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Repair and Renovation of the Reading Terminal in Philadelphia

Réparation et consolidation de la Grande Gare de Philadelphie

Reparatur und Erneuerung des Reading Terminal in Philadelphia

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SUMMARY

The Reading Terminal was constructed with wrought iron and hot rivets in 1893. This renovation dealt with the repair of deteriorated elements and the addition of framing for a ballroom and meeting rooms. The roof arch trusses were preserved, as the three-hinged structure was one of the world's largest when originally constructed. Evaluation of existing conditions and development of repair techniques are discussed.

RÉSUMÉ

La Grande Gare de Philadelphie, communément appelée "Reading Terminal Station", a été construite en 1893, d'acier forgé et de rivetage. La réparation et la consolidation de la structure existante a permis la création d'un nouvel ensemble multifonctionnel et de plusieurs salles de conférences. Les arcs en treillis à trois articulations, dont la portée était l'une plus grandes à l'époque, ont été préservés. L'évaluation des conditions existantes et les techniques de réparation utilisées sont présentées.

ZUSAMMENFASSUNG

Der Zugschuppen des Reading- Hauptbahnhofs in Philadelphia wurde 1893 aus Schmiedeeisen und Heissen gebaut. Bei dieser Renovierung handelte es sich um die Reparatur der verfallenen Bauteile sowie die Hinzusetzung des Balkenwerks für einen neuen Ballsaal und verschiedene neue Versammlungszimmer. Die ursprünglich gebauten gebogenen Dachträger sind als wesentlicher Bestandteil eines der grössten dreischarnierigen Bauwerke der Welt erhalten geblieben. Die Entwicklung der Reparaturtechnik sowie die Auswertung der vorhandenen Zustände sollen hier diskutiert werden.

1. DESCRIPTION OF PROJECT

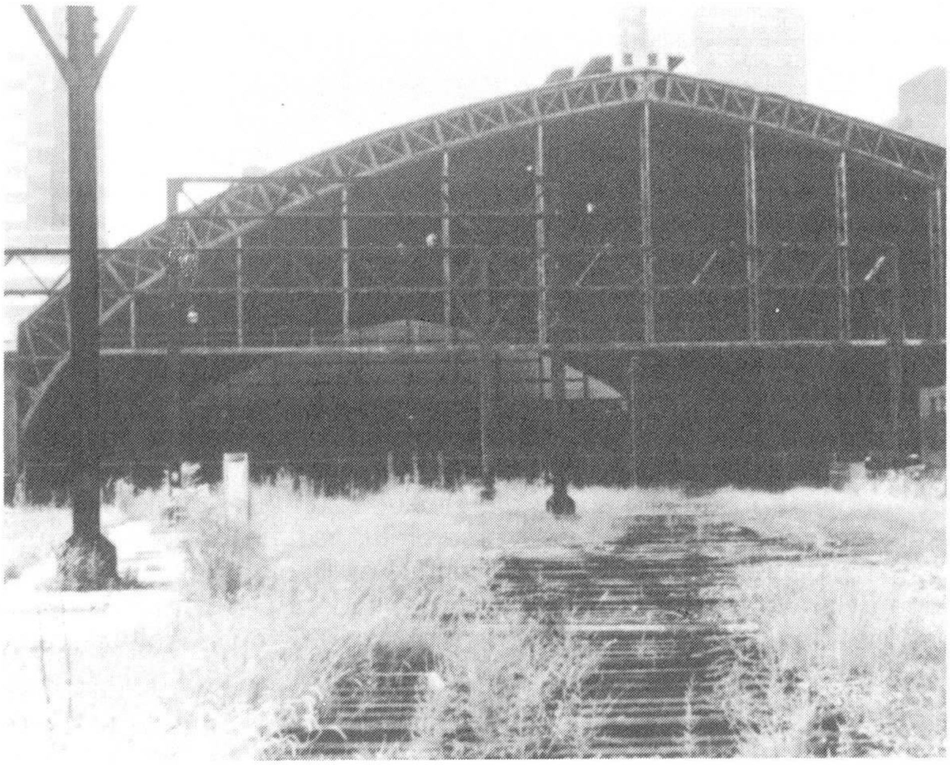
In 1983, the City of Philadelphia and the State of Pennsylvania held a competition to select a site for a convention center in Philadelphia. The site they chose was the Reading Railroad Terminal and four downtown city blocks. This combination repre-sented a site with historical significance that was also choice business district property.

Originally, the Reading Terminal project was to be financed by capital from the Reading Company, the real estate company that remained after the railroad went bankrupt. As the project changed from a private development, the Reading Terminal had to be purchased from the Reading Company. The initial purchase consisted of the upper portions of the structure, leaving the first floor market and structure in place. Some renovation of columns was required and necessitated work in the Market area.

The Terminal renovation would prove to be challenging for several reasons, not the least of which was contamination with PCBs, which delayed the existing conditions investigation several years. The historical significance of the Terminal was basic to its inclusion in the project. To provide some background for the project, that issue is examined thoroughly below.

2. READING TERMINAL HISTORY

In the 1890s, the Philadelphia and Reading Railroad decided to locate a passenger terminal in downtown Philadelphia. The commuter and passenger traffic into Philadelphia necessitated such a development. A site was selected at the northeast corner of Market and 12th streets. The site had a frontage on the south of Market Street and extended north past Filbert Street to Arch Street.



Rail lines in the city were elevated on rubble-filled viaducts with cut stone gravity retaining walls. Arches of steel rail and brick infill crossed streets so that neither rail nor street traffic would impede each other. For that reason, the tracks were required to enter the terminal on the second level which was 7.6 meters above street grade. Placing the tracks this way enabled the first floor to be available for other uses. As it happened, the site contained two important market houses between Filbert and Market streets which were to be demolished and relocated by the terminal construction. The markets were offered space on the first floor. The terminal building was to begin north of the Head House on Market Street. The construction of the Terminal building before the Head House allowed the markets to operate continuously, which set a precedent for the latest renovation when the markets were also kept open.

By the 1980s, the basement was no longer in use. Wastewater was discharged directly through the first floor to the basement, which had 0.6 meters of standing water. The foundations for the terminal were 3 meters below the basement floor. The riveted wrought iron columns sat on a base plate which transferred the load to a cut granite criss crossed stack of lengthening stones that rested on a cast concrete base footing. The presence of water over the years had not caused any appreciable settlement. The bearing level remained intact and capable of 65,000 kilograms per square meter bearing capacity.

The Terminal was constructed of hot riveted wrought iron plates and angles. Tension elements in the trusses were to be double rolled from the muck bar, and no scrap was allowed to be added in the rolling. The wrought iron for tension elements was to be capable of sustaining an ultimate stress of 358.5 MPa on a full section of test piece with an elastic limit of 179 MPa. Wrought iron for other elements was to have an ultimate stress of 331 MPa and an elastic limit of 179 MPa except for plates of over 61 cm. width for which the ultimate was 317 MPa.

The Terminal was designed by Wilson Brothers & Company and reported to the ASCE annual convention of 1895 by Joseph M. Wilson. The Terminal roof is the most significant part of the building. The track area covered was 79.25 meters x 168 meters. Pairs of arch trusses were placed at 15.3 meters apart. These elements formed a three hinged arch, which at the time of its construction was the longest such span in the world. Compound curves were used to form the shape of the arch trusses which sprang up 26.8 meters from their base pins to the center pin of the arch.

3. EXISTING CONDITIONS STUDY

Determining the base line for the beginning of restoration is a critical step in any restoration project. Access to the terminal was limited. Due to its contamination with PCBs, a release was signed each time access was granted to the space. During this phase, access could not be obtained to place high reach equipment in the terminal for examination of the truss arches and the wooden roof framing. Visual observation of the roof was performed from the track floor. The roofing membrane had failed in previous years, which allowed water to flow through the roof. Sheathing and purlins were stained from years of water flow. Our estimate was that complete sheathing replacement would be required, as would 60% of the 10 x 15 cm wood purlins.

Access to the Terminal became more constricted because the transfer of ownership was bogged down. Reading had not reached an agreement with the Convention Authority for sale of the Terminal. The delay ran on for several years with no access to the Terminal for evaluation. Fortunately, a historical repository of documents, the Athenaeum, was available where the original ink on linen drawings were stored. The documents proved to be very accurate. The truss arches were designed by a graphical solution which was contained in the original documents. The graphical solutions for the load cases were very helpful in fine tuning our computer analysis of the arch trusses. Six radii were used to develop the compound curve of the arch. As the computer model was constructed graphically, the original loading cases were applied and the analysis values for member forces were checked against the graphical solution.

During this phase of the project, a survey of the basement and Market floor was performed to determine the condition of the structure and confirm the dimensions on the design drawings of the Athenaeum. Any renovation must begin with a survey to confirm layout and accuracy of construction. The original drawings depicted a building which was slightly out of square. The sheet layout around the property was off 90° square by 19 minutes. This allowed the Terminal to completely fill the site with a slight variance side by side and end to end. The field survey determined that the building was built in accordance with the plans. This left two options as far as any added framing. One option would have been simply to frame new columns on top of old ones and accept the 19 minute variation. The other option was to square up the new design and superimpose it on the existing framing. Unfortunately, the second option was chosen by the Architects. This required the use of control lines to lay out the newly added structure. The contractor never caught on to this approach and coordination problems plagued fitup during construction.

A condition of the sale of the Reading Terminal was that all contaminants be removed before the property was turned over. This required the removal of all roadbed top surfaces and all ties and other associated material and left only the structural framing to move onto for examination of arch trusses. Wooden pads of 30.5 x 30.5 cm bolted together were purchased to provide a work platform for the high reach equipment. We could not cover the areas completely where we wanted the high reach, so we used a hydraulic crane to leap frog the platforms down the tracks. This allowed us to lift our equipment into the Terminal and move it down track lines so each truss could be examined.

In the past, truss arches had been repaired by welding by the Reading Railroad maintenance crews. Repairs were functioning well, but we still needed some test weld specimens to confirm design strengths that could be used. Coupons would be taken from beams and/or girders to provide for such testing. This was done during the demolition phase using beams that were being removed from the track floor. Weldability was confirmed, although a strength loss of 30% was experienced when welds ran across the grain. Consequently, weld values were lowered for such a case.

The track floor had large areas which were in reasonable condition. Deterioration was focused at certain points such as the following:

- Side stringers of passenger platforms;
- North end framing where water was blown in by storms; and
- Side framing, particularly side wall trusses, where water was not discharged by the drainage pipes.

The 2 x 14 cm pine sheathing began to break down over the years as the roofing failed and water gained access to the sheathing. The pieces of sheathing flowed down to the roof drains and gradually filled them. Because these pipes were filled with toothpick-like fragments, the drainage system because useless. The rainwater directed to the downspouts would spill over onto the track floor and run down onto the Market ceiling. The Market ceiling had a waterproof coating at one time, but this too had failed, allowing water to run through the ceiling into the Market.

4. DESIGN OF TERMINAL RENOVATION

The architectural plan for the terminal involved adding two levels of new framing at the north end. These new levels would frame meeting rooms with movable partitions on the track floor and a ballroom with a movable wall on the upper level. The track floor required renovation of deteriorated beams and the placement of a new concrete slab. Once the new slab was in place, it would serve as a work platform for new framing and renovation of the terminal roof above.

Renovation of track floor beams or girders was done by replacement or welding of auxiliary plates to an existing section after it was cleaned. Since lead-based paint was used, the beams could not be sandblasted to clean them. A chemical compound called Stripeze was used to dissolve and remove paint and rust as a semi-liquid.

Two components of the Terminal roof structure had to be addressed in the track level renovation. Eye bars provided the tension tie at the base of the three hinged arch trusses. It was obvious that some deterioration of the eye bars had occurred by oxidation. To evaluate the condition of the eye bars would mean placing a redundant system to take the tension forces and then removing and examining the eye bars. The design decision was to place a redundant system of rods anchored at each end to the arch bases. Anchor plates were attached to the back of the truss arch base and the rods passed through these plates into a nut on the back side. These 57 mm diameter A36 rods were tightened slightly so that any tension which developed at the arch bases would flow into the rods.

The truss arches were fixed at the east side but sat on rollers to form an expansion bearing at the west. These roller bars were 5 cm diameter with a center groove. The base shoe of the arch had a corresponding plate tab which fit in the groove. The six roller bars would then roll east or west as the structure expanded and contracted. Heavy oxidation was present on the rollers and shoe. A replacement system was needed to recreate the expansion bearing. Teflon™ bonded to stainless steel plates was chosen to form the joint. Teflon on Teflon would provide the expansion capability.

To place the Teflon bearing assembly would require lifting the expansion end of the truss arch. Dead weight of the existing arch was 55 kips which was a very reasonable lift. The structural drawings were prepared showing a lifting frame with hydraulic jacks to raise the truss. During the renovation, the lifts proceeded quickly. A truss arch base was raised by the hydraulic jacks on the lifting frame which allowed removal of rollers, cleaning of the bearing, and placement of the Teflon assembly. As an added precaution, these lifts were made after the tension rods were in place.

4.1 Column Design Review: Renovation or Upgrade

In our existing conditions study, we found a number of columns with reduced section at the Market floor due to oxidation. The loss was enough that capacity of some columns had to be limited to dead weight only above the Market. Plating was to be used at the Market floor to reestablish the column cross section. This work had to be phased with Market tenants and had to proceed the new construction within the Track floor above. Phasing of tenants was done by quadrants to allow a segment of columns to be repaired.

Exposed wrought iron columns in the Market required a rational fire protection system. A flooding technique with four sprinkler heads around each column both above and below the Market ceiling was proposed and accepted by codes. The columns below the Market did not have to be exposed so a concrete encasement was chosen. This concrete encasement allowed a composite column for added capacity and effectively fireproofed the wrought iron. To renovate each column, the Market floor was cut away to allow plating. The column encasement was cast and the Market floor was recast with concrete after the plating was completed.

4.2 Roof Systems

The original arch truss roof system was designed for the following conditions:

First: Snow (0.6 kPa) on one side + dead load
Second: Snow (0.6 kPa) on both sides + dead load
Third: Wind on one side (1.7 kPa vertical surface) + dead load
Fourth: Snow and wind (1.7 kPa vertical surface) one on one side; snow only on the other side + dead load

Current code requirements show ground snow load at 1 kPa, but considering exposure and roof slope, the minimum snow load is 0.6 kPa. The significant change is design for snow drifting at changes in roof elevation. Vertical faces at skylights result in drift loads. The roof eaves along the east and west sides have the roof drains in crickets. The parapet along the eave also creates drifting which calls for higher snow loads along the edges. Snow guards were placed on the roof to hold the snow in place and allow melting at the roof surface. The snow guards help prevent ice dams in the drainage crickets as long as they hold the snow. Wind loading is much different now than it was in 1893. Primary roof loading is negative in wind conditions. This was beneficial in the current analysis for load combinations.

Joseph Wilson set allowable tension for the wrought iron at 96.5 MPa and compression at 83 MPa. The wrought iron test specimens revealed a material reasonably consistent with ultimate strengths of 248 MPa (+) and yields of 228 MPa (+). Computer analysis indicated only a few members with stresses above the original 96.5/83 MPa allowable. A modest increase of allowable to 110/96.5 MPa provided a capacity envelope.

5. CONSTRUCTION ISSUES

During the existing conditions phase, the wood purlins, though stained, appeared sound from the bottom. We reduced our original estimate of 60% replacement based on this data. Unfortunately, the purlins had rotted from the top from the water migrating along the sheathing. As each three boards of sheathing stopped over a purlin, the water collected and promoted decay. Ultimately, just over 60% of the purlins were replaced based on rotted cores. Obviously, first thoughts were more accurate in this instance.

Other segments of the renovation and construction proceeded on course. Opening was in the spring of 1994 after 17 snow storms in the northeast during the winter of 1993. Snow loading was frequent and drifting along the eaves was present. The roof performed well and is ready for the next 100 years.