REHABILITATION OF THE HISTORIC KATE SHELLEY HIGH BRIDGE

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ABSTRACT

This 2,700-foot long, century-old, steel viaduct bridge with 300-foot main deck truss span, is one of the most critical structures on the Union Pacific system. A major rehabilitation and strengthening project was recently completed on it. The evaluation included analytical rating calculations, an in-depth inspection, oscillation tests to identify unevenly stressed elements of the main span truss, and the use of strain gauging to determine the actual stresses in critical truss elements. During rehabilitation, flame shortening was used to equalize stresses in various truss eyebar members. An extensive, but selective strengthening of poorly performing and weak members was implemented. Finally, a load test involving the acquisition of strain data was performed under static and moving loads. Upon the completion of the project, the bridge, which has long been limited to single-track usage, was permitted to accommodate simultaneous, two-track loading.

This paper describes one approach for dealing with the growing problem of old steel bridges which are at the end of their life expectancy. They are often weak, poorly performing and troublesome to maintain, but frequently too expensive to replace. The case history presented shows the benefit of a detailed investigation, resulting in strengthening and rehabilitation efforts at manageable costs to increase the capacity and extend the life of the bridge.
INTRODUCTION AND BRIDGE DESCRIPTION

The Boone High Bridge (Union Pacific Railroad Structure Number 207.42 of the Boone Subdivision, later known as the Kate Shelley Bridge) crosses the Des Moines River west of Boone, Iowa. It was designed by the renowned George S. Morison, and constructed from 1899 to 1901 as a replacement for a low-level structure that crossed the river on an alignment several miles downstream. At the time of its construction, it was the largest two-track, viaduct-type bridge in the world. The structure is almost 2,700 feet in length and up to 190 feet tall (equivalent to almost 20 stories). It consists of 40 steel deck girder spans supported by steel towers and founded on massive stone abutments at each end. The main river span is a 300 foot long by 60 foot deep deck truss supported by two, A-shaped steel towers, with each tower founded on four cylindrical, concrete piers that are ten feet in diameter. The other spans are alternate 75-foot and 45-foot long deck girder spans supported by tall steel towers. The entire structure is open deck.

WHO WAS KATE SHELLEY?

In 1881, 15 year-old Kate Shelley lived near the former Chicago & Northwestern line (now a part of the Union Pacific Railroad system), about a mile east of the Des Moines River Bridge. On the evening of July 6, 1881, a heavy storm washed out the Honey Creek Bridge near her home, collapsing it under a locomotive. Kate heard the crash and went out into the torrential rain, curious to investigate. She saw two of the crew in the swollen creek, clinging for their life to tree limbs. Kate knew that the Midnight Express was due within the hour and would crash into the creek unless it could be stopped at the station.
on the far side of the Des Moines River. She set out along the track in the storm, carrying her lantern. As she started across the open deck of the Des Moines River Bridge, a gust of wind knocked her down, breaking the lantern. Kate continued, crawling across the structure, snagging her long dress on spikes and splinters. The bridge shook as floating trees struck the low-level crossing. Finally, she reached the station and told the railroad employees of the bridge collapse. The *Midnight Express* was stopped safely, and the surviving locomotive crew members were rescued. Kate received a cash award from the grateful express passengers. She was offered and accepted the position of station agent with the railroad. The Boone High Bridge was renamed in her honor after her death in 1912.

**THE PROBLEM**

Sometime prior to the mid-1950s, traffic on the bridge was limited to one train at time. It appears that the reason for this restriction was concern regarding the structural capacity of the bridge, taking into consideration the ever-increasing train loads. As the structure aged, corrosion and wear weakened several components of the bridge. Additional damage was incurred in 1986 when a windstorm blew more than a dozen containers off the structure, causing impact damage to several of its towers.

The bridge carries approximately 140 MGT per year, which roughly translates into about 60 trains per day. Many of the trains are heavy coal trains, but the line also carries container, tank, grain, auto-rack, and special trains. There is no other, more convenient route from the north, western, and mountain states and from the coal-rich Powder River Basin to Chicago and the Great Lakes area. However, with its one-track load restriction, speed limit and progressive deterioration, the bridge became a serious 'bottleneck' in the railroad system. In the fall of 2000, the Union Pacific Railroad decided to study the possibility of reopening the bridge to simultaneous two-track traffic. Modjeski and Masters, Inc., worked with Union Pacific on this study.

**INITIAL ANALYSIS, RATING AND REHABILITATION PLAN**

The initial study involved rating the structure in its as-built condition. Ratings were performed in accordance with the American Railway Engineering and Maintenance of Way Association (AREMA) *Manual for Railway Engineering*. Coupon samples of the superstructure steel were taken to provide
information on the actual strength of the materials used to construct the bridge. Based on the structural ratings, it was determined that several members of the deck truss span would require strengthening in order to carry modern traffic.

Routine inspections and field observations revealed that a number of the deck truss eyebars were loose, and the original sway bracing and lateral bracing members of the deck truss spans were severely worn and largely ineffective. The combination of these two defects resulted in excessive lateral movement of the deck truss span under load, which was clearly visible as trains moved across the structure.

Based on the ratings and the field observations, a rehabilitation plan aimed at reopening the bridge to two-track traffic was developed. The plan included a detailed field inspection of the structure to identify structural deficiencies and some initial strain gage measurements of bridge members under train loading. The results of these field investigations would be used to develop detailed repair and strengthening plans. A preliminary cost estimate for the budgeting of the rehabilitation and strengthening work was developed at this time. Based on these recommendations and estimates, the Railroad decided to move ahead with the rehabilitation and strengthening project.

FIELD INSPECTION

A detailed field inspection was performed in the summer of 2001. A UPRR snooper truck was used to access portions of the structure below the deck level. The towers and portions of the deck truss span that were inaccessible with the snooper truck were inspected using rappelling equipment and by free climbing. The relative tightness of the deck truss eyebars was checked by oscillating them. The structure was also observed during passage of trains to monitor its behavior.

Defects identified in the inspection were rated for their severity. The most serious defects were repaired immediately by UPRR bridge maintenance personnel. Others were added to the planned rehabilitation contract. Measurements of the most significant defects were taken to aid in the preparation of repair details.
INITIAL FIELD TESTING

The initial field testing of the structure included measuring member strains using strain gauges and observation of deck truss deflections using visual targets and surveying equipment. Measurements were taken under routine train traffic.

Strain gages were installed on several bridge components, including deck truss top chords and diagonals, as well as the bottom flanges of approach span deck girders. Targets with a grid measuring to the nearest half inch were mounted on the deck truss near the center panel points of both the north and south truss lines. A surveying instrument and a video camera were used to monitor the vertical and horizontal movement of the targets under train loads. Video was also taken of the behavior of deck truss eyebars and bracing rods under live load.

REHABILITATION PLANS

Several items were added to the proposed rehabilitation plans based on the findings of the inspection. The final rehabilitation plans included:

1. Strengthening of the deck truss upper chord.
2. Strengthening of deck truss counters and diagonals.
4. Flame shortening of deck truss eyebars to equalize eyebar stresses.
5. Repair of damaged tower components.
6. Replacement of original deck truss “tie-rod” sway frames and bottom lateral bracing with more substantial bracing members.

**CONSTRUCTION**

The Railroad selected American Bridge Company as the Contractor for the repair work. The Contractor provided all necessary equipment and cranes for the project and constructed a gravel drive to provide access to the construction site at the west bank of the river. A caged staircase was constructed at the base of the structure near the west end of the deck truss to provide access to the highly elevated structure. Most of the work was performed at elevations between 130 feet and 190 feet above the river level, while maintaining the necessary safety requirements.

The construction schedule was largely governed by the daily traffic and the frequency of trains crossing the bridge. The Contractor was required to work around train crossings in sporadic and relatively infrequent windows as they were available. This created a significant challenge in the planning of construction operations and required close cooperation between the Contractor and Railroad. In addition, the frequent high winds and severe temperatures at the site, ranging from the bitter cold of winter to the extreme heat of summer, also increased the difficulty of keeping an efficient and productive construction schedule.

**STRENGTHENING**

Selected members of the deck trusses were strengthened. The objective of the strengthening was to allow simultaneous passage of two trains consisting of 286,000 lb. cars. Upper chord members were strengthened with steel angles that were bolted to the side plates of the existing built-up members. Diagonals were strengthened using built-up hairpin-type elements that extended around the existing truss
pins, parallel to the existing eyebars. Deck truss floorbeam stiffeners were replaced with new vertical stiffener angles that were supplemented with vertical plates to provide adequate bearing area to the underside of the top flange angles at the stringer seats. Also, cracked floorbeam top cover plates were replaced at selected locations.

**FLAME SHORTENING**

During the inspection of the deck truss, it was noted that eyebars in some of the main span members were not equally tensioned. After more than a century of service, many of the eyebars had become significantly loose and, therefore, carry little to no load. As a result, other eyebars had been forced to carry increased loads and become overstressed. An inventory was compiled for the deck truss members to evaluate the relative tightness of each eyebar. As part of the rehabilitation effort, it was determined that the eyebars should be flame shortened to ensure more equal participation of all eyebars and thus improve the behavior of the deck truss.

Section 8.2 (Chapter 15) of the AREMA Manual contains a description of a method for shortening eyebars. A specification package, using the method in the AREMA Manual as a guideline, was prepared to flame shorten the eyebars. Some of the procedures in the AREMA Manual regarding the maximum steel temperature and cooling process were modified in the specification package. The flame-shortening work was to be performed prior to the other deck truss strengthening and rehabilitation.
Prior to flame-shortening, frequency of vibration tests were independently conducted by American Bridge Company to check the tightness of the eyebars. Modifications were made to the frequency of vibration test as the work progressed to account for site specific conditions. As the work progressed, it was noted that the eyebars to be tightened could not necessarily be determined from the initial inventory. The process of tightening some members loosened or tightened other eyebars. As a result, the flame shortening process was iterative and required several rounds of tightening and inventory. Tightening was also performed with consideration given to bridge symmetry. For example, the dead load stress in truss member L4-M5 was compared with the stress in the same member in the other truss line and at the other end of the truss. After several rounds of tightening and inventory, the flame-shortening work resulted in dead load stresses to be within 15% of the average dead load stress for eyebar elements within a particular member and for each similar type of member.

**BRACING REPLACEMENT**

In the original construction of the deck truss, sway bracing and bottom lateral bracing members were constructed of tie rods, which were typical at the time of the bridge construction. Over time, and under the increased loading, these elements have become ineffective, largely due to bends in the rods and wear at the end connections. These conditions contributed to the excessive lateral deflections observed under train loading. In order to remedy this deficiency, the original tie rods were replaced with more substantial
bracing composed of structural steel shapes and built-up sections. The bracing was replaced one bay at a
time and in convenient, individual sections, thus minimizing the need for track outage windows.

![Figure 8: New Sway Bracing](image1)
![Figure 9: New Bottom Lateral Bracing](image2)

**FINAL INSTRUMENTATION**

Following the conclusion of the initial instrumentation and analysis and the subsequent strengthening and
rehabilitation of the structure, a second round of instrumentation was performed. The purpose of the
repeat instrumentation was to help quantify the improved structural behavior of the deck truss. The
results were used to identify the redistributed load-sharing of eyebars, the participation of strengthening
members and to assess the improved stiffness of the deck truss due to the new bracing members.

Strain gauges were installed on both the north and south truss upper chords and two upper
diagonals. The upper chords were primarily tested to determine the distribution of single-track loads to
each of the truss lines. The diagonals were gauged for similar information but also for the purpose of
determining load sharing between individual eyebars of each member. Strain gauges were also installed
to one of the new transverse sway frame members to determine the participation of the sway frame under
loads. Visual deflection targets were attached to the structure near mid-span of the upper chords at both
the north and south truss lines to acquire both vertical and lateral deflection readings.

Data was collected for a combination of routine traffic and test trains. Test trains were specially
arranged by the UPRR. Special authorization was required for simultaneous occupancy of both tracks for
testing. Each of the test trains consisted of several 263,000-pound coal cars with a six-axle engine at each end of the train. The use of cars with known loads permitted the comparison of the actual, field-measured stresses under live loads to the theoretical loads that were assumed in the prior rating and analysis of the structure.

![Figure 10: Instrumentation Data Collector](image1)

![Figure 11: Instrumentation Data Analysis](image2)

**REPLACEMENT STUDY**

In order to assist in long-term planning for the structure, the Railroad requested that Modjeski and Masters conduct a conceptual study for the placement of a parallel structure just to the north of the existing bridge. The study proposed reusing the superstructure of existing UPRR Bridge Number 349.30 of the Ankeny Subdivision at the Saylorville Reservoir. The proposal was that the Saylorville Bridge would be relocated approximately 15 miles upstream and supported atop new substructure in the general vicinity of the Kate Shelley Bridge. The objective of the relocation would be to provide additional tracks that would allow high-speed operation over the Des Moines River near Boone. The cost of the relocation was estimated at $18,000,000 or $25,000,000 (in 2001 dollars) if the substructure was built to accommodate a future second track. This led to the conclusion that, while construction of a parallel structure was feasible, it would also be quite costly for a double-track structure. The studied alternatives give some indication of the value of the rehabilitation and strengthening project, as it defers the need for replacement of the entire structure for some time.
CONCLUSIONS

The rehabilitation of the Kate Shelley High Bridge has improved the structural condition of the structure. The initial rating, inspection, and instrumentation of the structure laid a foundation for evaluating the existing condition of the structure and providing recommendations for the improvements, with the goal of restoring the bridge to two-track service.

Following the rehabilitative efforts and the final instrumentation, it was confirmed that load sharing among individual components of flame-shortened eyebars was improved and the upper chord strengthening angles were contributing significantly to the load carrying capacity of the upper chords. The diagonal strengthening, while carrying only a small percentage of the load, will provide substantial redundancy for the diagonals. The improved steadiness of the structure, better distribution of loads to both truss lines under single-track loading, and smaller vertical and lateral deflections indicate that the new sway frames and bottom laterals are providing added structural stability.

With the improved structural performance of the deck truss, the UPRR was able to ultimately remove the single-track restriction from the bridge and open the structure to two-track traffic, with a speed limit of 25 miles per hour. While it is expected that the event of two trains meeting on the deck truss will be infrequent, considerable wear and increased stresses will undoubtedly occur under two-track loading. Therefore, precautionary measures have been implemented in an effort to monitor the response of the structure to such loading conditions. Inspections have been increased in frequency and the UPRR has initiated a plan to record the actual number of train meets on the structure.

In the future, a subsequent evaluation of the structure, based on the inspection findings and other monitoring efforts, may be completed in an effort to see if further adjustments to the track operations are warranted.

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