St. Paul's Union Depot: Revitalization of a Historic Concrete Train Depot

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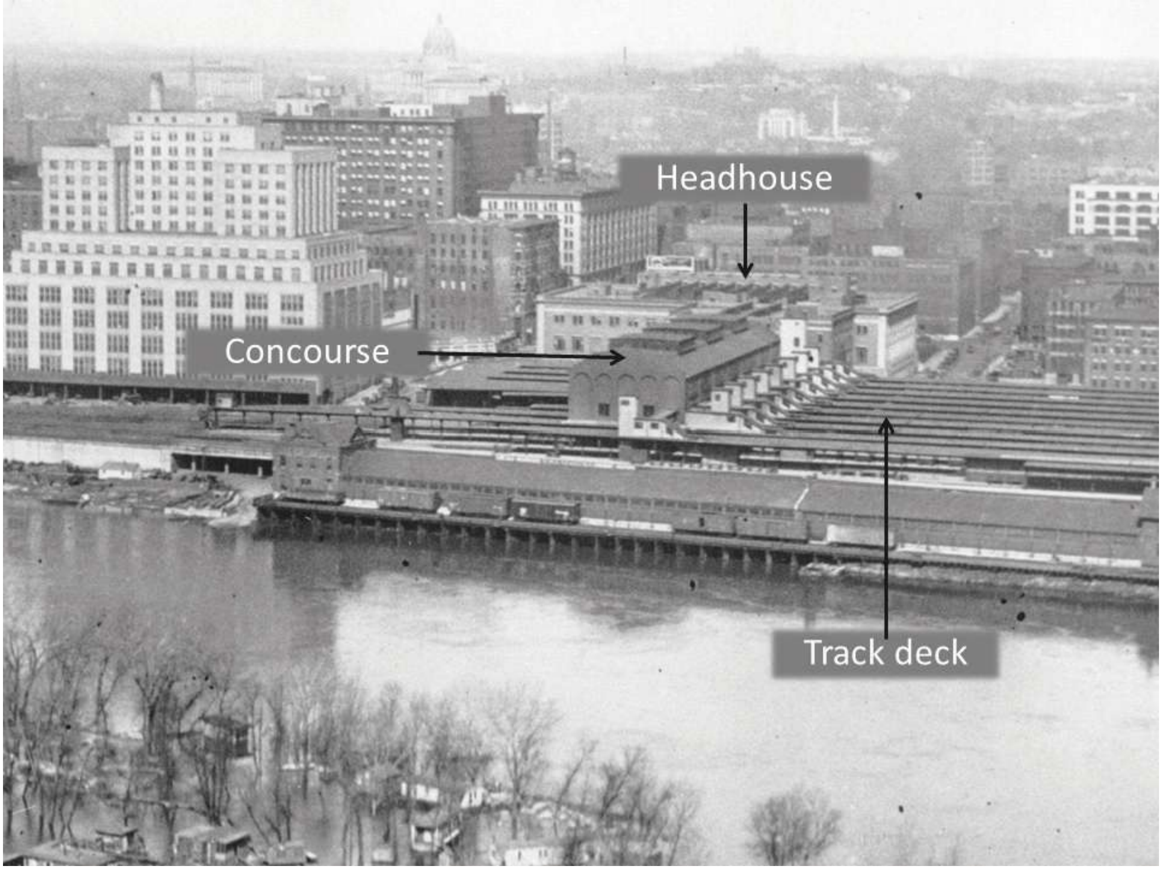

Fig. 1: Historic photograph of Union Depot, looking north, provided by Ramsey County Historical Society

The historic Union Depot railroad terminal, constructed circa 1925 along the Mississippi River in St. Paul, Minnesota, was a very active train station through the mid-1960s. The head house and elevated track deck structure (Fig. 1), which occupied 6 acres (2.4 hectare) and accommodated 20 railroad tracks, served 20,000 passengers daily at its peak in the 1920s. Over the decades, though, passenger rail service declined and then ceased in 1971. In the decades following, the Depot was converted into a postal distribution center and most of the railroad tracks, platforms, and ballast on the topside were replaced with soil fill and paving, and the lower level baggage handling service area was converted into a parking facility.

In 2009, the Ramsey County Regional Railroad Authority acquired the Depot and embarked on a US $240 million rehabilitation to turn the facility into a modern multi-modal transportation hub. Completed in 2012, the revitalized Depot and surrounding area accommodates passenger rail, local light rail, buses, taxis, and bicycles, and was designed with the potential for future high-speed rail service.

Track Deck Structure

The Depot's sprawling track deck includes approximately 600 21-ft (6.4 m) square bays of reinforced concrete superstructure, with 21 in (533 mm) thick, reinforced concrete slabs spanning between circular concrete columns and perimeter walls. The columns and walls are, in turn, supported on below-grade concrete pile caps and approximately 9,000 untreated timber piles, typically occurring in 14-pile groups per pile cap.

The small portion of the original drawings that was found provided some indication of typical reinforcing steel layout, pile cap and timber pile layouts, and limited construction details. According to journal articles published during original construction, the structure was designed for Cooper E-60 standard train loading with 25% added for impact. The deck was an early two-way slab designed according to the "Chicago ruling using a flat slab principle," and used both orthogonally and diagonally-oriented bands of reinforcing to carry the load.

The Challenge

Approximately 90 years of exposure to a harsh northern climate had taken their toll on the track deck superstructure. The concrete structure exhibited advanced deterioration due to leakage, freeze-thaw cycles and corrosion. Loss of timber pile integrity was also suspected because of obvious signs of settlement and structural cracking in several areas of the track deck. Feasibility of the rehabilitation hinged on whether the existing structure had sufficient remaining capacity, or could be effectively and practically repaired, to reliably support the anticipated loads of the rehabilitated Depot for the desired 50-year service life extension.

Assessment of Timber Pile Foundations

Deterioration of timber piles is typically caused by brown- and white-rot fungi (the most common types of decay observed in above-grade structures) and soft-rot fungi related to molds. Brown and white rot require high wood moisture content (typically above 20%) and sufficient oxygen, so they typically do not occur in wood that is submerged in water or buried deep below grade. However, they can exhibit rapid growth and thus are typically the more destructive forms of decay in piles near or above the groundwater line. Soft-rot can tolerate high moisture levels and requires less oxygen, so it can be significant in wood that is submerged, very wet, or below-grade. Slow-growing bacterial decay can also occur in wood that is submerged; and insect attack (e.g., termites) is prominent above groundwater in warmer climates.

Geotechnical surveys were conducted to define the soil characteristics and the position of the water table relative to the tops of the timber piles. Surveys showed the tops of all of the piles were likely above permanent groundwater and thus vulnerable to decay; however, due to the downward slope of the water table toward the river, only the top 2 ft (0.6 m) of the piles were above groundwater at the north side of the site, whereas the top 12 ft (3.7 m) of the piles were above groundwater at the south side (closest the river). Soil characteristics were variable but predominantly granular (sandy) toward the south, with sandy clays toward the north. Decay of timber piles is more likely in granular soils than in cohesive soils because of the potential for increased moisture fluctuation and greater oxygen concentration. These site conditions suggested that the piles to the south were the most vulnerable.

A field investigation exposed 54 timber piles through exploratory test pits (Fig. 2), or about one-half of 1% of the approximately 9,000 timber piles. Locations of the test pits were guided by a comprehensive visual inspection and elevation survey across the underside of the track deck to locate any structural distress or unusual gradients in the deck elevation that might be indicative of timber pile degradation below. Within each test pit, conditions of the pile caps and timber piles were documented, soil type was noted, in-situ tests were conducted on the piles, and timber samples including core samples and full-diameter sections representing a range of conditions were removed for subsequent laboratory testing. In addition, in-situ load testing of two representative piles that did not exhibit significant wood decay was conducted.

Considering the small sample size of exposed piles and the variability in conditions identified, Monte Carlo statistical simulations were performed considering pile diameter, wood species, and percent of cross sectional area loss due to decay to estimate the probability that any pile cap on the site had a certain vertical-load-carrying ability. The simulations predicted that only about 30% of the pile caps could reliably support heavy Class 1 rail loading now, and only about 5% would be able to do so after 50 years (considering a rough extrapolation of future pile deterioration). On the other hand, roughly 80% of the pile caps should be able to reliably support the light rail and bus loading in 50 years.

Based on the results of the investigation and analysis, it was concluded that the timber pile foundations supporting the southern third of the track deck should not be relied upon to support the heavy Class 1 rail loads programmed for that portion of the rehabilitated facility. In this area, the majority of the deck and foundations were demolished and reconstructed to replicate the original historic appearance. For the northern two-thirds of the track deck where the pile conditions were better, it was concluded that the existing foundation should have sufficient capacity to support the anticipated light rail, bus and vehicle loads for the next 50 years. Accordingly, the existing concrete structure was repaired and the existing timber pile foundations were left undisturbed to support the rehabilitated facility.

Fig. 2: Test pit exposing concrete pile caps and timber piles

Fig. 3: Representative conditions at underside of track deck before rehabilitation

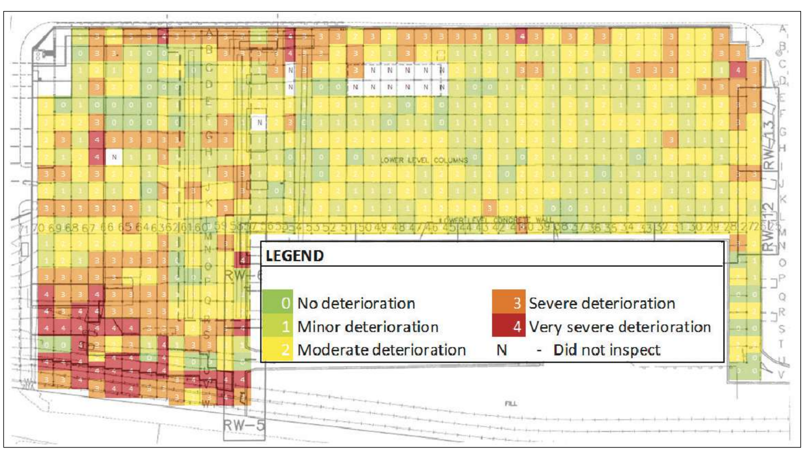

Fig. 4: Visual condition survey ratings

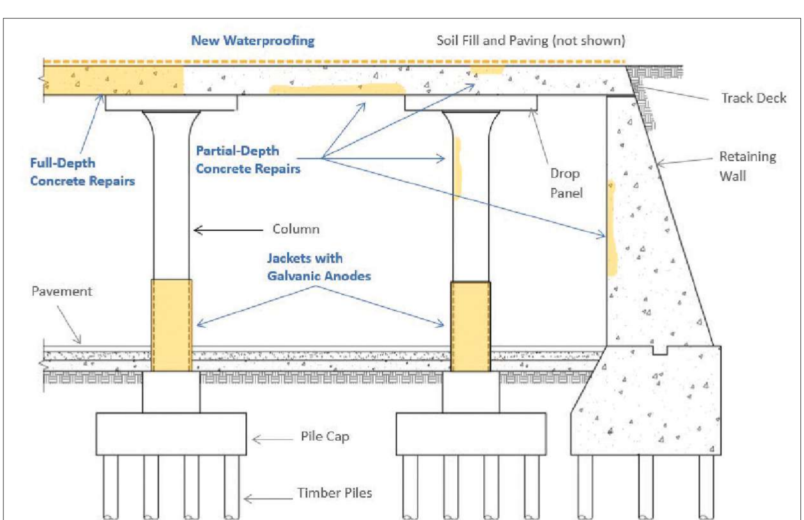

Fig. 5: Typical section through track deck structure showing concrete repair scope

Assessment of Concrete Superstructure

The existing approximately 260,000 sf (24,155 sm) concrete superstructure was assessed through a combination of visual inspection of the entire structure, detailed examination and field testing at representative study areas, laboratory testing of material samples, and structural analysis. The concrete superstructure exhibited deteriorated conditions (Fig. 3) in varying degrees, including:

- Cracks in the track deck and retaining walls, some with efflorescence deposits and leakage;
- Delamination and spalling of original concrete at the deck underside, columns, and walls;
- Delamination and spalling of 20-year old shotcrete repairs at the deck underside and walls;
- Exposed and corroded reinforcing steel at most spalls;
- Scaling and disintegration of concrete surfaces, especially at deck edges and column bases; and
- Water staining, efflorescence, and leakage at drains and original construction joints in the deck.

To efficiently assess the overall condition of the large-area track deck, visual observations of conditions at the underside of every bay were documented in detail, and a visual condition rating ranging from 0 to 4 was assigned to each bay based on the types and quantity of deterioration noted. The visual inspection data were then used to calculate the quantity and frequency of the deterioration conditions. Using these data, an algorithm was developed to calculate a numerical condition rating ranging from 0 to 100 for each bay. The calculated and visual field ratings showed the same overall pattern of deterioration (Fig. 4) and provided a basis to select representative bays for in-depth investigation, as well as a means to infer the condition of the top of the deck, which was covered by 3 ft (0.9 m) of fill and pavement.

Four deck bays and two perimeter wall bays that represented the range of existing conditions were selected for in-depth study. Paving and soil fill were removed to expose the top side of the deck, and close-up visual examination, hammer sounding, reinforcing steel surveys, localized concrete excavation, half-cell potential testing, and core sample removal were performed. Hammer sounding detected delaminated areas that were not identified by visual survey. Previous shotcrete repairs, while visually appearing intact, were typically delaminated. Additional bays beyond the study areas were sounded to more accurately estimate the repair quantities. All columns were visually inspected and six different types of steel or concrete jackets were identified on approximately 70% of the column bases. Representative jackets were removed, typically exposing deteriorated concrete and corroded column reinforcement.

Sixty concrete cores were subjected to laboratory testing, including petrographic examinations, carbonation depth testing, chloride ion profiling, and compressive strength testing, in order to determine deterioration mechanisms and long-term durability potential of the concrete. Mechanical properties of the reinforcing steel were evaluated by metallurgical testing of ten samples.

Structural analyses of representative portions of the existing superstructure were conducted using material properties determined by laboratory testing to evaluate the structure's ability to support the anticipated design loads. Load rating was performed according to the *AREMA Manual for Railway Engineering* published by the American Railway Engineering and Maintenance-of-Way Association (www.arema.org) and general industry practice. The analyses indicated that the track deck is capable of supporting the light rail and bus loading, as well as heavy rail up to Cooper E-40 design load; more refined analysis would likely justify locally heavier rail loads up to Cooper E-60.

Fig. 6: Repairs in progress

Fig. 7: Column jacket repairs during construction (left) and five years after rehabilitation (right)

Concrete Superstructure Repairs

The investigation determined that the primary causes of the concrete deterioration were long-term water leakage through cracks and joints, localized chloride-induced corrosion of reinforcing steel from exposure to deicing salts, localized carbonation-induced corrosion, and freezing and thawing of saturated concrete, which is not air-entrained. While the concrete deterioration was widespread and advanced in some areas, the investigation concluded that the structure could be repaired. The driving forces of future deterioration are corrosion of the reinforcement and freeze-thaw damage of the concrete, both of which require moisture and are accelerated by chlorides, so the repair strategies included protecting the concrete against water and chloride ingress (Fig. 5).

Partial-depth concrete repairs extending beyond the near surface reinforcing steel mat were specified for the deck underside and perimeter walls (Fig. 6). Given the volume of concrete removal required, hydrodemolition was utilized and proved to be cost-effective for repair area preparation. Shotcrete was utilized for overhead and vertical concrete repairs and included a form-board finish to match existing. Full-depth repairs were necessary along expansion joints and around drains. For the deck topside, to mitigate water and deicing salt infiltration, heavy duty waterproofing systems, expansion joint seals, crack and construction joint sealing, and improved drainage were specified. For the deck underside, a breathable coating was utilized to slow future carbonation. These repairs were deemed sufficient for the 50-year service life extension, with recognition that some localized concrete repairs should be anticipated over time.

Because of advanced corrosion and chloride contamination at the column bases down to the pile caps, as well as the difficulty in making these repairs in the future with the facility in service, column repair included removing all existing jackets and concrete cover to the vertical reinforcing bars, installing distributed galvanic anodes for corrosion control, and encapsulating the repair with new, fully grouted steel jackets (Fig. 7). The new jackets are a barrier against additional chlorides, and the galvanic anodes mitigate corrosion in the underlying already-chloride-contaminated concrete.

Accurately estimating concrete repair quantities before construction can be challenging, especially for very large structures. The comprehensive visual inspection data in combination with the condition ratings for each bay of the deck underside were extremely helpful in this project. Repair quantities were developed using calculations that considered the average area of deterioration for each condition rating, the area of existing shotcrete patches (all of which were recommended for replacement), and growth factors to account for actual repair areas being larger than the surveyed areas. Final repair quantities logged during construction were very close to the estimated quantities.

Summary

Rehabilitation of the historic railroad terminal hinged on whether the 90-year-old structure with widespread and locally severe deterioration had sufficient remaining capacity, or if the structure could be effectively and practically repaired to support the anticipated loads of the rehabilitated facility. The unique engineering approach used to assess the concrete superstructure and timber pile foundations of this very large facility was sufficiently thorough while still being cost-effective and efficient. Comprehensive inspections followed by targeted testing showed the extent and causes of deterioration, allowed the development of repairs to address the underlying deterioration mechanisms, and provided a means of accurately estimating concrete repair quantities. The resulting information substantiated the ability for most of the original structure to be retained and effectively repaired for the desired 50-year service life. The extensive rehabilitation was completed in just 23 months and the revitalized Depot opened in December 2012 (Fig. 8 and 9). A walk-through of the structure in 2018 confirmed overall good performance of the concrete repairs to the track deck, with no new signs of structural settlement or unexpected deterioration. ■

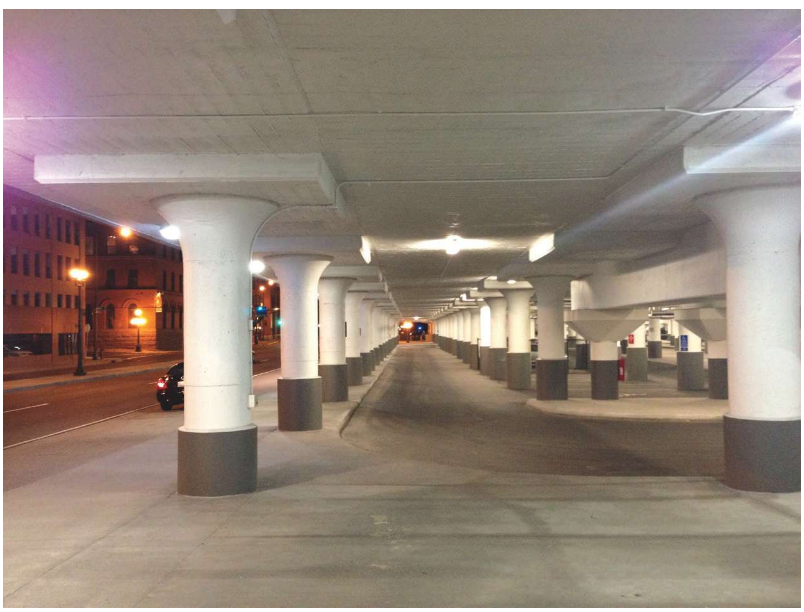

Fig. 8: Rehabilitated Depot structure

Fig. 9: Rehabilitated Depot entrance

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