Non-Conventional Crane Runway Upgrade Solutions

Abstract

A non-conventional method of crane runway upgrade solutions converts the girder into a truss-type structure. This paper explores the mechanics behind this proposed method and its advantages over conventional methods of girder reinforcement.

Authors

Raymond S. Milman
senior staff engineer, Middough Inc.
Cleveland, Ohio, USA
milmanrs@middough.com

Chip Hoppel
discipline manager — industrial structural, Middough Inc.
Cleveland, Ohio, USA
hoppelcl@middough.com

The increase of existing crane runway lifting capacities, in most cases, requires the replacement or reinforcement of the existing crane runway girders.

Crane runway girder replacement is the most expensive alternative in crane runway modification. It is implemented only when crane reinforcement is physically impossible or more costly than girder replacement.

Crane girder reinforcement is a challenging task for a design engineer, because it involves not only a design that meets strength and serviceability criteria, but also problems such as downtime in the crane operation to construct the reinforcement, interference with the existing structures and equipment, and modification of elements attached to the girder (walkways, hot rails, piping, electrical conduit supports, etc.).

The first two questions asked by the plant engineers responsible for the plant production results are:

- How long will the expected shutdown be?
- How much will this upgrade cost?

The approach proposed in this paper permits a facility to minimize or eliminate crane runway operation downtime and avoid unnecessary work on the girder top flange (temporary rail removal, top flange reinforcement, walkway plate modifications, etc.), which is usually considered in the conventional approach.

Conventional Method of Girder Reinforcement

According to conventional methods of beam reinforcement, an increase of the crane lifting capacity requires an increase of the crane runway girder vertical and horizontal section properties to satisfy biaxial bending criteria under the action of the increased crane vertical and horizontal loads. Additionally, if vertical web shear design stresses exceed available strength criteria, the girder will need to be reinforced.

The reinforcement of the girder top and bottom flanges is labor-intensive and time-consuming work. The top flange reinforcement, in most cases, requires the removal of the crane rail, which means a considerable amount of crane operation downtime. A continuous welded or bolted attachment of the reinforcement parts to the top and bottom flanges is extremely costly from a labor point of view.

If a substantial increase of the crane-lifted load is considered, the total cost (fabrication and field work) of a conventional approach to crane girder reinforcement could exceed the cost of girder replacement.

Non-Conventional Method of Girder Reinforcement

This method is based on the idea of breaking the girder span on two or more continuous spans supported by elastic springs. This can be achieved by the girder conversion into a truss-type structure, where the girder performs the function of the top chord of the truss.

All components of the reinforcement truss (bottom chord, diagonals and posts) are shop-fabricated and installed below the girder bottom flange, using bolted connections to the girder and the columns.

Sizing of the reinforcement truss members is performed based on the analysis of the modified girder system as an elastic frame. A computer program with moving load features can be a convenient tool to determine a force envelope for each member of the system. By changing the sizes of the new reinforcement members, the designer could achieve a desirable force distribution between the existing crane girder and the new reinforcement members.

The installation of the truss-type modification also has a positive effect on the crane columns. It increases column stability against out-of-plane buckling, which could govern the crane column design. In addition, it reduces the crane maximum vertical load on the girder seat due to shear redistribution effect.

This approach of crane girder reinforcement is extremely effective for small- and medium-span girders of 20–40 feet long. However, the conversion of two 25' 0" girders into a 50' 0" span structure and crane upgrade from 50 to 75 tons has been performed recently (Figure 1).

The only deficiency of the girder-into-truss conversion method is a requirement of available space below the crane girder bottom flange to install the reinforcement details. If the space below the girder bottom flange is limited, a second approach — the girder load sharing method — is applicable.

An example of the crane load sharing between the crane girder and a new beam installed below the crane girder is shown in Figure 2c. The size of the reinforcement beam can be determined by the analysis of the double beam system.

The following examples demonstrate a design application of the non-conventional crane girder reinforcement approach.

Figure 1

Column removal and mid-span reinforcement.

Example No. 1 — It is proposed to replace the existing 50-ton crane with a new 80-ton crane. The crane wheel vertical loads will be increased from the present 64 kips to 89.5 kips, and the horizontal side truss wheel loads will be increased from the existing 5 kips to 8 kips (per AIST's *Technical Report No. 13,* 2003 edition).

The existing crane runway 25' 0" girder is a built-up riveted girder made of F_y = 33 ksi steel.

Allowable bending stresses:

- Top flange $F_{bx} = 0.66\ F_y = 21.8$ ksi, $F_{by} = 0.6\ F_y = 19.8$ ksi
- Bottom flange $F_{bx} = 0.6\ F_y = 19.8$ ksi
- Allowable shear stress $F_s = 0.4\ F_y = 13.2$ ksi

Design stress in the existing girder due to action of the 80-ton crane:

- Top flange f_{bx} = 22.4 ksi with impact, f_{by} = 6.1 ksi

Combined biaxial bending checking per AIST *TR No. 13,* Equation 5.1 for the top flange:

$$\frac{22.4}{21.8}+\frac{6.1}{19.8}=1.03+0.31=1.34>1.0$$

design limit exceeded

(Eq. 1)

- Bottom flange f_{bx} = 27.7 ksi with impact > 19.8 ksi, which is too high.
- Vertical web shear f_a = 16.2 ksi > 13.2 ksi which is too high.

The crane girder reinforcement analyses were performed using Structural Analysis and Design Software (STAAD-III). The crane runway was modeled as a longitudinal frame loaded with moving crane loads.

Truss-Type Girder Reinforcement — After several computer program runs with various member properties for diagonals and struts, the optimal diagonals 2L's 6 x 6 x 5/8, steel ASTM 572, Grade 50 were chosen for design.

Analysis results (Figure 2b):

- $M_{max.\ vert.}$ = 694.5 ft~kips vs. 1,494 ft~kips for single-span girder (Figure 2b).
- $V_{max.\ vert.}$ = 212.6 kips vs. 291 kips for single-span girder (Figure 2a).
- Top flange f_{bx} = 10.3 ksi with impact f_{by} = 5.6 ksi

Combined biaxial bending checking per AIST *TR No. 13,* Equation 5.1 for the top flange:

$$\frac{10.3}{21.8}+\frac{5.6}{19.8}=0.47+0.28=0.75<1.0$$

design limit not exceeded

(Eq. 2)

- Vertical shear F_s = 11.8 ksi < 13.2 ksi is also within limits

Reinforcement detail is shown in Figure 3 — Detail 1.

Crane Load Sharing With Mid-Span Support Beam — Crane girders located over the entrance door and over the electrical room do not have enough space to install the truss-type reinforcement. An installation of the load-sharing beam requires substantially less space below the girder.

Analysis results (Figure 2c):

- After a few attempts, a proper size of the support beam was accepted as W33 x 152.
- Load distribution between the existing girder and the W33 support beam are shown in Table 1.

Reinforced girder checking:

- Top flange f_{bx} = 13.5 ksi with impact
  f_{by} = 5.6 ksi

Combined biaxial bending checking per AIST *TR No. 13,* Equation 5.1 for the top flange:

$$\frac{13.5}{21.8}+\frac{5.6}{19.8}=0.62+0.28=0.90 \quad \text{(Eq. 3)}$$

Since 0.9 < 1.0, limit is not exceeded.

- Vertical shear F_s = 12.7 ksi < 13.2 ksi within limits.
- W33 support beam checking – f_{bx} = 16.5 ksi < 21.6 ksi within limits.

Reinforcement detail is shown on Figure 3 — Detail 2.

Example No. 2 — It was proposed to replace the existing 15-ton crane with a new 25-ton crane. The design crane wheel load increased from 39.5 kips to 56 kips. The 42' 3" crane girder consists of W33 x 132 with a cap channel MC18 x 42.7 (steel F_y = 33 ksi).

Allowable bending stresses:

- Top flange F_{bx} = 15.7 ksi (ASD 89, Eq. F 1-6)
- Bottom flange F_{bx} = 0.6 F_y = 19.8 ksi

Design stresses in the existing girder due to action of the 25-ton crane:

- Top flange f_{bx} = 17.8 ksi with impact > 15.7 ksi exceeds limits.

Table 1

Load Distribution Between Existing Girder and W33 Support Beam

	Existing girder	W33 x 152
Vertical bending M_{max} (ft~kip)	904	671
Vertical shear V_{max} (kip)	228	54

- Bottom flange f_{bx} = 27.8 ksi with impact > 19.8 ksi exceeds limits.

Horizontally, the top flange is well braced, and the vertical shear design stresses are within allowable limits.

Solution No. 1: Replace the girder — The built-up girder, W36 x 194 with MC18 x 42.7 cap channel, satisfies design loads.

Solution No. 2: Reinforce the girder — It is proposed to reinforce the girder with a sub-diagonal frame, as shown schematically in Figure 4.

After a few attempts, the optimal sizes of the reinforcement frame (diagonals, posts and a strut) were chosen: 2 L's 6 x 4 x 3/8.

Figure 4 shows the maximum vertical bending moments and axial forces in the existing and modified systems for different crane positions. The maximum bending moment in the existing girder is reduced from 1,040 ft~kips to 408 ft~kips, with a small compression force of 74.4 kips (stress = 1.5 ksi). This results in a top flange bending stress f_{bx} = 7.0 ksi and a bottom flange bending stress f_{bx} = 10.9 ksi.

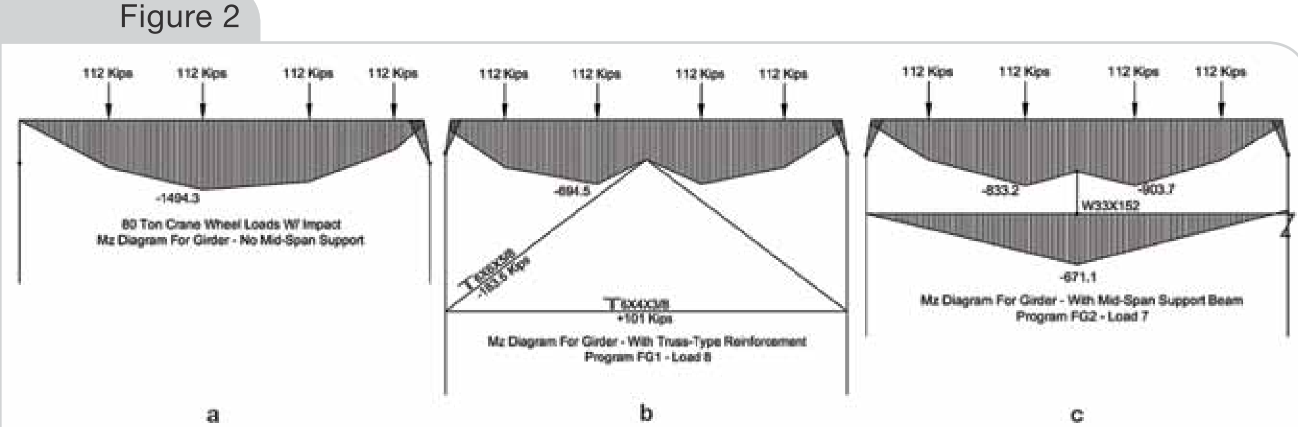
Checking for biaxial bending, shear and fatigue-related stress ranges proved that the reinforced girder meets the strength criteria for the 25-ton crane loads.

Solution No. 2 was implemented (Figure 5).

The methods presented in this paper have been implemented in several projects, resulting in significant economic effects.

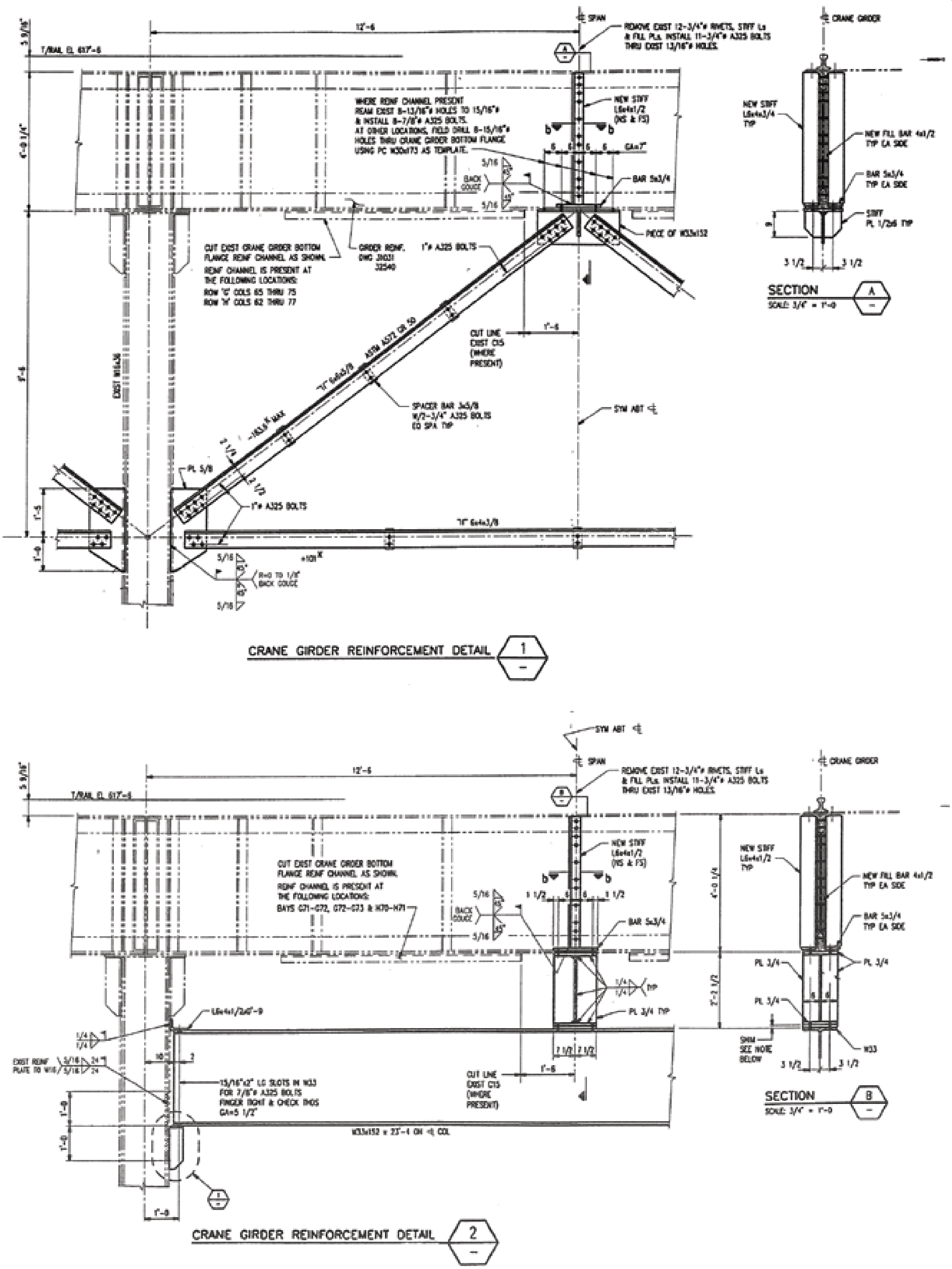
Figures 5–7 illustrate a few examples of non-conventional crane girder reinforcements.

Figure 2



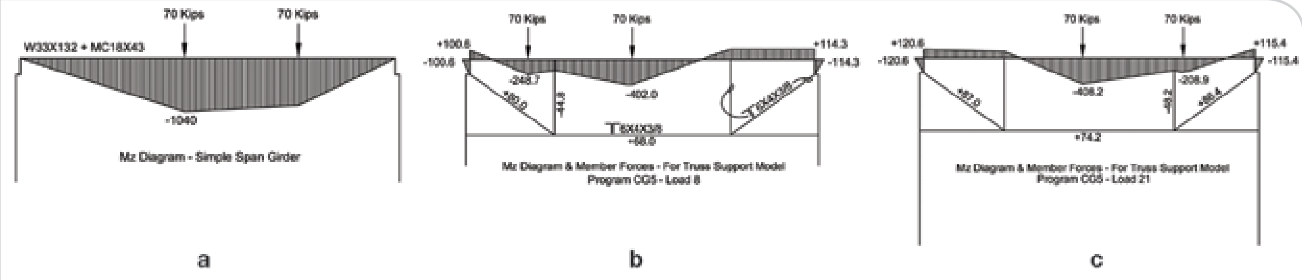
25' 0" crane girder reinforcement.

Figure 3



25' 0" crane girder reinforcement details.

Figure 4



42’ 3” crane girder reinforcement.

Figure 5

Truss-type reinforcement (example 2).

Summary

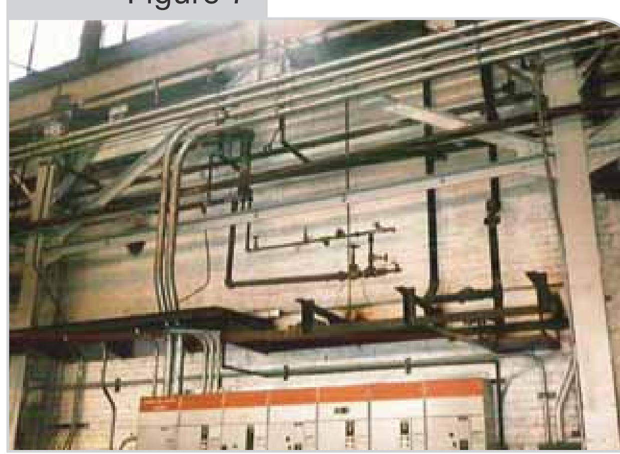
The approach demonstrated in this paper for crane runway girder reinforcement provides the following advantages over conventional crane girder reinforcement:

- This method permits a substantial increase in the crane runway lifting capacity.
- All field work of girder reinforcement is performed below the crane runway. This permits installation of the reinforcement details with short, if any, interruptions in crane operations.
- No crane rail removal is required, unless rail replacement is scheduled.
- Labor-consuming field work is minimized, because all structural elements are shop-fabricated.
- No girder bottom flange attachment and/or hot rail support relocation is required.
- A significant reduction of the girder vertical bending stresses permits an increase of the top flange horizontal bending stresses without exceeding overall biaxial bending criteria. ✦

Figure 6

Truss-type reinforcement.

Figure 7



Truss-type reinforcement.

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