Research Record

Issue Number 94 CONSTRUCTION AND TECHNOLOGY April 2002

Pack Rust on A-588 Weathering Steel Bridges Causes Safety Concerns

MDOT Investigation Helps Prevent Bridge-mounted Sign Failures

In the summer of 2001, MDOT's Structural Research Unit investigated problems found on signs mounted to ASTM A-588 weathering steel bridge beams. The investigators found broken, missing, short, and stripped bolts, and large build-ups of pack rust between the sign mounts and beam webs (Figure 1). The investigators suspected that the pack rust led to bolt failures, which would explain the missing bolts.

Inspection

A sign failure poses a serious safety risk, so MDOT coordinated a prompt statewide inspection of sign supports on all weathering steel bridge beams. Technicians and engineers inspected sign connections from the ground using binoculars to look closely at beam/sign mount connections. Viewing the back side of fascia beams from the shoulder of the roadway easily revealed if bolts were missing (Figure 2), and viewing the front side of the fascia beam revealed if there was pack rust between the connection (Figure 1). The expedited inspection found 16 out of 25 (64 percent) bolted A-588 sign supports with missing bolts, rusted bolts, short bolts or pack rust. Fortunately, on MDOT's 528 weathering steel bridges, there are only 31 weathering steel sign supports (including welded connections). Most A-588 weathering steel supports are found on bridges built before 1974. Bridges built after that date, and sign supports that have been placed or replaced since that time, are galvanized steel. Although only four out of 264 galvanized supports had missing bolts and pack rust, the investigation did show that pack rust could also be a problem on galvanized sign supports attached to weather steel bridge beams.

Investigation and Analysis

In order to explain the cause of the pack rust and fractured bolts, MDOT engineers researched current information on A-588 weathering steel and pack rust. As part of their comprehensive investigation, engineers also performed laboratory analysis on the bolts and examined the sign support detail.

A-588 weathering steel is a high-strength, low-alloy structural steel formulated to have better atmospheric corrosion resistance capabilities than traditional steel alloys. Advocates of this steel claim that it does not need to be painted because

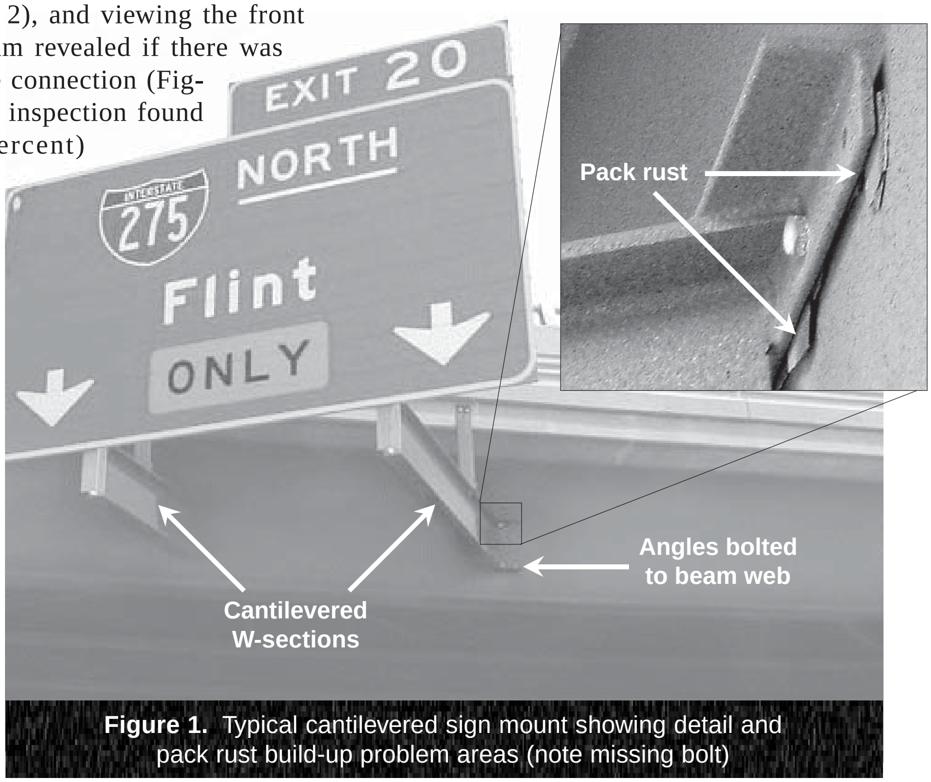

Figure 1. Typical cantilevered sign mount showing detail and pack rust build-up problem areas (note missing bolt)

Recommendations

Based on the research reported on here and on the overall condition of A-588 sign mounts in Michigan, MDOT engineers have decided to replace all A-588 sign mounts with galvanized sign mounts. The following recommendations guide engineers and bridge inspectors when inspecting and specifying sign supports on A-588 weathering steel bridges.

A. Replace all A-588 bridge-mounted sign supports with galvanized steel sign supports. Replacement/repair procedures are outlined in the following changes to the MDOT Sign Standard Plans VIII-820E and VIII-830E:
   i. The connection interface (faying surface on the beam web, and the support angle, if it is not galvanized) should be blast cleaned and primed with organic zinc-rich paint.
   ii. If the beam is unpainted A-588 steel, the paint color shall be "Brown Weathering Steel," Federal Code Number 10062, and the paint shall overlap the perimeter of the connection by 2 inches, otherwise blend the paint to the existing paint.
   iii. Bolts shall be long enough to extend beyond the top of the nut at least two thread pitches.
   iv. The perimeter of the connection should be sealed with an approved silicone sealant in accordance to Subsection 713.03F of the Standard Specifications.
   v. High strength A-325 Type 3 bolts should be used when attaching a support to A-588 steel.
   vi. The bolted connection of the sign support to the beam web shall be according to Subsection 707.03.D.9 of the Standard Specifications.

B. Bridge inspectors should inspect bridge-mounted sign supports for pack rust, missing bolts, short bolts (bolts that do not project completely through the nut), or impact damage.

C. Damaged or failed mounts should be scheduled for replacement or taken down.

D. If any bolts are missing or fractured, or if pack rust is discovered in the connection interface, all bolts on the support should be replaced immediately. All joints, whether repaired or not, should be sealed with silicone sealant.

E. Figure E1 shows recommended changes to Sign Standard Plans VIII-820E and VIII-830E. The redesign, which adds two additional bolts to each connection angle, satisfies AASHTO Standard Specifications for Highway Bridges, Sixteenth Edition, 1996, Subsection 10.24. 6.1, Sealing Against Moisture Penetration. The vertical leg of the angle is made longer to allow the bolt to be moved closer to the center of the connection, without interfering with the W-section/angle weld.

Exhibit 1. Bridge-Mounted Sign Inspection and Maintenance Recommendations

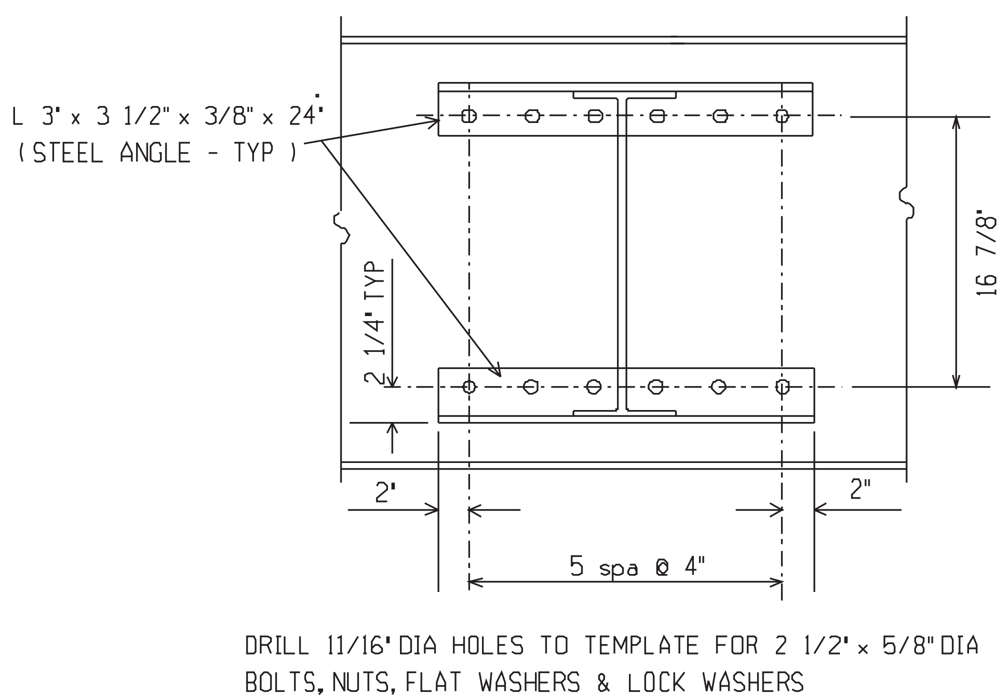

Figure E1. Sign mount detail changes

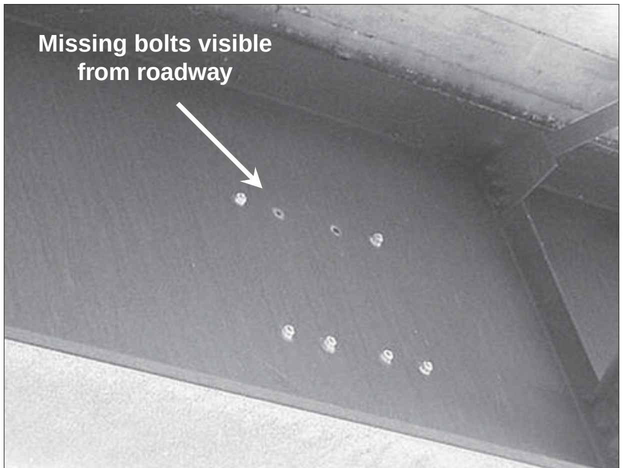

Figure 2. Example of what inspectors should look for during roadside inspections of bridge

it develops a protective oxidation coating that prevents further significant material deterioration. Even though surface corrosion on weathering steel may not be a problem affecting the steel's structural performance, localized accelerated corrosion can lead to serious problems. One such problem is the build-up of pack rust. Pack rust is a thick build-up of corrosion product that tends to develop between the surfaces of closely joined, unprotected metal objects (unpainted bolted connections, for example). The close-fitting joint holds moisture and the resulting oxidation between the joint surfaces, further accelerating oxidation and the build-up of rust. Pack rust is known to create tremendous prying force that can fracture bolts like the ones found during the sign mount investigation.

To confirm that the bolts used on the sign supports had adequate strength, and to demonstrate how pack rust could fracture the bolts, investigators tested bolts, comparing bolts fractured in the laboratory with fractured bolts found in the field. Bolts removed from a sign support were tested in accordance with ASTM A-370, Section A3, "Mechanical Testing of Steel Products, Annex 3.2.1.5 - Tension Testing of Full Size Bolts with a Wedge." The bolts were 5/8-inch diameter, galvanized ASTM A-325 Type 2. Test results for the wedge test are shown in Table 1. All bolts met the required tensile strength of 27.1 kips. Figure 3 shows a bolt recovered from a sign mount and a bolt fractured by a wedge test in the laboratory. The failure surfaces are similar, indicating a similar wedge effect produced by the pack rust. Bolt head displacement for bolts subjected to tension tests in the laboratory (Table 2) show how far the test bolts stretch before failing. Investigators measured pack rust on the failed sign connection, finding build-up 0.225 inches thick, which is more than the 0.171 inches required to fracture a test bolt.

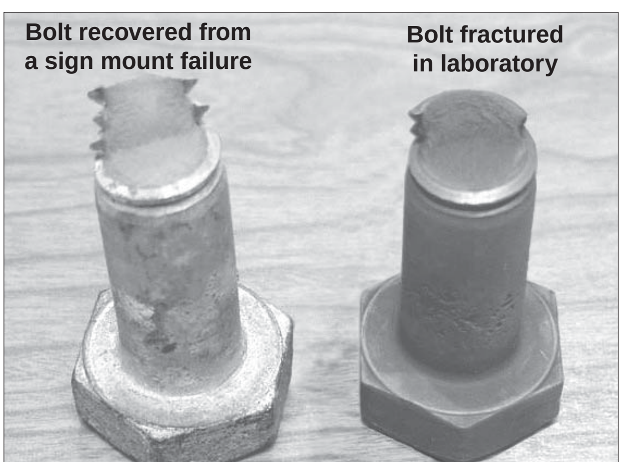

Figure 3. Recovered and Test Bolt Comparison

Table 1. Wedge Test Tensile Values

33.5 kips
32.6 kips
31.7 kips
34.8 kips
34.6 kips

Table 2. Tension Test Values

Tension	Displacement
33.1 kips	0.171 in
33.3 kips	0.152 in
32.6 kips	0.164 in

Tables 1 & 2. Laboratory test results

To protect against pack rust, a bolted connection must either have its perimeter sealed with paint or a caulking compound, or bolt spacing must meet the American Association of Highway and Transportation Officials (AASHTO), Standard Specifications for Highway Bridges, Sixteenth Edition, 1996, Subsection 10.24.6.1, Sealing Against Moisture Penetration. An FHWA Technical Advisory on uncoated A-588 weathering steel structures discusses the importance of sealing overlapping surfaces:

> [I]f water is allowed to flow over overlapping joints, capillary action can draw the water into the joint and cause "rust-pack" to form. Therefore, the contact surfaces of overlapping joints must be protected from intrusion of rainfall and runoff. This applies to nonslip-critical bolted joints as well as to overlapped joints such as those tapered high mast lighting poles. The faying (contact) surfaces should be painted or sealed to prevent the capillary penetration. In slip-critical bolted splices, "rust-pack" should not occur when the bolts are spaced per AASHTO specification. (FHWA, 1989).

Furthermore, designers must also consider connection stiffness when protecting against moisture penetration of A-588 steel connections. In their NCHRP report, Albrecht and Naeemi found:

> […I]f stiffness of the joint is adequate and the joint is tight, the crevice between two contact surfaces seals itself as corrosion products form

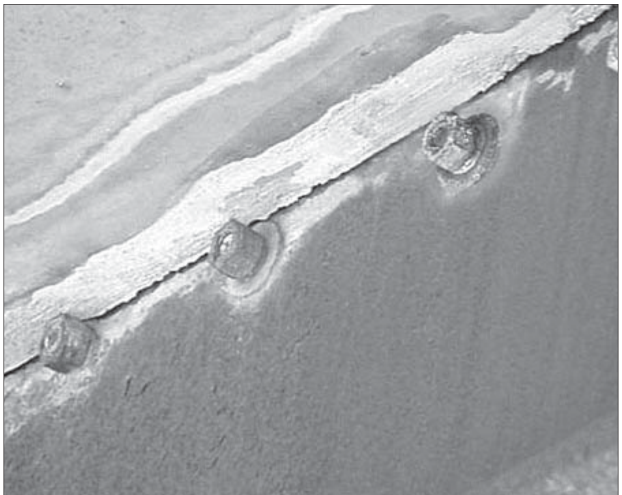

Figure 4. Inadequate thread engagement (short bolting)

> around the periphery of the joint. However, if the joint design does not provide sufficient stiffness, continuing crevice corrosion and subsequent accumulation of corrosion products in the crevice induce expansion forces which can deform the connected elements, and cause large tensile loads on the bolts (135).

Another problem found was short bolts. For a bolt and nut to offer full design strength, it must have full thread engagement with the end of the bolt, extending to at least flush with the face of the nut. Several sign support connections found during the investigation had improper thread engagement (Figure 4). Common industry practice specifies that two thread pitches protrude above the top of the nut to avoid chamfered threads at the bolt ends (Short Bolting).

Conclusions

The expedited inspection effort undertaken by the Department in the summer of 2001 prevented several overhead sign failures. As a result of the investigation, MDOT provides new guidance to bridge inspectors to help them identify problems when inspecting sign supports on bridges with A-588 weathering steel beams (see Exhibit 1). MDOT has decided to replace all A-588 sign supports with galvanized steel sign supports. Before placing sign supports on A-588 steel beams, the connection interface (faying surface) is blast cleaned, and primed with a zinc-rich paint. The perimeter of the connection is sealed with a silicone sealant. Additional bolts are being added to MDOT's sign support standard plan to meet AASHTO requirements for *Sealing Against Moisture Penetration* (Figure E1).

The new inspection and installation practices, combined with the new design detail (Exhibit 1), will help find potential sign mount problems on all bridge types and help prevent pack rust from developing in the future. Other agencies can use Michigan's experience to quickly identify and solve problems from pack rust. MDOT strongly encourages other agencies to inspect their signs attached to unpainted A-588 bridge beams.

Contact Information

For more information regarding pack rust on A-588 bridges in Michigan and this study, please contact David Juntunen, P.E. at (517) 322-5707 or by e-mail at JUNTUNEND@michigan.gov. Additional information about this or other research projects is also available from Michigan LTAP at (906) 487-2102.

References

FHWA. "Uncoated Weathering Steel in Structures." Technical Advisory T 5140.22. Federal Highway Administration (FHWA). 3 October 1989.

Albrecht, P., and A. H. Naeemi. "Performance of Weathering Steel in Bridges." NCHRP Report 272. National Cooperative Highway Research Program. July 1984.

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Correction

In *Research Record No. 93, Thin Whitetopping: Rehabilitation Alternative*, the editors incorrectly converted values from kg/m^3 to lbs/m^3 in Table 2 on page 4. The corrected table in lbs/yd^3 is shown here:

Component	Quantity
Portland Cement	521 lbs.
2NS fine aggregate	1424 lbs.
6AA coarse aggregate	1634 lbs.
Water	237 lbs.
Air-entraiment admixture	1.7-2.0 oz. / 100 lbs.
Water-reducing admixture	2.0 oz / 100 lbs.

C&T Research Record is produced by:

Michigan's Local Technical Assistance Program

Research Writer/Editor .... John Velat

MDOT Michigan Department of Transportation

C&T Research Record is a news bulletin authorized by the transportation director to disseminate technical information to MDOT personnel and is published by the Construction and Technology Division. The cost of printing 480 issues is $133.00, and it is printed in accordance with Executive Directive 1991-6.