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Riveted Steel Repair Methods at a Historic Train Station

Méthodes de réparation d'une structure en acier riveté dans une gare

Methoden zur Reparatur einer vernieteten Konstruktion an einem Bahnhof

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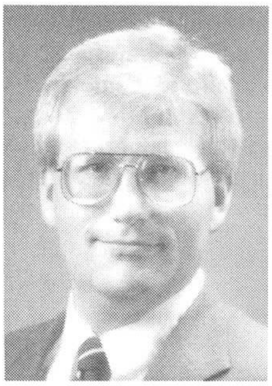

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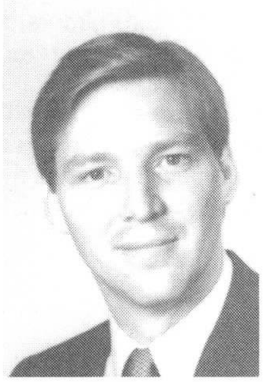

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SUMMARY

This paper describes the variety of methods used to repair the 85-year-old riveted steel in a historic train station in downtown Chicago. Exposure to salt-laden moisture took a severe toll on the steel members. Corrosion damage was extensive; complete flange angle deterioration and large web rust holes were a common occurrence. The steel rehabilitation approach on this project is addressed. Factors influencing repair need and guidelines for repair selection are provided. Examples of repair design and details are described, including a discussion of welding criteria, replacing rivets with bolts, composite construction and supplemental members.

RÉSUMÉ

L'article présente différentes méthodes utilisées pour la réparation d'une structure en acier riveté, construite il y a 85 ans dans la gare ferroviaire du centre de Chicago. L'exposition à une atmosphère humide saline entraîna la corrosion de nombreux éléments en acier. Les auteurs traitent de la réhabilitation de la partie métallique de l'ouvrage; ils indiquent les facteurs qui influent sur la réparation et sur les directives du choix de la réparation; ils décrivent diverses études de remise en état, traitent des critères de soudure, des possibilités de remplacer les rivets par des boulons, une construction composite et des éléments complémentaires.

ZUSAMMENFASSUNG

Dieses Referat beschreibt die verschiedenen Methoden, die zur Reparatur für den 85-jährigen vernieteten Stahl im Zugbahnhof der Innenstadt Chicago benutzt wurden. Die Aussetzung an der salzhaltigen Atmosphäre hat schweren Schaden an vielen Teilen angerichtet. Der Ansatz zur Stahlreparatur wird gezeigt. Die Faktoren, die die Reparatur und die Richtlinie für Reparaturenauswahl beeinflussen, sind erwähnt. Beispiele für Reparaturentwurf und Einzelheiten sind beschrieben, eingeschlossen ist eine Besprechung über Schweiss-Kriterien, das Ersetzen von Nieten mit Bolzen, gegliederten Aufbau, und zusätzlichen Teilen.

1. DESCRIPTION OF STRUCTURE

Built in 1910, the Chicago and North Western Trainshed covers a 2½ square city block area in downtown Chicago. The downtown terminus of the C&NW/METRA commuter rail lines is a two-story structure serving 200 trains per day, which enter one story above street level on the first supported level. To accommodate 45,000 daily commuters, the historic trainshed building is being rebuilt in nine construction phases under a four-year, $72 million (US) renovation project. Construction phasing is commencing in longitudinal slices so only 3 of 16 tracks are out-of-service at any one time. Each construction phase includes canopy replacement and rehabilitation at track and street levels.

The trainshed structure is constructed of built-up, riveted steel members. Transverse bent lines, typically spaced on 7.8 m (25 ft-6 in.) centers, consist of double web, floor beams spanning between columns. These double channel columns below each track are founded on "wedding cake" pedestals supported by timber piles. Track stringers, curb girders, and platform stringers forming a built-up, I-section frame into the floor beams (Figure 1). In most areas, a track stringer is located below each rail and a 33 cm (13 in.) concrete slab forms the track deck. Canopy columns, located at the platform centerline, fit between floor beam webs at the bent lines. The train boarding areas are covered with a 2.4 hectare (6 acre) canopy structure containing smoke slots for engine exhaust. Ballasted track supported by a corrugated steel and concrete deck is used at the structure's north end where the individual tracks merge. The structure is enclosed with granite and brick masonry walls.

2. NATURE OF DETERIORATION

With limited maintenance, 85 years of exposure to moisture and salts took a severe toll on the steel members. Deterioration of the trackbed and platform concrete led to moisture leakage through the track level. The built-up, riveted steel members provided several horizontal surfaces, crevices, pockets, and gaps for salt-laden moisture collection, which led to extensive corrosion damage.

Corrosion damage from the top-side moisture migration was often severe but highly localized. Common corrosion damage included complete flange angle deterioration, rust holes or extensive section loss on floor beam webs, and section loss at critical connections. Overall section loss on some members caused enough loss in member properties that buckling, or severe deformations and distortions resulted.

Street level corrosion damage was also a problem. In each street viaduct, salt water splashing on the exposed steel columns gradually reduced their cross-sections at the ground line. Moreover, water flowing through track level breaches oftentimes collected at interior column bases, sometimes causing rust holes.

To address the steel damage from corrosion, an extensive steel repair program was planned and later refined as the project progressed. As discussed in the next section, several factors guided the decision on where to call for repairs.

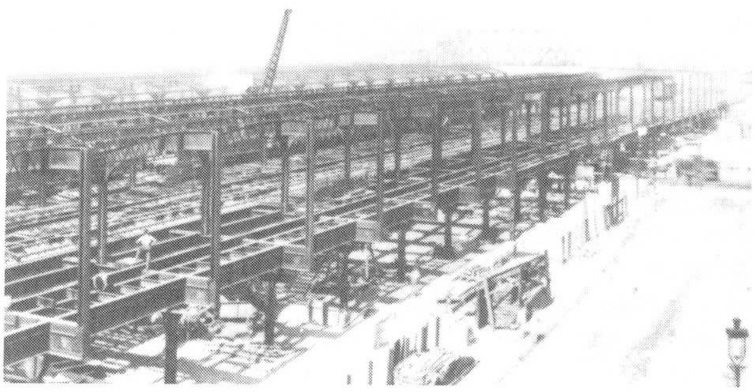


Fig. 1 C&NW Trainshed looking along the east side (circa 1910)

3. DECIDING WHERE REPAIRS WERE NEEDED

3.1 Structural Review

It was very important to have a sense of the reserve strength at typical locations when deciding on repair necessity. For example, we found that the original design was generally conservative, and therefore some strength loss could be accepted without repair. On the other hand, some new canopy column loads were greater than the original. In these locations, significant strength loss could not be tolerated.

3.2 Effect of Corrosion on Strength

The effect of section loss on strength of riveted steel is not always obvious. At a typical floor beam, a 75 percent horizontal leg thickness reduction in the top flange angles reduces the section modulus (S_x) by only 21 percent with no effect on shear strength. However, this section loss could generally not be tolerated because the flanges would be prone to compression buckling and out-of-plane bending from top flange loads.

It was also difficult to evaluate the effect of corrosion of rivet heads, which sometimes occurs before appreciable section loss of the adjacent steel. Testing by the authors in conjunction with a prior investigation[1] showed corrosion of rivet heads had very little effect on shear strength provided the rivet shanks were still intact.

3.3 Aesthetic Considerations

From a structural standpoint, web rust holes in low shear areas and flange deterioration near a simple support can be tolerated. However, the appearance and public perception of rust holes in a recently rehabilitated facility was not acceptable. Also, there is a possibility that future inspectors may not reach the same conclusion as to the structural necessity for repair. For these reasons, rust holes were almost always repaired where the member would remain exposed to view.

3.4 Inspection

A reasonably thorough inspection of the trainshed was made before repair work began. However, most members were at least partially concealed, and where exposed, thick layers of rust byproducts generally concealed the deterioration. It was therefore anticipated that final determination of repair type and location would be made after the steel members were exposed *and* sandblasted to remove rust by-products. In some locations, the contractor prime painted immediately after sandblasting to avoid re-sandblasting flash rust. The prime-painted surfaces were easiest to inspect, although a sandblasted surface could be inspected with close access and good lighting. The degree of corrosion damage could then be accurately assessed visually, sometimes with the aid of simple tools such as a straight edge and calipers.

4. REPAIR GUIDELINES

A repair decision usually comes down to finding the most economical repair that provides an acceptable level of strength, durability, and appearance. If the repair work effects the project schedule, fabrication and installation time becomes an extremely important factor. There were four basic repair approaches that recurred on this project: *1) fix the damage, 2) make the member composite, 3) replace the member*, and *4) find another load path*. To decide among these alternatives, the following guidelines held true for the trainshed repairs:

- *If the damaged area was accessible, it could be fixed* - Provided there was access, the ironworkers skillfully installed intricate welded and bolted repairs.
- *Where possible, make the member composite* - Shear studs are inexpensive compared to structural steel repairs. Of course, enough steel must remain for stud welding.
- *If a badly damaged member comes out easily, replace it* - Provided the member could be easily removed, it proved less expensive to replace an entire member than make extensive repairs, due to high labor costs involved in the repairs. On the contrary, it was all but impossible to replace a majority of members that were partially encased by the track deck or framed into several other members.

- *If there is no other choice, examine alternate load paths* - Much of the corrosion damage at the trainshed occurred in inaccessible regions of members that could not be easily replaced. In these instances, the most viable solution was to bypass the damage by providing a load path to supplemental members.

The following sections describe some of the difficulties with the steel repairs and their solutions.

5. REPAIR DETAILS

5.1 Welding to 85-Year-Old Corroded Steel

Provided the live-load stress range was low, welded doubler plates and stiffeners worked well to repair corrosion-damaged areas where the deteriorated steel had few interferences from rivets, connections, or other framing members. Metal thickness beyond the deterioration had to be sufficient for welding. If corrosion pitting was minimal, minor grinding was used to remove paint and surface rust. Heavier pitting on the existing steel required more aggressive surface preparation for welding. Heavy grinding with disc grinders was employed to even out surface amplitudes and building-up weld metal was allowed to fill gaps. Testing revealed the 1910 vintage trainshed steel had a chemistry closely matching ASTM A7[2] steel. A higher-than-usual phosphorous content required an adjustment in welding procedures.

5.2 Field Bolting

Areas with rivet or connection interferences lent themselves to combination welded and bolted plates, or completely bolted repair plates. Heavily pitted or moderately distorted steel usually precluded welded plate use. In the latter case, bolted repairs were not only used to strengthen an area, but also to draw the steel plys together, thus reducing distortion.

Reusing existing rivet holes for bolting provided an efficient repair means to address difficult repair situations containing many interferences, as shown in Figure 2. The rivet pattern was field measured before fabricating repair plates or flange angles. Additional bolts and interior stitch fasteners used on these repairs were field drilled. On bolted repairs without existing rivet holes, new holes were field drilled in the existing steel using the new repair plate with holes as a template.

The shear strength of high-strength bolts is greater than the existing rivets. Bearing connections using high-strength bolts, with and without shear plane thread exclusion, were often specified to increase

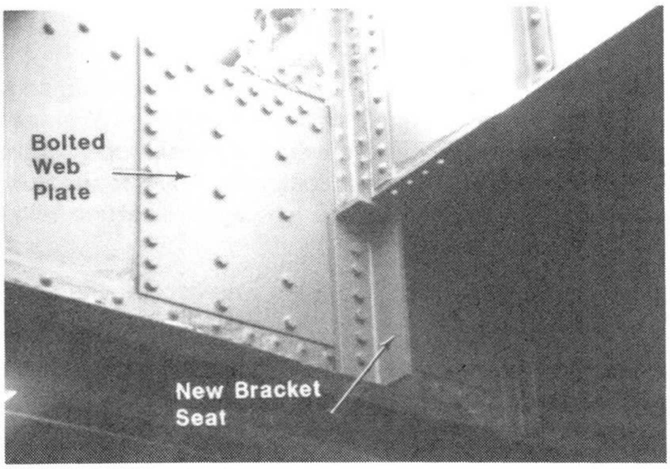


Fig. 2 Bolted web and bracket seat repairs using existing and new holes

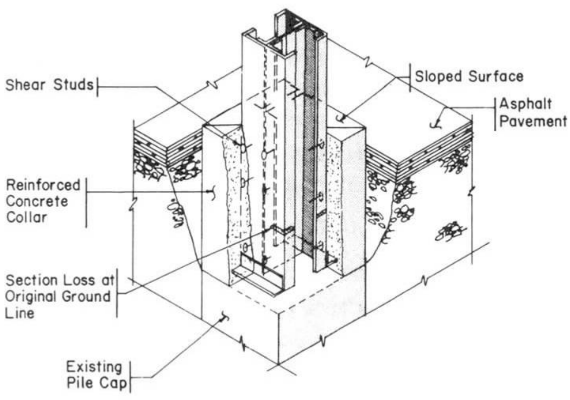


Fig. 3 Composite concrete column encasement

connection capacities at several repair locations. Bolted connections were also used on doubler plates and flange angle replacements.

5.3 Fatigue Considerations

On train-carrying members, where train live load was the predominant stress, the use of welded repairs was avoided. Even though live load stresses were below accepted allowable levels for fatigue, there was concern about residual stresses in the welds and their influence on the existing steel. Bolted repairs were the predominant repair type on these members.

Welded repairs were used throughout the trainshed for the past 30 years, some in tension zones where the live load stress range was relatively high. Although the fatigue resistance was dubious, these repairs performed well where the weld quality was good. The only significant crack found at the trainshed occurred at a poor quality butt weld between two existing patch plates. The butt weld cracked and drove a crack through a *compression* flange to which the plates were welded.

5.4 Composite Construction

Making a steel member composite with concrete is an effective and inexpensive means of repair because welded studs are inexpensive. Two repair types used this principal quite extensively.

To address column base corrosion, the column bases were excavated to their foundation and steel studs were attached. Concrete column encasements were then cast to the final grade elevation, while founded on the footing. The composite column encasement provided a supplemental load path for any minor section loss and gave the deteriorated column steel additional protection (Figure 3). At locations of severe section loss, welded and bolted repair plates were installed prior to stud installation.

The other composite repair was located on curb girders. The top half of these members were designed to be encased in concrete curbs that would later support one precast platform edge. Demolition around the curb girders revealed heavy top flange section loss on several members. To increase the member capacity, additional studs were installed to make the curb girders fully composite with the curb.

5.5 Member Replacement

At the trainshed, steel members that were candidates for replacement were platform stringers and floor beams in the platform area. During in-phase demolition, the existing platform was demolished, thus exposing these members. Replacement members were easily installed by lowering them into position. Little or no shoring was required.

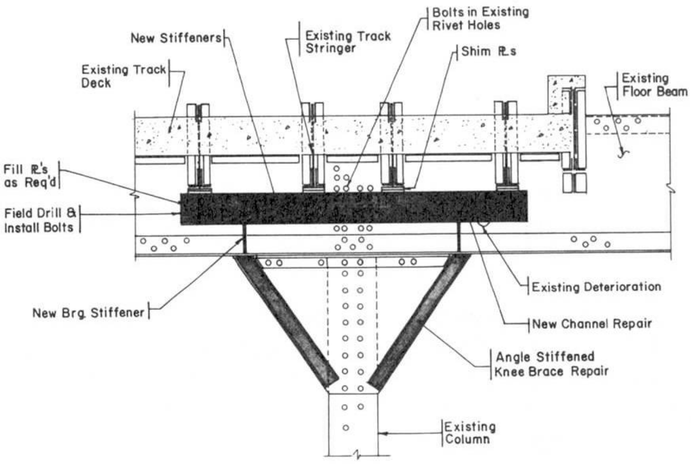
5.6 Supplementing Members

Supplementing members to strengthen deteriorated connection regions or provide alternate load paths was a repair method used on numerous floor beams at the trainshed, as an economical alternative to member replacement. In its most basic form, this repair consisted of adding bearing brackets or stiffeners below deteriorated framed beam connections (Figure 2).

Figure 4 illustrates an example of two innovative means used to supplement the column to floor beam connection region by providing an alternate load path. At many locations, this connection experienced various degrees of deterioration, and using standard repairs was very impractical. Each trainshed column contained a knee brace plate directly below the floor beam connection. Instead of using a bolted web plate in this region with extensive shoring, the knee brace plate was stiffened with angles to give an alternate load path. Besides providing lateral resistance, the knee brace plates were activated to carry a portion of the gravity load.

Another repair shown in Figure 4 consisted of placing a channel against the deteriorated floor beam web. This repair supplemented the existing connection region by providing an alternate live load path that bypassed the original connection; additional live load was transferred to the stiffened knee brace below.

New sister girders (Figure 5) were used where web deterioration on floor beams was quite extensive, and transverse framing members and the concrete trackbed precluded using bolted web plates. The sister beams were installed from below when the track above was closed.



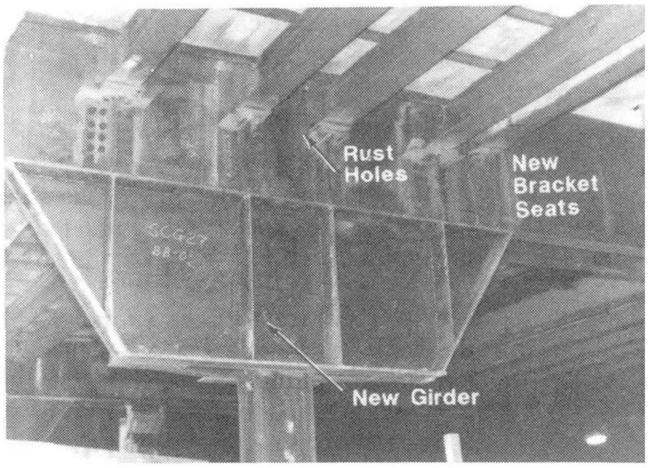


Fig. 4 *Alternate load path repair utilizing a channel and stiffened knee brace plate*

Fig. 5 *Supplemental girder below the existing floor beam*

6. FUTURE PROTECTION

To insure the repairs will last, several protection means were employed:

- Cleaning the entire track deck framing steel to grade and repainting with a two-component epoxy coating. Viaduct areas are receiving a polyurethane top coat for added protection.
- Replacing the entire cast-in-place concrete passenger platforms with new precast platform panels with a "belt and suspenders" joint seal system.
- Casting a new, high performance concrete overlay on the trackbed. A heavy-duty, urethane waterproofing system is applied atop of the overlay where the trackbed is exposed. In the ballasted area, the track deck and overlay are protected with a fully adhered, butyl-rubber membrane below the ballast.

7. ACKNOWLEDGEMENT

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