Research Record

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Michigan's Link Plate and Pin Assemblies

MDOT Examines Current Performance, Use, Repair, and Maintenance Procedures

There are nearly eleven thousand bridges located throughout Michigan. It's difficult to imagine driving anywhere in the state without crossing a bridge of some sort. Bridges in Michigan come in all shapes and sizes, crossing everything from ditches to the Mackinac Straits. Maintaining these bridges ensures public safety, and keeps the ever-increasing traffic loads moving in an efficient manner. In an effort to satisfy these two objectives, the Construction and Technology (C&T) Division of the Michigan Department of Transportation (MDOT) continually studies and monitors bridges around the state. Through these studies, bridge engineers not only keep tabs on existing bridges, but they are also able to determine trends and develop construction and maintenance methods for the future. One recent study took a comprehensive look at the condition of bridges constructed with link plate and pin assemblies, often referred to as pin and hangers (please refer to Figure 1). These assemblies allow for the expansion and contraction of the bridge deck as environmental conditions change.

A review of the condition ratings of bridges with link plate and pin assemblies shows that about 15% of the bridges are rated poor or serious, and 54% of the bridges are rated as good condition or better.

Link plate and pin assemblies are replaced when a bridge undergoes scheduled maintenance such as painting or deck joint replacements, or when a problem related to the assembly is discovered. The decision to update the link plate and pin assembly is made by the scoping engineer or designer. It is estimated that 20 to 30% of Michigan's structures with link plates have had the original link plate and pin assemblies replaced with new assemblies.

There are twelve bridges in Michigan with link plate assemblies on non-redundant spans. A non-redundant span refers to a bridge where only two beams provide primary support for the span, or beam spacing is wide enough that if one beam fails, the structure could become unstable. These bridges are given detailed inspections annually, and in the mid-1980's MDOT replaced the link plates on all of these bridges.

Background

Roughly 10% of the bridges in Michigan are constructed with link plate and pin assemblies. Many of these have been in service for 20 to 30 years. The Structural Research Unit of C&T decided that it would be prudent to evaluate the condition of Michigan's link plates, and to study the actual live loads that these details experience. With this in mind, a number of bridges were instrumented to record the stress range resulting from various loads. Concurrently, the Structural Research Unit also evaluated various problems associated with link plate and pin assemblies.

Figure 1: Typical Link Plate and Pin Assembly

Problems Discovered

Fractured Link Plate

Michigan has at least one known experience where a link plate has fractured. This occurred on the structure carrying M-46 over the Tittabawasee River, approximately 4 miles west of Saginaw. The bridge has seven spans with 14 steel beams supporting a reinforced concrete deck with a longitudinal open joint running along the centerline of the bridge. There are three suspended spans supported by link plate and pin assemblies. An MDOT bridge inspector discovered the fractured link plate during a routine bridge inspection. The link plate was broken near the top of the bottom pin hole. Since the structure was scheduled for link plate and pin replacement, the link plate was temporarily repaired with a welded plate crossing the fracture. No further analysis was done to determine the cause of the fracture, although the bridge inspector observed that the expansion joint at the link plate had closed causing the diagonal portion of the beam webs across the link plate to push against each other.

Corroded Link Plates

Corrosion is the most common problem associated with the link plate and pin assemblies. Expansion joints above the detail leak water contaminated with road salts on to the link plates, causing them to corrode. Michigan has experienced corrosion buildup between the link plate and the beam web. On the bridge carrying I-75 over the Huron River, an MDOT bridge inspector discovered this problem on several of the link plates. The corrosion product caused the linkplate to move outward, causing the pin end cap to cup. These corrosion products can also cause the assembly to bind up, inhibiting the ability of the assembly to rotate properly. There was also an instance where in-plane bending was measured in the link plates, resulting from corrosion products.

Beam Ends in Contact

A repeated problem Michigan has encountered with link plate and pin assemblies is when the expansion gap between the beams closes. When this happens, the beam ends can make contact along the diagonal portion of the beam web. As the bridge expands during warm weather, the beam ends push against each other. The resulting force is directed into the link plates across the diagonal portion of the beam webs.

Loading Patterns in Link Plates

In an effort to measure the stress increase from temperature changes, MDOT mounted vibrating wire strain gages on the link plates of the bridge carrying I-196 over the Grand River in Grand Rapids, Michigan. In the link plate where the beam ends were in contact, strain was measured for one year to see if dead load stress varied with seasonal changes in temperature. It was discovered that the stress increases can be substantial. From the strain data that was collected, it is estimated that the stress in the link plate increased at a rate of roughly 330 pounds per square inch (psi) per every 2°F. MDOT personnel then mounted another set of vibrating wire strain gages on a similar link plate where the beam ends were in contact. When the link plate was removed from the bridge, there was a change of about 33,000 psi, which was a substantial amount of additional dead load stress on the link plate.

As several bridges with beam ends in contact were inspected, signs of high stress became evident. It was found that if a large compressive force is present in the beam web across the beam ends, the web may bulge, or possibly even buckle. In some cases, the buckling can actually cause the link plate to become disengaged from the pin.

During this study, three types of load conditions were observed; axial loading, in-plane bending, and out-of-plane bending.

Axial Loading

Axial loading is a load passing concentrically through the body of the link plate as shown in Figure 2. This is the type of load that is assumed when a link plate is designed. Because stress concentrations occur at the pin holes, the net section of the link plate across the pin hole is the critical section of the link plate for carrying load. For static design strength, the American Association of State Highway Transportation Officials (AASHTO) Bridge Specification requires that the net section be sized 40% larger than otherwise required to account for the stress concentration.

For the live load study, MDOT needed to understand the nature of the stress flow through the link plates. Strain gages were placed at the midsection and at the pin hole of a reduced size link. Test results indicate that there is a much higher load near the pin holes.

In-plane Loading

As mentioned, a known problem with link plate and pin details is corrosion. Over time, corrosion product causes resistance to rotation of the link plate about each pin. Corrosion buildup between the link plate and the beam web also causes the assembly to bind up. As a result, in-plane bending occurs in the link plate when large loads are applied, such as trucks driving over the bridge, or with changes in temperature. Please refer to Figure 2.

Out-of-Plane Loading

This refers to the weak-axis bending. This is caused by vehicles impacting an expansion joint that is at an angle to traffic flow, from thermal forces on skewed and horizontally curved bridges, from differential deflection of the adjacent beams, radial force exerted by a vehicle on a horizontal curve, and from misalignment of the beam web. Please refer to Figure 2.

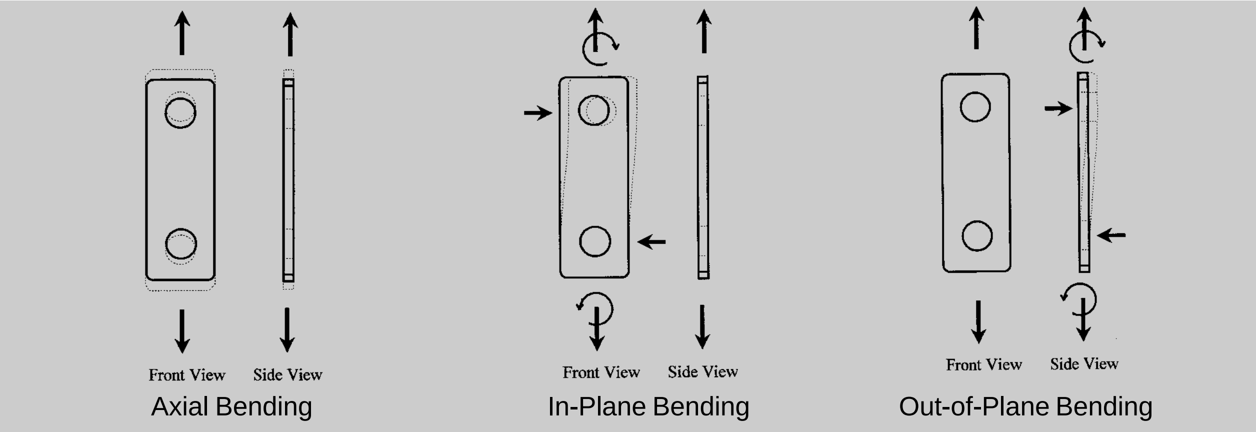

Figure 2: Examples of Common Loading Patterns in Link Plate and Pin Assemblies

The variables that affect the stress magnitudes in a link plate are truck weights, impact factor, lateral distribution of the truck loads, length of the span, redundancy of beams, angle of crossing, and corrosion in the link plate. Additional variables that affect the fatigue life of the link plate are average daily truck traffic (ADTT), number of traffic lanes, percentage of trucks in a given lane, and number of stress occurrences per truck passage.

Live Load Testing

During this project, MDOT studied live load strains in the link plates on three bridges. All the bridges had high ADTT counts. The first bridge was in good condition with new link plates, the second bridge had non-redundant spans, and the third bridge had very old, corroded link plates. A fatigue analysis was done for each bridge and live load strains were measured. The measured values were compared to allowable values as per the AASHTO codes.

The purpose of the live load testing was to compare the measured effective stress in the link plates to the calculated effective stress from equations in the AASHTO codes. The effective stress at the net section of the link plate across the pin hole was calculated using the AASHTO Guide Specifications for Fatigue Evaluation of Existing Steel Bridges, 1990 (*AASHTO Fatigue Guide*). Due to the fact that the weight limit in Michigan is 164,000 lb., versus the Federal limit of 80,000 lb., the weight of the Michigan Fatigue Truck used in the analysis was adjusted to be more representative of the truck loads on bridges in Michigan.

Using the *AASHTO Fatigue Guide*, calculations were made to determine the link plate's finite life and mean life, which is defined by the *AASHTO Fatigue Guide* as the best possible estimate of the detail's fatigue life. The safe life was also calculated, which provides a probability of 97.7% that fatigue cracks will not occur for redundant members, and a 99.9% probability for non-redundant members.

Finally, the AASHTO Bridge Design Specifications, and AASHTO LRFD were used to calculate the size of the link plates to meet fatigue requirements. These calculated results were compared to the actual size of the existing link plates, which were designed based on tensile strength. Generally speaking, it was found that the *AASHTO Fatigue Guide* better reflected measured values.

Recommendations

This study brought to light a number of issues that bridge inspectors and engineers need to be cognizant of during their routine inspections.

Fractured or Cracked Link Plates

Look for cracking in the link plate near the pin hole. If a crack is suspected, it should be confirmed by ultrasonic inspection. If a crack is confirmed, the beam should be supported, and the fractured link plate should be replaced immediately. The link plate should be subsequently investigated to determine the cause of the fracture. The remaining link plates should be closely inspected for cracking or signs of distress. Most likely, if one of the link plates has fractured, then the remaining link plates will require replacement.

Corroded Link Plates

This is the most common problem associated with link plate and pin assemblies. Heavily corroded link plates and pins should be replaced. Deck expansion joints that leak water onto the link plates should also be replaced.

Beam Ends in Contact

When the beam ends are in contact, the link plates and beam ends should be inspected for distress. Types of distress that are known to occur include; the link plate is cracked or fractured, the beam web may bulge or buckle near the link plate and pin assembly, out-of-plane bending of the link plate, and general movement of the link plate an/or pin.

In addition to the inspection of the link plates and the immediate vicinity nearby, the inspector should also look at other portions of the bridge for signs of distress that could be related to problems with the link plates. Two common things to check for are tilting of the rocker bearing on adjacent piers, and the beams pulling out of abutments. These two events are often related to closed expansion joins. This could be an indication that the expansion joint above the link plates may close in the future. If it is determined during the course of the inspection that more than half of the beam ends make contact, and three or more of the beams in contact are adjacent, or if there are signs of distress to the link plates, pins, or the beams, then corrective action is needed.

Corrective Actions

- **Replace the pin and hanger assembly -** This will remove any built-up stress in the link plate. A larger link plate (50% greater section than normally required) should be used for replacement to resist any additional stress resulting from the beam ends making contact. Most often the link plate will be made thicker with an appropriately longer pin.
- **Cut relief joint in the approach pavement (if concrete) -** Do this when pavement growth is suspected.
- **Provide fixity at the link plates and move the expansion joint elsewhere -** Many times, a suspended span will have a fixed and expansion pin and hanger assembly. The fixed end will have a splice plate connecting the top flange of the beams. This splice plate can be removed from the original fixed end and a new splice plate attached to the original expansion end. Expansion can also be moved to the abutments. Designers need to determine how this changes the expansion characteristics of the bridge and design accordingly. Both of these methods require work on the bridge deck.
- **Provide a gap between the beam webs that are touching (Trim the Beam Web) -** When the distress from the beam ends pushing against each other is severe a gap should be provided between the beam webs that are touching. To do this, special procedures are required. Possible methods are: thermal cutting, realign the spans, or provide longer replacement link plates and adjust the deck height accordingly. Prior to doing any of these methods, precautions should be taken to prevent the spans from returning to the position where the beam ends are touching. Methods to prevent this are: cut relief joints in the approach pavement, plumb or replace rocker bearings, and provide greater restraint at the field ends.

Non-Redundant Spans Supported by Link Plates

Non-redundant bridges with link plates should receive detailed inspections annually. Link plates on non-redundant spans should be maintained in excellent condition. Any sign of distress to the link plates or the beams near the link plates should be addressed immediately.

Design and Analysis Recommendations

Further research needs to be done to show that Fatigue Category E is appropriate for link plates on highway bridges. Until this research justifies a higher fatigue category, designers should detail link plates for Fatigue Category E, as specified in the AASHTO Bridge Specifications or the AASHTO LRFD. When designing as per AASHTO LRFD, the Michigan Fatigue Truck may be used to calculate live load.

When analyzing existing link plates, the 1990 Fatigue Guide should be used with the Michigan Fatigue Truck. When designing or analyzing link plates for fatigue, 2 stress cycles per truck can be used when estimating load cycles if the span has multiple beams, the angle of crossing is greater than 80 degrees, and the deck is not on a horizontal curve. If these criteria are not met, 10 cycles per truck should be used for the estimation.

Contact Information

For more information regarding this study, contact Dave Juntunen at (517) 322-5707, or via email at JUNTUNEND@mdot.state.mi.us.

Reference Material

Much of the text within this Research Record was used with permission from the following report:
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