

In-Depth Inspection of Arizona's Steel Bridges

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ABSTRACT

Bridge deterioration is a significant problem facing highway agencies nationwide. In order for these agencies to make sound decisions regarding their bridge maintenance and rehabilitation efforts, they require comprehensive and detailed information on bridge conditions. In 1997, the Arizona Department of Transportation selected Burgess & Niple (B&N) to perform in-depth inspections of 172 steel bridges throughout the state. Bridges were up to 1,800 feet long and 700 feet high and located in mainly rural areas of the state. The primary objective was to perform a close (hands-on) visual inspection of each steel bridge in order to detect and document any deficiencies of the bridge components. Difficulty of access was not allowed to interfere with performing a thorough inspection. Visual observations were to be supplemented with non-destructive testing when necessary to define the limits of deterioration or document the condition of items such as bridge pins. Special emphasis was placed on fatigue prone details and fracture critical members. A separate report on inspection findings was issued for each bridge. This report included such information as deficiencies found, NBIS condition ratings, PONTIS element data, channel profile/vertical clearance diagrams, repair/maintenance recommendations, suggested inspection frequency and the inspection cost. This paper describes the procedures taken by B&N in preparing for and performing the inspections as well as the results.

BACKGROUND

Bridge deterioration is a significant problem facing highway agencies nationwide. In order for these agencies to make sound decisions regarding their bridge maintenance and rehabilitation efforts, they require comprehensive and detailed information on bridge conditions. Recently, the Arizona Department of Transportation retained Burgess & Niple (B&N) to perform thorough condition assessments of 172 steel bridges located on the state highway system.

Project Objectives

This project had a number of objectives. The primary objective was to perform a close (hands-on) visual inspection of each steel bridge in order to detect and document any deficiencies of the bridge components. Difficulty of access was not allowed to interfere with performing a thorough inspection. Therefore, specialized access techniques would be required for some of the larger bridges. Visual observations were to be supplemented with non-destructive testing when necessary to define the limits of deterioration or document the condition of items such as fatigue cracks, defective fasteners, bearings,

pins, etc. Special emphasis was placed on documenting the condition of fatigue prone details and fracture critical members. Fatigue cracking if not detected, or left unrepaired, can lead to sudden, catastrophic failure of non-redundant steel structures. Another goal was to obtain all the necessary information for compliance with Federal Highway Administration requirements outlined in the National Bridge Inspection Standards. Additionally, we were to determine and justify a recommended inspection frequency for each structure based on, among other items, bridge type, fatigue prone details, fracture critical members and any ongoing deterioration. Finally, an inspection cost was to be established for each individual bridge. This data would be used for planning and scheduling future bridge inspection projects.

Project Overview

Work on this extensive project began in July of 1997, and the last reports were submitted in December of 1998. This inspection program included a very diverse group of steel bridges including arch, truss and girder bridges. A complete breakdown of bridge types inspected is presented in Table 1. Bridges varied greatly in age. The oldest was constructed in 1913, and the most recently constructed bridge was only three years old at the time of inspection. Bridges involved in this project were up to 1,800 feet long and up to 700 feet high and included the Glen Canyon and Navajo Bridges. These structures are Arizona's largest arch and truss bridges, respectively. The Navajo Bridge is depicted in Figure 1.

The scope of this inspection program presented engineers from Burgess & Niple with many interesting challenges that required innovative solutions to successfully complete this large, complex project.

MOBILIZATION PHASE

Adequate planning, preparation, and development of a realistic schedule are key elements that contribute to the success of a major inspection project. The first step taken in preparing for this project was to prepare a comprehensive database that contained the pertinent information on each of the bridges. To develop the database, information supplied by the client such as route and milepost was input to the database. Bridge plans were reviewed and data on size, superstructure type and required methods of access was also incorporated. Additionally, bridges with special needs, i.e., ultrasonic pin testing or

Table 1: Summary Steel of Bridge Types

Primary Steel Type	Count	%
Continuous Rolled Beam	82	48
Simple Span Rolled Beam	12	7
Plate Girder (welded or riveted)	60	35
Arch	7	4
Truss	10	6
Rigid Frame	1	< 1
Total	172	

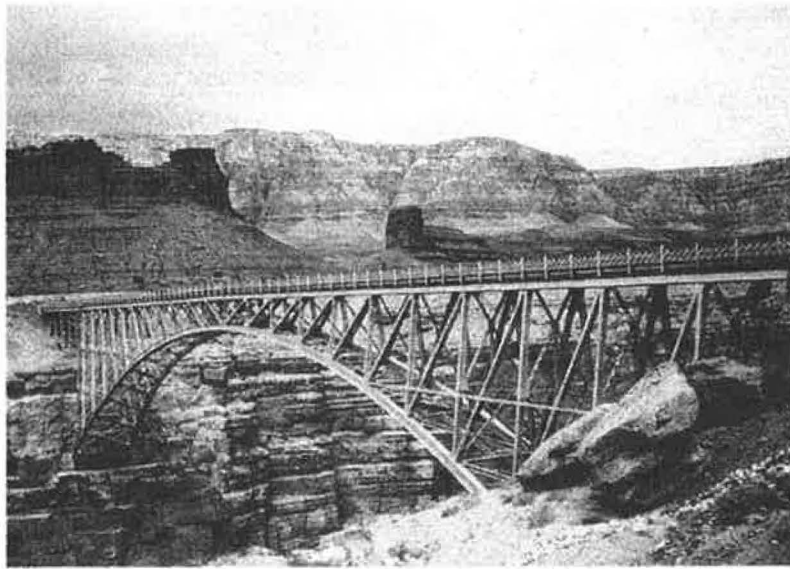


Figure 1: Navajo Bridge: Marble Canyon, Arizona.

arches requiring control surveys, were highlighted in the database. Utilizing all this data, estimates of required field inspection time were generated and added to the database.

After information on the individual bridges had been compiled, a system was then needed for locating the bridges, not only for scheduling and tracking purposes, but also for the inspection crews to eventually use in the field to find them. A computerized Graphical Information System or GIS was developed for the project. Bridge locations were input into a computer software package that contained a detailed highway map of the state. This map was scalable, allowing the user to select the level of detail desired and hardcopies were easily producible. Using this software package, efficient routes for inspection crews to follow were computed.

Another major element of the mobilization phase was the development of the field schedule that would be followed for the duration of the project. A planning and scheduling software package was used to develop and maintain the schedule. For this project, each individual bridge to be inspected was denoted as a separate activity in the schedule. A list of project resources was assembled and integrated into the program. These resources included such items as manpower (inspection engineers), traffic control, required access equipment, survey crews, and ultrasonic testing crews. The estimated time was input in the program for each activity (bridge inspection) and the activities were arranged according to the proposed inspection sequence. This first schedule became the baseline for the project. Milestone dates and progress targets were established based on this initial schedule.

This scheduling software package allowed us to create a "dynamic" schedule. Periodic updates were made during the course of the project. These updates allowed us to track the actual progress of the project and accurately model and anticipate schedule changes for future activities. Output reports from the program were used to keep our subconsultants and client informed of any schedule changes and of the progress to date of the inspection work.

At this stage of the project, the process of obtaining right-of-entry permits from the regional highway districts and the railroads began. A permit was required from each regional district. These permits allowed us to enter onto the highway right-of-way, close down traffic lanes and perform the inspection work. Seventeen of the bridges in this project spanned railroad tracks. These tracks were owned by four different railroad entities. To perform the inspection of these particular seventeen bridges it was anticipated that we would utilize underbridge access equipment such as a "Snooper" truck. This truck rides on the roadway and has a boom with a platform that extends over the side and under the bridge. When the platform was under the bridge, no trains would be able to pass beneath the bridge. Railroad flagmen were required onsite to control the rail traffic. It took a total of eleven months to obtain all the necessary permits from the railroads and coordinate the inspection of those particular bridges.

INSPECTION PHASE

The actual field inspection work began in August of 1997. Typically, inspection teams in the field consisted of between 2 and 4 engineers depending on the size of the bridge. These engineers were all required to have prior experience with steel bridge inspections. Having multiple engineers onsite provided thorough observation of the bridges and allowed for discussion of deficiencies in the field. A registered professional engineer led each inspection team. In addition to the engineers, each inspection team also included a traffic control crew of two men with all the equipment necessary for both merge set-ups on multi-lane highways and flagging set-ups on two lane roads. From time-to-time the inspection teams also included subconsultants performing survey work or pin testing.

Methods of Access

Due to the variety of bridges on this project, different methods of access were required to perform hands-on inspection of all bridge elements. Both mechanical and climbing procedures were utilized during the course of this project. In many cases a combination of techniques were used to access a bridge and perform an efficient and thorough inspection. Access methods utilized to inspect these bridges are shown in Table 2.

Climbing techniques were used on 30 of the bridges in the project. Close-up, in-depth inspections require access to many components of the structure that are difficult to reach. Burgess & Niple developed an innovative approach to bridge inspections that utilizes rock-climbing techniques and equipment to achieve hands-on access. Since 1981,

Table 2: Methods of Access

Access Method	Count	% of Total
Climbing	30	17
Bucket Truck	63	37
Platform Snooper	92	53
Ladder	18	10

this method had been used to successfully inspect hundreds of bridges. Additionally, these techniques comply with the fall protection safety rules of the Occupational Safety and Health Administration (OSHA) and Federal Railroad Administration (FRA).

All of the engineer-climbers are outfitted with a prefabricated nylon rock climbing harness. Typical breaking strength of these harnesses is approximately 4,500 pounds. This harness attaches the climber to ropes or nylon webbing anchors that are attached to bridge components and act as the climber's safety system. The three primary methods used by our engineers on this project were climbing with webbing, belaying, and rappelling.

Climbing with Webbing

This is the most efficient method used during climbing inspections. With this technique, engineers can climb and inspect independently of one another. Nylon webbing looped around bridge elements provides the engineers a fall protection system while they use their hands and feet to climb members. Webbing techniques were used to access most of the truss and arch bridges on this project. Figure 2 depicts an engineer accessing a large truss bridge utilizing this technique.

Belay Techniques

With this technique engineers work in pairs. One engineer remains stationary (belayer) while the other moves about the bridge (climber). A rope is run between both engineers and through a friction device. As the climber moves along the bridge, anchors are set on bridge elements and the rope is run through these anchors. The belayer's function is to feed out and retrieve the rope through the friction device so that any fall by the climber will be as short as possible. The friction device can be locked off and secured if the

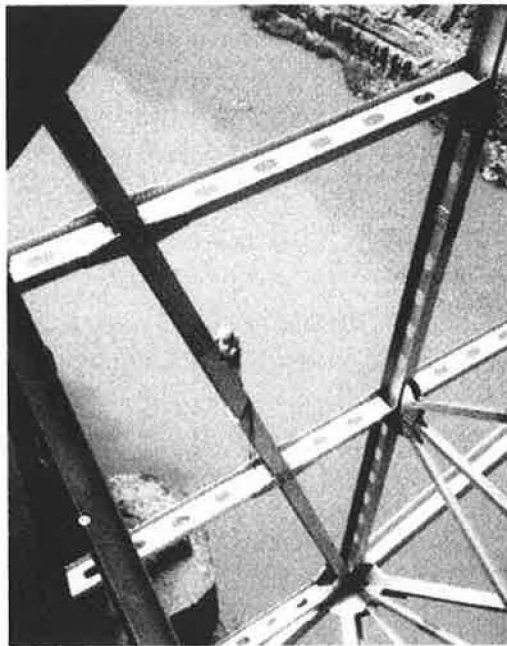


Figure 2: Engineer utilizing climbing techniques to visually inspect primary members on a truss bridge.

climber is stationary or if the belayer needs to be away from the rope. Once the climber has used the total length of rope available, the climber then belays his partner. By the engineers alternating between climber and belayer, the team is able to "leap frog" its way along the bridge. This technique was used when inspecting bridges with deep girders and large truss members, where anchoring locations were greater than an arm's length apart.

Rappelling

Rappelling is a means of descending by sliding down a rope. A friction device attached to the engineer's harness provides control over the rate of descent and the ability to stop at specific locations when necessary. This technique was used to inspect vertical members that were not climbable and to provide hands-on access to tall concrete piers and abutment faces.

One bridge which required the use of rappelling techniques was the Glen Canyon Bridge. The arch verticals were solid walled box members that could not be climbed. They were rappelled from the top down. The vertical members were up to 150 feet tall and located 700 feet above the Colorado River.

Mechanical Access Equipment

Traditional mechanical access equipment was used on the bridges whose members were too small to climb. One of our inspection crews was outfitted with a single bucket lift truck. This piece of equipment was used to inspect the highway overpass bridges. For bridges over rivers, canyons, dry washes and railroad tracks a Paxton Mitchell Snooper was utilized. A Snooper truck rests on the bridge deck and has an articulated, mechanical boom with a bucket or platform that extends over the side and under the bridge. An operator remains in the vehicle and drives it along the bridge as inspection work progresses. Alignment of the boom and platform or bucket is controlled by the engineers under the bridge. We equipped one of our inspection crews on this project with a platform snooper. Up to three engineers could work on the platform at one time. Additionally, the platform was long enough to reach all the way across many of the bridges.

Inspection Items

In the field, the primary components of each bridge were inspected. Comments were recorded for any distress or deficiencies observed. Components inspected are outlined in Table 3.

Nondestructive Testing Techniques

When necessary, visual observations were supplemented with nondestructive testing (NDT) techniques to document the condition of components and accurately define the limits of deterioration. NDT methods utilized for this inspection program include magnetic particle testing, ultrasonic testing, mechanical sounding of concrete and rivet rebounding.

Table 3: Inspection Items

Item	Comments
Approaches	Including pavement, guardrails, shoulders, slopes and drainage
Channel/ Vertical Clearance	Perform channel profile survey, measure vertical clearance, monitor scour
Substructure	Piers and abutments
Superstructure	Girders, beams, stringers, truss chords, diaphragms, connections, bolts, rivets, welds, special emphasis on fatigue prone details and fracture critical members
Bearings	Bearing devices, anchor bolts, grout pads, pedestals
Bridge Deck	Condition of wearing surface and underside, bridge rail, curbs, movable joints measurements and conditions
Durability	Paint condition
Miscellaneous	Encroachments and excessive vibrations or deflections

Magnetic Particle Testing

Magnetic Particle Testing (MP) was performed by engineers to confirm the existence of suspected cracks in steel members and welds and define the limits of known cracks. MP inspection is a test procedure for identifying surface and near-surface discontinuities in ferromagnetic materials such as steel. In MP, the steel in the area of the suspected defect is magnetized with an electromagnet. Any crack that is positioned generally perpendicular to the direction of the magnetic field will form a leakage field on the surface of the steel member. Ferromagnetic particles sprayed over the area of the suspected defect align with the leakage field, thus visually indicating the limits of the crack. Tests on this project were performed using a hand-held electromagnetic yoke.

Ultrasonic Testing

B&N's retained subconsultant MQS Inspection, Inc., to perform ultrasonic testing (UT) of bridge pins on 12 of the 172 bridges in the ADOT inspection project. Pins tested were located at pin and hanger joints in continuous beam, plate girder and truss bridges. Straight beam and angle beam examinations were performed to detect the presence of fatigue or corrosion cracks.

Sounding and Rebounding

Inspectors utilized the basic NDT techniques of sounding concrete and rebounding rivets and bolts to document the condition of items. A hammer was used to pound concrete surfaces where deterioration was suspected. When delaminated or "unsound" concrete is located the sound emitted from the pounding provides an easily recognizable dull, hollow, or low-pitched sound. In contrast, good or "sound" concrete provides a reverberating high pitched sound that is easy to recognize. Rivet rebounders were used to check the tightness of a minimum of 10% of the bolts or rivets in each connection. A rebounder is used by placing it on one side of a fastener and striking the other side with a hammer. If the fastener is loose, the rebounder bounces away from the piece. Loose bolts were tightened by B&N to save state maintenance staff a return trip to the bridge. Additionally, sheared or missing rivets and bolts were replaced with new high strength bolts where possible.

Survey Work

Horizontal alignment and vertical profile control surveys were performed on the arch bridges as part of this project. Data was obtained to determine what horizontal deviation, if any, exists between the "As-Built" centerline of the structure or from previously referenced surveys at bridge panel points. Survey data was also collected to establish the existing profile grade of each structure and any deviations from control datum were recorded.

REPORT PHASE

After the field inspection work was completed, an inspection report was generated for each bridge. These reports contained comments and photos on deficiencies found during the inspection work. Condition ratings were assigned to each primary inspection item based on rating descriptions given in the *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* produced by the Federal Highway Administration. Reports also included updated PONTIS element data, tabulated results from any NDT work, channel profile surveys, vertical clearance diagrams, maintenance/repair recommendations, and a recommended inspection frequency. To determine the inspection frequency a fracture critical ranking factor (FCRF) was calculated for each bridge (*I*). The value of this factor was based on the type of structure, type of members, the fatigue crack susceptibility of member details, the assumed material properties of the steel and the average daily truck traffic estimates (ADTT). The report also contained information on any revisions necessary to the Structural Inventory and Appraisal form used by the client. Finally, a table depicting actual field inspection costs for the bridge was produced and included for use in planning and scheduling future inspection projects.

PROJECT FINDINGS

In general, the 172 steel bridges inspected were found to be in good condition, with only a small percentage containing deficiencies significant enough to warrant structural repairs. Table 4 summarizes the notable deficiencies found during the project. Very few of the bridges contained members with significant section loss due to corrosion processes. The mild, dry climate prevalent throughout much of the state has resulted in these structures having much less corrosion-related distress than other similar bridges located in harsher environments.

Table 4: Significant Superstructure Deficiencies

Deficiency	Number of Bridges
Cracked pin	2
Cracked welds at transverse diaphragms connections	31
Cracks in beam and girder webs	10
Cracked weld at beam bottom flange cover plate	6
Collision damage to beam/girder	10

The most serious deficiency found during the inspection program was the presence of two cracked pins. A total of 290 pins were tested. One cracked pin was found in a 23-span steel bridge originally constructed in 1957. It had a superstructure comprised of five continuous rolled beams. This structure had pin and hanger connections on the beams in Spans 3, 6, 9, 12, 15, 18 and 21. A total of 105 pins were located and examined on this bridge. The distressed pin was located in Span 9 at the center beam. UT indicated that the crack ran almost completely through the diameter of the pin at the shoulder. Subsequent examination of the pin after removal and replacement verified the existence of the crack. Visual observations strongly suggest that the crack was initiated by the development of packrust corrosion between the hanger plates and the pin plates on the beam web. Due to the accumulation of corrosion byproducts, the pins of this structure were subjected to not only shearing forces but also torsional and tensile forces. Also, there was evidence that due to packrust corrosion the hanger plates were being subjected to high shear and flexural stresses.

Another cracked pin was located in a 5-span steel beam bridge constructed in 1955. It had a superstructure comprised of six continuous rolled beams with one set of pin and hanger joints in the center span. A total of 12 pins were examined on this bridge. The cracked pin was located on an exterior girder. UT indicated that the distressed pin was cracked almost completely through the diameter at one shoulder and another crack had initiated at the opposite shoulder but had not yet propagated through the pin. This author has not yet received information on the physical condition of this pin subsequent to its removal.

Most of the other significant deficiencies noted were fatigue or impact related. Distress was usually found at the superstructure connection details between transverse diaphragms and girders or beams. Typically, transverse diaphragms were bolted or welded to vertical stiffeners on the girder webs. When cracks were found, they were commonly located in the weld between the vertical stiffener and web or top flange. Figure 3 depicts this type of distress. This type of cracking is commonly caused by out-of-plane forces



Figure 3: Cracked connection weld between girder top flange and diaphragm connection stiffener.

induced in the girder webs by the diaphragms. Differential deflections of adjacent girders during vehicular loading are the source of these forces. On older girder bridges (those constructed around the 1950s), it was typically welds between vertical stiffeners and diaphragms that failed. Often this weld was a field weld of marginal quality. A cracked weld at a diaphragm to stiffener connection is shown in Figure 4.

Cracks were also found in girder webs where vertical connection plates at transverse diaphragms terminated a distance above the bottom flange of the girder. This condition is depicted in Figure 5. This particular bridge was also skewed and the diaphragms were perpendicular to the girders. Out-of-plane distortions were induced in girder web plates by diaphragm connection plates. When the bottom flange is relatively thick and stiff, as was the case on this bridge, diaphragm forces are accommodated by the out-of-plane bending of the web plate between the bottom flange and toe of the connection plate. Cracks, such as the one pictured, were found in the girder webs on this and other similar bridges.

Weld cracks at the toe of fillet welds on bottom flange cover plates were noted on six bridges. These cover plates were located on bottom flanges of beams on continuous beam bridges over the piers. Typically, this type of bottom flange cover plate is located where the bottom flange experiences only compression forces; thus cracks are uncommon. Cracks that do form in this region do not tend to propagate. These cracks may be the result of defects in the original weld or possibly the cover plates extend past the beam inflection point into a region where the bottom flange experiences tensile forces.

Some of the older riveted bridges inspected contained cracked clip angles at stringer to floorbeam connections. These connection angles are subjected not only to vertical shear forces, but also bending moments. Differential expansion and contraction between continuous deck sections and supporting steelwork appears to be responsible for

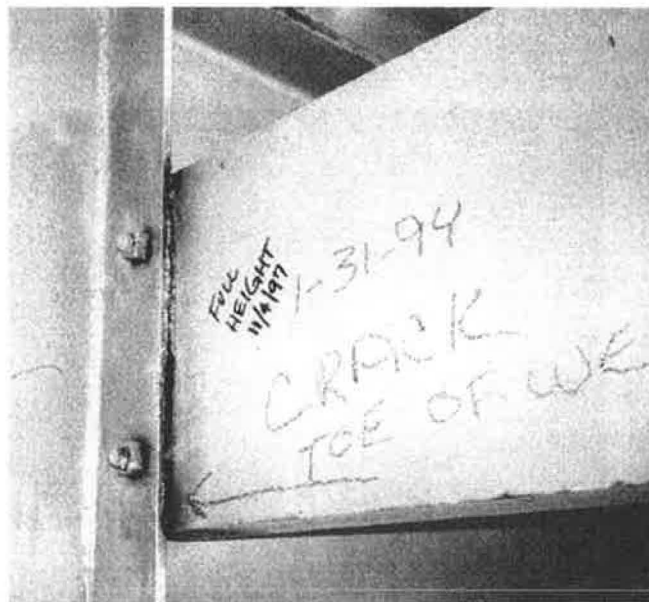


Figure 4: Cracked connection weld between the transverse diaphragm and vertical connection stiffener.

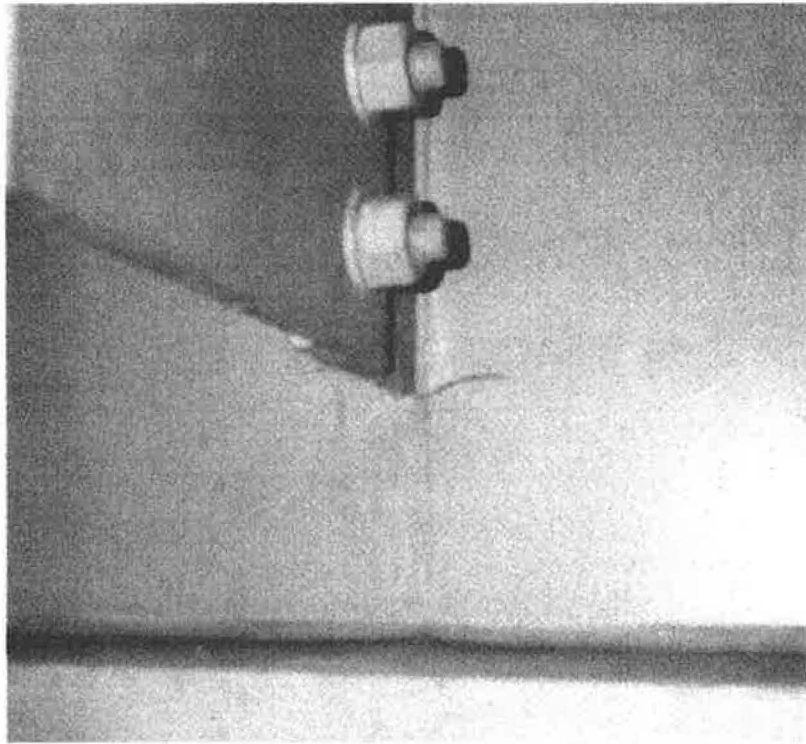


Figure 5: Crack in girder web below termination of transverse diaphragm connection plate.

the cracked clip angles. A typical distressed clip angle is depicted in Figure 6. The bending axis of this connection is close to the top of the member due to the composite action with the deck. The bottom portion of the clip angle is subjected to the highest stresses. Two parallel cracks have formed near the bottom of this angle.

Fatigue related distress was also noted in the lower lateral bracing components of several girder bridges. In Figure 7, a gusset plate at the connection between a lower lateral brace and a girder web is pictured. The gusset plate attachment welds have completely fractured, allowing the gusset plate and bracing to drop and rest on the bottom flange of the girder. This distress can be attributed to secondary stresses induced by dynamic vertical vibrational movement and out of plane distortions caused by vehicular live load on the bridge.

CONCLUSIONS

Thorough planning and preparation, specialized climbing techniques, innovative computer tools, as well as traditional inspection methods and procedures all contributed to the success of this extensive and complex project. This project was completed on time and under budget and has supplied the client with the detailed information required on bridge conditions. The data is now being used to make sound, informed decisions regarding bridge maintenance and rehabilitation needs. At this time, retrofit repair details have been developed by B&N for over 20 bridges where significant deficiencies were found. These repairs will prolong the service life of these structures and provide for the safe movement of vehicular traffic for many years.

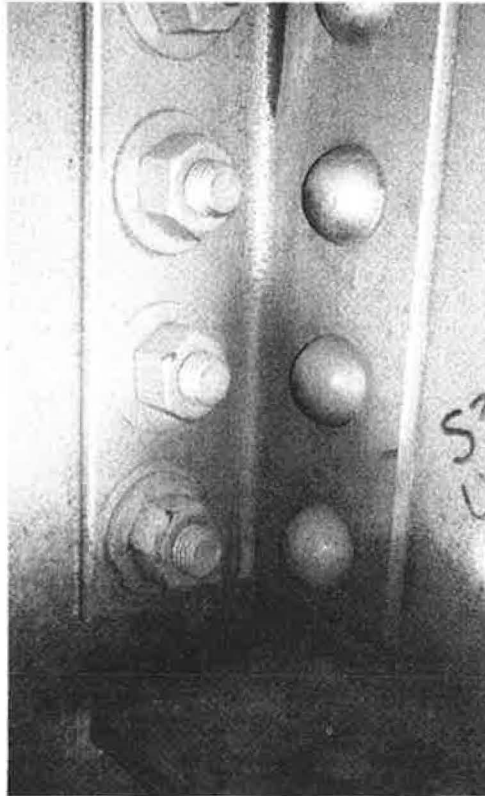


Figure 6: Distressed clip angle at stringer to floorbeam connection.

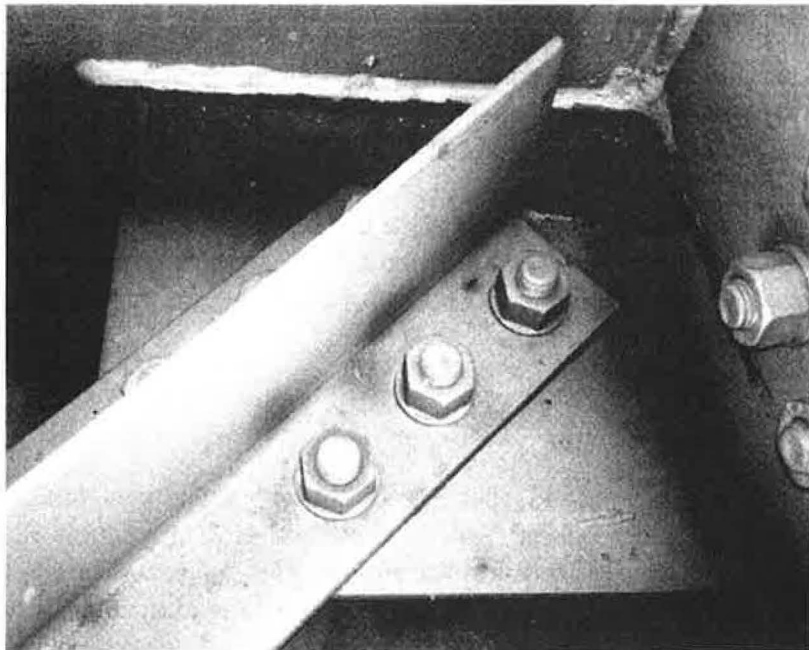


Figure 7: Fractured bottom lateral gusset plate welds.

ACKNOWLEDGMENT

Dr. Pe-Shen Yang, Phd, PE, Arizona Department of Transportation, Bridge Management Section, Phoenix, Arizona.

REFERENCE LIST

1. Yang, P., *In-Depth Steel Bridge Inspection Program*. Arizona Department of Transportation, Bridge Group, Bridge Management Section, July 20, 1996.