VARIATIONS ON THE STRUCTURAL SCHEME FOR WACKER DRIVE RECONSTRUCTION

Tony F. Shkurti, PhD, SE, Teng and Associates, Inc., Chicago, IL
Hubert Janssen, SE, PE, Teng and Associates, Inc., Chicago, IL

ABSTRACT

Having gracefully reached and surpassed its service life, the ten-block section of the Wacker Drive Viaduct in Chicago, running between Randolph Street and Michigan Avenue is being reconstructed. Originally built in 1925, Wacker Drive is one of the main traffic arteries within the Downtown Chicago Loop, and is also a significant architectural landmark of the City. The viaduct comprises a double deck vehicular traffic that provides service level access at the lower level and pedestrian access and vehicular traffic at the upper level.

The new structure has been designed to increase the vertical clearance from 12'-4" to 13'-9", and to upgrade traffic patterns to modern standards. The vertical clearance constraint necessitated a relatively shallow structural system. Also, the diverse geometry of the roadway in the upper and lower levels necessitated the use of different structural schemes. A post-tensioned continuous concrete slab with different rib and post-tensioning layout was used to meet these requirements.

Keywords: Bridge, Concrete, Post-tensioned, Slab, HPC, Tendons, Viaduct, Wacker, Chicago, Teng.

INTRODUCTION

Wacker Drive is one of the main traffic arteries within the Dontown Chicago Loop, and is also an architectural landmark of the City. The oldest section of Wacker Drive was built between 1924 and 1926. It was built as a double-deck roadway with the intention of providing lower level access to ships loading-off goods onto trucks for distribution to the city. However, today it provides service level access to the buildings at the lower level, and pedestrian and vehicular traffic at the upper level. More than 65,000 vehicles use the two-level roadway each day and another 125,000 vehicles use the eight streets crossing Wacker Drive each day. Also, it provides access to several corporate headquarters, and to other architectural landmarks of the City.

After having served for more than 75 years it was in great need of replacement. Not only had its functionality become obsolete, but the structure itself had been showing signs of distress. An extensive structural inspection of the upper deck by the city authorities in 1996 documented several signs of structural deterioration like open cracks, concrete spalling, exposed and corroded reinforcing steel, extensive chloride infiltration, and loss of structural capacity. Based on the inspection findings a 15 ton load limit was posted [1] and temporary shoring was required at some locations

The original viaduct had a posted clearance of 12'-4" which proved to be a challenge to modern trucks trying to service lower level businesses. In addition, an irregular array of concrete and steel columns, that supported respectively the viaduct and the Chicago Transit Authority (CTA) trains elevated above the viaduct, restricted visibility in the lower level and constrained applicable curvatures in both the upper and lower level.

The proposed structure has been designed to increase the vertical clearance to 13'-9" throughout the viaduct's lower level. This design constraint necessitated a relatively shallow structural system to provide the additional vertical clearance within the envelopes provided by the existing cross-streets and building entrances on the upper level and the underground utilities, existing caissons and loading docks at the lower level.

To meet all the challenges presented here a post-tensioned concrete structure comprised of continuous slabs with wide shallow stiffening beams, with the slab post-tensioned in both directions, was selected as the most appropriate solution. However, based on the geometrical challenges presented in each section of the roadway this scheme was applied creatively.

For the more typically configured mid-block sections which run on a straight alignment the original design concept specified a 13" deep post-tensioned slab structure with 4' wide by 24" deep longitudinal ribs spanning from column to column along the roadway alignment running parallel to each other at a typical distance of 32'-6". In these sections, the regular geometry allowed for the structure to be designed and pre-cast using match-cast segments. This design scheme was specified in three out of nine units of the viaduct designed by Teng.

The structural scheme with 13” deep slab and 4’ wide by 24” deep longitudinal ribs post-tensioned in both directions was also used in curved sections where the geometry of the ribs and the spacing between them was found to be somewhat regular and similar to the straight portions of the roadway. However, complexity in the geometry of the segments and of the post-tensioning tendons combined with utilities passing through made the use of pre-cast segmental construction impractical. Therefore this part of the structure was designed as cast-in-place post-tensioned concrete. This design scheme was used in two out of nine units of the viaduct designed by Teng.

The limited thickness of the 13” slab restricted the deviation range available for the transverse post-tensioning. The deviation of these transverse tendons was constrained even further by the presence of the longitudinal post-tensioning. In order to obtain the required deviation forces required while being able to thread the transverse tendons through the longitudinal post-tensioning 4 x 0.6” flat tendons were utilized. Typically, they were placed at about every 2’-0”. These tendons provided enough post-tensioning force for the available deviation range to meet the loading requirements. They also are flexible enough to allow them to be threaded through the longitudinal tendons.

In other sections of the viaduct, constraints from the lower level roadway and existing structures underneath restricted possible locations for the column lines, thus dictating a complex alignment of the longitudinal ribs which are supported on these columns. Distance between longitudinal ribs flaring out reaches cross spans of as much as 61’ in one instance, which is almost double of the typical span of 32’-6”. Structurally, using the typical 13” slab to span across longitudinal ribs was not an option. It was found that the 13” slab could not carry the loads transversely to the longitudinal ribs and that live load deflections were at unacceptable levels. Therefore, in order to accommodate the larger spans resulting from the irregular geometry, transverse ribs were introduced that spanned transversely between longitudinal ribs at an average 6’-6” apart. These transverse ribs consisted of a 24” deep trapezoidal cross section 18” wide at the bottom of the slab and tapering down to 14”. The introduction of these transverse ribs allowed for trimming of the slab thickness to 9” and thus making the structure lighter. This design concept was used in the remaining four out of nine units comprised in Teng’s portion of the viaduct.

Besides the stiffening effect these 24” transverse ribs provided more vertical clearance for tendon deviation in the transverse direction thus allowing the use 9-0.6” tendons. Typically, there were two such tendons per each transverse rib. In this structural scheme the transverse tendons were not threaded through, instead they were consistently deviated below the longitudinal slab tendons.

Another structural variation of the post-tensioned slab was used to design a ramp linking the upper and lower levels of the viaduct. Because the width of the single lane roadway was small, tapering from 22’ at the upper level to 16’ at the lower level, transverse moments were small and efficiency of the transverse post-tensioning limited. Therefore, it was designed as a cast-in-place slab with longitudinal ribs and post-tensioned only in the longitudinal direction. The slab was designed to be crack free at its top surface.

Longitudinal post-tensioning was provided both in the ribs and in the slab. The ribs were post-tensioned with 9-0.6” tendons which were deviated to provide resistance to varying moment in the slab, while the slab was post-tensioned using 5-0.6” tendons which were only intended to provide the P/A effect and therefore they were not deviated.

Independent of the structural variations in the slab, edge beams were used at the end of each structural unit, along the transverse expansion joints. While stiffening the beam to minimize edge live load deflection, they also provided enough space to accommodate the longitudinal slab post-tensioning anchors and the expansion joint assembly.

The viaduct structure was designed to deliver at least 100 years of service before requiring any major rehabilitation. In order to achieve such a projected service life the design limited tension allowed in the slab to a minimum, High Performance Concrete (HPC) is being used for the superstructure, and a sacrificial layer of latex-modified concrete is specified for the topmost layer of the structural deck. In addition, the specification for grouting of post-tensioning tendon ducts prescribe the use of prepackaged grout with enhanced properties and most importantly zero bleed water requirement which ensures that the ducts remain entirely filled after setting of the grout. The grouting was specified to be carried out only by experienced and certified personnel.

Loading considered for the design typically included: self weight of the slab, super-imposed medians and sidewalks, 7 lanes of HS-20 traffic (3 lanes in each direction plus a left turn lane), planters as applicable (weighting as much as 320 psf), 100 psf pedestrian loading on the sidewalks combined with a H-20 maintenance truck (loadings exclusive of each other or the planters), temperature, creep and shrinkage.

Analyses were carried out using finite elements. All the loads were separated into simpler loading cases. The effects of the longitudinal and transverse post-tensioning were analyzed separately and later combined in extensive spreadsheets. Post-tensioning loads were modeled using equivalent loads. Effects from all loading cases were super-imposed in combinations based on AASHTO criteria for Service Loads the overall stresses at each point in the slab were calculated. Tendon deviation and amount were varied until stress limits specified were achieved.

A special consideration was given to creep and shrinkage. In order to accommodate the movements in the superstructure because of creep and shrinkage combined with elastic shortening the structure was designed to be floating on pot bearings.

The new superstructure is much lighter than the original one and therefore all of the existing caissons that could fit into the new column layout were reused. A new connection was developed that would use the existing caisson reinforcement but would supplement it with additional reinforcement in a new caisson cap to transfer the larger moments. Columns were designed to be single columns cantilevering from the existing caissons wherever possible. In many instances, when column locations could not match with existing caissons, grade beams were designed between these caissons to support some of the new columns. New caissons were placed wherever was possible and economically feasible.

Several other challenges had to be addressed in the design stage. Traffic crossing the river and access to the 57 buildings that face Wacker Drive and rely on it as their only source of access was to be maintained at all times. The new viaduct while conforming with modern highway standards had to preserve the roadway's historic character. Conflicts between utilities going through the viaduct, like drainage and electrical, and the post-tensioning were carefully avoided by close coordination between the different disciplines and consultants involved in the project.

Despite the complexity of the project and the constraints imposed by a congested urban setting, the innovative use of a post-tensioned deck system combined with close coordination between the City of Chicago and the several consultants involved in the design has allowed the contractor to provide a quality viaduct while maintaining an aggressive construction schedule.

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