Finding Creative Concrete Solutions at LAX

Designing the Automated People Mover at Los Angeles International Airport to reduce traffic impact and meet seismic resiliency requirements

by Chester Werts and Rob Richardson, HDR Inc.

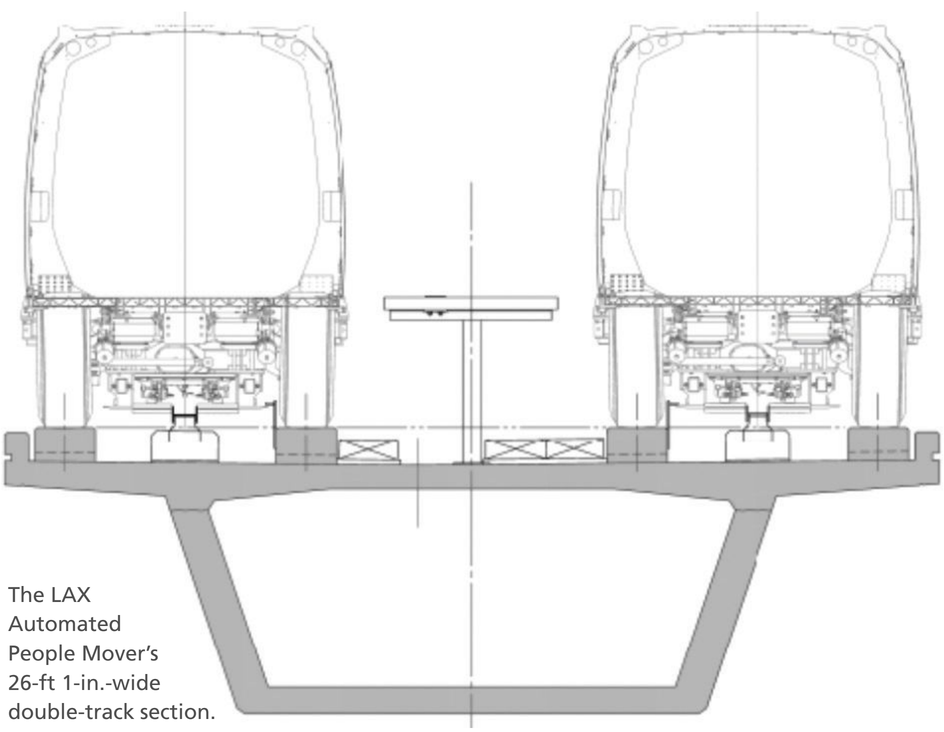
Los Angeles World Airports' (LAWA's) Automated People Mover (APM) at Los Angeles International Airport (LAX) will enhance the travel experience and provide a long-awaited connection to greater Los Angeles regional transportation systems. But designing and constructing more than 2 miles of elevated guideway at the world's fifth-busiest airport involves some complex challenges.

Most notably, the project requires that traffic be kept moving in LAX's Central Terminal Area—an extremely busy hub from which passengers arrive and depart. Furthermore, given the APM's Southern California location, engineers also had to ensure that the design would meet strict seismic resiliency requirements.

Project Overview

The $2 billion APM project—which includes the fixed facilities, systems, vehicles, and vehicle controls—is being built using the public-private partnership delivery method. The APM is the centerpiece of LAX's Landside Access Modernization Program and overall transformation. It will connect the airport to regional public transportation and provide dependable access to the terminals. It will also eliminate the need for shuttles to rental-car lots—a current source of traffic congestion—by connecting the airport to the new Consolidated Rent-A-Car (ConRAC) facility. The APM project includes 2.25 miles of elevated guideway, five passenger stations, two intermodal transportation facilities, and a maintenance and storage facility.

The guideway alignment weaves through LAX's Central Terminal Area and across State Route 1 at a deck height of approximately 65 ft before it turns across Century Boulevard and descends to a height of approximately 38 ft to remain clear of the runway protection zone. The alignment then turns sharply



The LAX Automated People Mover's 26-ft 1-in.-wide double-track section. Figure: HDR Inc.

profile

LAX AUTOMATED PEOPLE MOVER PROJECT / LOS ANGELES, CALIFORNIA

BRIDGE DESIGN ENGINEER: HDR Inc., Los Angeles, Calif.

OTHER CONSULTANTS: Geotechnical consultant: Group Delta; architecture and station design: HNTB; station design: Kleinfelder, IDS Group; guideway independent design checks: MGE Engineering, PacRim Engineering

PRIME CONTRACTOR: Fluor/Balfour Beatty/Flatiron/Dragados

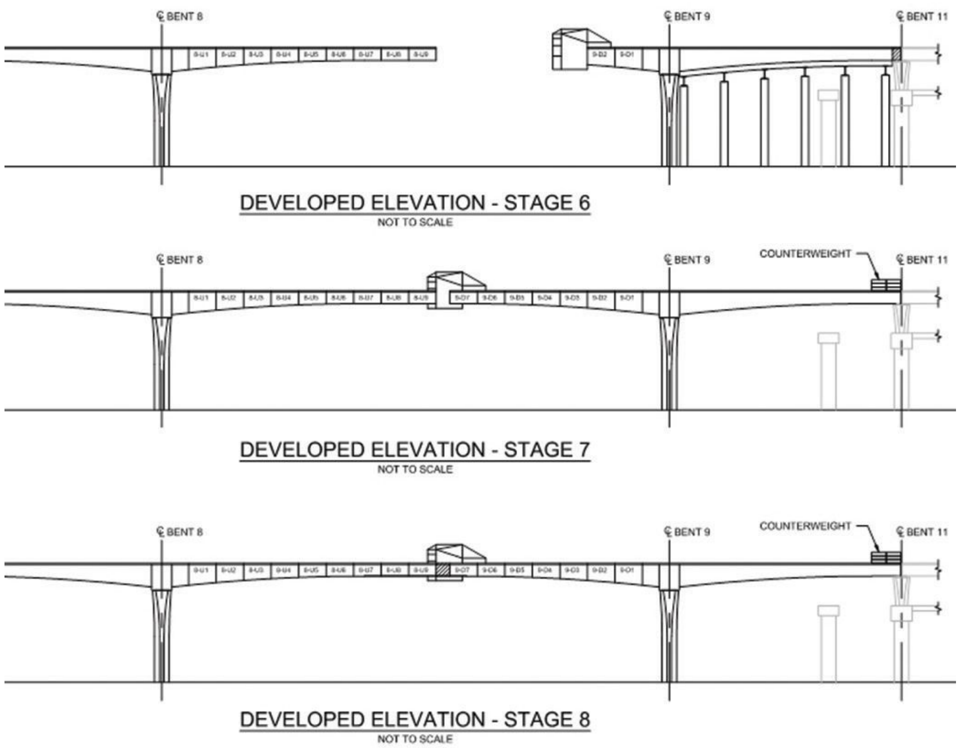
CONCRETE SUPPLIERS: CalPortland, Glendora, Calif.; Cemex, Inglewood, Calif.

OTHER MATERIAL SUPPLIERS: Bearings: RJ Watson, Alden, N.Y.; reinforcing steel: Integrity, Perris, Calif.; post-tensioning: DSI, Bolingbrook, Ill.

Nighttime view of form travelers being used during concrete segmental construction of the 212-ft span over Sepulveda Boulevard. Photo: Los Angeles World Airports.

to run adjacent to 96th Street, and the height increases to approximately 50 ft to meet the ConRAC station. Although divided into 11 segments for permitting purposes, there are actually 19 multispan bridge frames, with the longest frame nearly 1000 ft in length. Typical 140-ft-long spans have a constant depth of 7 ft, while longer spans are haunched, with a maximum depth of 13 ft at the pier for spans up to 277 ft.

The concrete segmental guideway is composed of two basic structure types. A 26-ft 1-in.-wide dual-track box girder makes up most of the guideway, but at every station there are two 21-ft



Stages of concrete segmental construction on a span that used form travelers. The concrete box girders of both back spans were cast in place on falsework. Form travelers were then used to construct the segments of the intermediate main span with a closure pour connecting the two cantilevers. Figure: HDR Inc.

LOS ANGELES WORLD AIRPORTS, OWNER

BRIDGE DESCRIPTION: 2.25-mile-long, 76-span (not including stations), combination single-track and dual-track cast-in-place concrete segmental box-girder structure

STRUCTURAL COMPONENTS: Superstructure consists of 21-ft 0-in.-wide single-track and 26-ft 1-in.-wide dual-track cast-in-place post-tensioned concrete box-girder sections. Substructure is cast-in-place concrete single-column bents ranging from 6 to 9 ft in diameter, flared at the top to match the superstructure side slopes, and two-column straddle bents in limited locations where required. Columns are supported on 107 cast-in-drilled-hole piles, ranging from 8 to 11 ft in diameter.

The guideway under construction in front of the iconic Los Angeles International Airport theme building. Note the expansion joint visible in the guideway at the pier. Photo: HDR Inc.

0-in.-wide single-track box girders, one on each side. Transition spans are used to connect the two girder types. Almost all concrete segments are post-tensioned; however, only conventional reinforcement is used in a few areas. Including all frames of dual-track and single-track box girders within the elevated guideways, there are 76 spans, with additional single-track box-girder spans within the station structures.

The guideway superstructure is mostly composed of concrete post-tensioned box girders constructed on falsework, but four spans were constructed using a form traveler (with the back span segment cast on falsework). Post-tensioning for the conventional box girders consists of draped tendons in the webs; there are typically three tendons in each web, with nineteen 0.6-in.-diameter strands per tendon. For the concrete segmental spans constructed using form travelers, tendons are located in the top and bottom slabs. The hybrid approach of concrete segments cast-in-place using form travelers and cast-in-place on falsework provides an unusual post-tensioning layout in which three pairs of cantilever tendons in the deck transition over the piers to provide draped post-tensioning in the back spans.

View of the guideway under construction. The guideway elevation varies to provide clearance over streets and buildings while maintaining the Federal Aviation Adminstration's overhead clearance requirements. Photo: HDR Inc.

The substructure generally consists of architecturally flared circular columns founded on drilled shafts of up to 11 ft in diameter. Single-column bents are used for most of the guideway, but there are also two-column straddle bents where single-column bents were not feasible. The maximum height of the columns is approximately 60 ft and occurs in the Central Terminal Area, where the elevated guideway is at a constant elevation of 168.50 ft. In the east half of the project, the guideway descends to an elevation of 137.17 ft to maintain airspace clearances.

Design on the first segments began in early 2018, with construction beginning in mid-2019. Concrete for the last elevated section was placed in April 2022, and all guideway segments are now constructed. In a span of more than two years (and during a pandemic),

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

It is such a pleasure to see a large and complex project developed as a consistent assembly of compatible and interlocking parts, each contributing to a high-quality result, no matter where it occurs in the project. Because of the complex configuration of the people mover system, the intricate needs of existing traffic, and the seismic redundancy required, the Los Angeles International Airport (LAX) Automated People Mover presented a plethora of challenging design issues. Too often, such projects are addressed by optimizing the individual solutions for each group of challenges and then mashing together the whole agglomeration of solutions and living with whatever the final assembly looks like.

At LAX, the parts begin with the post-tensioned concrete box girders supporting the tracks. They all look similar to each other, regardless of whether they support one track or two, what their spans are, or whether they were cast in place on falsework or using form travelers. The torsional stiffness of the box form minimizes the distracting details, brackets, and fittings often required to address complex structural situations. If a box must be deeper to accommodate a longer span, the basic box shape stays the same—its webs are simply extended. All the piers resemble each other, too. They are round shafts that flare smoothly to blend into the box girder above, regardless of the box width or whether it is haunched. Even at the stations, the piers all look the same.

All these smooth and streamlined shapes are made of the same light-colored concrete. The mass of the concrete dampens noise and vibration, and the light color and smooth surfaces keep the spaces below bright and pleasant. The Automated People Mover visually unifies the whole LAX terminal area. Wherever you are among the terminals, the system adds functionality and attractiveness to its immediate surroundings. I don't get to Los Angeles often, but I'm tempted to make a trip just to enjoy this new facility.

The guideway's sweeping alignment offers travelers remarkable views of the iconic theme building. Photo: HDR Inc.

nearly 70,000 yd^3 of concrete were placed. Installation of appurtenances (such as the steel guide beam that will direct the vehicles on the guideway), switches, and other equipment continues on top of the guideway as of this writing. Operational testing of the vehicles on the system is expected to be initiated in phases, starting in 2023 with the track that connects the maintenance and storage facility and the ConRAC.

Concrete Segmental Construction

The biggest challenge on this project was completing construction in the Central Terminal Area while maintaining traffic. One major solution involved cantilever construction using form travelers to span over buildings and major roadways, where falsework was either prohibited or impractical. These four cast-in-place concrete segmental spans range from 196 to 277 ft and cross two major roadways, Sepulveda Boulevard and Century Boulevard at the entrance to LAX, as well as an existing parking structure within the Central Terminal Area.

The use of concrete segmental construction allowed traffic to continue unimpeded on these important roads even as the guideway was being constructed. No falsework or temporary supports were constructed within the right-of-way, and all traffic lanes remained open. The parking structure, which had initially been expected to be demolished and rebuilt as part of construction, was instead preserved for continued use throughout construction. This concrete segmental work was built using a relatively uncommon hybrid construction method that incorporated balanced-cantilever concepts. All the segmental spans incorporate one cast-in-place concrete segmental span with cast-on-falsework back spans. For example, the span over Sepulveda Boulevard was built with 12 cast-in-place concrete segments, each about 15 ft long, and completed with a 7.5-ft closure pour. As each segment was formed, cast, and cured, the segment was post-tensioned, and then the form traveler moved ahead to construct the next segment. The original design assumed a single traveler would be used; however, to speed construction, the contractor used two travelers.

This hybrid construction method required extra attention to construction loads imparted on the structure, as well as permanent built-in forces. For example, after falsework in the back spans was removed, there were large dead-load moments in the columns supporting the concrete segmental span. These dead-load moments in the columns gradually reduced as cantilever construction continued. By the end of cantilever construction at closure, the change was so great that the net direction of the moment reversed at the top of the columns, leaving a built-in moment that had to be accommodated in the design.

Each stage of the work required detailed structural analysis, with interim phase calculations for each step of the process. Beyond dead-load reactions, other effects such as creep and shrinkage and locked-in erection forces also needed to be considered. These effects were mitigated by adjustments to variables such as the timing of falsework removal, and by physically jacking the superstructure closure apart on one of the guideway spans before placing the closure segment.

Seismic Resiliency

The guideway is located in one of the areas with the most earthquake activity in the United States, so the design had to comply with strict requirements for seismic resiliency. The design accounted for multiple levels of seismic events with specific performance requirements at each level. The two-level approach included designing for an operating design earthquake with strains limited to provide essentially elastic behavior, and also designing for a 2500-year maximum design earthquake with steel and concrete strains reduced from California Department of Transportation standards so that only repairable damage occurs. Accelerometers positioned at two locations along the guideway monitor seismic activity and trigger action in the APM system depending on the severity of seismic activity.

In the event of an emergency stop and shutdown, wherever possible, passengers traveling in a vehicle on the guideway will be taken to the nearest station to safely disembark. Elevated emergency walkways are provided along the entire guideway length so that emergency responders can escort passengers to safety on foot in the unlikely event that a train cannot get to a nearby station.

Designing the system to meet all these seismic requirements was a challenging task, complicated by the guideway's complexity—its significant horizontal curvature, varying elevations, the multiple combinations of segment structures and supports, and segments that abut stations. The resulting unconventional behavior and complex displacement profiles meant that a typical inelastic static analysis was not sufficient to predict the structure's displacement capacity. Instead, designers used a multimodal, inelastic pushover-analysis technique that incorporates contributions of multiple seismic modes and associated modal displacements. This led to an inelastic pushover analysis that mimics the displaced shape profile from a response spectrum analysis and allowed the designers to better understand the structure's performance in the design seismic events. This understanding provided the basis for the engineers to design and detail the critical structural elements to meet the project's stringent seismic resiliency criteria.

Other Challenges and Considerations

While the concrete segmental construction and seismic considerations were major challenges, the project team also overcame numerous other challenges. For example, with a congested site and limited right-of-way, choosing locations for the columns was an early task that proved to be daunting. The selected locations required careful consideration of span length and curvature to fit the guideway between and over existing parking structures, the airport's iconic theme building, future and active roadways and intersections, existing underground utilities, and more. As design progressed, designers also had to meet extremely tight tolerances on the guideway, especially from one bridge frame to the next. Specialized expansion joints were used on the running plinths as well as the APM's guide beams and power rails. Limiting relative displacement between frames, especially under seismic loading, led to specialized bearing details to accommodate combined shear and uplift. Each bearing was custom made to meet the specific needs of the APM frame it supports.

Concrete design strengths were 4 ksi for the cast-in-drilled-hole piles and columns, 5 ksi for the typical box-girder superstructure, and up to 7 ksi for the box girders in the four spans constructed with form travelers. Mass concrete concerns were addressed by using a special concrete mixture that included Orca aggregate, which lowers the heat of hydration during curing by reducing the required amount of cement to create a high-performance concrete. Cooling tubes were also added in case the measured temperatures began to climb beyond acceptable levels.

Sustainability was another important consideration throughout the project. As work began, a large gathering of stakeholders, including representatives from LAWA, the design and construction team, and others, met to explore ideas and set a plan for encouraging sustainable design. That effort paid off as the project was honored in 2022 with an Envision Gold Award for Sustainable Infrastructure. The project was praised for minimizing light pollution, noise, and vibration, and improving the users' access to sustainable transportation options.

As the APM approaches completion, LAX travelers are becoming familiar with the gentle sweeping curves and clean uniform look of the concrete guideway. Once vehicle testing is complete, passengers will benefit from the new structure, which will provide a vastly improved experience for patrons of one of the world's busiest airports.

Chester Werts is a senior design principal for HDR Inc. and is the engineer of record on the LAX APM project. Rob Richardson is HDR's West Region bridge leader and led the guideway design.

The guideway transitions from a highly efficient dual-track box section to independent single-track sections that straddle the stations. Photo: HDR Inc.