

## EXTENDING THE SERVICE LIFE OF EXISTING BRIDGES

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This paper briefly discusses background material and statistical data regarding the nation's current bridge problems and the research presently underway that will aid in resolving this problem. Bridge deficiencies as uncovered in the inspection of over 140 bridges located in five states are outlined. These deficiencies are categorized as Structural, Mechanical, Geometric, and Safety and are discussed as they apply to various bridge types and bridge materials. A catalog of deficiencies is included which lists the deficiencies in the order of frequency of occurrence. Bridge rehabilitation techniques presently in use are outlined and some unique techniques discussed. These include techniques to increase live load capacity, correct mechanical deficiencies, and to improve geometrics. Improvements to rideability, to safety, drainage and other miscellaneous repairs are also discussed. Sketches are included depicting the concepts of some of these rehabilitation techniques. "Improvement Factor" curves are developed for various techniques that can be utilized to increase live load capacity. This factor is an indication of the percentage of increase in flexural strength that can be achieved by a particular technique. Cost information for each of these techniques is also provided so that a "Cost Effectiveness Factor" can be computed for each. This provides a convenient means of comparison of various techniques from both a cost and an improvement standpoint.

### CHAPTER I

#### INTRODUCTION

The United States highway network, recognized by many as being the world's finest, is quietly and even more quickly being threatened by the condition of our bridges. This has become one of our Nation's greatest problems. It is difficult to understand why, in an era where we have developed enough technical knowledge and expertise to put a man on the moon, we have not had and maybe still do not have the proper foresight to provide the necessary maintenance for our Nation's bridges. As a result

of this neglect, we have seriously jeopardized not only our surface transportation system, but our lives as well.

All of our problems, of course, are not due to neglect. Many of our Nation's bridges have become functionally obsolete because of heavier vehicle usage, inadequate roadway width and antiquated alignment.

#### Status of National Bridge Inventory

Currently, it is estimated that there are 564,000 bridges in the United States of which approximately 105,500 are either considered structurally deficient or functionally obsolete. A structurally deficient bridge is one that has been restricted to light loads or closed. A functionally obsolete bridge is one whose deck geometry, clearances, approach roadway alignment and load restrictions can no longer satisfactorily service the system of which it is an integral part. The inventory and inspection of all bridges on the Federal-aid highway system, encompassing 234,000 structures, is substantially complete. This inventory has uncovered approximately 33,500 deficient bridges.<sup>(1)</sup> The remaining 72,000 deficient bridges are not on any Federal-aid system and are the sole responsibility of the state and local governments. Each year, for various reasons, an estimated 125 to 150 of these deficient bridges sag, buckle or collapse--sometimes tragically.

In an attempt to alleviate this problem, several bills regarding funding for a Special Bridge Replacement Program have been introduced in Congress and have generated a great deal of discussion. While there is a general feeling that more Federal money will become available for bridge inspection, replacement and/or rehabilitation, it is not realistic to expect that all of the deficient bridges can be attended to in a short period of time. Consequently, our direction and purpose at this time should be to initiate and develop procedures for extending the service life of existing bridges until such time as we have the money, time and manpower to replace those deficient structures in an orderly manner.

## Current Research

With this endeavor in mind, the Federal Highway Administration, in an effort to respond to the bridge problem, has sponsored a research project entitled "Extending the Service Life of Existing Bridges by Increasing Their Load Carrying Capacity." (2) Another project, sponsored by the National Cooperative Highway Research Board is entitled "Bridges on Secondary Highways and Local Roads - Rehabilitation and Replacement." (3) While these research projects do have different objectives, both are studying bridge deficiencies and various rehabilitation techniques that are currently being utilized by several different state highway departments. The results of these studies should prove invaluable to the practicing bridge engineer.

While many deficiencies are caused by normal traffic, weather and deterioration, some deficiencies are the direct result of cracks appearing in the steel. These occur in both old and new metal and in old and new designs. In an effort to detect cracks, two instruments using nondestructive test principles were developed specifically for field inspection. The Acoustic Crack Detector and the Magnetic Crack Definer were used respectively for detecting cracks in metal and for defining the limits of the cracks. Cracks have also been detected with tests involving dye penetrants, radiography, magnetic particle inspection and acoustic emission. Ongoing research in this area includes the development of equipment to identify fractures in prestressing bars used in concrete structures, the determination of stress corrosion fatigue characteristics of new steels and continued research into the toughness of weld materials.

Additional research is underway regarding bridge deck protective systems. These include studies of various membrane waterproofing systems, reinforcing bar coatings, cathodic protection, latex and low slump overlays, wax beads in the concrete and systems for heating bridge decks.

## Intent of Paper

The total bridge problem which we must resolve is obviously quite broad and has many facets. This paper will deal only with a few of these involving deficiencies and rehabilitation techniques. Certain aspects such as fatigue cracking, deck protection systems and cosmetic repairs will be touched only briefly.

## CHAPTER II

### BRIDGE DEFICIENCIES

Bridge deficiencies evolve from a variety of situations and conditions. Basic design criteria, traffic usage, environmental factors, and other site conditions are all involved to some extent and are responsible for specific deficiencies. An additional, and perhaps the most important, contributor to bridge deficiencies is the level of maintenance employed.

Deficiency causes can be categorized into two broad areas: (1) those which result from the design of the facility and are thus inherent deficiencies, and (2) those which result from the use of the facility and are essentially the result of wear. Deficiencies from either cause are subdivided into four areas: Structural, Mechanical, Geometric and Safety.

## Structural

Structural deficiencies are defined as those which affect the structure's ability to carry imposed loads. These are caused most frequently by lack of proper maintenance, poor design details and light original designs.

**Steel Structures.** In steel structures, paint system breakdown permits corrosion of the base metal to begin. Once started, the process accelerates as larger areas become exposed. Eventually the metal corrosion can result in section loss serious enough to have an impact on the load-carrying capacity of the member. If left uncorrected, the process will continue, resulting in the ultimate collapse of the bridge.

The corrosion process is accelerated when snow laden with chemical de-icing agents comes in contact with the primary structural elements either as splash or storage. This is particularly true in through girders and trusses.

Webs of through girders become "paper thin" and bearing stiffeners are known to have been totally lost. Truss members likewise become severely corroded in critical areas.

**Concrete Members.** Concrete members also deteriorate at a rapid rate when exposed to adverse environmental conditions. Penetration of brine solution through the unprotected concrete surface causes the reinforcing steel to oxidize and expand, ultimately leading to spalling and cracking of the concrete cover. Once the process begins, it accelerates at a rapid pace as more of the corrosive materials reach the reinforcing steel.

This process, which is very common in bridge decks, also occurs in primary structural members. Prestressed girders and mild steel reinforced concrete members deteriorate when conditions permit penetration by a corrosion conducive solution. Observations of bridges in a number of areas have shown that this condition occurs as a result of salt water splash where low level bridges cross bodies of water with a high saline level or where roadway joints and drainage details permit runoff to come in contact with concrete beams and girders for prolonged periods of time.

**Timber Members.** Timber members, too, deteriorate as a result of general weathering when unprotected. Wet-dry cycles that occur frequently accelerate the process.

**Light Designs.** Many of the structures currently an integral part of our highway system were not designed initially to carry the loads being imposed on them by modern traffic. These "light designs" were based on vehicle weights much less than those in present use and on load frequency rates that are only a small percentage of those now utilizing the crossings. Some of these older structures were designed for 3 or 4 lanes of H15 traffic and now carry heavier vehicle loads by restricting the traffic to one or two lanes. It is a credit to the designers of these antiquated structures that many of them remain serviceable today in spite of the heavy use by modern traffic loads.

These deficiencies apply to sub-structure members as well as to superstructure members. In addition, substructure elements can be structurally deficient because of foundation conditions. Pile deterioration, scour, and deep failures in underlying soil strata can cause significant reduction in the load-carrying capability of the bridge.

## Mechanical

These deficiencies are defined as those which prohibit the structure from reacting in a controlled manner to environmental factors. These are primarily caused by corrosion of metal elements, the accumulation of debris and silt around bearings and joints, lateral movement of substructure units, and poor design details.

Build-up of debris around bearing areas often completely covers metal bearings. This debris is composed of bird droppings, nesting materials and other deposits that are highly corrosive. When this material is saturated with a salt solution from roadway runoff it becomes even more corrosive. The bearings freeze as a result of this corrosion and prevent the bridge from functioning as intended.

Pavement "shove" pressures often add to this problem. This is the result of temperature expansion and contraction in the approach roadway combined with traffic generated pavement movements. Stub abutments move longitudinally as a result of these forces and backwalls deflect and eventually crack. As a result, it is no longer possible for the bridge to function as intended without exerting loads on the structure beyond those considered by the designers.

Settlement as well as lateral movements in piers can cause a similar situation. Pier rotation causes roadway joints to close and bearings to exhaust their capability to accommodate movement. Ensuing temperature changes can then result in serious overstress in other elements of the bridge.

## Geometric

These deficiencies are those that relate to the geometrics of the roadway as it approaches and traverses the bridge. Vertical and horizontal alignment, roadway width, vehicle sight distance, and traffic capacity are included. In almost every instance these are inherent deficiencies that were built in as a result of the initial design.

## Safety

Deficiencies relating to the safety of the motorist include those that jeopardize the safety of the vehicle as it passes over the structure. Many of these are geometric in nature (roadway width, clearance, etc.). Others pertain to the roadway appurtenances such as a bridge railing, approach guardrail protection, and traffic control devices.

Rideability deficiencies are those that impact on the riding quality of the crossing and are included in the safety category. Bridge deck deficiencies are the most common involving rideability. They can impair the load carrying capability of the bridge if the deck is designed as an integral part of the primary structural member such as in concrete T-beams and composite designs. Even with these designs the roadway becomes virtually impassable due to potholes and general deterioration of the deck before failure occurs.

Approach slab settlement can impair the structural integrity of the abutments and cause an increase in live load impact but usually has a greater effect on the safety of vehicles utilizing the facility since severe bumps and dips are created by the settlement.

Other safety deficiencies are those which occur because structure members are located in a position

where they become a hazard to the motorist. End posts on through trusses, ends of through girders, pier and abutment pylons placed close to travelled lanes are examples.

## Bridge Deficiency Catalog

A catalog of bridge deficiencies is included. This is based on inspection of approximately 140 deficient bridges located in five states which was part of a research project done for the Federal Highway Administration.(2)

Photos and descriptive information on these and other deficiencies can be obtained in the USDOT Training Manual 70(4), AASHTO Manual for Bridge Maintenance (5) and other publications.

## CHAPTER III

### REHABILITATION PROCEDURES

The process of rehabilitating a deficient bridge can vary extensively depending on the degree and the severity of the problems needing correction. The work can include a deck replacement and minor repair or can be an involved procedure including strengthening of critical members, correcting settlement problems, replacing bearings and others.

For bridges of the types discussed in this paper, rehabilitation procedures are included in six general categories:

1. Increase live load carrying capacity
2. Improve geometrics
3. Correct mechanical deficiencies
4. Correct drainage problems
5. Improve rideability
6. Miscellaneous repairs

### Increase Live Load Carrying Capacity

There are many ways in which the live load carrying capacity of a bridge can be increased. These can be divided into four general categories. First, strengthen critical members by adding additional material to the member itself or replace with a new member; second, add supplemental supports or members to assist in carrying loads; third, reduce the dead load on the bridge and thereby provide additional capacity for live loads; and fourth, change the structural system in a manner that will provide additional live load capacity.

### Strengthen Critical Members

The routine procedures for strengthening steel bridges followed by most agencies is to add cover plates to steel beams or girders or to add plates to steel truss members to increase the available section. Many of these details have been developed utilizing welding to attach the new material. In some cases, the welding operation on the existing steel, because of the location and the particular detail employed has had an adverse effect on the structural capacity of the member. Stress raisers that are susceptible to fatigue failures have unwittingly been incorporated in the structure through lack of attention to detail or to state-of-the-art knowledge of welding procedures.

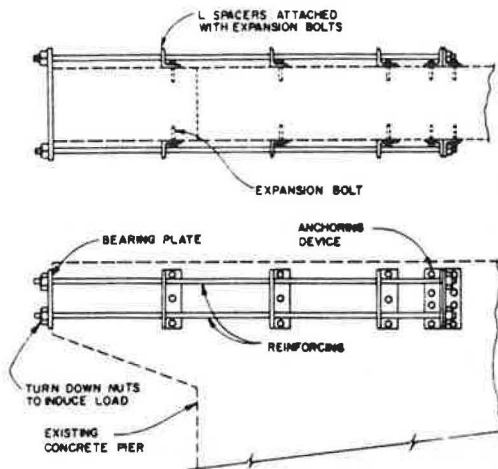
Material can be added successfully by welding to existing primary members providing that the design and details are developed in accordance



with current specifications, including those dealing with fatigue characteristics. (6) The other obvious requirement is the weldability of the material used in the existing member.

**Concrete Members.** Reinforced concrete primary members pose a different problem. Designs have been successfully developed wherein external steel reinforcing is attached to the member by connections utilizing bolts extending through the member (see Figure 1). Reinforcing can be post tensioned as necessary.

Figure 1. External Concrete Reinforcing



Other designs have been developed for post-tensioning concrete girders, anchoring the tendons with attachments at the bearings. The tensioning strands are then placed in a concrete section added to the beams or are confined in a protective metal conduit which is left exposed.

A method has been developed and implemented in England and in South Africa for strengthening concrete beams by adding steel plates that are "glued" to the concrete. (7) This has proven to be a very simple and effective method. Plates are added to the underside of simply supported concrete beams to increase flexural capacity and to the sides of the beams near the bearings, to increase shear capacity.

#### Provide Supplemental Members

Adding additional members is a technique used routinely in strengthening bridges. Structurally inadequate floor systems on truss and girder bridges can be rehabilitated by erecting additional members between the existing stringers to provide necessary overall capacity. On girder bridges, additional floor beams can be added to provide added strength.

Concrete beam and girder bridges can be strengthened by adding steel beams or precast concrete beams between or adjacent to the existing concrete sections. Timber bridges likewise can be strengthened by adding additional primary steel members.

Critical members that are defective can be replaced. This is frequently done in situations where collision damage to a key member has weakened the bridge. End posts of through or pony type trusses are recurring examples. Concrete or steel fascia stringers in overpass structures are often damaged by oversized vehicles and must be replaced.

Truss member replacement requires careful analysis and development of step-by-step procedures. Shoring must be developed to insure the integrity of the structure during the replacement operation. If this is not feasible then an alternate support system must be developed utilizing post-tensioned cables or other such devices to carry temporary loads.

Adding new stringer or floor beam members will often require the removal and replacement of at least a portion of the bridge deck. Procedures have been developed, however, to eliminate the need to remove any of the bridge deck. These procedures utilize supplemental supports jacked into place from below the structure. By drilling through the deck and pressure grouting, any void that exists between the top of the supplemental support and the underside of the deck can be filled. Lifting cables threaded through the same holes drilled through the deck can also be utilized for lifting the supplemental supports into place.

The addition of crutch bents and/or pony bents to pick up the load of a defective pile or pile bent is commonly used and is an effective rehabilitation technique. Likewise, the addition of supplemental cap beams laced to the existing cap beam provides an efficient means of strengthening a deteriorated bent. The transfer of load from the strengthened member to the vertical supports must be carefully considered and proper details developed.

#### Reduce Dead Load

Dead load reduction can most easily be effected by removing the existing deck and providing a lighter weight substitute. In some instances, removal of asphalt wearing surface buildup can provide significant reduction in dead loads.

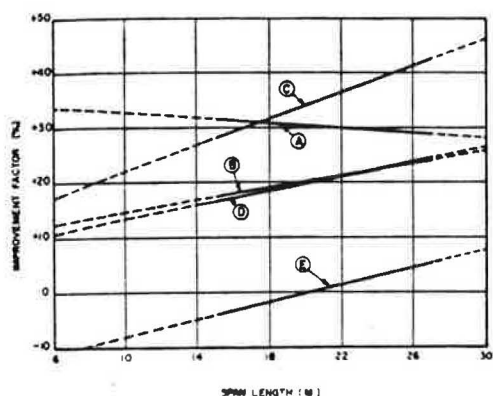
A number of deck systems have been developed to provide a lightweight yet structurally adequate system. The most familiar of these are:

1. Open steel grid deck.
2. Concrete filled steel grid.
3. Corrugated metal with asphalt wearing surface.
4. Laminated timber with asphalt wearing surface.
5. Metal plate (Orthotropic) with asphalt wearing surface.

**Improvement Factor.** Employing each of these concepts, (8) flexural requirements were determined for a 15 m (50 feet) and a 27 m (90 feet) simple span using stringers spaced at 2.1 m (7 feet) center to center. Requirements for a comparable span and stringer spacing using a conventionally reinforced concrete deck were also made. A comparison of these two values provides an indication of the merits of each concept. This comparison figure is termed the "Span Improvement Factor." A graphical presentation of these values is shown in Figure 2.

It should be noted that the requirements calculated reflect not only a change in dead load associated with each concept, but also a change in live load distribution developed in accordance with AASHTO specifications. The combined effect can produce a negative factor as evidenced by the shorter spans utilizing a laminated timber deck. Also an increase in live load stress due to distribution factor changes can also cause changes in stress range effecting the fatigue life of the member. This is not considered in the development of the improvement factor.

Figure 2. Span-Improvement Factor. Dead Load Reduction Systems.



| COST PER SQ. M. |        |
|-----------------|--------|
| A               | \$ 410 |
| B               | \$ 270 |
| C               | \$ 290 |
| D               | \$ 310 |
| E               | \$ 310 |

CONVERSION FACTOR  
1 M = 3.28 FT

- A. STEEL PLATE  $\frac{3}{4}$ " ASPHALT WEARING SURFACE SUPPLEMENTAL DECK SUPPORT SYSTEM.  
B. CORRUGATED METAL  $\frac{3}{4}$ " ASPHALT WEARING SURFACE SUPPLEMENTAL DECK SUPPORT SYSTEM.  
C. OPEN STEEL GRID.  
D. CONCRETE FILLED STEEL GRID.  
E. LAMINATED TIMBER.

NOTE: DASHED LINES REPRESENT EXTRAPOLATED VALUES OF THE CURVES.

**Cost Effectiveness Factor.** By dividing the improvement factor by the estimated cost per square foot (shown in Figure 2 for the Washington, D. C. area) a "Cost Effectiveness Factor" can be determined. The higher the value of this factor the greater the cost effectiveness for a given situation. For example, comparing the cost effectiveness of modifying a 25 m (82 feet) span by utilizing either an open grid deck or a corrugated metal deck with an asphalt wearing surface, indicates that the open grid deck provides a factor of 0.138 ( $40 \div 290$ ) and the corrugated metal deck provides 0.085 ( $23 \div 270$ ). Therefore, the open grid deck will provide the most cost effective technique.

Each of the concepts for which data was developed have other factors that must be considered in addition to initial cost. These include both maintenance and operational considerations.

**Steel Grid.** The open grid flooring can become slippery when wet or ice-covered. Serrated top bars or welded studs can significantly reduce this problem. The open grid has the advantage of permitting snow and rain to pass through the structure, thereby eliminating the need for bridge drainage and the use of snow and ice control chemicals on the bridge. Details should be developed that eliminate pockets over the main support members that will collect debris and cause corrosion in these members. Care should also be taken in selecting the proper grating design. Welded details often fail due to impact and fatigue. Riveted grates can provide a more reliable deck.

Concrete filled floor grating has the advantage of improving skid resistance and reducing the impact and fatigue failures in the internal connections. The disadvantage is the added weight as compared to the open grid and subsequent reduction in live load capacity of the bridge. Also, it is necessary to provide and maintain an adequate deck drainage system and to employ chemicals for snow and ice control.

**Corrugated Metal.** The use of corrugated metal plate deck with an asphalt wearing surface is a

recent development. Installations have shown that the system can be designed to withstand modern design loading. Length of service can be increased by properly designing the drainage system to remove surface runoff and by providing adequate protection for the metal sheets against corrosion.

When replacing a concrete deck with this system, it will usually be necessary to add lightweight supplemental support beams between the existing stringers in order to reduce the effective deck span. On multiple stringer bridges, these can be framed to floor beams placed between existing stringers or to existing diaphragms. On truss bridges and other structures with similar floor systems, these beams can be framed to existing floor beams. The "Improvement Factor" curve developed in Figure 2 is based on framing the supplemental stringers to new floor beams spanning between existing stringers.

**Timber.** Laminated timber bridge decking is also a relatively new concept. This provides some reduction in dead load but live load distribution factors increase resulting in little or no betterment for the shorter spans. It does provide advantages from a maintenance point of view since it is less susceptible to chemicals used in snow and ice control. It is important to provide details for fastening the panels to stringer supports that will not be conducive to insect infestation and resulting deterioration. The joint between panels must also be carefully detailed to provide shear transfer and to provide a proper seal. Clamping devices that do not require drilling or nailing are preferred to drilling and bolting.

**Metal Decking.** Steel plate decking as a replacement for deteriorated concrete provides significant weight reduction. This can also provide additional carrying capacity for the primary members if properly designed. Ribs or supplemental lightweight flooring must be included with the decking to provide adequate roadway support. Adhesion between the steel plate and asphalt wearing surface is a potential maintenance problem, but through careful attention to specifications and with proper construction techniques, this problem can be greatly reduced.

#### Modify Structural System

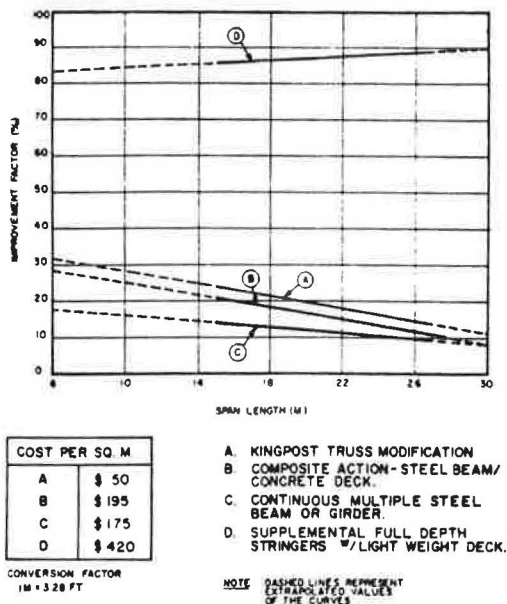
The structural system in a bridge can be modified in a number of ways to provide additional capacity to support live loads. Three such concepts are composite action, beam continuity and kingpost truss.

For each of these concepts, "Improvement Factor" curves have been developed in a manner similar to that already described for procedures used to reduce dead load. Cost factors have also been developed and are included with the "Improvement Factor" curves in Figure 3.

**Composite Action.** This procedure changes an existing steel beam or girder system to a composite system so that the steel support and the concrete slab act together in resisting live loads. Composite action is provided through suitable shear connection between the beam and concrete slab. The most practical device used to accomplish this is the welded stud.

The rehabilitation procedure includes removing the deteriorated concrete deck, welding shear connectors to the top flanges of the steel beam, and casting a new deck slab. In situations where the

Figure 3. Span-Improvement Factor. Structural Modification Systems.



deck slab is sound and does not have to be replaced, holes can be drilled through the slab from the roadway to the steel support for welding the studs. Epoxy grout is then placed in the void between the slab and the stud. Another process now in the experimental stage, provides shear resistance by pressure injecting epoxy adhesive into the void between the steel flange and the underside of the concrete slab.(9) This is injected through drilled holes in the deck. Early test data indicates that this can become an effective and economical method for developing shear resistance. Construction specifications and testing procedures must be further developed, however, before this method can be used with the necessary reliability.

**Steel Beam Continuity.** This procedure is employed to change a series of simple steel beam spans to a continuous system. Through the interaction between spans, additional load-carrying capacity can be obtained.

The procedure utilized in this modification includes first, the removing of a portion of the deck and the deck joint over the pier. Next, a splice is installed between the adjacent beams. The existing bearings are removed and a single bearing is installed. Bearing stiffeners are added as necessary. The deck slab is then replaced, completing the installation. A conceptual detail of this is shown in Figure 4.

In addition to providing greater live load capacity and reducing live load deflections, this system also reduces future maintenance requirements since it eliminates a roadway joint and one set of bearings, both of which cause constant maintenance problems.

**Kingpost Truss.** In situations where under-clearance permits, the modification of either a stringer or a floor beam to a kingpost truss (trussed-beam) system provides an excellent means to increase live load capacity. The procedure requires the installation of a "kingpost" truss to the bottom flange of the member. Threaded end connections are provided so that proper tension

can be induced into the system. A conceptual detail of this is shown in Figure 5.

Figure 4. Conceptual Details. Simple Span Steel Beam to Continuous

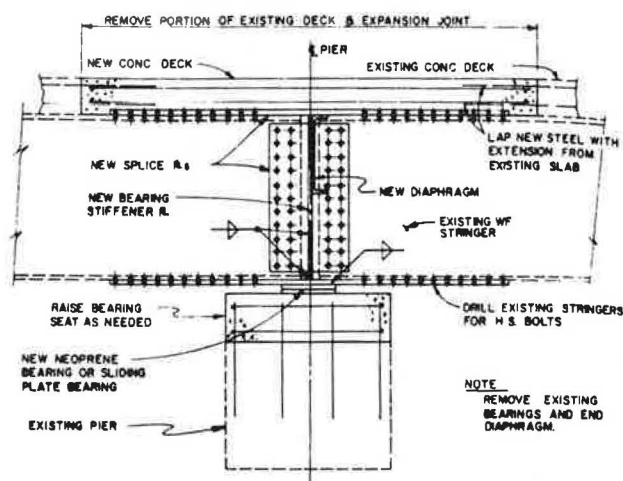
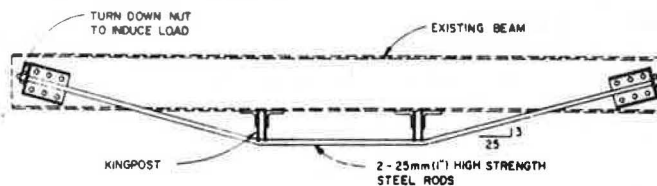


Figure 5. Kingpost Truss Beam Reinforcement.



The "Improvement Factor" curve as shown in Figure 3 is based on a single post system with a 3:25 bevel on the struts. Struts are stressed to 11.2 kN (25 kips). This predetermined force must be induced in the system by tightening at the end connections. The installation must be carefully monitored by measuring the number of turns as well as resulting deflections in the original member. Other geometric configurations and induced loads will produce different "Improvement Factors."

#### Improve Geometrics

Rehabilitating a deficient bridge to improve geometrics includes increasing vertical clearance, widening usable roadway and improving approach horizontal and vertical alignment.

#### Vertical Clearance

Inadequate vertical clearance is a common geometric deficiency found in through truss type bridges. Additional clearance can be provided by reducing the depth of portal and sway frames. The resulting bracing system must be properly designed to transmit imposed loads.

In certain cases it may be possible to lower the floor system on through truss bridges and thereby increase vertical clearance. Where stringers ride over floor beams the roadway can be lowered by



framing the stringers into the floor beams, keeping the top of the stringers and the top of the floor beam in the same plane. Another possibility is to lower the floor beam connection to the truss itself thereby increasing vertical clearance.

As discussed under structural rehabilitation techniques, it is often desirable to replace an existing concrete deck with a lighter roadway support system to increase live load capacity. In most instances on through truss type bridges this will also provide additional vertical clearance due to the thinner deck system.

Improved vertical clearance on grade-separation structures can be most economically achieved by lowering the bottom roadway providing this can be done without undermining or otherwise jeopardizing pier or abutment footings. It is possible, although usually more costly, to raise the superstructure and adjust the vertical alignment of the overpass roadway. This requires adding to the height of the abutments and piers. These elements must be carefully analyzed to insure that they are capable of absorbing the increased loads imposed by the added height. If not adequate, structural modifications must be included with the rehabilitation plans.

#### Roadway Widening

On multiple girder or multiple beam bridges of either concrete or steel construction, it is a straightforward and fairly routine process to widen the roadway. Parapets and sidewalks must be removed, piers and abutments extended, new stringers added and a new deck and curb installed. Control of traffic during construction of the new deck is necessary to insure that excessive deflection and vibration from heavy vehicles are controlled.

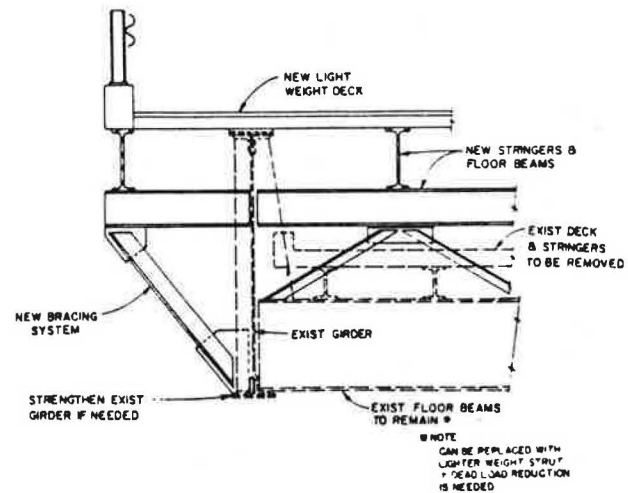
Through systems are more difficult to widen. Short of removing the entire superstructure and replacing with a new one, it is impracticable to consider widening a through truss and in most instances a pony truss. Providing site conditions will permit adjustments in grade of several feet, it can be practical to widen a through girder bridge by moving the floor system to the top flange of the girder and constructing a wider deck. The main girders may require strengthening. However, this can be minimized by utilizing a lightweight deck in conjunction with the rehabilitation. A conceptual cross section of this is shown in Figure 6.

#### Correct Mechanical Deficiencies

These repairs are those associated with bridge bearings, expansion joints, hangers, wind tongues, and similar devices that permit the structure to expand and contract. Such devices often freeze as a result of corrosion thereby losing all capability of reacting to movement. The usual rehabilitation technique is to replace the defective item or to clean the existing device and adjust it to the proper position. Vertical and longitudinal jacking of the superstructure is an integral part of this work. With careful planning, this work can be done without traffic interruption.

In situations where pavement shove, rotation of supports or other movements have caused the expansion devices to become jammed, it may be necessary to rebuild the abutment backwall or to remove a portion of the longitudinal member adjacent to the backwall in order to provide sufficient gap for movement.

Figure 6. Conceptual Details. Thru Girder Deck Widening.



Replacement of roadway expansion joints is often required when rehabilitating the structure to correct mechanical deficiencies. Replacement joints should be watertight if possible. When open joints must be used, provision for drainage collection should be included to prevent pavement wash from reaching bearings or hangers beneath the joint. Scuppers located as close as practical to the open joint with drainage troughs under the joint provide an effective method for controlling runoff in these areas. The steel components of replacement joints should be galvanized or constructed of weathering steel to control corrosion.

#### Correct Drainage Problems

An ineffective bridge deck drainage system is a major cause of bridge deterioration. Rehabilitation should include replacement with an adequate drainage system. Special attention should be given to details that will prevent deck wash from reaching bearings, superstructure members, piers, and abutments. Scuppers must be properly spaced and should be large enough to minimize clogging from roadway deposits. Proper provision must be included for maintenance cleaning of downspouts and collection pipes. Discharge points should be detailed to prevent erosion. Consideration should be given to galvanizing all parts of the drainage system or using weathering steel.

#### Improve Safety and Rideability

##### Safety

Replacement of inadequate bridge railing, alteration of parapet and railing ends where these face oncoming traffic, protection with attenuators at ends of through girders or through trusses, in gore areas on structures, or in front of piers within the recovery zone (9 m, 30 feet from pavement edge) are all measures that should be considered in bridge rehabilitation plans.

Adequate protection for pedestrian traffic should also be provided. Redirectional barriers provided between the sidewalk or bikeway and the roadway can be effective in providing safety for pedestrians as well as for vehicles.

Approach roadway alignment improvements can have substantial impact on improving safety at the bridge site. This is often more difficult to achieve due to right-of-way requirements and other local restrictions than from an engineering standpoint.

### Rideability

Bridge rehabilitation to improve riding quality includes repairs to approach roadway for settlement and to the bridge deck. Deck repairs vary from full deck replacement to patching of isolated areas. Deck replacement should include adequate protection of reinforcing steel to prevent corrosion and subsequent concrete deterioration. State-of-the-art indicates that this can best be provided by coating the rebars with an epoxy sealant or by constructing a high density concrete overlay on the structural slab. Cathodic protection systems are under development and appear to be promising.

On existing decks that require repair but not replacement, the rehabilitation should include a sealing system which will prevent or at least reduce the further buildup of chlorides in the deck. A procedure to reduce the chloride content in the existing deck should be considered with the rehabilitation program.

### Miscellaneous Repairs

Many other repair techniques are available to correct deficiencies in bridge components but have not been discussed in this paper. These include cosmetic repairs as well as repairs needed to increase capacity and improve the structural integrity of the bridge.

## CHAPTER IV

### SUMMARY

The results of research and practical experience in the bridge maintenance area have shown that bridge rehabilitation can be done in a cost effective manner. When proper attention is given to current rehabilitation practices, additional years of service can be obtained from existing structures.

Current techniques employed to renovate deficient bridges include increasing the live load capacity of the bridge by decreasing the dead load, strengthening critical members, providing supplemental members and modifying the original structural system. In addition, substructure stabilization, proper cleaning of bearing and roadway joints, improved geometrics and safety improvements such as new or modified bridge railing systems have also played a significant role in improving the serviceability and extending the life of existing structures.

While each bridge rehabilitation project has unique features, there are general concepts that can be compared and evaluated to determine the most practical technique to be used. Because of these unique features, there is always a need for creative thinking and the development of innovative procedures in bridge rehabilitation projects. New products and techniques are constantly being developed that provide more efficient and longer lasting repairs to be made.

The deficiencies outlined and discussed in this paper include many that are encountered in fixed spans ranging in length from short to medium. The

discussion of rehabilitation procedures has covered many of these deficiencies, although in many instances has been cursory and conceptual only. The ideas and suggestions as presented are intended to provide the basis for further development for application to a specific situation.

As we are in a time period where many bridge departments have little maintenance money and must make the most of what they have, we should, through creative engineering, utilize our talents to the utmost to attack our nationwide bridge problems. The concepts for increasing the load carrying capacity presented herein are a start. However, much additional work needs to be done. More research is needed and new rehabilitation concepts must be developed. We must do our homework thoroughly in order to eventually resolve our current bridge crisis.

### REFERENCES

1. Seventh Annual Report to Congress, Federal Highway Administration, 1977.
2. Berger, R. H. "Extending the Service Life of Existing Bridges by Increasing Their Load Carrying Capacity." FHWA Research Report, 1978.
3. "Bridges on Secondary Highways and Local Roads-Rehabilitation and Replacement." Virginia Highway and Transportation Research Council. NCHRP 20-5.2. Not complete.
4. "Bridge Inspector's Training Manual 70." U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, 1971.
5. "AASHTO Manual for Bridge Maintenance." American Association of State Highway and Transportation Officials, 1976.
6. Fisher, John W. "Bridge Fatigue Guide, Design and Details." American Institute of Steel Construction, 1977.
7. Sommerard, T. "Swanley's Steel-Plate Patchup." *New Civil Engineer*, June 16, 1977, London.
8. "Standard Specifications for Highway Bridges," Twelfth Edition. American Association of State Highway Officials, 1977.
9. Kahn, Larry. "Strengthening of Existing Bridges by Epoxy Injection." School of Civil Engineering, Georgia Institute of Technology.

### BRIDGE TYPE AND DEFICIENCY CATALOGUE SUPERSTRUCTURE

#### I. PRIMARY SUPPORT SYSTEM

##### A. Steel

1. Multiple Beam or Girder (Simple or Continuous Span).

Paint deterioration  
Flange and/or web corrosion  
Bearings inoperable  
Collision damage fascia stringers  
Stiffener and other detail corrosion  
Brittle fracture.

2. Thru Girder or Twin Deck Girder (Simple or Continuous Span).

Paint Deterioration  
Flange and/or web corrosion  
Bearings inoperable  
Connections, stiffener and miscellaneous detail corrosion  
Bracing member corrosion and damage  
Collision damage - Girder, kneebraces



3. Deck Truss, Thru Truss, Pony Truss (Simple Span).
  - Paint deterioration
  - Flange and/or web corrosion - Stringers and floor beams
  - Bearings inoperable
  - Truss member corrosion.
  - Collision damage - Portal, truss member, sway frame
  - Bracing member corrosion, failure
  - Connection corrosion
  - Inadequate design

B. Concrete

1. Slab (Simple or Continuous Span).
  - Surface delamination
  - Surface spall--Rebar exposure and corrosion.
2. Multiple Beam and T Beam (Simple or Continuous Spans).
  - Web cracks
  - Surface spall - Rebar exposure and corrosion
  - Collision damage
  - Bearings inoperable
3. Prestressed or Post Tensioned Beams (Simple or Continuous Spans)
  - Surface spall - Tendon exposure
  - Web and Flange cracks
  - Bearings inoperable

C. Timber

1. Multiple Stringer (Simple or Continuous Spans).
  - Timber rot, surface weathering and splits
  - Bearings inoperable

II. DECKS

A. Reinforced Concrete

- Wearing Surface Breakdown
- Delamination
- Surface Spall and Cracks
- Joint Inoperable

B. Open Grid Steel

- Connection Failure
- Corrosion

C. Corrugated Metal

- Wearing Surface Breakdown
- Protective Coating Deterioration
- Corrosion

D. Timber

- Wearing Surface Breakdown
- Weathering - splits, cracks and rot
- Failure of Connections to Support Members

SUBSTRUCTURE

I. ABUTMENTS

A. Masonry

- Mortar Deterioration
- Bearing Seat Deterioration
- Scour

B. Concrete, Stub/Spill Thru

- Cracking and Surface Spall
- Bearing Seat Deterioration
- Settlement and/or Rotation
- Back wall failure
- Erosion - Scour

C. Concrete, Full Height

- Cracking and Surface Spall
- Bearing Seat Deterioration
- Settlement and/or Rotation

Back wall failure

Erosion - Scour

D. Timber - Bulkhead

- Decay - Rot
- Insect infestation

II. PIERS

A. Reinforced Concrete - Hammerhead/Solid Wall

- Cracks
- Bearing seat deterioration
- Pier nose deterioration
- Settlement and/or tilting
- Scour

B. Reinforced Concrete - Rigid Frame

- Cap Bm. Spall - Rebar exposure and corrosion
- Cracking in Cap
- Bearing seat deterioration
- Column Concrete deterioration
- Settlement and/or tilting

C. Masonry

- Mortar deterioration.
- Erosion/scour

III. BENTS

A. Timber Piles and Cap

- Pile Decay - Rot
- Cap weathering - splits, cracks
- Insect infestation - marine borers
- Scour

B. Concrete Pile & Cap

- Longitudinal Cracks in pile
- Bearing seat deterioration
- Pile spall - rebar exposure & corrosion
- Cap spall - Rebar exposure and corrosion
- Collision damage
- Scour

C. Steel H Pile - Concrete Cap

- Pile corrosion - Section loss
- Cap Spall - rebar exposure and corrosion
- Bearing seat deterioration
- Scour

MISCELLANEOUS

A. Drainage

- Inadequate deck drainage (Number and/or size of Scuppers).
- Drainage discharge on primary members
- Snow and Ice storage in contact with primary members
- Leaking deck joints
- Ground erosion at discharge point.

B. Geometrics

- Inadequate roadway width
- Inadequate vertical clearance
- Approach alignment poor

C. Safety

- Narrow roadway
- Inadequate railing
- Alignment - site distance
- Roadway surface deterioration