T-REX SEGMENT 3 LRT BRIDGES

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ABSTRACT

The design of eight, light rail transit (LRT) structures in Segment 3 of Denver's Transportation Expansion Project (T-REX) required strategic planning, collaborative coordination efforts, and the implementation of many unique design and construction elements by the project team.

Challenging project site constraints within this heavily traveled portion of Interstate 25 (I-25) required the project team to design and develop various superstructure and substructure components that helped minimize impacts to the existing interchanges along I-25. Special superstructure design elements included HPC concrete for the prestressed-precast Bulb-Ts, precast panels in the deck, and a modified approach to the estimate of camber because the girders were often erected "green". Substructure design and construction included the use of concrete straddle bents (pier cap and column) and hammerhead piers, along with staggered MSE abutments on deep foundations, which allowed the designers the flexibility to strategically refine span layouts to optimize fabrication and construction methodologies and minimize the influence of direct fixation forces associated with LRT rail forces. The straddle bent beams were designed to be either cast-in-place or cast on the ground and lifted into place. Single drilled shaft foundations were common because they introduced flexibility (reducing the direct fixation forces), had small footprints (reducing the number of conflicts with utilities and ROW) and did not generate pile-driving noise.

Keywords: T-REX, Design-Build**,** Light Rail Transit, Bridges, Precast, Girders, Straddle Bents, MSE Abutments

INTRODUCTION

The I-25 Transportation Expansion Project (T-REX) is a $1.67B design-build project located along the southeast corridor of Interstates 25 and 225 in Denver, Colorado. This 5-year multi-modal project will add 19 miles of light rail facilities and improve 17 miles of highway through a highly congested portion of metro Denver. Planned improvements require the construction of light rail along the west side of Interstate 25 with a connecting line along the median of Interstate 225 and additional traffic lanes along I-25 and I-225. The T-REX project started in the summer of 2001 and is scheduled for completion before December 2006.

This paper will discuss the light rail transit (LRT) bridge requirements within Segment 3. General project coordination, project site constraints along the corridor, design issues, construction plan development, and specific construction details will be presented.

SEGMENT 3 LIMITS AND STRUCTURE REQUIREMENTS

To expedite production of the design-build construction plans the T-REX design-build team divided the project into three design segments. Project teams were assigned to the individual segments. These teams were responsible to plan and design their individual segments and develop construction documents for the design-build contractor.

Figure 1. Segment 3 TREX Project Limits.

Of the three segments designated within the T-REX project limits, Segment 3 (See Figure 1) required numerous LRT grade-separation overpasses. This segment is located along the southern portion of the project between Belleview and Lincoln Avenues. Light rail within this segment spans across six highway interchanges; one state highway and one water tank facility requiring a total of eight prestressed girder structures with bridge lengths between 117-ft and 990-ft. The following table (Table 1) summarizes the LRT structures within the Segment 3:

Table 1. Segment 3 LRT Bridge Matrix

Location	Length	Girder	Spans	Max Span	Deck Type
Belleview Avenue	405.00	BT63	4	118	Ballasted
Orchard Road	990.00	BT84	7	161.5	Direct Fixation
Greenwood Village	117.00	BT63	1	117	Ballasted
Arapahoe Road	774.42	BT72	6	140	Direct Fixation
Dry Creek NB	491.50	BT63	5	105	Ballasted
Dry Creek SB	441.50	BT63	5	101	Ballasted
County Line Road	990.25	BT84	7	160	Direct Fixation
C470	182.50	BT54	2	90	Ballasted

PRELIMINARY DESIGN

Preliminary design efforts prior to the design-build activities in 2001 allowed the multi-agency task force led by Colorado Department of Transportation (CDOT), Regional Transit District (RTD), Federal Highway Administration (FHWA), and the Federal Transit Authority (FTA) to develop, coordinate, and evaluate the light rail alignment alternatives and resulting structure requirements along the corridor. Minimizing right-of-way requirements, reducing utility impacts, and maintaining traffic throughout this heavily congested segment of I-25 required the task force to recommend the use of precast elements to speed construction, specify longer span lengths to minimize substructure requirements and utility conflicts, and optimize span layouts to minimize design efforts and maximize girder fabrication. The use of structural steel superstructure types was considered for these structures but then eliminated due to its high material and fabrication costs. In addition, precast construction using prestressed girders has become a predominant structure type within Colorado due to its ease of construction and availability of precast manufacturers within the area. These conditions resulted in the selection of precast CDOT bulb-tee girders as the preferred preliminary structure alternative. This structure type was cost effective and provided an inherent ability to accommodate fast-track construction methodologies while providing longer span lengths through girder splicing techniques.

FINAL DESIGN EFFORTS

Upon award of the T-REX project, the design-build team confirmed planned project tasks and implemented the design file management system. This system database contained all project design and correspondence information necessary to effectively plan, coordinate and execute the development of the construction documents.

Weekly project review meetings between the design-build contractor's task supervisor, lead project engineers, and CDOT and RTD representatives assured that the development of plans and specifications were in compliance with the project criteria and provided a pro-active approach for the resolution of any potential constructibility conflicts and/or concerns.

The project design criteria developed in the RFP established a framework for the specific design elements of the LRT bridges. CDOT and RTD specification references were incorporated into this criteria to satisfy general design and construction requirements of each agency. AASHTO Standard Specifications using the LFD methodology was combined with RTD's Southeast Corridor Design Criteria to produce a single set of design data. The design-build team also implemented design directives throughout the duration of the project to address specific design parameters, recommended methodologies, and construction details that improved design protocol and reduced constructibility concerns. These directives provided a modified approach to the computation of camber in girders with concrete strengths in excess of 10 ksi and detailed specific ballasted inlets and underdrain requirements within MSE abutment sections. The computation of girder camber required the designers to: use a concrete strength of f'_c=10 ksi for determining the girder's material properties for modulus of elasticity; estimate short-term deflection using a 60 days to placement of bridge deck; and use modified factors to estimate the long-term effects of creep and shrinkage.

PRECAST HPC ELEMENTS

The Segment 3 LRT bridges incorporated precast elements to expedite the proposed construction and minimize traffic impacts to the surrounding interstate and local highway street network. These eight bridges provide a combined deck area of 127,450 square feet with 58,390 square feet of precast deck panels. The use of precast deck panels helped to reduce construction costs by reducing the amount of formwork for bridge decking. Current CDOT practice allows the use of precast deck panels for bridge construction and the decision to use the panels was quickly agreed upon by the design-build team. The following table (Table 2) summarizes the use of CDOT's Precast BT girders within T-REX's Segment 3:

Table 2. BT Girder Requirements

Girder	Total Length (ft)	Max Span (ft)
BT84	7921	161.5
BT72	3098	140
BT63	4476	118
BT54	730	90

Spliced-girder span configurations originally proposed in the preliminary design phase were eliminated by the design-build contractor. During construction, CDOT relaxed the traffic restrictions at several interchanges which allowed the design-build team to consider additional substructure placement alternatives and the use of girder segments without temporary towers or strong-backs. As a result, piers were allowed within the roadway template which helped to reduce costs associated with traffic control and protecting temporary false work. Thus girder designs incorporated lengths with the ability to span between adjacent pier supports.

Although project design criteria originally specified final prestressed concrete design strengths of 8.5 ksi, the precast manufacturer provided a concrete mix that yielded high performance characteristics and provided initial concrete release strengths in excess of 8.0 ksi and final (28-day) strengths up to 10.0 ksi. The use of admixtures and water reducing agents helped to produce mixes with w/c ratios as low as 0.3. This concrete mix design was the result of an accelerated girder production schedule. This concrete strength was incorporated into the calculation of girder cambers only. Design strengths utilized the original concrete strengths of 8.5 ksi.

SPECIFIC PROJECT SITE CONSTRAINTS

The LRT Bridges along Segment 3 encountered significant project site constraints that warranted specific solutions and project details. These structures all spanned major arterials (See Figures 2 and 3) with significant utility conflicts, traffic control requirements, and limited right-of-way easements. The design-build team developed span configurations and bridge details using single shaft piers supported on drilled caissons to minimize foundation footprints, specified precast elements to speed construction, and incorporated MSE abutment construction to minimize structure excavation and temporary easement requirements along existing right-of-way.

Figure 2. LRT Bridge over Arapahoe Rd

Figure 3. LRT Bridge over County Line Rd

The use of hammer-head pier and straddle bent supports provided the design-build team with the flexibility to satisfy roadway horizontal and vertical clearance requirements. Pier placement was strategic to the overall span configuration to accommodate roadway alignments during all phases of construction. The use of drilled caissons for the deep foundations helped to minimize the substructure footprints and necessary utility relocations.

Figure 4. Girder Erection at Arapahoe Road

Precast concrete girders and straddle bent beams were designed to speed construction throughout these interchange locations. Eliminating the construction time associated with cast-in-place construction significantly reduced traffic impacts. The erection of the precast girders was performed at night (See Figure 4) to minimize disruptions to the existing traffic. The straddle bent beams were designed to be precast on the ground and lifted into place or cast-in-place, providing the design-build contractor the flexibility to coordinate the construction activities into the project schedule.

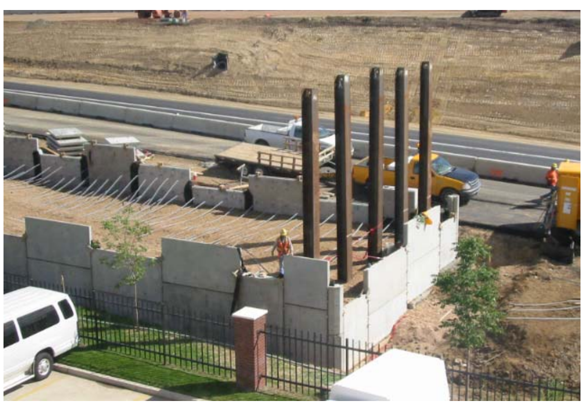

Figure 5. MSE construction at Dry Creek Rd

Figure 6. MSE construction at Orchard Rd

MSE abutments (See Figures 5 and 6) were designed for all Segment 3 LRT bridges. This substructure type is advantageous because of the tall (15-ft to 20-ft) substructure height requirements for the Segment 3 bridges, relatively inexpensive costs, ease of construction, and ability to minimize structure excavation and right-of-way and temporary easement requirements. MSE abutments have the flexibility for construction along challenging alignments by staggering wall layouts, or stepping wall tiers to catch grades minimizing grading requirements. These abutments were supported on deep foundations using steel H-piles. These piles provided the required flexibility necessary to help minimize design forces associated with temperature and braking loads. To eliminate the noise normally related with pile driving activities the design-build contractor specified that all piles be set within pre-drilled holes and encased in concrete caissons. Caissons were constructed below the limits of the MSE embankment thus allowing pile flexibility within the MSE zone. The design of the piling incorporated different lateral soil parameters within the MSE zone and subsurface material below. Shear studs welded along the length of the embedded piles provided the transfer mechanism between the steel pile and concrete caisson segments. The caisson design ignored the effects from the steel pile and relied on nominal reinforcement for the flexural requirements.

PROJECT STRUCTURE FEATURES

The following paragraphs briefly describe project elements and/or design methodologies implemented along the Segment 3 LRT Bridges for use in the preparation of the construction documents.

BALLASTED VS. NON-BALLASTED STRUCTURES

Design criteria mandated that all bridges with total lengths less than 500-ft be constructed using ballasted bridge decks (See Figure 8). Bridges with greater lengths were to be designed with non-ballasted decks using concrete plinth construction (See Figure 9). The concrete plinths were designed to support the LRT rail and guardrail sections. Plinths were approximately 6” high by 24” wide concrete pedestals cast-in-place on the bridge deck surface. These pedestals were designed full-length along the bridge and helped transfer the longitudinal rail forces into the superstructure elements (See Figure 7).

Figure 7. Concrete plinth construction. Note the exposed “crank-shaft” shaped bars at the plinth and deck interface locations.

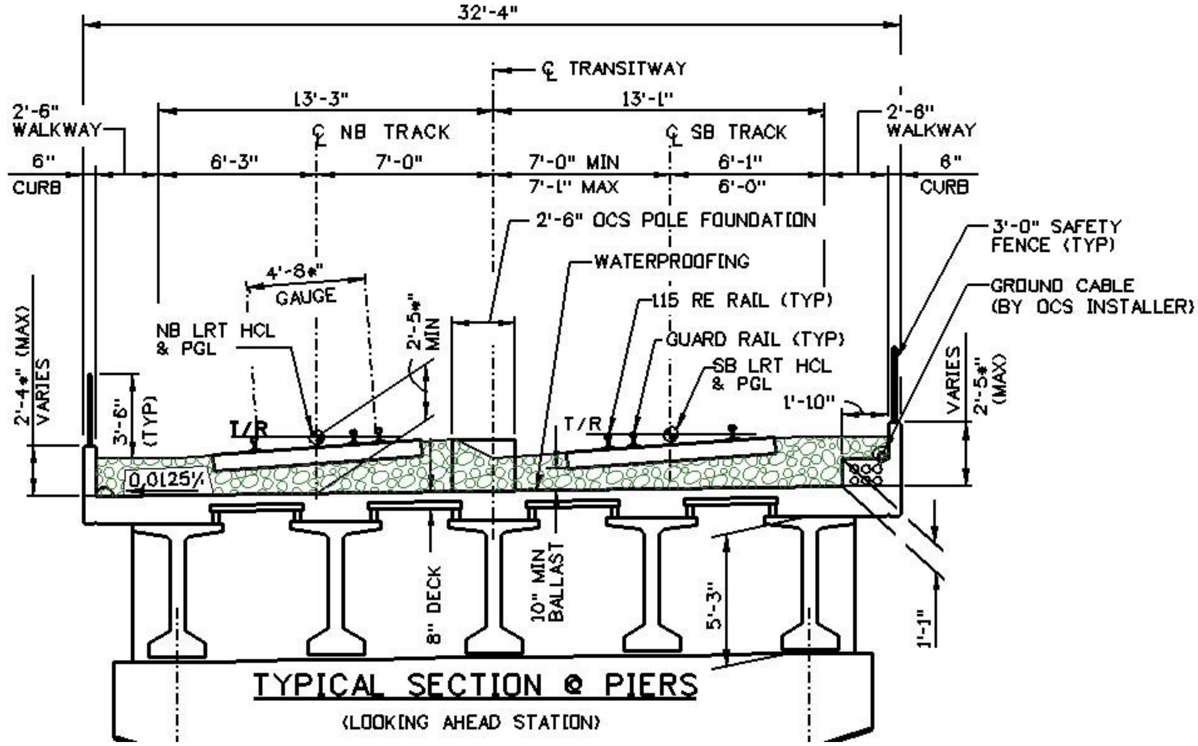

Figure 8. Ballasted Bridge Typical Section

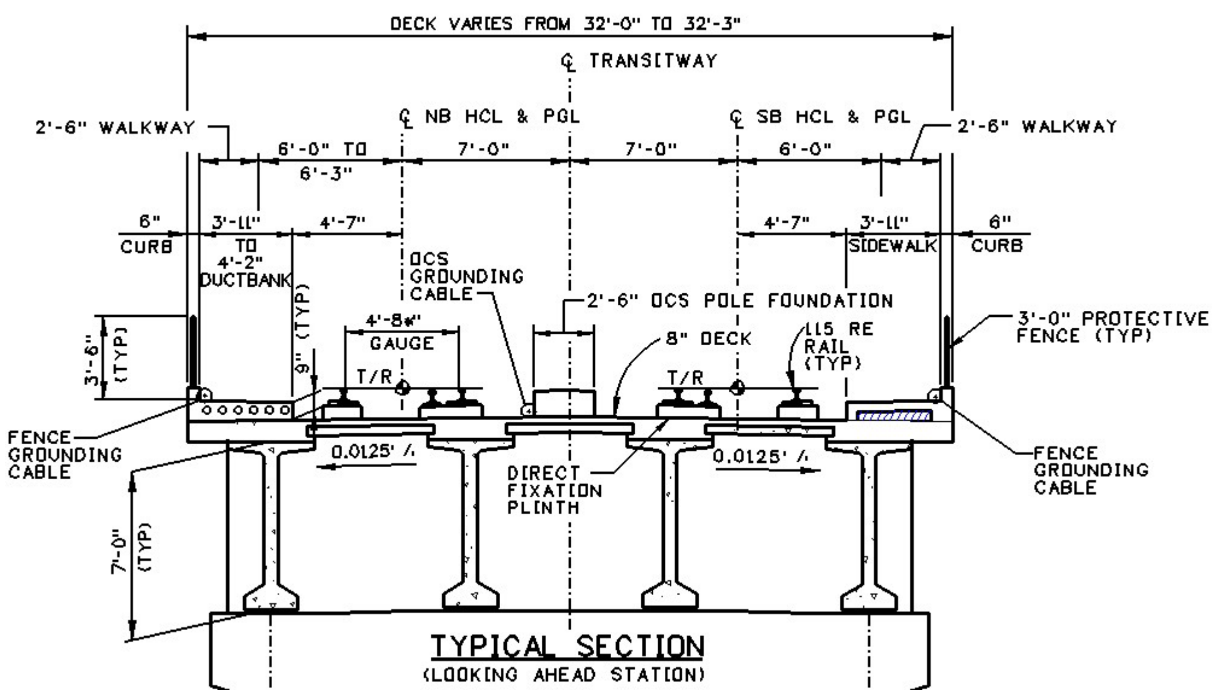

Figure 9. Non-Ballasted Bridge Typical Section

PRESTRESSED GIRDER DESIGN GUIDELINES

The design of the prestressed concrete girders followed the provisions contained with CDOT's Bridge Design Manual. Girders were designed simply supported for non-composite dead loads and continuous for composite dead and live loads. Transformed girder section properties and positive moment restraining details were specified as required to effectively utilize BT girder sections.

SUPERSTRUCTURE DESIGN DETAILS

The Segment 3 LRT Bridges incorporated various superstructure elements that were common throughout the design-build segments. Abutment transition slabs for both ballasted and non-ballasted bridges were constructed beneath the LRT track and supported by the abutment backwalls. Detailed corrosion control plans for the non-ballasted bridges were developed that required a positive connection from the bridge deck reinforcement to a grounded cable junction box. Waterproofing details for ballasted bridges specified a 3/8" twin layer of asphalt matting on a rubberized asphalt and plastic film membrane waterproofing sheet. During construction the D/B team changed the waterproofing system to a polyurethane product (See Figure 10). This system was more resistive to stray currents and could be spray applied.

Figure.10. Spray applied waterproofing system of LRT over C-470.

RAIL FIXATION FORCE

Three-dimensional finite-element analysis was used to evaluate the longitudinal and radial forces associated with the continuous welded rail "direct-fixation" temperature forces on the non-ballasted bridge decks. The flexibility associated with the single shaft pier columns and specified rail clips provided a design mechanism necessary to help reduce the direct fixation force effects on the structure. Concrete plinth construction on the bridge deck and the use of "crank-shaft" shaped reinforcement were specified for all non-ballasted structures. These crank-shaft shaped bars were placed longitudinally within the plinth and bridge deck to transfer the longitudinal and radial rail forces into the superstructure deck.

INTEGRAL MSE ABUTMENTS

Integral and semi-integral MSE abutments (See Figures 11 and 12) were specified for the Segment 3 LRT Bridges. Both types could accommodate anticipated expansion and contraction requirements through the flexibility of the steel H-piles and/or shear deformation of the elastomeric bearings. The steel piles were installed prior to the construction of the MSE panels and soil reinforcement. To minimize the bending stresses on the steel piling, the design-build team specified lateral stability parameters for the surrounding reinforced soil within the limits of the MSE fill embankment.

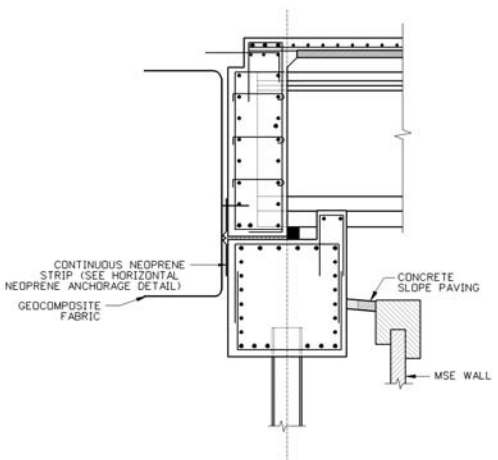

Figure 11. Semi-Integral Abutment

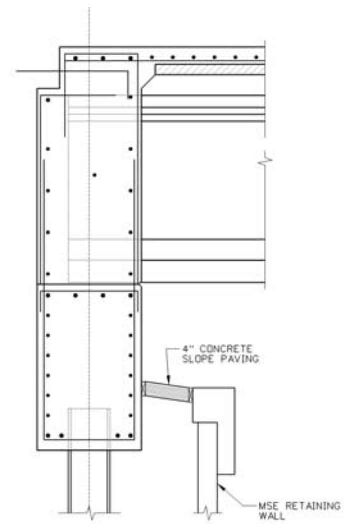

Figure 12. Integral Abutment

PIER DESIGN DETAILS

Several different pier types were utilized for the Segment 3 LRT Bridges. Hammer-head piers supported on drilled caissons were used predominately throughout this segment. Straddle bent substructures also supported on drilled caissons were specified when right-of-way, utility and/or clear-zone requirements mandated pier columns beyond the footprint of the LRT structure. Pier caps for the straddle bents were designed and detailed as post-tensioned sections with pinned connections at the column tops. Key recess locations at each column location were reinforced with spiral vertical reinforcement and filled with concrete at column tops to provide the required pin connection between the pier cap and the column. These precast bent beams (See Figures 13 and 14) were never constructed since the design-build contractor elected to cast these bent beams in place.

Figure 13. CIP straddle bent construction

Figure 14. CIP straddle bent construction

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Project constraints associated with the limited amount of lay-down area necessary for precasting operations at each bridge site, large pick weights, crane access restrictions and costs associated with the crane operations made precasting the straddle bent beams on the ground cost prohibitive.

Expansion joints were required at the Orchard Road, Arapahoe Road, and County Line Road LRT locations. These structures had lengths between 775-ft and 990-ft and required provisions to accommodate the anticipated movements and minimize longitudinal thermal forces. Strip seal and modular expansion joints were designed as required by the predicted movements. Diaphragms at expansion piers were cast to the bottom girder web location to accommodate clearance for the lateral shear keys in the piercaps.

CONCLUSION

The bridges for T-REX's Segment 3 LRT corridor required extensive planning and design efforts by the design-build team. Project site constraints associated with right-of-way requirements, utility coordination, and traffic control impacts mandated the use of precast construction and design details that addressed constructability concerns. The information contained within this paper summarizes the materials and construction practices employed while providing effective solutions for the Segment 3 LRT Bridges.

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