Assessing Existing Theater Structures and Rigging Infrastructure for Large Production Demands

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ABSTRACT

The ever increasing load demands placed on existing theaters by modern live entertainment pose unique challenges for the structural engineer. One of the more difficult aspects for the engineer is the fact that many of the older theaters have limited, or no, design/construction documentation in existence. In the absence of drawings, investigations must be based solely on surveys of the existing conditions of the stage supporting structures and the grid-iron and fly systems. Typically, one finds that structural modifications have been made over the years for various shows without the benefit of engineering reviews. The Hammerstein Ballroom Theater (circa 1906) and the Howard Gilman Opera House at the Brooklyn Academy of Music (circa 1908) are two particularly interesting examples of old theaters requiring structural reviews for recent productions of new shows whose loads would impose a high demand on the existing structures.

BACKGROUND

Theater stagehouses provide an area over the stage for the rigging of hanging show elements. A stagehouse of a typical theater with a seating capacity of 1300 would usually have clear dimensions (with no obstructions from beams, columns, floors, etc.) of 50 ft x 90ft wide x 90ft high. Within the stagehouse is a counterweighted hanging system called a *Fly System* that allows technicians to move scenic elements such as lighting, video, audio, scenic flats and special effects vertically between the show's visible performance area behind the stage proscenium opening to the large stagehouse directly above. A schematic of a single manually operated lineset in a typical theater Fly System is depicted in Figure 1.

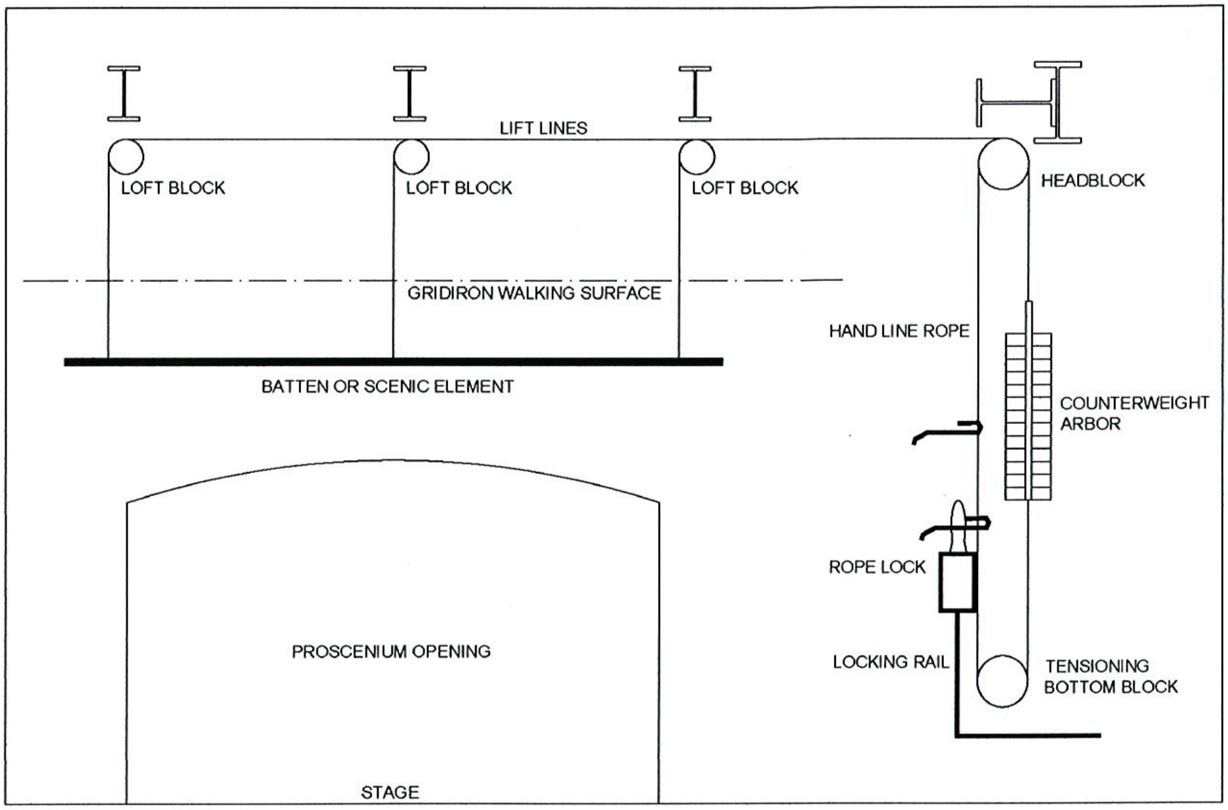
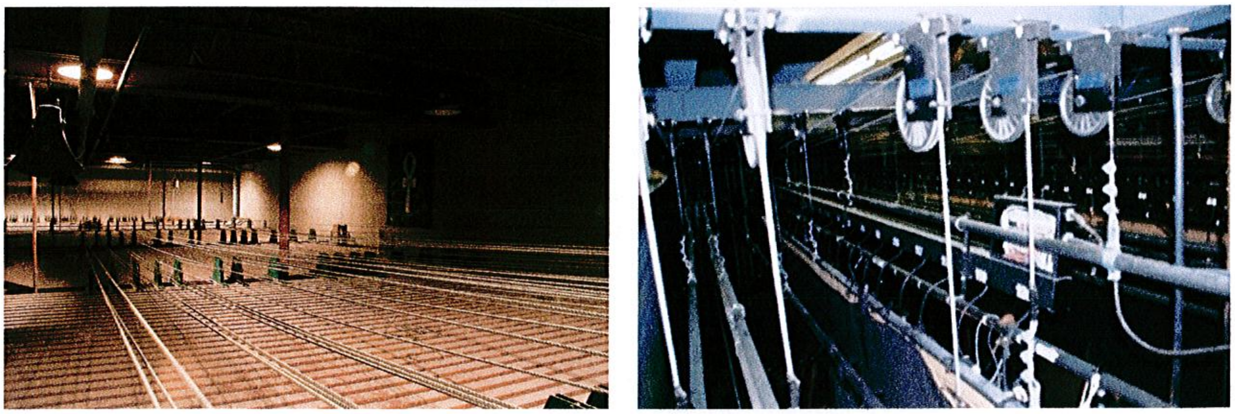


Figure 1 – Schematic of a Typical Manual Lineset in a Fly System

The counterweight arbor is brought into balance with the scenic load by adding and removing arbor weight plates. The average small theater, such as found in a high school, has 10 to 40 of these linesets. Theater facilities such as performing arts centers, and commercial Broadway and local theaters can have hundreds of linesets with multiple catwalk 'bridges' located along the side of the stagehouse wall to facilitate the loading and unloading of counterweight plates. A single lineset can have a lifting capacity of as much as 1600 lbs. The linesets range across the ceiling of the stagehouse spaced at 4 to 12 inches on center. Larger theaters typically employ a lattice grid of structural steel (called the *flygrid* or *Gridiron*) which is used as a walking surface to service the loft blocks and to support other rigging. The narrow spaces between the grid steel members allow the lift lines to pass through. The loft blocks may be attached to the gridiron itself or the stagehouse ceiling above. Figure 2 shows these two most common configurations.



(a) Gridiron Mounted Loft Blocks (b) Ceiling Mounted Loft Block

Figure 2 – Typical Stagehouses with a Gridiron (a) or without a Gridiron (b)

Occasionally, temporary rigging may be employed where chain hoists are attached to the gridiron or ceiling of the stagehouse. Typical chain hoists used in the entertainment industry have lifting capacities of 1 and 2 tons. It is not uncommon for productions to use more than 100 of these units to rig the scenic elements of a show.

Recent advances over the last 20 years have added automated, computerized rigging systems to theaters which provide accuracy of timing and positioning of scenery and special effects. As a consequence of going to motorized systems, operating speeds have increased along with the attendant dynamic loads. Automated rigging systems typically use a grooved drum wire rope hoist, which eliminates the need for counterweights and consequently lowers the gravity loads on the stagehouse structure.

Modern theaters are designed using recent code criteria where previously there were no or only limited provisions for stagehouse rigging loads. The NYC Building Code requires stage structures that support rigging to carry 100% of the rigging loads plus a 25% impact factor as well as a 50 psf live load on the gridiron. The International Building Code and the State of California also now have minimum design criteria for theater stagehouse rigging loads. For automated systems, there are also provisions in the International Building Code and ASCE for machinery impact loads.

Typically, gridirons are supported by the stagehouse roof structure. Therefore, design criteria for rigging loads are usually considered as an additional live load and used within load combinations that include environmental loads. Since there is a remote possibility that 100% of the rigging loads would be acting simultaneously over the entire gridiron, a reduction factor is typically employed. In practice, many engineers will reduce the load over the entire area, often by up to 25%.

Older theater fly systems were designed to hang simple wood-frame and painted scenery flats and other light weight loads. Although one finds that the early gridirons were built conservatively for the loads of yesteryear, modern productions push the limits of the gridiron and stagehouse structure's capacity. Making matters worse, one finds that structural modifications have been made over the years for various shows without the benefit of engineering reviews or guidance.

Two interesting examples of old turn-of-the-century theaters requiring structural reviews for new shows whose loads would impose a high demand on the existing structures are presented herein.

HOWARD GILMAN OPERA HOUSE AT THE BROOKLYN ACADEMY OF MUSIC

Built around 1908, the Howard Gilman Opera House at the Brooklyn Academy of Music (BAM) is one of the oldest theaters in New York City and is a typical example of a large playhouse with a full stagehouse gridiron and loft blocks attached to the ceiling structure – see Figure 3.

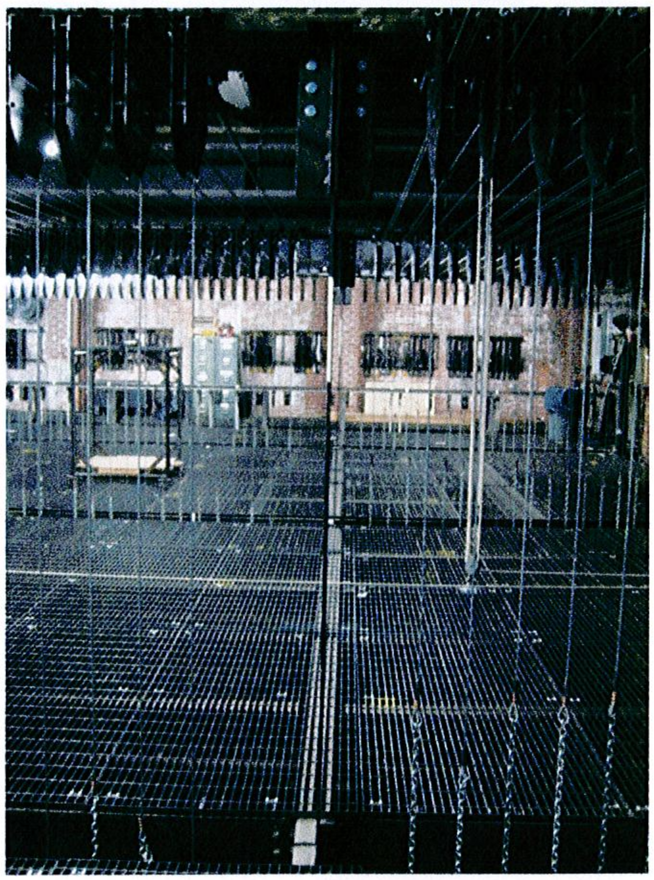


Figure 3 –Brooklyn Academy of Music Stagehouse Gridiron

In the summer of 2009, VH1's Diva/HHH show was engaged by BAM for a one-time event. The show wanted to rig fifty one (51) 1-ton chain motors to the gridiron of BAM's stagehouse. See Figure 4.

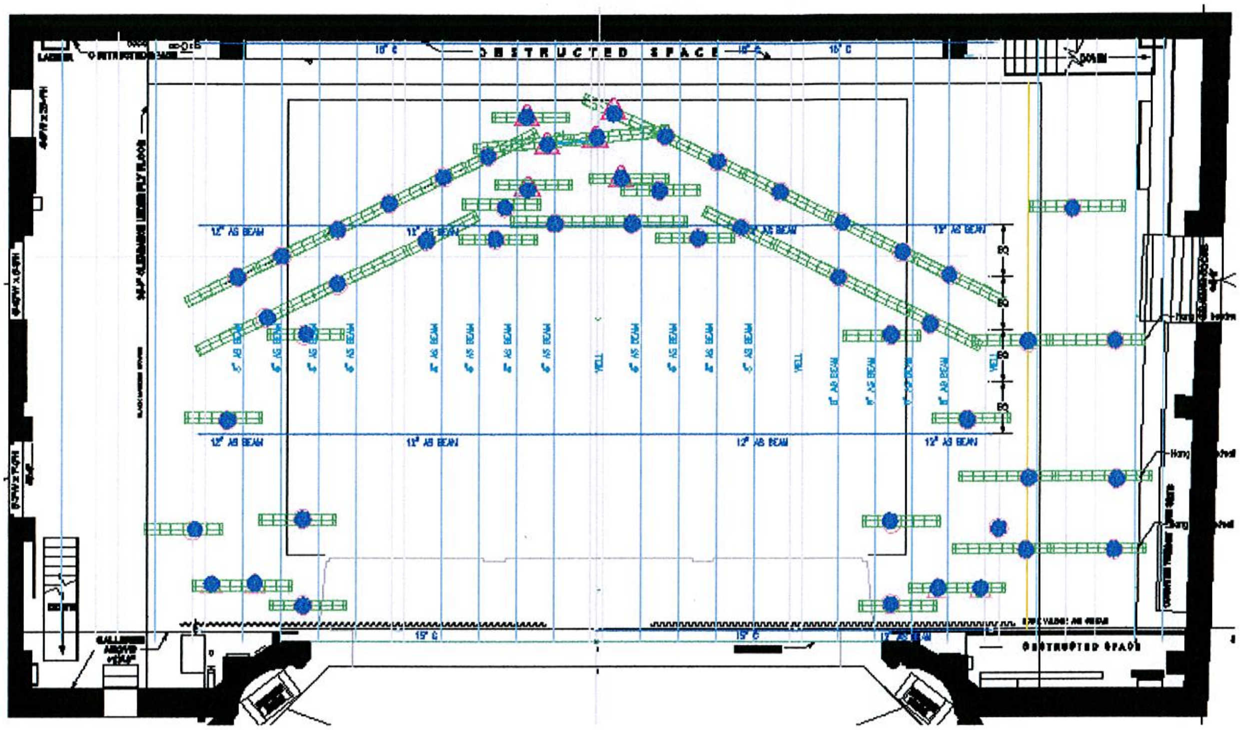


Figure 4 – VH1 Divas/HHH Show Rigging Points on Brooklyn Academy of Music Gridiron

As is common with most gridiron structures, BAM's gridiron is hung from the roof structure and is approximately 76' feet above the stage deck in the stagehouse. All loft blocks are hung from the roof structure, so the gridiron does not support loads from the permanent fly system. As a consequence, the gridiron steel structure is only used to support small hung loads and loads from the bar grating walking surface.

The Divas/HHH show required rigging from the gridiron's steel structure, so the engineering review concentrated on the capacity of the gridiron support structure. Since the Divas/HHH show did not take place in winter, the fly house roof structure was not reviewed because the roof's snow load capacity was assumed to be greater than the Divas/HHH show loads.

Based upon on-site inspections, it was found that the gridiron's original walking surface of 2" x ¼" steel slats had been replaced by modern bar grating sometime in the 1980s. It is easy to understand why the facility replaced the slats; they were bouncy and had 'dished' over the years as riggers walked on it. This left the slatted surface across the gridiron wavy with hills over the beams and valleys in between. Evidence was found of the original slats' attachments along all of the tops of the gridiron support beams. The original attachments consisted of clamping bars that grabbed both edges of the top flanges of the beams of the gridiron support structure. A small area containing some of the original slats as can be seen in figure 5.

Figure 5 – Section of Original Slat Walking Surface of Gridiron (note modern bar grating to left)

The original slats provided continuous lateral beam bracing to most of the gridiron support structure. However the new bar grating with four hold-down clips at each corner of each grating panel did not provide the same level of lateral bracing for the beams. See Figure 6.

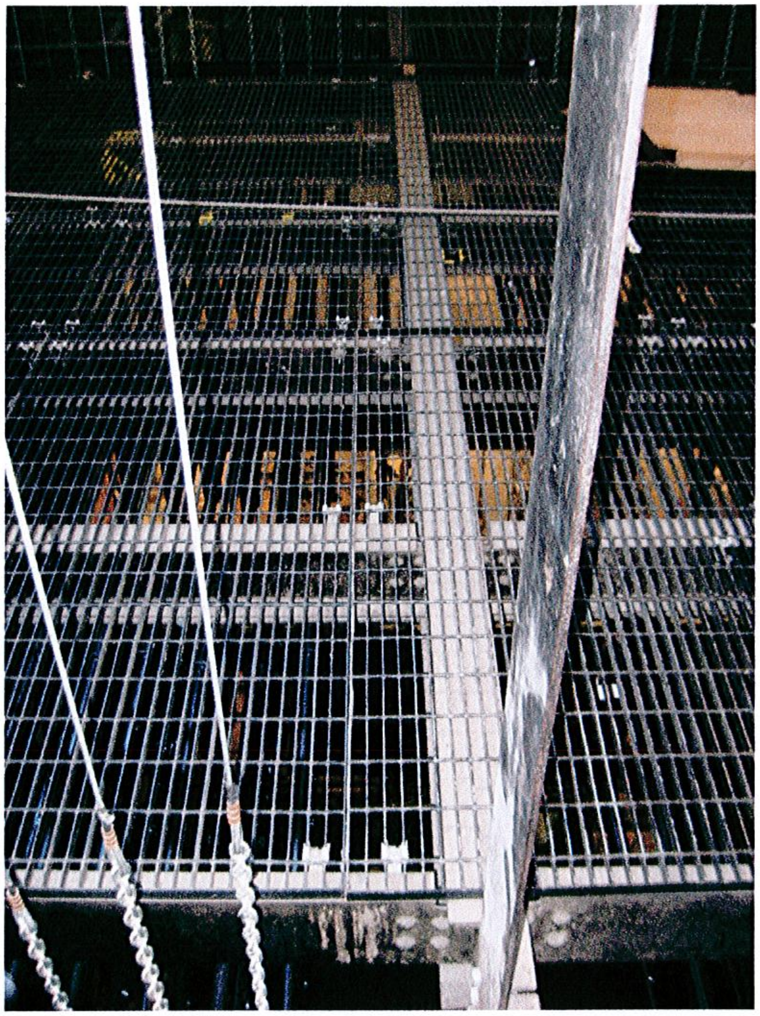


Figure 6 – Bar Grating Panels with Each Panel Secured With a Clip at Each Corner

The reduction in the amount of lateral bracing meant that the gridiron structure had very low rigging load capacity above the minimum required loads for the grating surface. To rig the Divas/HHH show, the production was required to remove the bar grating panels in the affected areas and add temporary blocking/bracing between the beams. The bracing had to be installed between the webs of the beams so as not to protrude above the tops of the flanges which would prevent the bar grating panels from being replaced. See Figure 7

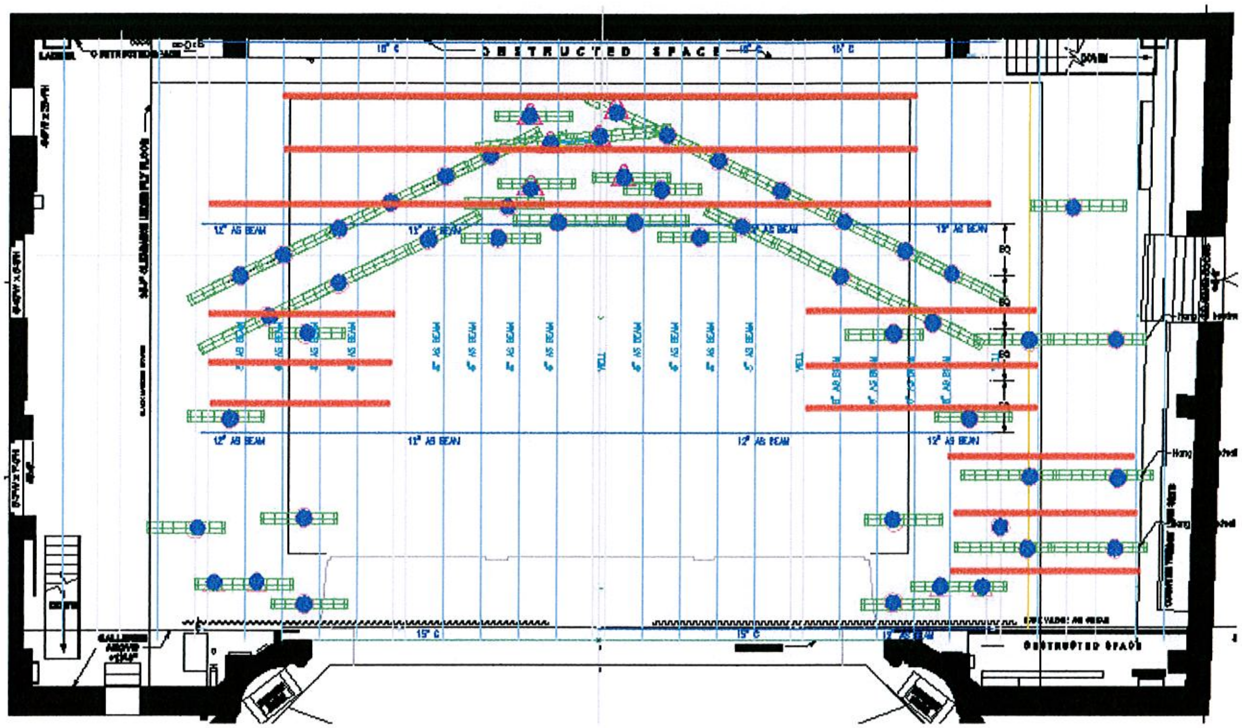


Figure 7 – Divas/HHH Show Gridiron Beam Bracing Plan

By replacing the original gridiron slats, the theater unwittingly had drastically reduced the load capacity of their gridiron. Unless and until they install permanent beam bracing, any show that desires to rig from the gridiron must now have temporary bracing added to the structure. This situation is typical of structural modifications made in theaters without the benefit of engineering guidance. This type of occurrence is possible because theaters are able to install shows and make modifications without building permits. Over the years a mindset develops where it is thought that theater rigging alterations do not warrant engineering review.

THE HAMMERSTEIN BALLROOM

Built around 1906, the Hammerstein Ballroom may be the oldest theater in New York City. Sometime in the 1970s, major renovations of the Ballroom were undertaken. The renovation included the construction of an addition to the original Hammerstein Ballroom structure. This newer structure is called the Grand Ballroom. The Grand Ballroom's stage was built on top of the Hammerstein Ballroom's original stagehouse roof. See Figure 8.

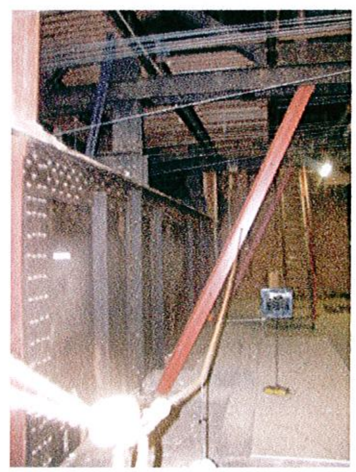
(a) Hammerstein Gridiron and Original Stagehouse Roof

(b) Grand Ballroom Stage Added to Hammerstein Stagehouse Roof

Figure 8 – Renovated Hammerstein Stagehouse with Added Stage Structure

Three Hammerstein stagehouse trusses help support the Grand Ballroom's stage. The fly house trusses are supported by deep plate girders at the stagehouse's left and right walls. See Figure 9.

(a) A Hammerstein Stagehouse Truss



(b) Hammerstein Plate Girders

Figure 9 –Hammerstein Stagehouse Gridiron and Grand Ballroom Support Structure

The original fly system had loft blocks attached to the stagehouse roof but this fly system was removed so there was a reduction of rigging loads on the stagehouse roof. While the Hammerstein stagehouse trusses were originally designed to carry gridiron and roof loads that include snow and wind, the addition of the Grand Ballroom stage has caused a net increase in the loads the trusses must support despite the removal of the snow, wind, and fly system loads. The engineering evaluation was to determine by how much the added loads from the Grand Ballroom stage reduced the capacity of the fly house trusses and how that impacted the rigging capacity of these trusses for shows in the Hammerstein Ballroom.

Computer analysis models were created for the three typical fly house trusses and the plate girder based on the site visit sketches and notes. Site visit sketches were compared to existing drawings and calculations from previous renovations to the structure. Note that while the existing documentation found was incomplete regarding the stagehouse, enough information was obtained to properly evaluate the stagehouse trusses and plate girder (but not the plate girder connections hidden within the masonry of the proscenium and stagehouse walls).

Loads applied to the computer analysis models were determined from the site visit notes, knowledge of typical construction material weights, and AISC reference materials pertaining to turn of the 20th century steel construction. Many steel mills at that time had their own steel shapes and identification of sections and materials were made from the manufacturer's markings on beams. See Figure 10.

Figure 10 – Turn of the 20th Century Steel Beam Manufactured by Steel Mill 'PHOENIX'

Codes require a 150 psf live load for stage structures. However, in determining a realistic tributary load for the three main structural elements, 100 psf was chosen since it is highly unlikely that the full 150 psf would be reached over the entire stage area all at once.

Initial findings indicated that the stagehouse trusses' top chords were at 110% of capacity per allowable AISC code stresses when a 100 psf load was applied to the Grand Ballroom stage which directly loads these trusses. This overstress condition precluded additional capacity for handling any rigging over the Hammerstein stage which would be tributary to these same trusses. Essentially, no rigging should occur in the Hammerstein stagehouse if there is any event occurring at the same time in the Grand Ballroom. Indeed, any Hammerstein Ballroom rigging should be evaluated with the stagehouse trusses' limited capacities in mind, whether there was a concurrent event in the Grand Ballroom or not.

Further investigation also found that the plate girders supporting the stagehouse trusses would be over capacity if a 100 psf live load is applied to the Grand Ballroom stage at the same time as rigging loads for the Hammerstein Ballroom. There was no exploration of possible solutions for reinforcing the stagehouse trusses and plate girders.

CONCLUSION

It is common to find that significant renovations have been made to theaters' structural components that are involved in supporting show loads. Because theatrical productions have historically been outside the purview of building departments, these renovations were often implemented without engineering oversight. For this reason, extra care should be taken to capture the structural ramifications of previous, perhaps undocumented changes when one is inspecting and evaluating existing theater structures.