.125	0.250	0.500	0.250	0.250	0.125	0.000	0.125	0.000	0.500	0.250	0.000	0.000	37.078	0.00	2.65	0.00	0.00	2.65	0.00	0.00	5.30
	2	0.429	0.429	0.451	0.500	0.475	0.451	0.429	0.000	0.023	0.024	0.500	0.025	0.000	0.000	23.781	0.00	0.47	0.25	0.00	0.26	0.00	0.00	0.98
	3	0.226	0.226	0.238	0.500	0.475	0.238	0.226	0.000	0.012	0.238	0.500	0.025	0.000	0.000	31.653	0.00	0.24	2.43	0.00	0.26	0.00	0.00	2.93
	4	0.226	0.226	0.238	0.500	0.475	0.238	0.226	0.000	0.012	0.238	0.500	0.025	0.000	0.000	31.072	0.00	0.24	2.38	0.00	0.25	0.00	0.00	2.87
	5	0.407	0.429	0.451	0.500	0.475	0.451	0.429	0.021	0.023	0.024	0.500	0.025	0.000	0.000	23.414	0.63	0.45	0.23	0.00	0.25	0.00	0.00	1.56
	6	0.429	0.429	0.451	0.500	0.475	0.451	0.429	0.000	0.023	0.024	0.500	0.025	0.000	0.000	22.138	0.00	0.44	0.23	0.00	0.24	0.00	0.00	0.91
	7	0.429	0.429	0.451	0.500	0.475	0.451	0.429	0.000	0.023	0.024	0.500	0.025	0.000	0.000	21.710	0.00	0.43	0.23	0.00	0.24	0.00	0.00	0.89
	8	0.451	0.451	0.475	0.500	0.475	0.475	0.451	0.000	0.024	0.000	0.500	0.025	0.000	0.000	20.441	0.00	0.44	0.00	0.00	0.23	0.00	0.00	0.68
	9	0.451	0.451	0.475	0.950	0.475	0.475	0.451	0.000	0.024	0.000	0.050	0.475	0.000	0.000	20.029	0.00	0.43	0.00	0.00	4.33	0.00	0.00	4.77
	10	0.451	0.451	0.475	0.950	0.475	0.475	0.451	0.000	0.024	0.000	0.050	0.475	0.000	0.000	19.618	0.00	0.42	0.00	0.00	4.25	0.00	0.00	4.67
	11	0.451	0.451	0.475	0.950	0.475	0.475	0.451	0.000	0.024	0.000	0.050	0.475	0.000	0.000	19.206	0.00	0.42	0.00	0.00	4.16	0.00	0.00	4.57
	12	0.451	0.451	0.475	0.950	0.475	0.475	0.451	0.000	0.024	0.000	0.050	0.475	0.000	0.000	18.795	0.00	0.41	0.00	0.00	4.07	0.00	0.00	4.47
	13	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	4.778	0.00	0.76	0.00	0.00	0.40	0.00	0.00	1.15
	14	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	3.193	0.00	0.78	0.00	0.00	0.00	0.00	0.00	0.78
	15	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	3.120	0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.76
	16	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	3.047	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.74
	17	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	2.974	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.72
	18	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	2.901	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.71
	19	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	2.828	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.69
	20	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	2.754	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.67
	21	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	2.681	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.65
	22	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.338	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	23	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.263	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	25	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.225	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.188	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	27	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.156	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.119	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.108	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.26
	30	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.035	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.25
	31	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	1.962	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.48
	32	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.889	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.23
	33	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	35	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	37	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.744	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	41	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	42	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	43	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	44	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.519	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	45	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.481	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	46	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.444	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	47	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	48	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	49	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	51	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	52	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	53	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	54	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	55	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	56	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	57	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	58	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXAMPLE CALCULATION NO 3

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED

CRACKED WIRES IN ADJACENT PANELS

PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

fract crkd, p_k		fract uncr, q_k		redevelopment factor, C_α					broken wires		fraction of circle	
$p_2 =$	0.00	$q_2 =$	1.00	panel	1	2 & 3	4 & 5	6 & 7	Total Group 4	2175	all sectors	0.125
$p_3 =$	0.05	$q_3 =$	0.95	C_α	0.00	0.25	0.50	0.75	Group 4 w/o Broken	2069		
$p_4 =$	0.50	$q_4 =$	0.50						Factor	0.951		

SEGMENT		TOTAL WIRES IN RING	NO WIRES IN SEGM	RANGE 1							RANGE 2							RANGE 3						
				k = CORROSION STAGE IN PANEL i							p_{ij} = FRACTION WIRES CRACKED IN PANEL i							q_{ij} = FRACTION WIRES NOT CRACKED IN PANEL						
				(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)						
SECTOR	RING		n_i	75-76 7	76-77 5	77-78 3	**77-78** 1 EVAL	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6
3	1	344.4	43.1	3	3	4	**4**	4	2	3	0.05	0.05	0.5	0.5	0.5	0	0.05	0.95	0.95	0.5	0.5	0.5	1	0.95
	2	338.4	42.3	3	3	3	**4**	4	3	4	0.05	0.05	0.05	0.5	0.5	0.05	0.5	0.95	0.95	0.95	0.5	0.5	0.95	0.5
	3	332.4	41.5	4	4	3	**4**	4	3	4	0.5	0.5	0.05	0.5	0.5	0.05	0.5	0.5	0.5	0.95	0.5	0.5	0.95	0.5
	4	326.3	40.8	4	4	3	**4**	4	2	4	0.5	0.5	0.05	0.5	0.5	0	0.5	0.5	0.5	0.95	0.5	0.5	1	0.5
	5	320.3	40.0	4	3	3	**4**	4	2	4	0.5	0.05	0.05	0.5	0.5	0	0.5	0.5	0.95	0.95	0.5	0.5	1	0.5
	6	314.2	39.3	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	7	308.2	38.5	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	8	302.1	37.8	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	9	296.1	37.0	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	10	290.1	36.3	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	11	284.0	35.5	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	12	278.0	34.7	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	13	271.9	34.0	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	14	265.9	33.2	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	15	259.8	32.5	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	16	253.8	31.7	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	17	247.8	31.0	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	18	241.7	30.2	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	19	235.7	29.5	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	20	229.6	28.7	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	21	223.6	27.9	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	22	217.5	27.2	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	23	211.5	26.4	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	24	205.5	25.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	25	199.4	24.9	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	26	193.4	24.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	27	187.3	23.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	28	181.3	22.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	29	175.2	21.9	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	30	169.2	21.2	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	31	163.2	20.4	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	32	157.1	19.6	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	33	151.1	18.9	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	34	145.0	18.1	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	35	139.0	17.4	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	36	132.9	16.6	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	37	126.9	15.9	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	38	120.9	15.1	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	39	114.8	14.4	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	40	108.8	13.6	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	41	102.7	12.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	42	96.7	12.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	43	90.6	11.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	44	84.6	10.6	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	45	78.6	9.8	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	46	72.5	9.1	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	47	66.5	8.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	48	60.4	7.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	49	54.4	6.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	50	48.3	6.0	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	51	42.3	5.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	52	36.3	4.5	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	53	30.2	3.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	54	24.2	3.0	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	55	18.1	2.3	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	56	12.1	1.5	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	57	6.0	0.8	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	58	1.0	0.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1

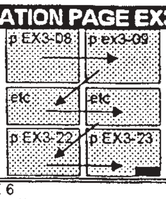
CALCULATION PAGE EX3-13

EXAMPLE CALCULATION NO 3	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH I
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

RESULTS OF THIS SPREADSHEET CALCULATION THAT ARE
USED IN STRENGTH CALCULATION ARE SHOWN IN FIELDS
ON LAST PAGE OF SPREADSHEET WITH ASTERISKS (*)

ARRANGEMENT OF PAGES >



		RANGE 4							RANGE 5								RANGE 6							
SEGMENT		e_{ij} = FRACTION WIRES NOT CRACKED IN PANEL i THAT ARE ALSO NOT CRACKED IN PANELS < i							r_{ij} = FRACT DISCRETE CRCKD WIRES IN PANEL i THAT ARE NOT CRACKED IN PANELS < i							# OF WIRES CRACKED, $n_{c,j} = \Sigma n_i * r_{ij}$, i = 1 thru 7	$n_{r,ij}$ = # OF EFFECTIVE CRACKED WIRES IN PANEL i = $n_j * r_{ij} * C_{di}$							# CRKD WIRES REDEVELOPED IN PANEL 1, $n_{r,1} = \Sigma n_{r,ij}$ i = 1 thru 7
		(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)								(<<WEST) PANEL, i (EAST >>)							
SECTOR	RING	75-76 7	76-77 5	77-78 3	77-78 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	77-78 1	76-77 2	75-76 4	74-75 6		75-76 7 0.75	76-77 5 0.5	77-78 3 0.25	77-78 1 0	76-77 2 0.25	75-76 4 0.5	74-75 6 0.75	
3	1	0.107	0.119	0.125	0.500	0.250	0.125	0.113	0.006	0.006	0.125	0.500	0.250	0.000	0.006	37.834	0.18	0.13	1.32	0.00	2.65	0.00	0.19	4.47
	2	0.102	0.214	0.238	0.500	0.250	0.226	0.107	0.005	0.011	0.013	0.500	0.250	0.012	0.107	37.387	0.17	0.23	0.13	0.00	2.60	0.25	3.35	6.73
	3	0.028	0.113	0.238	0.500	0.250	0.226	0.056	0.028	0.113	0.013	0.500	0.250	0.012	0.056	39.722	0.86	2.31	0.13	0.00	2.55	0.24	1.73	7.82
	4	0.030	0.119	0.238	0.500	0.250	0.238	0.059	0.030	0.119	0.013	0.500	0.250	0.000	0.059	38.934	0.89	2.38	0.13	0.00	2.51	0.00	1.79	7.70
	5	0.056	0.226	0.238	0.500	0.250	0.238	0.113	0.056	0.012	0.013	0.500	0.250	0.000	0.113	37.272	1.67	0.23	0.12	0.00	2.47	0.00	3.34	7.84
	6	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	8.766	0.00	0.83	0.44	0.00	0.46	0.00	1.18	2.91
	7	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	8.596	0.00	0.81	0.43	0.00	0.45	0.00	1.16	2.86
	8	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	8.427	0.00	0.80	0.42	0.00	0.44	0.00	1.14	2.80
	9	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	8.257	0.00	0.78	0.41	0.00	0.43	0.00	1.11	2.74
	10	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	8.087	0.00	0.77	0.40	0.00	0.42	0.00	1.09	2.69
	11	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.918	0.00	0.75	0.39	0.00	0.42	0.00	1.07	2.63
	12	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.748	0.00	0.73	0.39	0.00	0.41	0.00	1.05	2.57
	13	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.578	0.00	0.72	0.38	0.00	0.40	0.00	1.02	2.52
	14	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.409	0.00	0.70	0.37	0.00	0.39	0.00	1.00	2.46
	15	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.239	0.00	0.69	0.36	0.00	0.38	0.00	0.98	2.40
	16	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.069	0.00	0.67	0.35	0.00	0.37	0.00	0.95	2.35
	17	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	5.658	0.00	0.65	0.34	0.00	0.36	0.00	0.00	1.36
	18	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	5.518	0.00	0.64	0.34	0.00	0.35	0.00	0.00	1.33
	19	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	5.379	0.00	0.62	0.33	0.00	0.34	0.00	0.00	1.29
	20	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	2.754	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.34
	21	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	2.681	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.33
	22	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	2.608	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.32
	23	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	2.535	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.31
	24	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.263	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	25	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.225	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.188	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	27	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.156	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.119	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.108	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.26
	30	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.035	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.25
	31	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	1.962	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.48
	32	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.889	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.23
	33	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.816	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.22
	34	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.743	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.21
	35	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.670	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.20
	36	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.597	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.19
	37	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.523	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.19
	38	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.450	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.18
	39	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.377	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.17
	40	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.304	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.16
	41	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	42	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	43	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	44	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.519	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	45	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.481	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	46	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.444	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	47	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	48	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	49	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	51	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	52	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	53	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	54	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	55	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	56	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	57	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	58	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXAMPLE CALCULATION NO 3	
PROJECT:	
CENTENNIAL BRIDGE	
CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

fract crkd, p_k		fract uncr, q_k		redevelopment factor, C_d					broken wires		fraction of circle	
p_2 =	0.00	q_2 =	1.00	panel	1	2 & 3	4 & 5	6 & 7	Total Group 4	2175	all sectors	0.125
p_3 =	0.05	q_3 =	0.95	C_d	0.00	0.25	0.50	0.75	Group 4 w/o Broken	2069		
p_4 =	0.50	q_4 =	0.50						Factor	0.951		

SEGMENT		TOTAL WIRES IN RING	NO WIRES IN SEGM n_i	RANGE 1							RANGE 2							RANGE 3						
				k = CORROSION STAGE IN PANEL i							p_{ij} = FRACTION WIRES CRACKED IN PANEL i							q_{ij} = FRACTION WIRES NOT CRACKED IN PANEL						
				(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)						
SECTOR	RING			75-76 7	76-77 5	77-78 3	**77-78** **1** EVAL	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6
4	1	344.4	43.1	3	4	4	**4**	4	3	4	0.05	0.5	0.5	0.5	0.5	0.05	0.5	0.95	0.5	0.5	0.5	0.5	0.95	0.5
	2	338.4	42.3	3	4	4	**4**	4	4	3	0.05	0.5	0.5	0.5	0.5	0.5	0.05	0.95	0.5	0.5	0.5	0.5	0.5	0.95
	3	332.4	41.5	3	4	4	**4**	4	3	3	0.05	0.5	0.5	0.5	0.5	0.05	0.05	0.95	0.5	0.5	0.5	0.5	0.95	0.95
	4	326.3	40.8	3	4	4	**4**	4	3	3	0.05	0.5	0.5	0.5	0.5	0.05	0.05	0.95	0.5	0.5	0.5	0.5	0.95	0.95
	5	320.3	40.0	3	4	4	**4**	4	2	3	0.05	0.5	0.5	0.5	0.5	0	0.05	0.95	0.5	0.5	0.5	0.5	1	0.95
	6	314.2	39.3	3	3	3	**4**	3	2	3	0.05	0.05	0.05	0.5	0.05	0	0.05	0.95	0.95	0.95	0.5	0.95	1	0.95
	7	308.2	38.5	3	3	3	**4**	3	2	3	0.05	0.05	0.05	0.5	0.05	0	0.05	0.95	0.95	0.95	0.5	0.95	1	0.95
	8	302.1	37.8	3	3	3	**3**	3	2	3	0.05	0.05	0.05	0.05	0.05	0	0.05	0.95	0.95	0.95	0.95	0.95	1	0.95
	9	296.1	37.0	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	10	290.1	36.3	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	11	284.0	35.5	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	12	278.0	34.7	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	13	271.9	34.0	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	14	265.9	33.2	2	3	3	**3**	3	3	3	0	0.05	0.05	0.05	0.05	0.05	0.05	1	0.95	0.95	0.95	0.95	0.95	0.95
	15	259.8	32.5	2	3	3	**4**	3	3	3	0	0.05	0.05	0.5	0.05	0.05	0.05	1	0.95	0.95	0.5	0.95	0.95	0.95
	16	253.8	31.7	2	3	3	**4**	3	3	3	0	0.05	0.05	0.5	0.05	0.05	0.05	1	0.95	0.95	0.5	0.95	0.95	0.95
	17	247.8	31.0	2	3	3	**3**	3	3	2	0	0.05	0.05	0.05	0.05	0.05	0	1	0.95	0.95	0.95	0.95	0.95	1
	18	241.7	30.2	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	19	235.7	29.5	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	20	229.6	28.7	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	21	223.6	27.9	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	22	217.5	27.2	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	23	211.5	26.4	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	24	205.5	25.7	2	3	3	**3**	2	2	2	0	0.05	0.05	0.05	0	0	0	1	0.95	0.95	0.95	1	1	1
	25	199.4	24.9	2	3	3	**3**	2	2	2	0	0.05	0.05	0.05	0	0	0	1	0.95	0.95	0.95	1	1	1
	26	193.4	24.2	2	3	3	**3**	2	2	2	0	0.05	0.05	0.05	0	0	0	1	0.95	0.95	0.95	1	1	1
	27	187.3	23.4	2	3	3	**3**	2	2	2	0	0.05	0.05	0.05	0	0	0	1	0.95	0.95	0.95	1	1	1
	28	181.3	22.7	2	3	3	**3**	2	2	2	0	0.05	0.05	0.05	0	0	0	1	0.95	0.95	0.95	1	1	1
	29	175.2	21.9	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	30	169.2	21.2	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	31	163.2	20.4	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	32	157.1	19.6	2	2	3	**3**	3	2	2	0	0	0.05	0.05	0.05	0	0	1	1	0.95	0.95	0.95	1	1
	33	151.1	18.9	2	2	3	**3**	3	2	2	0	0	0.05	0.05	0.05	0	0	1	1	0.95	0.95	0.95	1	1
	34	145.0	18.1	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	35	139.0	17.4	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	36	132.9	16.6	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	37	126.9	15.9	2	2	3	**3**	2	2	2	0	0	0.05	0.05	0	0	0	1	1	0.95	0.95	1	1	1
	38	120.9	15.1	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	39	114.8	14.4	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	40	108.8	13.6	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	41	102.7	12.8	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	42	96.7	12.1	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	43	90.6	11.3	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	44	84.6	10.6	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	45	78.6	9.8	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	46	72.5	9.1	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	47	66.5	8.3	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	48	60.4	7.6	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	49	54.4	6.8	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	50	48.3	6.0	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	51	42.3	5.3	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	52	36.3	4.5	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	53	30.2	3.8	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	54	24.2	3.0	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	55	18.1	2.3	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	56	12.1	1.5	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	57	6.0	0.8	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	58	1.0	0.1	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1

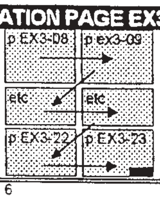
EXAMPLE CALCULATION NO 3
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

RESULTS OF THIS SPREADSHEET CALCULATION THAT ARE USED IN STRENGTH CALCULATION ARE SHOWN IN FIELDS ON LAST PAGE OF SPREADSHEET WITH ASTERISKS (*)

ARRANGEMENT OF PAGES >



SEGMENT		RANGE 4							RANGE 5								RANGE 6							
		e_{ij} = FRACTION WIRES NOT CRACKED IN PANEL THAT ARE ALSO NOT CRACKED IN PANELS < i							r_{ij} = FRACT DISCRETE CRCKD WIRES IN PANEL i THAT ARE NOT CRACKED IN PANELS < i							# OF WIRES CRACKED. $n_{c,j} = \Sigma n_i * r_{ij}$, i = 1 thru 7	$n_{r,ij}$ = # OF EFFECTIVE CRACKED WIRES IN PANEL i = $n_j * r_{ij} * C_{di}$							# CRKD WIRES REDEVELOPED IN PANEL 1. $n_{r,j} = \Sigma n_{r,ij}$ i = 1 thru 7
SECTOR	RING	(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)								(<<WEST) PANEL, i (EAST >>)							
		75-76 7	76-77 5	77-78 3	77-78 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	77-78 1	76-77 2	75-76 4	74-75 6		75-76 7 0.75	76-77 5 0.5	77-78 3 0.25	77-78 1 0	76-77 2 0.25	75-76 4 0.5	74-75 6 0.75	
4	1	0.028	0.059	0.125	0.500	0.250	0.119	0.030	0.001	0.059	0.125	0.500	0.250	0.006	0.030	41.180	0.05	1.26	1.32	0.00	2.65	0.13	0.94	6.35
	2	0.028	0.031	0.125	0.500	0.250	0.063	0.030	0.001	0.031	0.125	0.500	0.250	0.063	0.002	40.451	0.05	0.65	1.30	0.00	2.60	1.30	0.05	5.95
	3	0.054	0.059	0.125	0.500	0.250	0.119	0.056	0.003	0.059	0.125	0.500	0.250	0.006	0.003	38.685	0.09	1.21	1.28	0.00	2.55	0.13	0.09	5.35
	4	0.054	0.059	0.125	0.500	0.250	0.119	0.056	0.003	0.059	0.125	0.500	0.250	0.006	0.003	37.975	0.08	1.19	1.25	0.00	2.51	0.13	0.09	5.25
	5	0.056	0.063	0.125	0.500	0.250	0.125	0.059	0.003	0.063	0.125	0.500	0.250	0.000	0.003	37.272	0.09	1.23	1.23	0.00	2.47	0.00	0.09	5.12
	6	0.387	0.429	0.451	0.500	0.475	0.451	0.407	0.020	0.023	0.024	0.500	0.025	0.000	0.021	23.758	0.59	0.44	0.23	0.00	0.24	0.00	0.62	2.12
	7	0.387	0.429	0.451	0.500	0.475	0.451	0.407	0.020	0.023	0.024	0.500	0.025	0.000	0.021	23.298	0.58	0.43	0.23	0.00	0.24	0.00	0.61	2.08
	8	0.735	0.815	0.857	0.950	0.903	0.857	0.774	0.039	0.043	0.045	0.050	0.048	0.000	0.041	9.868	1.08	0.80	0.42	0.00	0.44	0.00	1.14	3.88
	9	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	8.257	0.00	0.78	0.41	0.00	0.43	0.00	1.11	2.74
	10	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	8.087	0.00	0.77	0.40	0.00	0.42	0.00	1.09	2.69
	11	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.918	0.00	0.75	0.39	0.00	0.42	0.00	1.07	2.63
	12	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.748	0.00	0.73	0.39	0.00	0.41	0.00	1.05	2.57
	13	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.578	0.00	0.72	0.38	0.00	0.40	0.00	1.02	2.52
	14	0.735	0.774	0.857	0.950	0.903	0.815	0.735	0.000	0.041	0.045	0.050	0.048	0.043	0.039	8.676	0.00	0.67	0.37	0.00	0.39	0.70	0.95	3.08
	15	0.387	0.407	0.451	0.500	0.475	0.429	0.387	0.000	0.021	0.024	0.500	0.025	0.023	0.020	19.620	0.00	0.34	0.19	0.00	0.20	0.36	0.49	1.58
	16	0.387	0.407	0.451	0.500	0.475	0.429	0.387	0.000	0.021	0.024	0.500	0.025	0.023	0.020	19.160	0.00	0.33	0.19	0.00	0.20	0.35	0.48	1.55
	17	0.774	0.774	0.857	0.950	0.903	0.815	0.774	0.000	0.041	0.045	0.050	0.048	0.043	0.000	6.900	0.00	0.62	0.34	0.00	0.36	0.65	0.00	1.98
	18	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	5.518	0.00	0.64	0.34	0.00	0.35	0.00	0.00	1.33
	19	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	5.379	0.00	0.62	0.33	0.00	0.34	0.00	0.00	1.29
	20	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	6.391	0.00	0.61	0.32	0.00	0.34	0.00	0.86	2.12
	21	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	5.101	0.00	0.59	0.31	0.00	0.33	0.00	0.00	1.23
	22	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	4.962	0.00	0.57	0.30	0.00	0.32	0.00	0.00	1.19
	23	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	4.823	0.00	0.56	0.29	0.00	0.31	0.00	0.00	1.16
	24	0.857	0.857	0.903	0.950	0.950	0.903	0.857	0.000	0.045	0.048	0.050	0.000	0.000	0.000	3.601	0.00	0.57	0.30	0.00	0.00	0.00	0.00	0.87
	25	0.857	0.857	0.903	0.950	0.950	0.903	0.857	0.000	0.045	0.048	0.050	0.000	0.000	0.000	3.494	0.00	0.55	0.29	0.00	0.00	0.00	0.00	0.84
	26	0.857	0.857	0.903	0.950	0.950	0.903	0.857	0.000	0.045	0.048	0.050	0.000	0.000	0.000	3.387	0.00	0.54	0.28	0.00	0.00	0.00	0.00	0.82
	27	0.857	0.857	0.903	0.950	0.950	0.903	0.857	0.000	0.045	0.048	0.050	0.000	0.000	0.000	3.298	0.00	0.52	0.27	0.00	0.00	0.00	0.00	0.80
	28	0.857	0.857	0.903	0.950	0.950	0.903	0.857	0.000	0.045	0.048	0.050	0.000	0.000	0.000	3.191	0.00	0.50	0.27	0.00	0.00	0.00	0.00	0.77
	29	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	2.108	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.26
	30	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	2.035	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.25
	31	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	1.962	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.24
	32	0.857	0.857	0.857	0.950	0.903	0.857	0.857	0.000	0.000	0.045	0.050	0.048	0.000	0.000	2.763	0.00	0.00	0.22	0.00	0.23	0.00	0.00	0.45
	33	0.857	0.857	0.857	0.950	0.903	0.857	0.857	0.000	0.000	0.045	0.050	0.048	0.000	0.000	2.656	0.00	0.00	0.21	0.00	0.22	0.00	0.00	0.43
	34	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	1.743	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.21
	35	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	1.670	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.20
	36	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	1.597	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.19
	37	0.903	0.903	0.903	0.950	0.950	0.903	0.903	0.000	0.000	0.048	0.050	0.000	0.000	0.000	1.523	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.19
	38	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.744	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.377	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.17
	40	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.304	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.16
	41	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.231	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.15
	42	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.158	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.14
	43	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.085	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.13
	44	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.012	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.12
	45	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.938	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.11
	46	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.865	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.11
	47	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.792	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.10
	48	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.731	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.09
	49	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.658	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.08
	50	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.585	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.07
	51	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.512	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.06
	52	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.439	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.05
	53	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.366	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.04
	54	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.293	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.04
	55	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.219	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03
	56	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.146	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02
	57	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.073	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
	58	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXAMPLE CALCULATION NO 3

PROJECT:

CENTENNIAL BRIDGE

CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED

CRACKED WIRES IN ADJACENT PANELS

fract crkd, p_k		fract uncr, q_k		redevelopment factor, C_α					broken wires		fraction of circle	
p_2 =	0.00	q_2 =	1.00	panel	1	2 & 3	4 & 5	6 & 7	Total Group 4	2175	all sectors	0.125
p_3 =	0.05	q_3 =	0.95	C_α	0.00	0.25	0.50	0.75	Group 4 w/o Broken	2069		
p_4 =	0.50	q_4 =	0.50						Factor	0.951		

SEGMENT		TOTAL WIRES IN RING	NO WIRES IN SEGM n_i	RANGE 1							RANGE 2							RANGE 3						
				k = CORROSION STAGE IN PANEL i							p_{ij} = FRACTION WIRES CRACKED IN PANEL i							q_{ij} = FRACTION WIRES NOT CRACKED IN PANEL						
				(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)						
SECTOR	RING			75-76 7	76-77 5	77-78 3	**77-78** 1 **EVAL**	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6
5	1	344.4	43.1	4	4	4	**4**	4	4	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	2	338.4	42.3	4	4	4	**4**	4	4	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	3	332.4	41.5	4	4	4	**4**	4	3	4	0.5	0.5	0.5	0.5	0.5	0.05	0.5	0.5	0.5	0.5	0.5	0.5	0.95	0.5
	4	326.3	40.8	3	4	4	**4**	4	3	4	0.05	0.5	0.5	0.5	0.5	0.05	0.5	0.95	0.5	0.5	0.5	0.5	0.95	0.5
	5	320.3	40.0	3	4	3	**4**	4	3	4	0.05	0.5	0.05	0.5	0.5	0.05	0.5	0.95	0.5	0.95	0.5	0.5	0.95	0.5
	6	314.2	39.3	2	3	3	**4**	3	3	4	0	0.05	0.05	0.5	0.05	0.05	0.5	1	0.95	0.95	0.5	0.95	0.95	0.5
	7	308.2	38.5	2	3	3	**4**	3	3	3	0	0.05	0.05	0.5	0.05	0.05	0.05	1	0.95	0.95	0.5	0.95	0.95	0.95
	8	302.1	37.8	2	3	3	**4**	3	2	3	0	0.05	0.05	0.5	0.05	0	0.05	1	0.95	0.95	0.5	0.95	1	0.95
	9	296.1	37.0	2	3	3	**4**	3	2	3	0	0.05	0.05	0.5	0.05	0	0.05	1	0.95	0.95	0.5	0.95	1	0.95
	10	290.1	36.3	2	3	3	**4**	3	2	3	0	0.05	0.05	0.5	0.05	0	0.05	1	0.95	0.95	0.5	0.95	1	0.95
	11	284.0	35.5	2	3	3	**4**	3	2	3	0	0.05	0.05	0.5	0.05	0	0.05	1	0.95	0.95	0.5	0.95	1	0.95
	12	278.0	34.7	2	3	3	**4**	3	2	3	0	0.05	0.05	0.5	0.05	0	0.05	1	0.95	0.95	0.5	0.95	1	0.95
	13	271.9	34.0	2	3	3	**4**	3	2	3	0	0.05	0.05	0.5	0.05	0	0.05	1	0.95	0.95	0.5	0.95	1	0.95
	14	265.9	33.2	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	15	259.8	32.5	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	16	253.8	31.7	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	17	247.8	31.0	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	18	241.7	30.2	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	19	235.7	29.5	2	2	3	**3**	3	2	3	0	0	0.05	0.05	0.05	0	0.05	1	1	0.95	0.95	0.95	1	0.95
	20	229.6	28.7	2	2	3	**3**	3	1	3	0	0	0.05	0.05	0.05	0	0.05	1	1	0.95	0.95	0.95	1	0.95
	21	223.6	27.9	2	2	3	**3**	3	1	3	0	0	0.05	0.05	0.05	0	0.05	1	1	0.95	0.95	0.95	1	0.95
	22	217.5	27.2	2	2	3	**3**	3	1	2	0	0	0.05	0.05	0.05	0	0	1	1	0.95	0.95	0.95	1	1
	23	211.5	26.4	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	24	205.5	25.7	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	25	199.4	24.9	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	26	193.4	24.2	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	27	187.3	23.4	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	28	181.3	22.7	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	29	175.2	21.9	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	30	169.2	21.2	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	31	163.2	20.4	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	32	157.1	19.6	2	2	2	**3**	3	1	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	33	151.1	18.9	2	2	2	**2**	3	1	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	34	145.0	18.1	2	2	2	**2**	3	1	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	35	139.0	17.4	2	2	2	**2**	3	1	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	36	132.9	16.6	2	2	2	**2**	3	1	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	37	126.9	15.9	2	2	2	**2**	3	1	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	38	120.9	15.1	2	2	2	**2**	3	1	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	39	114.8	14.4	2	2	2	**2**	3	1	1	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	40	108.8	13.6	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	41	102.7	12.8	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	42	96.7	12.1	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	43	90.6	11.3	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	44	84.6	10.6	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	45	78.6	9.8	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	46	72.5	9.1	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	47	66.5	8.3	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	48	60.4	7.6	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	49	54.4	6.8	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	50	48.3	6.0	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	51	42.3	5.3	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	52	36.3	4.5	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	53	30.2	3.8	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	54	24.2	3.0	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	55	18.1	2.3	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	56	12.1	1.5	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	57	6.0	0.8	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	58	1.0	0.1	2	2	2	**3**	3	1	1	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1

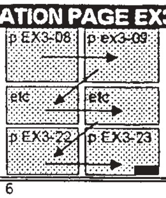
EXAMPLE CALCULATION NO 3
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

RESULTS OF THIS SPREADSHEET CALCULATION THAT ARE
USED IN STRENGTH CALCULATION ARE SHOWN IN FIELDS
ON LAST PAGE OF SPREADSHEET WITH ASTERISKS (*)

ARRANGEMENT OF PAGES >



SEGMENT		RANGE 4							RANGE 5								RANGE 6							
		e_{ij} = FRACTION WIRES NOT CRACKED IN PANEL THAT ARE ALSO NOT CRACKED IN PANELS < i							r_{ij} = FRACT DISCRETE CRCKD WIRES IN PANEL i THAT ARE NOT CRACKED IN PANELS < i							# OF WIRES CRACKED, $n_{c,j}$ $= \Sigma n_i * r_{ij}$, i = 1 thru 7	$n_{r,j}$ = # OF EFFECTIVE CRACKED WIRES IN PANEL i = $n_j * r_{ij} * C_{di}$							# CRKD WIRES REDEVELOPED IN PANEL 1 $n_{r,j}$ $= \Sigma n_{r,x}$ i = 1 thru 7
		(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)								(<<WEST) PANEL, i (EAST >>)							
SECTOR	RING	75-76 7	76-77 5	77-78 3	77-78 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	77-78 1	76-77 2	75-76 4	74-75 6		75-76 7 0.75	76-77 5 0.5	77-78 3 0.25	77-78 1 0	76-77 2 0.25	75-76 4 0.5	74-75 6 0.75	
5	1	0.008	0.031	0.125	0.500	0.250	0.063	0.016	0.008	0.031	0.125	0.500	0.250	0.063	0.016	42.044	0.25	0.66	1.32	0.00	2.65	1.32	0.50	6.70
	2	0.008	0.031	0.125	0.500	0.250	0.063	0.016	0.008	0.031	0.125	0.500	0.250	0.063	0.016	41.300	0.24	0.65	1.30	0.00	2.60	1.30	0.49	6.59
	3	0.015	0.059	0.125	0.500	0.250	0.119	0.030	0.015	0.059	0.125	0.500	0.250	0.006	0.030	40.268	0.46	1.21	1.28	0.00	2.55	0.13	0.91	6.54
	4	0.028	0.059	0.125	0.500	0.250	0.119	0.030	0.001	0.059	0.125	0.500	0.250	0.006	0.030	38.993	0.04	1.19	1.25	0.00	2.51	0.13	0.89	6.02
	5	0.054	0.113	0.238	0.500	0.250	0.226	0.056	0.003	0.113	0.013	0.500	0.250	0.012	0.056	37.383	0.08	2.23	0.12	0.00	2.47	0.23	1.67	6.81
	6	0.204	0.407	0.451	0.500	0.475	0.429	0.204	0.000	0.021	0.024	0.500	0.025	0.023	0.204	30.859	0.00	0.42	0.23	0.00	0.24	0.44	5.92	7.24
	7	0.387	0.407	0.451	0.500	0.475	0.429	0.387	0.000	0.021	0.024	0.500	0.025	0.023	0.020	23.298	0.00	0.41	0.23	0.00	0.24	0.43	0.58	1.88
	8	0.407	0.429	0.451	0.500	0.475	0.451	0.407	0.000	0.023	0.024	0.500	0.025	0.000	0.021	22.080	0.00	0.42	0.22	0.00	0.23	0.00	0.60	1.47
	9	0.407	0.429	0.451	0.500	0.475	0.451	0.407	0.000	0.023	0.024	0.500	0.025	0.000	0.021	21.635	0.00	0.41	0.22	0.00	0.23	0.00	0.59	1.44
	10	0.407	0.429	0.451	0.500	0.475	0.451	0.407	0.000	0.023	0.024	0.500	0.025	0.000	0.021	21.191	0.00	0.40	0.21	0.00	0.22	0.00	0.57	1.41
	11	0.407	0.429	0.451	0.500	0.475	0.451	0.407	0.000	0.023	0.024	0.500	0.025	0.000	0.021	20.746	0.00	0.39	0.21	0.00	0.22	0.00	0.56	1.38
	12	0.407	0.429	0.451	0.500	0.475	0.451	0.407	0.000	0.023	0.024	0.500	0.025	0.000	0.021	20.302	0.00	0.39	0.20	0.00	0.21	0.00	0.55	1.35
	13	0.407	0.429	0.451	0.500	0.475	0.451	0.407	0.000	0.023	0.024	0.500	0.025	0.000	0.021	19.857	0.00	0.38	0.20	0.00	0.21	0.00	0.54	1.32
	14	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.409	0.00	0.70	0.37	0.00	0.39	0.00	1.00	2.46
	15	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.239	0.00	0.69	0.36	0.00	0.38	0.00	0.98	2.40
	16	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.069	0.00	0.67	0.35	0.00	0.37	0.00	0.95	2.35
	17	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	6.900	0.00	0.65	0.34	0.00	0.36	0.00	0.93	2.29
	18	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	6.730	0.00	0.64	0.34	0.00	0.35	0.00	0.91	2.24
	19	0.815	0.857	0.857	0.950	0.903	0.857	0.815	0.000	0.000	0.045	0.050	0.048	0.000	0.043	5.379	0.00	0.00	0.33	0.00	0.34	0.00	0.93	1.60
	20	0.815	0.857	0.857	0.950	0.903	0.857	0.815	0.000	0.000	0.045	0.050	0.048	0.000	0.043	5.240	0.00	0.00	0.32	0.00	0.34	0.00	0.91	1.56
	21	0.815	0.857	0.857	0.950	0.903	0.857	0.815	0.000	0.000	0.045	0.050	0.048	0.000	0.043	5.101	0.00	0.00	0.31	0.00	0.33	0.00	0.88	1.52
	22	0.857	0.857	0.857	0.950	0.903	0.857	0.857	0.000	0.000	0.045	0.050	0.048	0.000	0.000	3.815	0.00	0.00	0.30	0.00	0.32	0.00	0.00	0.62
	23	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.535	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.31
	24	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.462	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.30
	25	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.389	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.29
	26	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.316	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.28
	27	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.255	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.27
	28	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.182	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.27
	29	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.108	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.26
	30	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.035	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.25
	31	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.962	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.24
	32	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.889	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.23
	33	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.931	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.23
	34	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.894	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.22
	35	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.856	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.21
	36	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.819	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.20
	37	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.781	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.20
	38	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.744	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.19
	39	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.706	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.18
	40	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.304	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.16
	41	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.231	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.15
	42	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.158	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.14
	43	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.085	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.13
	44	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	1.012	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.12
	45	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.938	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.11
	46	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.865	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.11
	47	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.792	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.10
	48	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.731	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.09
	49	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.658	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.08
	50	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.585	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.07
	51	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.512	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.06
	52	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.439	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.05
	53	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.366	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.04
	54	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.293	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.04
	55	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.219	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03
	56	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.146	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02
	57	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.073	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
	58	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	0.012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXAMPLE CALCULATION NO 3

PROJECT:

CENTENNIAL BRIDGE

CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED

CRACKED WIRES IN ADJACENT PANELS

fract crkd, p_k		fract uncr, q_k		redevelopment factor, C_d					broken wires		fraction of circle	
p_2 =	0.00	q_2 =	1.00	panel	1	2 & 3	4 & 5	6 & 7	Total Group 4	2175	all sectors	0.125
p_3 =	0.05	q_3 =	0.95	C_d	0.00	0.25	0.50	0.75	Group 4 w/o Broken	2069		
p_4 =	0.50	q_4 =	0.50						Factor	0.951		

SEGMENT SECTOR	SEGMENT RING	TOTAL WIRES IN RING	NO WIRES IN SEGM n_i	RANGE 1 k = CORROSION STAGE IN PANEL i (<<WEST) PANEL, i (EAST >>)							RANGE 2 p_{ij} = FRACTION WIRES CRACKED IN PANEL i (<<WEST) PANEL, i (EAST >>)							RANGE 3 q_{ij} = FRACTION WIRES NOT CRACKED IN PANEL (<<WEST) PANEL, i (EAST >>)						
				75-76 7	76-77 5	77-78 3	**77-78 1 EVAL**	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78 1**	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78 1**	76-77 2	75-76 4	74-75 6
6	1	344.4	43.1	4	4	4	**4**	4	2	4	0.5	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5
	2	338.4	42.3	3	4	4	**4**	4	3	4	0.05	0.5	0.5	0.5	0.5	0.05	0.5	0.95	0.5	0.5	0.5	0.5	0.95	0.5
	3	332.4	41.5	3	4	4	**4**	4	3	4	0.05	0.5	0.5	0.5	0.5	0.05	0.5	0.95	0.5	0.5	0.5	0.5	0.95	0.5
	4	326.3	40.8	3	3	4	**4**	4	3	4	0.05	0.05	0.5	0.5	0.5	0.05	0.5	0.95	0.95	0.5	0.5	0.5	0.95	0.5
	5	320.3	40.0	2	3	4	**4**	4	2	3	0	0.05	0.5	0.5	0.5	0	0.05	1	0.95	0.5	0.5	0.5	1	0.95
	6	314.2	39.3	2	3	3	**4**	3	2	2	0	0.05	0.05	0.5	0.05	0	0	1	0.95	0.95	0.5	0.95	1	1
	7	308.2	38.5	2	3	3	**4**	3	2	2	0	0.05	0.05	0.5	0.05	0	0	1	0.95	0.95	0.5	0.95	1	1
	8	302.1	37.8	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	9	296.1	37.0	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	10	290.1	36.3	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	11	284.0	35.5	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	12	278.0	34.7	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	13	271.9	34.0	2	3	3	**3**	3	2	3	0	0.05	0.05	0.05	0.05	0	0.05	1	0.95	0.95	0.95	0.95	1	0.95
	14	265.9	33.2	2	3	3	**3**	3	2	2	0	0.05	0.05	0.05	0.05	0	0	1	0.95	0.95	0.95	0.95	1	1
	15	259.8	32.5	2	3	3	**4**	3	2	2	0	0.05	0.05	0.5	0.05	0	0	1	0.95	0.95	0.5	0.95	1	1
	16	253.8	31.7	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	17	247.8	31.0	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	18	241.7	30.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	19	235.7	29.5	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	20	229.6	28.7	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	21	223.6	27.9	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	22	217.5	27.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	23	211.5	26.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	24	205.5	25.7	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	25	199.4	24.9	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	26	193.4	24.2	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	27	187.3	23.4	2	2	2	**2**	3	2	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	28	181.3	22.7	2	2	2	**2**	3	2	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	29	175.2	21.9	2	2	2	**2**	3	2	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	30	169.2	21.2	2	2	2	**2**	3	2	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	31	163.2	20.4	2	2	2	**2**	3	2	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	32	157.1	19.6	2	2	2	**2**	3	2	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	33	151.1	18.9	2	2	2	**2**	3	1	1	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	34	145.0	18.1	2	2	2	**2**	3	1	1	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	35	139.0	17.4	2	2	2	**2**	3	1	1	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	36	132.9	16.6	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	37	126.9	15.9	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	38	120.9	15.1	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	39	114.8	14.4	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	40	108.8	13.6	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	41	102.7	12.8	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	42	96.7	12.1	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	43	90.6	11.3	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	44	84.6	10.6	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	45	78.6	9.8	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	46	72.5	9.1	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	47	66.5	8.3	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	48	60.4	7.6	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	49	54.4	6.8	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	50	48.3	6.0	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	51	42.3	5.3	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	52	36.3	4.5	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	53	30.2	3.8	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	54	24.2	3.0	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	55	18.1	2.3	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	56	12.1	1.5	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	57	6.0	0.8	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	58	1.0	0.1	2	2	2	**2**	2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1

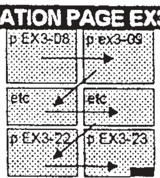
EXAMPLE CALCULATION NO 3
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

RESULTS OF THIS SPREADSHEET CALCULATION THAT ARE
USED IN STRENGTH CALCULATION ARE SHOWN IN FIELDS
ON LAST PAGE OF SPREADSHEET WITH ASTERISKS (*)

ARRANGEMENT OF PAGES >



SEGMENT		RANGE 4							RANGE 5								RANGE 6							
		e_{ij} = FRACTION WIRES NOT CRACKED IN PANEL THAT ARE ALSO NOT CRACKED IN PANELS < i							r_{ij} = FRACT DISCRETE CRCKD WIRES IN PANEL i THAT ARE NOT CRACKED IN PANELS < i							# OF WIRES CRACKED, $n_{c,j} = \Sigma n_i * r_{ij}$, i = 1 thru 7	$n_{r,ij}$ = # OF EFFECTIVE CRACKED WIRES IN PANEL $i = n_j * r_{ij} * C_{di}$							# CRKD WIRES REDEVELOPED IN PANEL 1 $n_{r,j} = \Sigma n_{r,ij}$ i = 1 thru 7
		(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)								(<<WEST) PANEL, i (EAST >>)							
SECTOR	RING	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6		75-76 7 0.75	76-77 5 0.5	77-78 3 0.25	**77-78** 1 0	76-77 2 0.25	75-76 4 0.5	74-75 6 0.75	
6	1	0.016	0.063	0.125	0.500	0.250	0.125	0.031	0.016	0.063	0.125	0.500	0.250	0.000	0.031	41.713	0.50	1.32	1.32	0.00	2.65	0.00	0.99	6.79
	2	0.028	0.059	0.125	0.500	0.250	0.119	0.030	0.001	0.059	0.125	0.500	0.250	0.006	0.030	40.451	0.05	1.24	1.30	0.00	2.60	0.13	0.93	6.24
	3	0.028	0.059	0.125	0.500	0.250	0.119	0.030	0.001	0.059	0.125	0.500	0.250	0.006	0.030	39.722	0.05	1.21	1.28	0.00	2.55	0.13	0.91	6.13
	4	0.054	0.113	0.125	0.500	0.250	0.119	0.056	0.003	0.006	0.125	0.500	0.250	0.006	0.056	37.975	0.08	0.12	1.25	0.00	2.51	0.13	1.70	5.79
	5	0.113	0.119	0.125	0.500	0.250	0.125	0.113	0.000	0.006	0.125	0.500	0.250	0.000	0.006	35.044	0.00	0.12	1.23	0.00	2.47	0.00	0.18	4.00
	6	0.429	0.429	0.451	0.500	0.475	0.451	0.429	0.000	0.023	0.024	0.500	0.025	0.000	0.000	22.138	0.00	0.44	0.23	0.00	0.24	0.00	0.00	0.91
	7	0.429	0.429	0.451	0.500	0.475	0.451	0.429	0.000	0.023	0.024	0.500	0.025	0.000	0.000	21.710	0.00	0.43	0.23	0.00	0.24	0.00	0.00	0.89
	8	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	6.910	0.00	0.80	0.42	0.00	0.44	0.00	0.00	1.66
	9	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	6.771	0.00	0.78	0.41	0.00	0.43	0.00	0.00	1.63
	10	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	6.631	0.00	0.77	0.40	0.00	0.42	0.00	0.00	1.59
	11	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	6.492	0.00	0.75	0.39	0.00	0.42	0.00	0.00	1.56
	12	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	6.353	0.00	0.73	0.39	0.00	0.41	0.00	0.00	1.53
	13	0.774	0.815	0.857	0.950	0.903	0.857	0.774	0.000	0.043	0.045	0.050	0.048	0.000	0.041	7.578	0.00	0.72	0.38	0.00	0.40	0.00	1.02	2.52
	14	0.815	0.815	0.857	0.950	0.903	0.857	0.815	0.000	0.043	0.045	0.050	0.048	0.000	0.000	6.075	0.00	0.70	0.37	0.00	0.39	0.00	0.00	1.46
	15	0.429	0.429	0.451	0.500	0.475	0.451	0.429	0.000	0.023	0.024	0.500	0.025	0.000	0.000	18.282	0.00	0.36	0.19	0.00	0.20	0.00	0.00	0.75
	16	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	3.047	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.37
	17	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.974	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.36
	18	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.488	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	19	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.754	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.34
	21	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	2.681	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.33
	22	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.338	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	23	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	2.462	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.60
	25	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.225	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	2.316	0.00	0.56	0.00	0.00	0.00	0.00	0.00	0.56
	27	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	1.156	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.29
	28	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	1.119	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.28
	29	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	1.081	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.27
	30	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	1.044	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.26
	31	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	1.006	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.25
	32	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.969	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.24
	33	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.931	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.23
	34	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.894	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.22
	35	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.856	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.21
	36	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	37	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	41	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	42	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	43	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	44	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	45	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	46	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	47	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	48	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	49	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	51	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	52	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	53	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	54	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	55	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	56	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	57	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	58	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXAMPLE CALCULATION NO 3

PROJECT:
CENTENNIAL BRIDGE

CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

fract crkd, p_k		fract uncr, q_k		redevelopment factor, C_α					broken wires		fraction of circle	
p_2 =	0.00	q_2 =	1.00	panel	1	2 & 3	4 & 5	6 & 7	Total Group 4	2175	all sectors	0.125
p_3 =	0.05	q_3 =	0.95	C_α	0.00	0.25	0.50	0.75	Group 4 w/o Broken	2069		
p_4 =	0.50	q_4 =	0.50						Factor	0.951		

SEGMENT		TOTAL WIRES IN RING	NO WIRES IN SEGM n_i	RANGE 1							RANGE 2							RANGE 3						
				k = CORROSION STAGE IN PANEL i							p_{ij} = FRACTION WIRES CRACKED IN PANEL i							q_{ij} = FRACTION WIRES NOT CRACKED IN PANEL						
				(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)						
SECTOR	RING			75-76 7	76-77 5	77-78 3	**77-78** 1 EVAL	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** 1	76-77 2	75-76 4	74-75 6
7	1	344.4	43.1	3	3	2	**4**	4	2	2	0.05	0.05	0	0.5	0.5	0	0	0.95	0.95	1	0.5	0.5	1	1
	2	338.4	42.3	3	3	2	**4**	3	3	2	0.05	0.05	0	0.5	0.05	0.05	0	0.95	0.95	1	0.5	0.95	0.95	1
	3	332.4	41.5	2	3	2	**4**	3	2	2	0	0.05	0	0.5	0.05	0	0	1	0.95	1	0.5	0.95	1	1
	4	326.3	40.8	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	5	320.3	40.0	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	6	314.2	39.3	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	7	308.2	38.5	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	8	302.1	37.6	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	9	296.1	37.0	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	10	290.1	36.3	2	2	2	**3**	3	2	2	0	0	0	0.05	0.05	0	0	1	1	1	0.95	0.95	1	1
	11	284.0	35.5	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	12	278.0	34.7	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	13	271.9	34.0	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	14	265.9	33.2	2	2	2	**4**	3	2	2	0	0	0	0.5	0.05	0	0	1	1	1	0.5	0.95	1	1
	15	259.8	32.5	2	2	2	**2**	3	2	2	0	0	0	0	0.05	0	0	1	1	1	1	0.95	1	1
	16	253.8	31.7	2	3	2	**2**	3	2	2	0	0.05	0	0	0.05	0	0	1	0.95	1	1	0.95	1	1
	17	247.8	31.0	2	3	2	**2**	3	2	2	0	0.05	0	0	0.05	0	0	1	0.95	1	1	0.95	1	1
	18	241.7	30.2	2	3	2	**2**	3	2	2	0	0.05	0	0	0.05	0	0	1	0.95	1	1	0.95	1	1
	19	235.7	29.5	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	20	229.6	28.7	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	21	223.6	27.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	22	217.5	27.2	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	23	211.5	26.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	24	205.5	25.7	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	25	199.4	24.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	26	193.4	24.2	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	27	187.3	23.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	28	181.3	22.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	29	175.2	21.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	30	169.2	21.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	31	163.2	20.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	32	157.1	19.6	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	33	151.1	18.9	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	34	145.0	18.1	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	35	139.0	17.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	36	132.9	16.6	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	37	126.9	15.9	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	38	120.9	15.1	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	39	114.8	14.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	40	108.8	13.6	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	41	102.7	12.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	42	96.7	12.1	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	43	90.6	11.3	2	2	2	**3**	2	2	1	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	44	84.6	10.6	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	45	78.6	9.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	46	72.5	9.1	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	47	66.5	8.3	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	48	60.4	7.6	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	49	54.4	6.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	50	48.3	6.0	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	51	42.3	5.3	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	52	36.3	4.5	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	53	30.2	3.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	54	24.2	3.0	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	55	18.1	2.3	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	56	12.1	1.5	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	57	6.0	0.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	58	1.0	0.1	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1

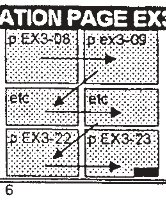
EXAMPLE CALCULATION NO 3
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

RESULTS OF THIS SPREADSHEET CALCULATION THAT ARE
USED IN STRENGTH CALCULATION ARE SHOWN IN FIELDS
ON LAST PAGE OF SPREADSHEET WITH ASTERISKS (*)

ARRANGEMENT OF PAGES >



SEGMENT		RANGE 4							RANGE 5								RANGE 6							
		e_{ij} = FRACTION WIRES NOT CRACKED IN PANEL THAT ARE ALSO NOT CRACKED IN PANELS < i							r_{ij} = FRACT DISCRETE CRCKD WIRES IN PANEL i THAT ARE NOT CRACKED IN PANELS < i							# OF WIRES CRACKED. $n_{c,j}$ $= \Sigma n_i * r_{ij}$, i = 1 thru 7	$n_{r,ij}$ = # OF EFFECTIVE CRACKED WIRES IN PANEL i = $n_j * r_{ij} * C_{di}$							# CRKD WIRES REDEVELOPED IN PANEL 1 $n_{r,j}$ $= \Sigma n_{r,ij}$ i = 1 thru 7
		(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)								(<<WEST) PANEL, i (EAST >>)							
SECTOR	RING	75-76	76-77	77-78	**77-78**	76-77	75-76	74-75	75-76	76-77	77-78	**77-78**	76-77	75-76	74-75		75-76	76-77	77-78	**77-78**	76-77	75-76	74-75	
		7	5	3	**1**	2	4	6	7	5	3	**1**	2	4	6		7	5	3	**1**	2	4	6	
																	0.75	0.5	0.25	0	0.25	0.5	0.75	
7	1	0.226	0.238	0.250	0.500	0.250	0.250	0.238	0.012	0.013	0.000	0.500	0.250	0.000	0.000	32.814	0.38	0.26	0.00	0.00	2.65	0.00	0.00	3.29
	2	0.407	0.429	0.475	0.500	0.475	0.451	0.429	0.021	0.023	0.000	0.500	0.025	0.024	0.000	24.673	0.67	0.47	0.00	0.00	0.26	0.49	0.00	1.89
	3	0.451	0.451	0.475	0.500	0.475	0.475	0.451	0.000	0.024	0.000	0.500	0.025	0.000	0.000	22.430	0.00	0.49	0.00	0.00	0.26	0.00	0.00	0.74
	4	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.723	0.00	0.91	0.00	0.00	0.48	0.00	0.00	1.38
	5	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.634	0.00	0.89	0.00	0.00	0.47	0.00	0.00	1.36
	6	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.527	0.00	0.87	0.00	0.00	0.46	0.00	0.00	1.33
	7	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.420	0.00	0.86	0.00	0.00	0.45	0.00	0.00	1.31
	8	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.313	0.00	0.84	0.00	0.00	0.44	0.00	0.00	1.28
	9	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.206	0.00	0.82	0.00	0.00	0.43	0.00	0.00	1.26
	10	0.903	0.903	0.903	0.950	0.903	0.903	0.903	0.000	0.000	0.000	0.050	0.048	0.000	0.000	3.486	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.42
	11	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	4.992	0.00	0.79	0.00	0.00	0.42	0.00	0.00	1.21
	12	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	4.885	0.00	0.77	0.00	0.00	0.41	0.00	0.00	1.18
	13	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	4.778	0.00	0.76	0.00	0.00	0.40	0.00	0.00	1.15
	14	0.475	0.475	0.475	0.500	0.475	0.475	0.475	0.000	0.000	0.000	0.500	0.025	0.000	0.000	17.194	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.20
	15	0.950	0.950	0.950	1.000	0.950	0.950	0.950	0.000	0.000	0.000	0.000	0.050	0.000	0.000	1.600	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.40
	16	0.903	0.903	0.950	1.000	0.950	0.950	0.903	0.000	0.048	0.000	0.000	0.050	0.000	0.000	3.047	0.00	0.74	0.00	0.00	0.39	0.00	0.00	1.13
	17	0.903	0.903	0.950	1.000	0.950	0.950	0.903	0.000	0.048	0.000	0.000	0.050	0.000	0.000	2.974	0.00	0.72	0.00	0.00	0.38	0.00	0.00	1.11
	18	0.903	0.903	0.950	1.000	0.950	0.950	0.903	0.000	0.048	0.000	0.000	0.050	0.000	0.000	2.901	0.00	0.71	0.00	0.00	0.37	0.00	0.00	1.08
	19	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	21	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	22	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	23	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	25	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	27	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.156	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.119	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	31	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.931	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.894	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	35	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.856	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.819	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	37	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.781	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.744	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.706	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.669	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	41	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	42	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	43	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.556	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	44	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	45	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	46	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	47	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	48	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	49	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	51	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	52	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	53	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	54	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	55	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	56	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	57	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	58	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

EXAMPLE CALCULATION NO 3
PROJECT:
CENTENNIAL BRIDGE

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

fract crkd, p_k		fract uncr, q_k		redevelopment factor, C_α					broken wires		fraction of circle	
p_2 =	0.00	q_2 =	1.00	panel	1	2 & 3	4 & 5	6 & 7	Total Group 4	2175	all sectors	0.125
p_3 =	0.05	q_3 =	0.95	C_α	0.00	0.25	0.50	0.75	Group 4 w/o Broken	2069		
p_4 =	0.50	q_4 =	0.50						Factor	0.951		

SEGMENT		TOTAL WIRES IN RING	NO WIRES IN SEGM n_i	RANGE 1							RANGE 2							RANGE 3						
				k = CORROSION STAGE IN PANEL i							p_{ij} = FRACTION WIRES CRACKED IN PANEL i							q_{ij} = FRACTION WIRES NOT CRACKED IN PANEL						
				(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)						
SECTOR	RING			75-76 7	76-77 5	77-78 3	**77-78** **1** **EVAL**	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6
8	1	344.4	43.1	3	4	2	**4**	4	2	2	0.05	0.5	0	0.5	0.5	0	0	0.95	0.5	1	0.5	0.5	1	1
	2	338.4	42.3	3	4	2	**4**	3	3	2	0.05	0.5	0	0.5	0.05	0.05	0	0.95	0.5	1	0.5	0.95	0.95	1
	3	332.4	41.5	2	4	2	**4**	3	2	2	0	0.5	0	0.5	0.05	0	0	1	0.5	1	0.5	0.95	1	1
	4	326.3	40.8	2	4	2	**3**	3	2	2	0	0.5	0	0.05	0.05	0	0	1	0.5	1	0.95	0.95	1	1
	5	320.3	40.0	2	3	2	**3**	3	2	2	0	0.05	0	0.05	0.05	0	0	1	0.95	1	0.95	0.95	1	1
	6	314.2	39.3	2	3	2	**3**	2	2	2	0	0.05	0	0.05	0	0	0	1	0.95	1	0.95	1	1	1
	7	308.2	38.5	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	8	302.1	37.8	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	9	296.1	37.0	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	10	290.1	36.3	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	11	284.0	35.5	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	12	278.0	34.7	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	13	271.9	34.0	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	14	265.9	33.2	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	15	259.8	32.5	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	16	253.8	31.7	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	17	247.8	31.0	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	18	241.7	30.2	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	19	235.7	29.5	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	20	229.6	28.7	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	21	223.6	27.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	22	217.5	27.2	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	23	211.5	26.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	24	205.5	25.7	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	25	199.4	24.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	26	193.4	24.2	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	27	187.3	23.4	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	28	181.3	22.7	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	29	175.2	21.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	30	169.2	21.2	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	31	163.2	20.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	32	157.1	19.6	2	2	2	**3**	2	2	2	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	33	151.1	18.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	34	145.0	18.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	35	139.0	17.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	36	132.9	16.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	37	126.9	15.9	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	38	120.9	15.1	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	39	114.8	14.4	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	40	108.8	13.6	2	2	2	**2**	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	41	102.7	12.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	42	96.7	12.1	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	43	90.6	11.3	2	2	2	**3**	2	2	1	0	0	0	0.05	0	0	0	1	1	1	0.95	1	1	1
	44	84.6	10.6	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	45	78.6	9.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	46	72.5	9.1	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	47	66.5	8.3	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	48	60.4	7.6	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	49	54.4	6.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	50	48.3	6.0	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	51	42.3	5.3	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	52	36.3	4.5	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	53	30.2	3.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	54	24.2	3.0	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	55	18.1	2.3	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	56	12.1	1.5	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	57	6.0	0.8	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	58	1.0	0.1	2	2	2	**2**	2	2	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	sum =	79920	9990																					
	sum/8 =	9990																						

EXAMPLE CALCULATION NO 3

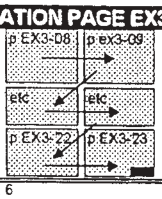
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ALL PANELS IN EFFECTIVE LENGTH ARE INSPECTED
CRACKED WIRES IN ADJACENT PANELS

RESULTS OF THIS SPREADSHEET CALCULATION THAT ARE
USED IN STRENGTH CALCULATION ARE SHOWN IN FIELDS
ON LAST PAGE OF SPREADSHEET WITH ASTERISKS (*)

ARRANGEMENT OF PAGES >



SEGMENT		RANGE 4							RANGE 5								RANGE 6							
		e_{ij} = FRACTION WIRES NOT CRACKED IN PANEL THAT ARE ALSO NOT CRACKED IN PANELS < i							r_{ij} = FRACT DISCRETE CRCKD WIRES IN PANEL i THAT ARE NOT CRACKED IN PANELS < i							# OF WIRES CRACKED. $n_{c,j} = \Sigma n_i * r_{ij}$, i = 1 thru 7	$n_{r,ij}$ = # OF EFFECTIVE CRACKED WIRES IN PANEL i = $n_j * r_{ij} * C_{di}$							# CRKD WIRES REDEVELOPED IN PANEL 1, $n_r = \Sigma n_{r,ij}$ i = 1 thru 7
		(<<WEST) PANEL, i (EAST >>)							(<<WEST) PANEL, i (EAST >>)								(<<WEST) PANEL, i (EAST >>)							
SECTOR	RING	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6	75-76 7	76-77 5	77-78 3	**77-78** **1**	76-77 2	75-76 4	74-75 6		75-76 7 0.75	76-77 5 0.5	77-78 3 0.25	**77-78** **1** 0	76-77 2 0.25	75-76 4 0.5	74-75 6 0.75	
8	1	0.119	0.125	0.250	0.500	0.250	0.250	0.125	0.006	0.125	0.000	0.500	0.250	0.000	0.000	37.343	0.20	2.65	0.00	0.00	2.65	0.00	0.00	5.50
	2	0.214	0.226	0.475	0.500	0.475	0.451	0.226	0.011	0.226	0.000	0.500	0.025	0.024	0.000	32.703	0.35	4.70	0.00	0.00	0.26	0.49	0.00	5.80
	3	0.238	0.238	0.475	0.500	0.475	0.475	0.238	0.000	0.238	0.000	0.500	0.025	0.000	0.000	31.167	0.00	4.85	0.00	0.00	0.26	0.00	0.00	5.11
	4	0.451	0.451	0.903	0.950	0.903	0.903	0.451	0.000	0.451	0.000	0.050	0.048	0.000	0.000	22.019	0.00	9.05	0.00	0.00	0.48	0.00	0.00	9.53
	5	0.857	0.857	0.903	0.950	0.903	0.903	0.857	0.000	0.045	0.000	0.050	0.048	0.000	0.000	5.634	0.00	0.89	0.00	0.00	0.47	0.00	0.00	1.36
	6	0.903	0.903	0.950	0.950	0.950	0.950	0.903	0.000	0.048	0.000	0.050	0.000	0.000	0.000	3.778	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.92
	7	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.900	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.863	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.825	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.788	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.750	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	16	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	19	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	21	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	22	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	23	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	25	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	27	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.156	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.119	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	31	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	35	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	37	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	41	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	42	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	43	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.556	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	44	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	45	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	46	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	47	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	48	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	49	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	51	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	52	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	53	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	54	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	55	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	56	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	57	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	58	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum =															totals	2420.4	10.4	118.2	49.6	0.0	131.6	9.6	61.5	380.8
sum/8 =																								

EVAL
1 EVAL
2 EVAL
3 EVAL
4

# of cracked wires, $N_{c,k}$, by stage		Adjst	$N_{c,k}$ Without Broken Wires * by group		rounded to nearest integer	
stage or group	$N_{c,k} = \Sigma(n_{c,ik})$	Factor	$N_{c,k}$	CARRIED TO STRENGTH CALCULATION	Adjust eff # redev crkd for broken wires *	
1	0.0	1.000			factor = $(N-N_c+N_r)/N$	0.989
2	25.3	1.000	25		where N = 9842	CARRIED TO STRENGTH CALCULATION
3	738.8	1.000	739		N_c-N_r = 106	
4	1656.3	0.951	1576			
total	2420.4		2340		eff # redev crkd. N_{cr}	377

EXAMPLE CALCULATION NO 3		BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
PROJECT:		**STEP BS(adj)-1**
CENTENNIAL BRIDGE		DATA FROM INSPECTION
CABLE	SOUTH	FRACTION OF CABLE IN EACH CORROSION STAGE
SPAN	EAST MAIN SPAN	ADJUSTMENT FOR CRACKED WIRES
PANEL	77-78	

FRACTION OF CABLE IN EACH CORROSION STAGE

	source >	p EX1-12	p EX3-02		calc	calc	p EX1-11
corrosion stage k		number of wires in each stage N_{sk}	net number of broken wires N_b-N_r		number of unbroken wires N_{0k}	fraction unbroken in each stage p_{0k}	fraction of each stage cracked $p_{c,k}$
1		0			0	0.000	
2		2274			2274	0.230	
3		5541			5541	0.561	0.05
4		2175	106		2069	0.209	0.50
total	N =	9990	106	N_{eff} =	9884	1.000	

IN THIS TABLE:

N_{0k} IS CALCULATED BY EQUATIONS 5.3.2.3-1 TO 3, $N_{0k} = N_{sk} - N_b + N_r$

p_{0k} IS CALCULATED AS N_{0k} / N_{eff}. THIS VALUE IS GIVEN FOR INFORMATION ONLY AND IS NOT USED IN FURTHER CALCULATIONS.

FRACTION OF CABLE REPRESENTED BY EACH GROUP OF WIRES

	source >	above	p EX3-23	calc	calc
wire group k		number of unbroken wires N_{0k}	discrete cracked wires in L_e $N_{c,k}$	number of wires in each group N_k	fraction of cable in each group p_k
2	stages 1 + 2 not cracked	2274	26	2248	0.227
3	stage 3 not cracked	5541	750	4791	0.485
4	stage 4 not cracked	2069	1600	469	0.047
5	all cracked wires			2376	0.240
totals		9884	2376	9884	1.000

from page EX3-23, eff no redev cracked, N_{cr} = 383

N_{cr}/N_5 = 0.1612

IN THIS TABLE:

N_{0k} FOR GROUP 2 IS THE SUM OF THE VALUES OF N_{0k} FOR STAGES 1 & 2

N_k IS CALCULATED BY EQUATION 5.3.2.5-2, $N_k = N_{0k} - N_{c,k}$

p_k IS CALCULATED BY EQUATION 5.3.2.6-1, $p_k = N_k / N_{eff}$

EXAMPLE CALCULATION NO 3	BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
PROJECT:	**STEP BS(adj)-2**
CENTENNIAL BRIDGE	CALCULATION OF WEIBULL DISTRIBUTION PARAMETERS

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

THE MEAN AND STANDARD DISTRIBUTION OF THE TENSILE STRENGTH OF EACH GROUP OF WIRES DETERMINED FROM THE LABORATORY TESTS ARE USED TO DETERMINE THE PARAMETERS OF THE WEIBULL DISTRIBUTIONS. THE METHOD PRESENTED IN APPENDIX A, ARTICLE A.4.2 IS USED BELOW. THE VALUE OF x_0 IS TAKEN AS ZERO AND THIS TERM IS OMITTED IN THE EQUATIONS SHOWN IN THE CALCULATION BELOW

TENSILE STRENGTH DISTRIBUTION FOR EACH WIRE CLASS

		source	wire group			
			good	fair	poor	cracked
k = corrosion stage of group			2	3	4	5
mean tensile strength, μ_s	ksi	p EX1-11	239.0	235.9	231.1	200.5
standard deviation, σ_s	ksi	p EX1-11	4.3	5.7	8.7	26.3
ALPHA (shape parameter) = m			70.6	52.4	33.4	9.1
BETA (υ)			240.9	238.4	235.0	211.6
x_0	ksi		0.00	0.00	0.00	0.00

CALCULATION OF WEIBULL PARAMETERS

	wire group					Excel
k = corrosion stage of group	0	2	3	4	5	parameter
m (assumed, then determined by solver)	This column may be used to develop the Weibull parameters for new wire if desired	**70.6**	**52.4**	**33.4**	**9.1**	alpha
(Γ = GAMMA function) $\Gamma(1+2/m)$		0.9844	0.9793	0.9688	0.9133	
$\Gamma(1+1/m)$		0.9920	0.9893	0.9836	0.9475	
$\Gamma(1+2/m)/\Gamma^2(1+1/m)$		1.0003	1.0006	1.0014	1.0172	
σ^2		18.490	32.490	75.690	691.690	
μ^2		57121	55649	53407	40200	
σ^2/μ^2		3.2E-04	5.8E-04	1.4E-03	1.7E-02	
SOLVE FOR m USING SOLVER: Equation A.4.2-6 is solved for m by making the value of the expression $\Gamma(1+2/m)/\Gamma^2(1+1/m) - 1 - \sigma^2/\mu^2$ equal to zero by varying m, using the "Solver" routine in Excel:						
$\Gamma(1+2/m)/\Gamma^2(1+1/m) - 1 - \sigma^2/\mu^2 = 0$		**-4.7E-10**	**-8.1E-10**	**-4.9E-10**	**2.6E-10**	
CALCULATE υ: The value of (υ) is found by solving Equation A.4.2-4 for this expression and substituting the value of m found above:						
$\upsilon = \mu/\Gamma(1+1/m)$		**240.9**	**238.4**	**235.0**	**211.6**	beta

EXAMPLE CALCULATION NO 3	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED

STEP BS(adj)-3

FORCE IN EVALUATED PANEL IN WIRES THAT ARE BROKEN IN ADJACENT PANELS

ARTICLE 5.3.4, EQUATION 5.3.4-2

ALL THE PANELS WITHIN THE EFFECTIVE DEVELOPMENT LENGTH FOR PANELM77-78 ARE INSPECTED, AND THE NUMBER OF BROKED WIRES IN EACH PANEL IS KNOWN. EQUATION 5.3.4-2 IS USED TO CALCULATE THE CONTRIBUTION OF THE BROKEN WIRES TO THE CABLE STRENGTH.

THE DATA NEEDED ARE:

EFFECTIVE DEVELOPMENT LENGTH	L_{eff}	7	PANELS
NOMINAL AREA OF ONE WIRE	a_w	0.0290	SQ IN
MEAN TENSILE STRENGTH OF GROUP 2 WIRES	μ_{s2}	239	KSI
REDEVELOPMENT COEFFICIENT	C_d	0.25	

NET NUMBER OF BROKEN WIRES IN EACH PANEL

	source >>		p. EX3-02
	bridge panel	calc panel i	net no broken $n_{bi} - n_{ri}$
	75-76	7	11
	76-77	5	6
	77-78	3	46
evaluated panel >>	**77-78**	**1**	12
	76-77	2	12
	75-76	4	3
	74-75	6	16

THE VALUE OF THE EXPRESSION INSIDE THE SUMMATION SIGN IN EQUATION 5.3.4-2, $p_i * (n_{bi}-n_{ri}) * C_d$, IS CALCULATED FOR EACH PANEL AND THE VALUES ARE SUMMED:

for panel 7, $p_7 = 3$, $p_7 * (n_{b7}-n_{r7}) * C_d = 3 * 11 * 0.25 =$	8.25
for panel 5, $p_5 = 2$, $p_5 * (n_{b5}-n_{r5}) * C_d = 2 * 6 * 0.25 =$	3.00
for panel 3, $p_3 = 1$, $p_3 * (n_{b3}-n_{r3}) * C_d = 1 * 46 * 0.25 =$	11.50
for panel 1, $p_1 = 0$, $p_1 * (n_{b1}-n_{r1}) * C_d = 0 * 12 * 0.25 =$	0.00
for panel 2, $p_2 = 1$, $p_2 * (n_{b2}-n_{r2}) * C_d = 1 * 12 * 0.25 =$	3.00
for panel 4, $p_4 = 2$, $p_4 * (n_{b4}-n_{r4}) * C_d = 2 * 3 * 0.25 =$	1.50
for panel 6, $p_6 = 3$, $p_6 * (n_{b6}-n_{r6}) * C_d = 3 * 16 * 0.25 =$	12.00
total $= \Sigma\, p_i * (n_{bi}-n_{ri}) * C_d =$	39.25

THE FORCE IN THE EVALUATED PANEL ATTRIBUTABLE TO WIRES THAT ARE BROKEN IN OTHER PANELS IS CALCULATED BY EQUATION 5.3.4-2:

$$R_b = a_w * (0.95 * \mu_{S2}) * \Sigma\, p_i * (n_{bi}-n_{ri}) * C_d$$
$$= 0.0290 * 0.95 * 239 * 39.25$$

$R_b =$ 258 KIPS

EXAMPLE CALCULATION NO 3		BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
PROJECT: CENTENNIAL BRIDGE		**STEP BS(adj)-4A**
CABLE	SOUTH	CALCULATION OF CABLE FORCE AT STRESS, s
SPAN	EAST MAIN SPAN	COMPOUND CUMULATIVE DISTRIBUTION
PANEL	77-78	OF TENSILE STRENGTH

THE CABLE DATA NEEDED TO DEVELOP THE COMPOUND CUMULATIVE DISTRIBUTION OF THE TENSILE STRENGTH ARE THE FRACTION OF UNBROKEN WIRES IN THE CABLE REPRESENTED BY EACH GROUP OF WIRES AND THE WEIBULL PARAMETERS FOR EACH GROUP. THESE ARE:

wire group	k	2	3	4	5
fraction of cable	p_k	0.228	0.486	0.050	0.237
Weibull parameters	m	70.6	52.4	33.4	9.1
	υ	240.9	238.4	235.0	211.6

THE VALUE OF THE CUMULATIVE WEIBULL DISTRIBUTION FOR TENSILE STRENGTH AT A SPECIFIC STRESS, s, IS GIVEN BY EQUATION 5.3.3.2.1-1. THIS EQUATION REQUIRES THE SUMMING UP OF THE WEIBULL DISTRIBUTIONS FOR EACH GROUP OF WIRES MULTIPLIED BY THE FRACTION OF THE UNBROKEN WIRES IN THE CABLE REPRESENTED BY EACH GROUP. IN THE FOLLOWING CALCULATION, THE VALUE OF THE WEIBULL DISTRIBUTION FOR THE INDIVIDUAL GROUPS IS CALCULATED, THEN SUMMED. THE EXAMPLE CALCULATION IS MADE FOR s = **220** KSI.

$F_c(s) = \Sigma p_k * F3_k(s)$ EQUATION 5.3.3.2.1-1

CUMULATIVE WEIBULL DISTRIBUTIONS FOR TENSILE STRENGTH (EQUATION A.4.2-1):

$F3_k(s) = 1 - e\text{^}(-(s/\upsilon)\text{^}m) = 1 - e\text{^}(-(220/240.9)\text{^}70.6)$

$F3_2(220) =$ 0.0016
$F3_3(220) =$ 0.0147
$F3_4(220) =$ 0.1054
$F3_5(220) =$ 0.7599

CUMULATIVE DISTRIBUTIONS MULTIPLIED BY FRACTION REPRESENTED BY EACH GROUP:

$p_k * F3_k(s) = 0.230 * 0.0016$

$p_2{*}F3_2(220) =$ 0.0004
$p_3{*}F3_3(220) =$ 0.0071
$p_4{*}F3_4(220) =$ 0.0053
$p_5{*}F3_5(220) =$ 0.1799

$F_c(s) = \Sigma p_k * F3_k(s)$

$F_c(200) =$ 0.1926

EXAMPLE CALCULATION NO 3
PROJECT:
CENTENNIAL BRIDGE

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED

STEP BS(adj)-4B

CALCULATION OF CABLE FORCE AT STRESS, s

THE DEVELOPMENT OF THE VALUE OF THE CUMULATIVE COMPOUND DISTRIBUTION AT A STRESS OF 220 KSI IS SUMMARIZED BELOW. THIS VALUE IS THEN USED TO CALCULATE THE CABLE TENSION AT A STRESS LEVEL OF 220 KSI. THE REDEVELOPED FORCE IN THE CRACKED WIRES THAT ARE BROKEN AT THIS STRESS AND THE REDEVELOPED FORCE IN THE WIRES FOUND BROKEN IN THE CABLE ARE THEN ADDED TO FIND THE TOTAL FORCE IN THE CABLE WHEN THE STRESS IN THE EVALUATED PANEL IS 220 KSI.

STRESS **s = 220 KSI**

p_2*F3$_2$(s) = 0.0004
p_3*F3$_3$(s) = 0.0071
p_4*F3$_4$(s) = 0.0050
p_5*F3$_5$(s) = 0.1827

CUMULATIVE DISTRIBUTION OF TENSILE STRENGTH **$F_c(s)$ = 0.1951**

EQUATION 5.3.3.2.2-1 GIVES THE CABLE FORCE IN THE UNBROKEN WIRES IN THE CABLE AT THE STRESS, s

NEEDED DATA:			
	NUMBER OF UNBROKEN WIRES IN CABLE	N_{eff} =	9884 WIRES
	NET STEEL AREA OF ONE WIRE	a_w =	0.0290 SQ IN

$T_u = N_{eff} * a_w * (s * (1 - F_c(s)) = 9884 * .0290 * 220 * (1- .1951)$ **T_u = 50672 KIPS**

THE FORCE THAT IS REDEVELOPED IN GROUP 5 (CRACKED) WIRES THAT ARE BROKEN AT STRESS s IS CALCULATED USING EQUATION 5.3.3.2.3-1.

EFFECTIVE NUMBER OF REDEVELOPED CRACKED WIRES IN ADJACENT PANELS WHEN ALL CRACKED WIRES BREAK	N_{cr} =	383 WIRES (p EX3-24)
MEAN TENSILE STRENGTH OF GROUP 2 WIRES	μ_{s2} =	239 KSI
FRACTION OF STAGE 5 WIRES BROKEN AT STRESS s	F3$_5$(s)	0.7599 (p EX3-27)

$T_{cr}(s) = N_{cr} * a_w * (0.95 * \mu_{s2}) * F3_5(s)$
$= 383 * .0290 * 0.95 * 239 * 0.7599$ **$T_{cr}(s)$ = 1913 KIPS**

THE FORCE THAT CAN BE DEVELOPED IN THE EVALUATED PANEL THROUGH FRICTION AT CABLE BANDS IN THE WIRES THAT ARE FOUND BROKEN WITHIN THE EFFECTIVE DEVELOPMENT LENGTH IS GIVEN BY EQUATION 5.3.4-2 ON PAGE EX3-26

CAPACITY IN EVALUATED PANEL OF WIRES FOUND BROKEN **R_b = 258 KIPS**

AT STRESSES LESS THAN ABOUT 75% OF THE MEAN TENSILE STRENGTH OF GROUP 2 WIRES, THE FORCE IN BROKEN WIRES AND IN BROKEN CRACKED WIRES MAY BE OVERSTATED, BUT THIS WILL NOT AFFECT THE CABLE STRENGTH, WHICH IS USUALLY DETERMINED AT A GREATER STRESS . THE TOTAL FORCE IN THE CABLE IN THE EVALUATED PANEL AT STRESS s IS:

TOTAL FORCE IN CABLE AT STRESS s = T = $T_u + T_{cr}(s) + R_b$ **T = 52,843 KIPS**

EXAMPLE CALCULATION NO 3	BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
PROJECT:	**STEP BS(adj)-5**
CENTENNIAL BRIDGE	CALCULATION OF CABLE STRENGTH

CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

THE DEVELOPMENT OF THE FORCE, T, IN THE CABLE AT STRESS s IS ILLUSTRATED ON THE PREVIOUS PAGE, AND IS SUMMARIZED BELOW. THE CABLE STRENGTH IS FOUND BY VARYING THE STRESS s TO MAXIMIZE T USING "SOLVER" IN EXCEL. A VALUE OF s IS ASSUMED; THE VALUE OF s CORRESPONDING TO THE CABLE STRENGTH REPLACES THIS ASSUMED VALUE DURING ITERATION.

STRESS **s = 214.5 KSI**

$F3_2(s) =$	0.00028	$p_2 * F3_2(s) =$	0.00006
$F3_3(s) =$	0.00396	$p_3 * F3_3(s) =$	0.00192
$F3_4(s) =$	0.04705	$p_4 * F3_4(s) =$	0.00235
$F3_5(s) =$	0.67841	$p_5 * F3_5(s) =$	0.16061
CUMULATIVE DISTRIBUTION OF TENSILE STRENGTH		$F_c(s) =$	0.16495

EQUATION 5.3.3.2.2-1 GIVES THE CABLE FORCE IN THE UNBROKEN WIRES IN THE CABLE AT THE STRESS, s

$T_u = N_{eff} * a_w * (s * (1 - F_c(s)) = 9870 * .0290 * s * (1- F_c(s))$ $T_u =$ 51270 KIPS

THE FORCE THAT IS REDEVELOPED IN GROUP 5 (CRACKED) WIRES THAT ARE BROKEN AT STRESS s IS CALCULATED USING EQUATION 5.3.3.2.3-1.

$$T_{cr}(s) = N_{cr} * a_w * (0.95 * \mu_{s2}) * F3_5(s)$$
$$= 994 * .0290 * 0.95 * 239 * F3_5(s)$$

$T_{cr}(s) =$ 1681 KIPS

THE FORCE THAT CAN BE DEVELOPED IN THE EVALUATED PANEL THROUGH FRICTION AT CABLE BANDS IN THE WIRES THAT ARE FOUND BROKEN WITHIN THE EFFECTIVE DEVELOPMENT LENGTH IS GIVEN BY EQUATION 5.3.4-2 (ON PAGEEX3-26)

CAPACITY IN EVALUATED PANEL OF WIRES FOUND BROKEN $R_b =$ 258 KIPS

AT STRESSES LESS THAN ABOUT 75% OF THE MEAN TENSILE STRENGTH OF GROUP 2 WIRES, THE FORCE IN BROKEN WIRES AND IN BROKEN CRACKED WIRES MAY BE OVERSTATED, BUT THIS WILL NOT AFFECT THE CABLE STRENGTH, WHICH IS USUALLY DETERMINED AT A STRESS GREATER THAN THIS. THE TOTAL FORCE IN THE CABLE IN THE EVALUATED PANEL AT A STRESS s IS THE SUM OF T_u, $T_{cr}(s)$ AND R_b.

THE CABLE STRENGTH IS FOUND BY VARYING THE STRESS s TO MAXIMIZE THE TOTAL CABLE FORCE USING "SOLVER" IN THE EXCEL SPREADSHEET PROGRAM:

CABLE STRENGTH IS MAXIMUM FORCE ACHIEVED

$\text{MAX } T = \text{MAX}(T_u + T_{cr}(s) + R_b)$ R = 53,209 KIPS

EXAMPLE CALCULATION NO 3A	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

EXAMPLE CALCULATION NO 3A

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LENGTH INSPECTED (CONDENSED FORMAT)

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EXAMPLE CALCULATION NO 3A	**BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED**
PROJECT:	**STEPS D(adj)-4, BS(adj)-1 AND BS(adj)-2**
CENTENNIAL BRIDGE	**CONDENSED FORMAT - SUMMARY OF CORROSION STAGES AND CABLE STRENGTH**

CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

CABLE STRENGTH =	53,092	kips
@ STRESS =	214	ksi
WIRES REMAIN = 0.83372 x 9884 =	8,240	wires

NO OF WIRES PER STRAND =	**270**
NO OF STRANDS IN CABLE =	**37**
TOTAL NO OF WIRES IN CABLE =	**9990**
NET WIRE DIAMETER (INCHES) =	**0.192**
AREA OF ONE WIRE SQ IN) =	**0.0290**

NOTE: SHADED AREAS REQUIRE INPUT FOR EACH PANEL

NO OF BROKEN WIRES IN EFFECTIVE DEVELOPMENT LENGTH & EFFECTIVE NO OF UNBROKEN WIRES IN PANEL

effective development length = 7 panels

C_d = 0.25

panel number i		p_i	number of wires observed broken: total	outer layer $n_{t1,i}$	depth at which no broken wires are found d_n	estimat'd number broken n_{ti}	number repaired n_{ri}	redeveloped broken wires $p_i*(n_{ti}-n_{ri})*C_d$
7		3	4	4	7	14	3	8.25
5		2	15	6	7	21	15	3
3		1	22	19	7	67	21	11.5
1	evaluat'd panel	0	8	5	7	18	6	0
2		1	20	9	7	32	20	3
4		2	1	1	7	4	1	1.5
6		3	12	8	7	28	12	12
				totals	N_t =	184	78	

NO OF BROKEN WIRES IN EFFECTIVE DEVELOPMENT LENGTH = N_t-N_r = 106

NO OF UNBROKEN WIRES = N - N_t + N_r = N_{eff} = 9884

EFFECTIVE NUMBER OF BROKEN WIRES THAT ARE REDEVELOPED = $n_{t,1}$* 0.5*(L_e-1) = 39.25

FRACTION OF CABLE IN EACH CORROSION STAGE

	source >	p EX1-12	above	calc	calc	p EX1-11		p EX3-23
corrosion stage k		number of wires in each stage N_{sk}	net number of broken wires N_b-N_r	number of unbroken wires N_{0k}	fraction unbroken in each stage p_{0k}	fraction of each stage cracked p_{ck}		number of cracked wires that are redeveloped $N_{cr k}/N_{0k})*N_{0k}$
1		0		0	0.000	0.00		
2		2274		2274	0.230	0.00		
3		5541		5541	0.561	0.05		
4		2175	106	2069	0.209	0.50		
total	N =	9990	106	9884	1.000	eff no redev cracked, N_{cr} =		383

FRACTION OF CABLE REPRESENTED BY EACH GROUP OF WIRES

	source >	above	p EX3-23	calc	calc	calc
wire group k		number of unbroken wires N_{0k}	cracked wires in eff dev length N_{ck}	number of wires in each group N_k	fraction of cable in each group p_k	fraction of Group 5 that are redeveloped N_{cr}/N_5
2	stages 1 + 2 not cracked	2274	26	2248	0.227	
3	stage 3 not cracked	5541	750	4791	0.485	
4	stage 4 not cracked	2069	1600	469	0.047	
5	cracked wires, all stages			2376	0.240	0.161
totals		9884	2376	9884	1.000	

WIRE STRENGTH DISTRIBUTION FOR EACH GROUP OF WIRES

		source	wire group: new	good	fair	poor	cracked
k = corrosion stage of group			0	2	3	4	5
mean tensile strength, μ_k	ksi	p. EX1-11		239.0	235.9	231.1	200.5
standard deviation, σ_k	ksi	p. EX1-11		4.3	5.7	8.7	26.3
ALPHA (shape parameter) = m		calc		70.6	52.4	33.4	9.1
BETA (υ)		calc		240.9	238.4	235.0	211.6
x_0	ksi	assumed		0.0	0.0	0.0	0.0

CALCULATION OF WEIBULL PARAMETERS

		wire group: 0	2	3	4	5	Excel parameter
k = corrosion stage of group		0	2	3	4	5	
m (assumed, then determined by solver)		This column may be used to develop the Weibull parameters for new wire if desired	70.6	52.4	33.4	9.1	alpha
(Γ = GAMMA function)	$\Gamma(1+2/m)$		0.9844	0.9793	0.9688	0.9133	
	$\Gamma(1+1/m)$		0.9920	0.9893	0.9836	0.9475	
	$\Gamma(1+2/m)/\Gamma^2(1+1/m)$		1.0003	1.0006	1.0014	1.0172	
	σ^2		18.490	32.490	75.690	691.690	
SOLVE FOR m USING SOLVER BY	μ^2		57121	55649	53407	40200	
VARYING m TO MAKE THIS EQUATION	σ^2/μ^2		0.000324	0.000584	0.001417	0.017206	
EQUAL TO ZERO >>>	$\Gamma(1+2/m)/\Gamma^2(1+1/m) - 1 - \sigma^2/\mu^2 = 0$		-4.72E-10	-8.10E-10	-4.90E-10	2.60E-10	
CALCULATE υ:	$\upsilon = \mu/\Gamma(1+1/m)$		240.9	238.4	235.0	211.6	beta

EXAMPLE CALCULATION NO 3A		BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
PROJECT:		**STEPS BS(adj)-3 TO BS(adj)-5**
CENTENNIAL BRIDGE		CONDENSED FORMAT - STRENGTH CALCULATION (SHORT FORMAT)
CABLE	SOUTH	**CABLE STRENGTH = 53,209 kips**
SPAN	EAST MAIN SPAN	**STRESS AT FAILURE = 215 ksi**
PANEL	77-78	

number of unbroken wires in thecable	N_{eff} =	9884	wires
net steel area of one wire	a_w =	0.0290	sq in
effective number of broken wires that are redeveloped	$n_{t\cdot1}{}^*C_{deff}$ =	39.25	
mean tensile strength of Group 2 wires	μ_{s2} =	239	ksi
fraction of Group 5 wires that are redeveloped	N_{cr}/N_5 =	0.161	

wire group	k	2	3	4	5
fraction of cable	p_k	0.228	0.486	0.050	0.237
weibull parameters: alpha	m	70.6	52.4	33.4	9.1
beta	υ	240.9	238.4	235.0	211.6

	wire group				
STRESS		s =	220		214.5 ksi
fraction of cable represented by each group	2	$p_2{}^*F3_2(s)$ =	0 0004		0.0001
x cumulative distribution of tensile strength for each group	3	$p_3{}^*F3_3(s)$ =	0.0071		0.0019
of wires = p_k * $F3_k(s)$ = p_k * (1 - EXP(- ((s/υ)^m)))	4	$p_4{}^*F3_4(s)$ =	0.0053		0.0023
or, in Excel, = p_k * WEIBULL(s, alpha, beta, true)	5	$p_5{}^*F3_5(s)$ =	0.1799		0.1606
total = compound cumulative distribution = $F_c(s) = \Sigma p_k$ * $F3_k(s)$		$F_c(s)$ =	0.1926	$F_c(s)$ =	0.1649
FORCE IN UNBROKEN WIRES IN CABLE = N_{eff} * a_w * (s * (1 - $F_c(s)$))		T_u =	50829	R_u =	51270 kips
fraction of cracked wires that are broken at stress s		$F3_5(s)$ =	0.7599	$F3_5(s)$ =	0.6784
fraction of group 5 wires redeveloped at stress s		$p_{cr}(s)$ =	0.122	$p_{cr}(s)$ =	0.109
FORCE REDEV IN CRKD WIRES BROKEN AT STRESS s = $N_{eff}{}^*a_w{}^*p_5{}^*p_{cr}(s)^*(0.95^*\mu_{s2})$		$T_{cr}(s)$ =	1883	$R_{cr}(s)$ =	1681 kips
CAPACITY IN EVALUATED PANEL OF WIRES FOUND BROKEN = $N_{redev}{}^*(0.95^*\mu_{s2})$		R_b =	258	R_b =	258 kips
FORCE IN CABLE		T =	52970 kips		
CABLE STRENGTH = MAXIMUM FORCE				R =	53209 kips

(cable strength is found by maximizing T by varying s, using Solver in the Excel spreadsheet program)

EXAMPLE CALCULATION NO 3A	
PROJECT:	
CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

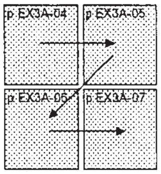
BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED

STEPS BS(adj)-3 TO BS(adj)-5

CONDENSED FORMAT

STRENGTH CALCULATION (LONG FORMAT)

ARRANGEMENT OF PAGES >



BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER
106 BROKEN WIRES (N_b), **39** REDEVELOPED BROKEN WIRES (N_{redev})
9990 TOTAL WIRES IN CABLE (N) AND **2376** DISCRETE CRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

	EVALUATED PANEL						**EVALUATED PANEL & ADJ PNLS**		
	Group 2 (Stages 1 & 2 without cracks)		**Group 3 (Stage 3 without cracks)**		**Group 4 (Stage 4 without cracks)**		**Group 5 (cracked wires, all stages)**		
p_k =	**0.2274**		**0.4847**		**0.0475**		**0.2404**		
mean =	239		235.9		231.1		200.5		
std dev =	4.3		5.7		8.7		26.3		
distr type=	WEIBULL		WEIBULL		WEIBULL		WEIBULL		fraction of
	alpha =	70.6	alpha =	52.4	alpha =	33.4	alpha =	9.1	failed redev
	beta =	240.9	beta =	238.4	beta =	235.0	beta =	211.6	N_{cr}/N_c =
	x_0 =	0.0	x_0 =	0.0	x_0 =	0.0	x_0 =	0.0	0.161
	good		fair		poor		crkd		crkd redev
stress	$p_2{*}f3_2(s)$	$p_2{*}(1-F3_2(s))$	$p_3{*}f3_3(s)$	$p_3{*}(1-F3_3(s))$	$p_4{*}f3_4(s)$	$p_4{*}(1-F3_4(s))$	$p_5{*}f3_5(s)$	$p_5{*}(1-F3_5(s))$	$p_5{*}p_{cr}(s)$
	eq A.4.2-2	see eq A.4.2-1	eq A.4.2-2	see eq A.4.2-1	eq A.4.2-2	see eq A.4.2-1	eq A.4.2-2	see eq A.4.2-1	p_5*eq B.5-1
	fract wires	fraction	fract wires	fraction	fract wires	fraction	fract wires	fraction	=(p_5 -
incr =		of wires		of wires		of wires		of wires	$p_5{*}(1-F3_5(s)))$
2		remaining		remaining		remaining		remaining	* N_{cr}/N_c
100	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0000	0.2401	0.0000
102	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0000	0.2401	0.0000
104	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0000	0.2400	0.0001
106	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0000	0.2400	0.0001
108	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0000	0.2399	0.0001
110	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0001	0.2398	0.0001
112	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0001	0.2397	0.0001
114	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0001	0.2395	0.0001
116	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0001	0.2394	0.0002
118	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0001	0.2392	0.0002
120	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0001	0.2390	0.0002
122	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0001	0.2388	0.0003
124	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0001	0.2386	0.0003
126	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0002	0.2383	0.0003
128	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0002	0.2380	0.0004
130	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0002	0.2376	0.0005
132	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0002	0.2372	0.0005
134	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0002	0.2367	0.0006
136	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0003	0.2362	0.0007
138	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0003	0.2356	0.0008
140	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0004	0.2349	0.0009
142	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0004	0.2342	0.0010
144	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0004	0.2333	0.0011
146	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0005	0.2324	0.0013
148	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0005	0.2313	0.0015
150	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0006	0.2302	0.0016
152	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0007	0.2289	0.0018
154	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0007	0.2275	0.0021
156	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0008	0.2259	0.0023
158	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0009	0.2242	0.0026
160	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0010	0.2223	0.0029
162	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0011	0.2203	0.0032
164	0.0000	0.2274	0.0000	0.4847	0.0000	0.0475	0.0012	0.2180	0.0036
166	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0013	0.2155	0.0040
168	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0014	0.2128	0.0044
170	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0015	0.2099	0.0049
172	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0017	0.2067	0.0054
174	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0018	0.2033	0.0060
176	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0019	0.1995	0.0066
178	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0021	0.1955	0.0072
180	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0022	0.1913	0.0079
182	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0024	0.1867	0.0087
184	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0025	0.1818	0.0094
186	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0027	0.1766	0.0103

EXAMPLE CALCULATION NO 3A	
PROJECT: **CENTENNIAL BRIDGE**	
CABLE	**SOUTH**
SPAN	**EAST MAIN SPAN**
PANEL	**77-78**

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED

STEPS BS(adj)-3 TO BS(adj)-5

CONDENSED FORMAT

STRENGTH CALCULATION (LONG FORMAT)

Cable strength = 53,209 kips
Stress at failure = 214.5 ksi

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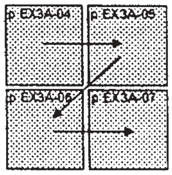


BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER
106 BROKEN WIRES (N_b), **39** REDEVELOPED BROKEN WIRES (N_{redev})
9990 TOTAL WIRES IN CABLE (N) AND **2340** DISCRETECRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

EVALUATED PANEL & ADJACENT PANELS

all wires — **stress x remaining area** — **cable force**

FORCE-STRAIN

data for force vs. strain diagram

p_k = **1.000**
mean =
std dev =
distr type= COMPOUND
compound distr curve

	panel 1	adj panels	
# crkd incl adj pnls, N_c		2340	strength of
# unbroken wires, N_{eff}	9884		redeveloped broken
area, one wire, a_w	0.0290	0.0290	wires (eq 5.2.4-2)
total area = N_{eff}*a_w	286.1706	67.74983	$R_b = N_{redev}*a_w*s_2$
0.95*mean tens strgth Stage 2 = s_2 =		227.1	258 kips

stress	all $f_c(s)$	$1-F_c(s)$	compound distr curve stress, s_1	$T_u(s)$	$T_{cr}(s)$	total force	stress	strain	force
incr = 2	$=\Sigma f3_k(s)_k$ k=2 to 5	see eq A.5.2-2 $=\Sigma(1-F3_k(s))$ k=2 to 5 =fract wire remaining	=stress * fract wire remaining	eq 5.3.3.2.2-1 $=s_1*N_{eff}*a_w$ =cbl frce	eq B.5-2 $= p_5*p_{cr}(s)$ $*s_2*N_{eff}*a_w$	$= T_u(s) +$ $T_{cr}(s) +$ R_t			in cable
			0.0	0	0	0	0	0.0000	0
100	0.0000	0.9997	100.0	28610	3	28870	100	0.0035	28,870
102	0.0000	0.9997	102.0	29181	3	29442	102	0.0035	29,442
104	0.0000	0.9996	104.0	29751	4	30013	104	0.0036	30,013
106	0.0000	0.9996	106.0	30321	5	30584	106	0.0037	30,584
108	0.0000	0.9995	107.9	30891	5	31154	108	0.0037	31,154
110	0.0001	0.9994	109.9	31460	6	31724	110	0.0038	31,724
112	0.0001	0.9993	111.9	32028	7	32294	112	0.0039	32,294
114	0.0001	0.9992	113.9	32596	9	32863	114	0.0040	32,863
116	0.0001	0.9990	115.9	33163	10	33432	116	0.0040	33,432
118	0.0001	0.9989	117.9	33729	12	33999	118	0.0041	33,999
120	0.0001	0.9987	119.8	34295	14	34567	120	0.0042	34,567
122	0.0001	0.9984	121.8	34859	16	35133	122	0.0042	35,133
124	0.0001	0.9982	123.8	35421	19	35698	124	0.0043	35,698
126	0.0002	0.9979	125.7	35982	22	36262	126	0.0044	36,262
128	0.0002	0.9976	127.7	36542	25	36825	128	0.0044	36,825
130	0.0002	0.9972	129.6	37099	29	37386	130	0.0045	37,386
132	0.0002	0.9968	131.6	37655	33	37946	132	0.0046	37,946
134	0.0002	0.9964	133.5	38207	38	38503	134	0.0046	38,503
136	0.0003	0.9958	135.4	38757	44	39059	136	0.0047	39,059
138	0.0003	0.9953	137.3	39304	50	39612	138	0.0048	39,612
140	0.0003	0.9946	139.2	39847	57	40162	140	0.0049	40,162
142	0.0004	0.9939	141.1	40387	64	40709	142	0.0049	40,709
144	0.0004	0.9930	143.0	40922	73	41253	144	0.0050	41,253
146	0.0005	0.9921	144.8	41452	83	41792	146	0.0051	41,792
148	0.0005	0.9911	146.7	41976	93	42327	148	0.0052	42,327
150	0.0006	0.9900	148.5	42495	105	42858	150	0.0052	42,858
152	0.0007	0.9887	150.3	43007	118	43383	152	0.0053	43,383
154	0.0007	0.9873	152.0	43511	133	43902	154	0.0054	43,902
156	0.0008	0.9858	153.8	44008	149	44415	156	0.0055	44,415
158	0.0009	0.9841	155.5	44495	167	44920	158	0.0056	44,920
160	0.0010	0.9822	157.2	44973	186	45417	160	0.0057	45,417
162	0.0011	0.9802	158.8	45441	207	45906	162	0.0057	45,906
164	0.0012	0.9779	160.4	45897	231	46386	164	0.0058	46,386
166	0.0013	0.9755	161.9	46341	256	46855	166	0.0059	46,855
168	0.0014	0.9728	163.4	46771	284	47313	168	0.0060	47,313
170	0.0015	0.9700	164.9	47187	315	47760	170	0.0061	47,760
172	0.0016	0.9668	166.3	47588	347	48193	172	0.0062	48,193
174	0.0018	0.9634	167.6	47972	383	48613	174	0.0063	48,613
176	0.0019	0.9598	168.9	48339	421	49019	176	0.0064	49,019
178	0.0020	0.9558	170.1	48688	462	49409	178	0.0065	49,409
180	0.0022	0.9516	171.3	49018	507	49782	180	0.0067	49,782
182	0.0023	0.9471	172.4	49327	554	50139	182	0.0068	50,139
184	0.0025	0.9423	173.4	49616	604	50478	184	0.0069	50,478
186	0.0026	0.9372	174.3	49883	658	50798	186	0.0070	50,798

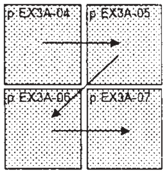
CALCULATION PAGE EX3A-06

EXAMPLE CALCULATION NO 3A
PROJECT:
CENTENNIAL BRIDGE

CABLE	**SOUTH**	
SPAN	**EAST MAIN SPAN**	
PANEL	**77-78**	

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
STEPS BS(adj)-3 TO BS(adj)-5
CONDENSED FORMAT
STRENGTH CALCULATION (LONG FORMAT)

ARRANGEMENT OF PAGES >



BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER
106 BROKEN WIRES (N_b), **39** REDEVELOPED BROKEN WIRES (N_{redev})
9990 TOTAL WIRES IN CABLE (N) AND **2376** DISCRETE CRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

	EVALUATED PANEL						**EVALUATED PANEL & ADJ PNLS**		
	Group 2 (Stages 1 & 2 without cracks)		**Group 3 (Stage 3 without cracks)**		**Group 4 (Stage 4 without cracks)**		**Group 5 (cracked wires, all stages)**		
188	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0028	0.1711	0.0112
190	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0030	0.1653	0.0121
192	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0031	0.1592	0.0131
194	0.0000	0.2274	0.0000	0.4847	0.0000	0.0474	0.0033	0.1528	0.0141
196	0.0000	0.2274	0.0000	0.4847	0.0000	0.0473	0.0034	0.1462	0.0152
198	0.0000	0.2274	0.0000	0.4847	0.0000	0.0473	0.0035	0.1393	0.0163
200	0.0000	0.2274	0.0000	0.4847	0.0000	0.0472	0.0036	0.1322	0.0174
202	0.0000	0.2274	0.0000	0.4846	0.0001	0.0471	0.0037	0.1249	0.0186
204	0.0000	0.2274	0.0000	0.4846	0.0001	0.0470	0.0038	0.1174	0.0198
206	0.0000	0.2274	0.0001	0.4845	0.0001	0.0469	0.0038	0.1099	0.0210
208	0.0000	0.2274	0.0001	0.4843	0.0001	0.0466	0.0038	0.1022	0.0223
210	0.0000	0.2274	0.0002	0.4841	0.0002	0.0463	0.0038	0.0945	0.0235
212	0.0000	0.2274	0.0003	0.4837	0.0002	0.0459	0.0038	0.0869	0.0247
214	0.0000	0.2274	0.0004	0.4830	0.0003	0.0454	0.0037	0.0793	0.0260
216	0.0000	0.2273	0.0007	0.4820	0.0004	0.0447	0.0037	0.0719	0.0272
218	0.0001	0.2272	0.0011	0.4803	0.0005	0.0437	0.0036	0.0647	0.0283
220	0.0001	0.2271	0.0017	0.4776	0.0007	0.0425	0.0034	0.0577	0.0294
222	0.0002	0.2267	0.0026	0.4734	0.0009	0.0408	0.0033	0.0511	0.0305
224	0.0004	0.2261	0.0041	0.4667	0.0012	0.0387	0.0031	0.0447	0.0315
226	0.0008	0.2250	0.0064	0.4563	0.0015	0.0361	0.0029	0.0388	0.0325
228	0.0014	0.2228	0.0097	0.4404	0.0018	0.0329	0.0026	0.0333	0.0334
230	0.0025	0.2190	0.0144	0.4166	0.0021	0.0291	0.0024	0.0283	0.0342
232	0.0045	0.2121	0.0205	0.3820	0.0023	0.0246	0.0022	0.0237	0.0349
234	0.0077	0.2002	0.0279	0.3337	0.0025	0.0198	0.0019	0.0196	0.0356
236	0.0125	0.1802	0.0350	0.2706	0.0024	0.0149	0.0017	0.0160	0.0362
238	0.0187	0.1491	0.0391	0.1957	0.0022	0.0102	0.0014	0.0129	0.0367
240	0.0238	0.1061	0.0365	0.1188	0.0018	0.0062	0.0012	0.0102	0.0371
242	0.0231	0.0578	0.0260	0.0553	0.0012	0.0033	0.0010	0.0080	0.0375
244	0.0139	0.0197	0.0123	0.0172	0.0007	0.0014	0.0008	0.0061	0.0378
246	0.0036	0.0029	0.0032	0.0029	0.0003	0.0005	0.0007	0.0046	0.0380
248	0.0002	0.0001	0.0003	0.0002	0.0001	0.0001	0.0005	0.0034	0.0382
250	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0025	0.0384
252	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0017	0.0385
254	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0012	0.0386
256	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0008	0.0386
258	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0005	0.0387
260	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0387
262	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0387
264	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0387
266	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0387
268	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0387
270	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0387
272	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0387
274	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0387
276	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0387
278	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0387
280	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0387
tot x incr	0.22744		0.4847		0.0475		0.2404		

FOR MAXIMUM CABLE FORCE = CABLE STRENGTH, USE SOLVER TO MAXIMIZE FIELD X121BY VARYING FIELD B121

214.3	0.0000	0.2274	0.0004	0.4829	0.0003	0.0453	0.0037	0.0781	0.0262

EXAMPLE CALCULATION NO 3A	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED

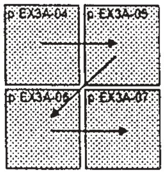
STEPS BS(adj)-3 TO BS(adj)-5

CONDENSED FORMAT

STRENGTH CALCULATION (LONG FORMAT)

Cable strength = 53,209 kips
Stress at failure = 214.5 ksi

ARRANGEMENT OF PAGES >



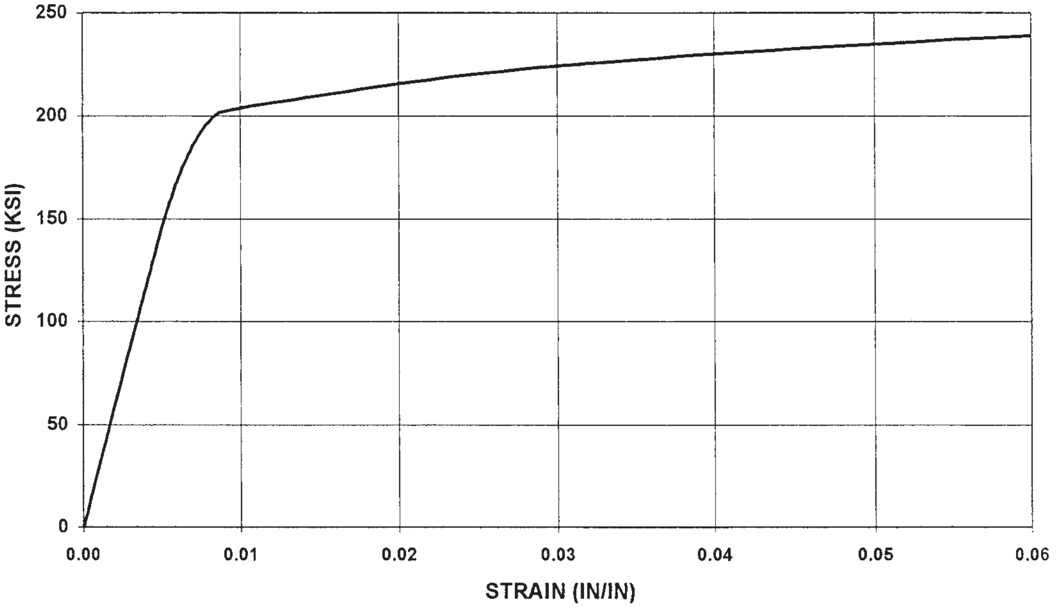
BASED ON: **270** WIRES / STRAND @ **0.192** INCH DIAMETER
106 BROKEN WIRES (N_b), **39** REDEVELOPED BROKEN WIRES (N_{redev})
9990 TOTAL WIRES IN CABLE (N) AND **2340** DISCRETECRACKED WIRES IN EFFECTIVE DEVELOPMENT LENGTH (N_5)

	EVALUATED PANEL & ADJACENT PANELS							**FORCE-STRAIN**	
	all wires		**stress x remaining area**					**data for force vs. strain diagram**	
				cable force					
188	0.0028	0.9317	175.2	50127	714	51100	188	0.0072	51,100
190	0.0029	0.9260	175.9	50350	774	51382	190	0.0073	51,382
192	0.0031	0.9200	176.6	50549	837	51644	192	0.0075	51,644
194	0.0032	0.9137	177.3	50725	903	51886	194	0.0077	51,886
196	0.0034	0.9071	177.8	50879	971	52108	196	0.0079	52,108
198	0.0035	0.9003	178.3	51011	1042	52311	198	0.0081	52,311
200	0.0036	0.8932	178.6	51120	1115	52494	200	0.0084	52,494
202	0.0037	0.8859	178.9	51208	1191	52657	202	0.0088	52,657
204	0.0038	0.8783	179.2	51276	1268	52802	204	0.0100	52,802
206	0.0039	0.8706	179.3	51323	1346	52927	206	0.0117	52,927
208	0.0040	0.8627	179.4	51350	1424	53033	208	0.0134	53,033
210	0.0041	0.8546	179.5	51356	1504	53117	210	0.0151	53,117
212	0.0043	0.8462	179.4	51337	1582	53178	212	0.0168	53,178
214	0.0045	0.8375	179.2	51289	1660	53207	214	0.0185	53,207
216	0.0047	0.8283	178.9	51201	1737	53196	216	0.0202	53,196
218	0.0052	0.8184	178.4	51057	1811	53127	218	0.0220	53,127
220	0.0059	0.8074	177.6	50829	1883	52970	220	0.0242	52,970
222	0.0071	0.7945	176.4	50473	1952	52683	222	0.0267	52,683
224	0.0088	0.7787	174.4	49919	2017	52194	224	0.0295	52,194
226	0.0115	0.7586	171.4	49062	2078	51398	226	0.0325	51,398
228	0.0156	0.7318	166.8	47745	2135	50138	228	0.0359	50,138
230	0.0215	0.6951	159.9	45749	2187	48194	230	0.0396	48,194
232	0.0297	0.6443	149.5	42779	2234	45271	232	0.0436	45,271
234	0.0401	0.5749	134.5	38497	2276	41031	234	0.0479	41,031
236	0.0519	0.4829	114.0	32614	2313	35185	236	0.0525	35,185
238	0.0616	0.3687	87.8	25114	2345	27718	238	0.0574	27,718
240	0.0634	0.2419	58.1	16613	2373	19244	240	0.0626	19,244
242	0.0514	0.1246	30.1	8626	2396	11280	242	0.0682	11,280
244	0.0278	0.0444	10.8	3099	2415	5772	244	0.0740	5,772
246	0.0078	0.0109	2.7	764	2431	3453	246	0.0801	3,453
248	0.0012	0.0038	0.9	268	2443	2969	248	0.0865	2,969
250	0.0004	0.0025	0.6	175	2453	2886	250	0.0932	2,886
252	0.0003	0.0017	0.4	124	2460	2843	252	0.1003	2,843
254	0.0002	0.0012	0.3	87	2466	2810	254	0.1076	2,810
256	0.0002	0.0008	0.2	59	2470	2787	256	0.1152	2,787
258	0.0001	0.0005	0.1	39	2473	2770	258	0.1232	2,770
260	0.0001	0.0003	0.1	25	2475	2758	260	0.1314	2,758
262	0.0001	0.0002	0.1	16	2476	2750	262	0.1400	2,750
264	0.0000	0.0001	0.0	10	2477	2745	264	0.1488	2,745
266	0.0000	0.0001	0.0	6	2478	2741	266	0.1580	2,741
268	0.0000	0.0000	0.0	3	2478	2739	268	0.1674	2,739
270	0.0000	0.0000	0.0	2	2478	2738	270	0.1772	2,738
272	0.0000	0.0000	0.0	1	2478	2737	272	0.1873	2,737
274	0.0000	0.0000	0.0	0	2478	2737	274	0.1976	2,737
276	0.0000	0.0000	0.0	0	2478	2737	276	0.2083	2,737
278	0.0000	0.0000	0.0	0	2478	2736	278	0.2193	2,736
280	0.0000	0.0000	0.0	0	2478	2736	280	0.2305	2,736
	1.0000								
214.5	0.0045	0.8351	179.2	51270	1681	53209	214.5		

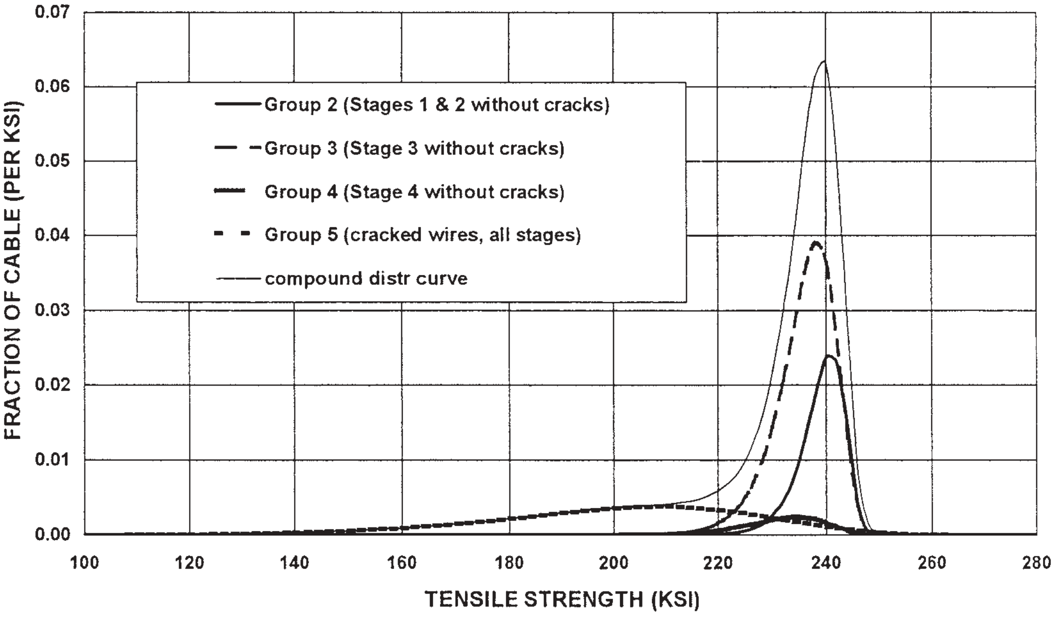
EXAMPLE CALCULATION NO 3A	
PROJECT: CENTENNIAL BRIDGE	
CABLE	SOUTH
SPAN	EAST MAIN SPAN
PANEL	77-78

BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
CONDENSED FORMAT
STRENGTH CALCULATION (LONG FORMAT)
GRAPHS: STRESS - STRAIN
TENSILE STRENGTH DISTRIBUTIONS

STRESS - STRAIN CURVE

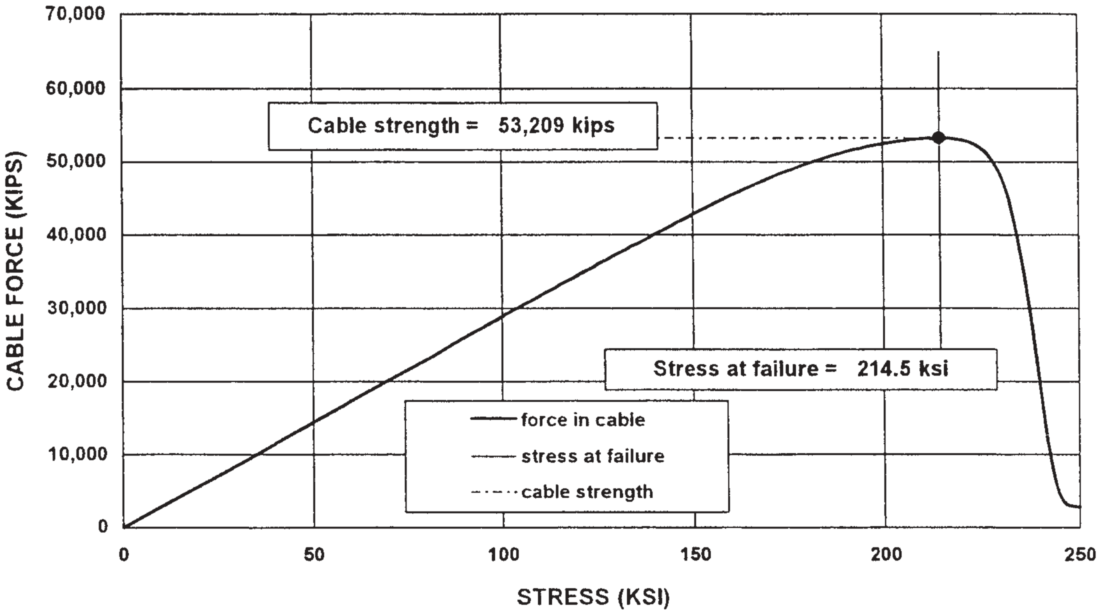


TENSILE STRENGTH DISTRIBUTION CURVES

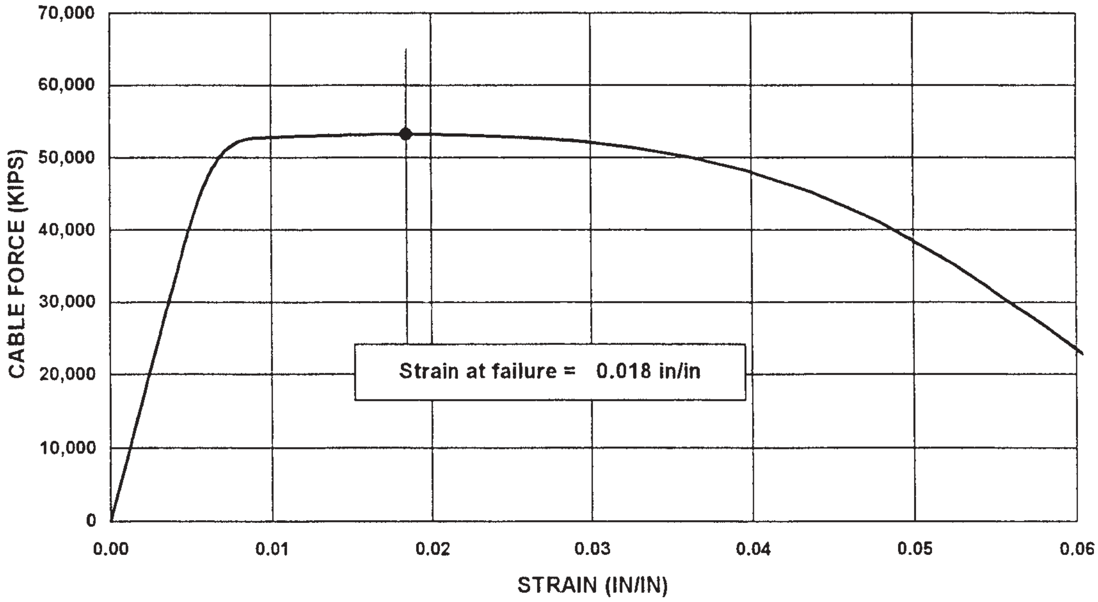


EXAMPLE CALCULATION NO 3A		BRITTLE-WIRE MODEL, ENTIRE EFFECTIVE LGTH INSPECTED
PROJECT:		CONDENSED FORMAT
CENTENNIAL BRIDGE		STRENGTH CALCULATION (LONG FORMAT)
CABLE	SOUTH	GRAPHS: CABLE FORCE VS STRESS DIAGRAM
SPAN	EAST MAIN SPAN	CABLE FORCE VS STRAIN DIAGRAM
PANEL	77-78	

CABLE FORCE VS STRESS DIAGRAM



CABLE FORCE VS STRAIN DIAGRAM



CONTENTS

D.1 SPLICING NEW WIRES INTO THE CABLE

D.1.1 Introduction

Whenever a sample wire is removed from the cable, or a broken wire is found there, it is necessary to replace the removed or corroded section of wire by splicing in a new wire. The usual method is to attach two lengths of new wire to the cut ends of the original wire with pressed-on, or swaged, ferrules, and then to connect the ends of the two new wires with a threaded ferrule that acts like a turnbuckle. The pressed-on ferrules can develop at least 90% of the strength of the wires. The threaded ferrule somewhat less, usually 75% to 85%, because of the section loss in the threads: rolled threads develop strength near the upper limit, cut threads near the lower limit.

D.1.2 Typical specification for splicing wires

D.1.2.1 WIRE SPLICING COMPONENTS

- The material for the new wires shall conform to ASTM A586 specifications for tensile strength, elongation in a 10-inch-gage length and reduction of area. Single wires of sufficient length for the longest replacement shall be provided, with a left-hand thread at one end and a right-hand thread at the other.
- Threaded ferrules, pressed-on ferrules and equipment for the installation shall be manufactured and certified subject to the engineer’s approval.

D.1.2.2 VERIFICATION TESTING OF WIRE SPLICING COMPONENTS

Verification testing shall be performed to confirm that the required specifications for these components have been met, as follows:

- Threaded ferrules shall be tested by fully connecting the ferrule to the threaded ends of two new wires. They shall develop at least 75% of the ultimate strength of the new wires.
- Pressed-on ferrules shall be tested by fully connecting the ferrule to the smooth ends of two new wires using field equipment. Pressed-on ferrules shall develop at least 90% of the ultimate strength of the new wires.
- Wires used in these tests shall have been previously tested and certified by the manufacturer and accepted.

Assemblies of ferrules and wires for testing shall be made by the contractor’s field personnel, in order to qualify them to do the work.

Testing shall be performed by an approved testing laboratory.

The wire used in verification testing shall be provided by the contractor from the lot of wire to be used in the actual work.

The sample for testing each component shall be 1% of each lot or 10 specimens, whichever is greater. A lot is defined as the number of components contained in a single shipment.

Each component shall be packed separately, and each package shall be clearly labeled, noting the specific component and the number of pieces. Packages that lack the required labeling may be returned to the place of manufacture uninspected, untested, and unaccepted. No extra compensation shall be granted, nor extension of time allowed for any delays attributable to the return of unlabeled or poorly labeled packages.

All of the specimens that constitute the first sample shall be tested before a second sample is taken. If more than one specimen from the first sample fails the required testing, then the entire lot shall be rejected. If one specimen of a sample fails the required testing, then an additional random sample, equal in number to the first sample, shall be taken. If one specimen of the second sample fails the required testing, then the entire lot shall be rejected.

The contractor is notified that the testing procedure will render the tested specimen unfit for further use, and that all tested specimens shall be discarded after testing has been completed. The contractor is advised to order a sufficient number of components to allow for testing and discards and still have enough left to do the work.

D.1.3 Wire splicing procedure

- Remove the wire sample or portion of broken wire as directed by the engineer.
- Cut one new wire into two pieces, numbered #2 and #3 on Figure D.1.3-1. Piece #2 shall be of a length that places the threaded ferrule at the desired location. One end of each of these pieces will be threaded, the other plain
- Clean the ends of wires #1 and #4 and the unthreaded ends of wires #2 and #3 to bright metal for a length of 2 inches. The (spliced) ends of wires shall be kept clean and free of dirt, oil and any other foreign material throughout the procedure.
- Connect the ends of the existing wires #1 and #4 to splice wires #2 and #3 as follows (see Figure D.1.3-1):
  - Splice existing wire end #1 to the unthreaded end of splice wire #2 using pressed-on ferrule A. This operation is shown in Figure D.1.3-2.
  - Splice the threaded end of splice wire # 2 to threaded end of splice wire #3 using threaded ferrule B.
- Tension wires #3 and #4 to a load equal to the dead load tension in the cable using come-alongs equipped with suitable wire grips. Trim the end of wire #3. A gap of approximately 1/4 to 3/8 of an inch shall be provided between wires # 3 and # 4.
- Disconnect the threaded ferrule between new wires #2 and #4.
- Splice the unthreaded ends of wires #3 and #4 using pressed-on ferrule C.
- Attach come-alongs and suitable wire grips to wires #2 and #3. Install threaded ferrule B. Tension the wire assembly to a load equal to the dead load tension in the cable. Use threaded ferrule B as a take-up system. A suitable dynamometer or load cell shall be used for wire tension control.

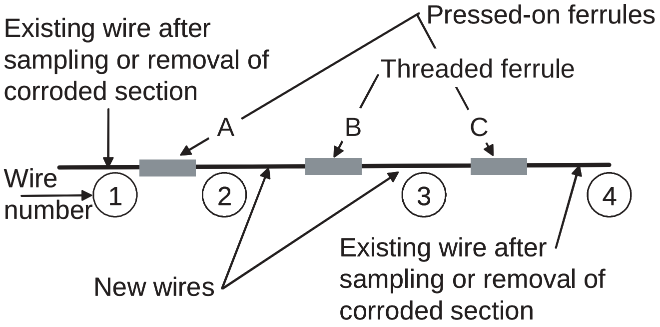


Figure D.1.3-1. Wire splicing.

Figure D.1.3-2. Applying ferrules with a hydraulic ram.

D.2 MEASURING THE WIRE TENSION

After the new wire is spliced into the cable, the tension shall be measured and adjusted to within 10% of the dead load tension in the wires. The tension is measured with the device shown in Figure D.2-1, which shall be fabricated and calibrated in advance of the work. Calibration is necessary rather than calculating the wire tension indicated by an induced offset, because the flexural stiffness of the wire as well as its cast will affect the force vs. deflection curve.

D.2.1 Calibration

Calibration shall be performed by an approved testing laboratory. A piece of bridge wire 20 feet long shall be placed in a testing machine and stressed in increments of 100 pounds. The force required to cause a deflection of the wire between the ends of the device shall be measured using the same spring balance that will be used in the field. The recommended offsets are given in Table D.2.1-1; these offsets should result in the required force of approximately 60 pounds.

Table D.2.1-1 Recommended offsets for various wire tensions

Wire Tension (pounds)	Offset (inches)
1500	0.70
2000	0.55
2500	0.45

A calibration curve shall be prepared, with applied force as the abscissa and wire tension as the ordinate. The offset used shall be shown on the calibration curve.

D.2.2 Measuring procedure

The device is held against the wire, which is in contact with the grooves in the end plates. Only enough pressure is used to achieve contact with the wire; the tube is not bent. The center hook is pulled outward with a spring balance until the offset is exactly equal to the calibration offset and the applied force is measured. The wire tension is determined from the calibration curve.

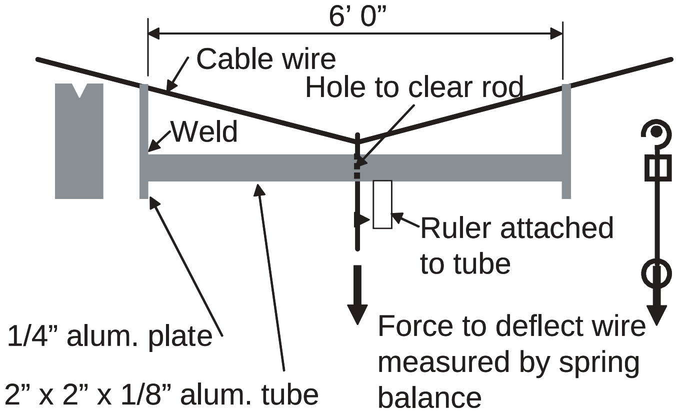


Figure D.2-1. Wire tension measuring device.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation