DENVER UNION STATION: PRECAST BRIDGE CONSTRUCTION FOR AN UNDERGROUND REGIONAL TRANSIT TERMINAL

David Holst, PE, AECOM, Denver, CO
Raymon Nickle, PE, AECOM, Denver, CO

ABSTRACT

The Denver Union Station Redevelopment Project represents a unique use of precast-prestressed bridge construction methods for an underground bus terminal to support regional multimodal transportation.

The underground transit hub combines bus, light rail, commuter rail, heavy rail (AMTRAK), and pedestrian transit with a 1,100 foot long by 150 foot wide underground space with above ground rail access and pedestrian pavilions. The 150 foot width is separated into three, 45 foot wide bays that are continuous along the length of the structure. The bottom of the terminal rests 30 feet below final grade and soil overburdens are in excess of 5 feet.

The project utilizes precast-prestressed concrete bridge construction methods to accelerate construction and realize efficiency savings associated with the scale of the underground structure. Precast-prestressed spread box girders, bulb tee girders, U girders and double tee are all utilized in different areas of the underground terminal, and composite deck slabs are cast on precast-prestressed partial depth deck panels. Additionally, precast-prestressed bent caps with temporary post-tensioning are utilized along the center of the terminal to support the structural spans and provide open access between the terminal bays.

Keywords: Bridge superstructure, Prestressed concrete, Deck panel, Composite construction

INTRODUCTION

Deep below 17th street in the heart of Denver, Colorado rests the unexpected. A 1,100 foot long underground bus terminal recently constructed and perfectly integrated into the surroundings. The evidence is there, massive skylights along the center of pedestrian plazas, closed structures with stairs and elevators that simply disappear into the ground. This is the new Denver Union Station, no longer an open field and an old building with an orange neon sign. Denver Union Station is the new heart of transportation in Denver, where rail will live again and where 200,000 people a day will pass through to get to work, to the airport and to see those who matter the most.

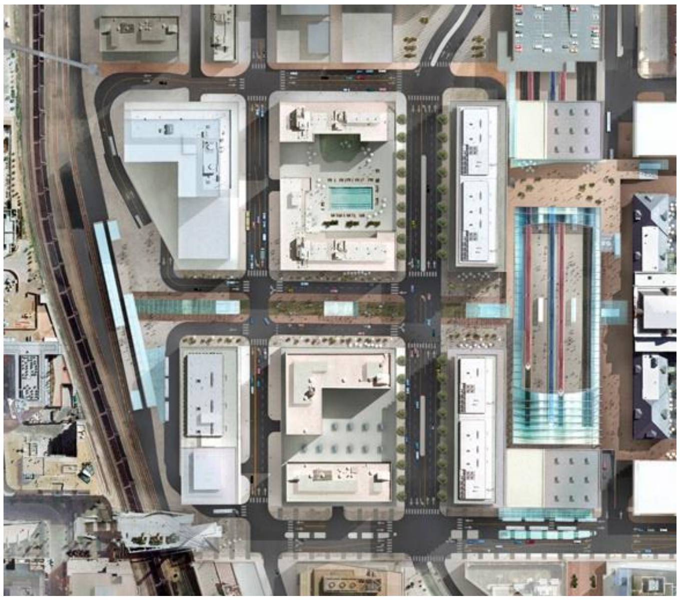

Figure 1: Proposed Site Plan for the Denver Union Station Redevelopment Transit Facility (North is Up).

The underground bus terminal, a major piece of the Denver Union Station (DUS) redevelopment project, exhibits a rare opportunity to combine the efficiencies from both bridge and building structural systems into one project. The project utilizes precast concrete bridge construction methods to accelerate construction and realize efficiency savings associated with the scale of the underground structure. Precast spread box girders, bulb tee girders, U girders and double tees are all utilized in different areas of the underground terminal, and composite deck slabs are cast on precast-prestressed partial depth deck panels. Additionally, precast-prestressed bent caps with temporary post-tensioning and architectural precast concrete helped ensure a beautiful, yet robust structure with lasting durability.

SITE HISTORY

June 1881, the first Union Station building was opened, reflecting a dream to put Denver on the map by providing a major centralized train station. By the 1920s, DUS saw as many as 80 trains a day and continued to be the major transportation hub in Denver until the mid-1950s. By 1958, air travel had surpassed train travel and the Union Station found itself on the decline.

Figure 2: Historic Denver Union Station Rail Yard (North is Up)

Rail transit continued its decline in the Denver area through the 1990s, and it was not until the introduction of the Light Rail, by Denver's Regional Transportation District (RTD), that the station saw new light. In 2002, a team of stakeholders including RTD, Colorado Department of Transportation (CDOT), the Denver Council of Regional Governments, and the City and County of Denver (CCD) began work on an Environmental Impact Statement (EIS) for the redevelopment of DUS, and RTD made arrangements to purchase the historic site. By 2009 the EIS was finalized and redevelopment of the site was approved, with the signing of the Union Station Record of Decision by the Federal Transit Administration.

PROJECT PURPOSE

The purpose of the DUS project is to provide a full use multimodal transportation hub, allowing for public access of public and private transportation methods all in one location. The transit hub will combine local and regional bus services, AMTRAK train service, regional light rail and commuter rail access. The improvements are expected to help alleviate traffic congestion, reduce air pollution, and provide increased mobility to the traveling public.

Figure 3: Train Hall Canopies during platform construction.

PROJECT STRUCTURE

The Denver Union Station Project Authority (DUSPA) was established in July 2008 to manage and implement a program of:

1. Transportation improvements for light rail, commuter rail, regional bus facilities, and intercity rail service,
2. Intermodal connections/public improvements (plazas, open space, pedestrian connections),
3. Renovation of Denver's historic, downtown train station, and
4. Economic redevelopment within the central downtown.

Under DUSPA, Kiewit/AECOM was selected to design and construct the new transportation facility. Design Notice to Proceed occurred in the fall of 2009 with the approval of the 30% documents and associated contractor's estimate. Design was estimated to be approximately 18 months. Construction NTP was received in May of 2010 with an estimated duration of 4 years.

PROJECT FINANCING

The project finance plan represented the results of a collaborative effort among four major governmental entities in Colorado, specifically:

- The City and County of Denver,
- The Regional Transportation District,
- The Colorado Department of Transportation, and
- The Denver Regional Council of Governments.

All four have been and remain active members in the development of this project through their continued membership in the DUSPA and their financial contributions to the project. DUSPA is the successor entity to an organization originally formed pursuant to an intergovernmental agreement among these four entities in 2001 which established an Executive Oversight Committee (EOC). Since that time they have worked together to develop a master plan and finance plan. The Master Plan envisions significant upgrades to the region's rail and bus transportation networks with the Denver Union Station (DUS) as the centerpiece.

The products of these efforts to date are a mutually agreeable governance mechanism, a master development plan, identified funding sources and the acquisition of the subject property. Each of the participating agencies supports this effort as one which will result in substantial improvements pertaining to regional and statewide transportation, air quality and urban development.

STRUCTURE DESIGN

While the station was always intended as a transportation project, in construction and design the project more closely resembled that of a building. With elevators, escalators, full skylights, integrated bathroom facilities, heating and cooling systems, as well as extensive ventilation and safety systems, utility coordination and full architectural integration would become imperative to the project's success. Precast concrete elements were used to aid in the integration of all disciplines required to successfully design and construct the project.

SITE LAYOUT AND STRUCTURAL SYSTEM

The total redevelopment of DUS, including private investments, covers nearly 19.5 acres, and the main transportation station is expected to handle in excess of 200,000 trips per day once the system is built out. The station portion of the project can be separated into 3 major areas; the Light Rail Transit station (LRT), the Commuter Rail Transit station (CRT), and the Bus Terminal (Figure 4).

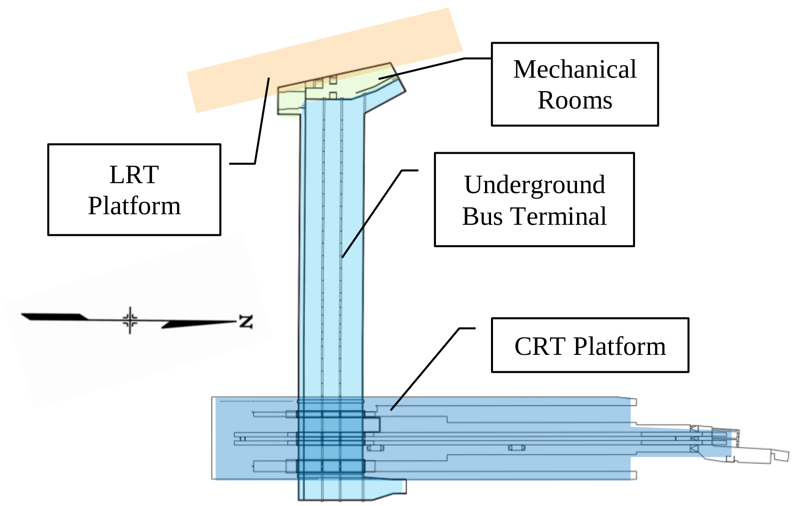

Figure 4: Denver Union Station Transit Site Plan

Above grade on the western most section of the underground bus terminal is the LRT station. The station consists of two light rail tracks and supporting pedestrian platforms, canopies and plazas. The LRT plazas house three large, precast concrete ventilation towers that handle all intake and exhaust to the underground facility. Additionally, large tear drop shaped planters, made up of precast segments, discretely divide the pedestrian areas and help to channel walking traffic between the LRT and Bus Facility (Figure 5).

Figure 5: Light Rail Plaza, Tear drop planters in the foreground and LRT canopies in the background.

Figure 6: Aerial View of the CRT Terminal (Looking North)

1100 feet away, at the eastern most end of the underground bus terminal, directly behind the historic Denver Union Station, is the CRT station. The CRT station runs perpendicular to the underground facility, and houses rail tracks for AMTRAK, SKI Train and RTD's Commuter Rail train system, which will ultimately consist of six additional train lines, including lines to Denver International Airport. The CRT platform area is approximately 1000 feet long and 200 feet wide. Over the bus terminal it is supported by precast concrete elements and outside of the bus terminal limits it is constructed on single level precast mechanically stabilized earth (MSE) retaining walls to the north of the underground terminal. Five rail lines cross over the underground terminal and are terminated on the south side of the bus station. The CRT platforms are protected by iconic steel arch trusses which provide protection from the sun and maintain corridor visibility (Figure 6). Access is provided to the platform by a pair of stairs in the middle of the station as well as stairs, elevators and escalators at the DUS pavilion, directly behind the station.

Figure 7: Partial Section of the Underground Bus Terminal.

The underground bus terminal consists of a 1,100 foot long by 150 foot wide underground bus station that rests 30 feet below grade. The facility allows for covered access to, and transfers between, the LRT, CRT and bus areas. The underground structure supports surface roads, pedestrian plazas, and community spaces; at the shallowest locations, a maximum of 6 feet of soil overburden exists, and at the CRT end of the box, pedestrian platforms are constructed directly over the top of the underground terminal. The underground space is built predominately of structural concrete, and is divided into four bays, three 45 foot bays house bus lanes and pedestrian areas, and an additional 15 foot wide ventilation plenum runs along the south side of the structure. Bus access to the underground terminal is provided via bus ramps on the east and west ends of the facility, and pedestrian access at stair, elevators, and escalators at five key locations distributed along the length of the bus terminal.

CONSTRUCTION STAGING

In order to maintain active light rail access and a minimum of one accessible city street through the project site, the bus terminal construction required staging. The existing LRT station was located directly behind the historic Denver Union Station, in the future location of the CRT terminal. In order to minimize ridership delays, construction on the planned LRT station needed to be completed to allow a seamless closure of the existing LRT station, and so that demolition could begin and construction could commence on the east end of the bus terminal. The planned LRT station was supported partially by the bus terminal roof system for the mechanical suits; therefore, the west end of the project was excavated first, and bus terminal construction commenced from the west towards the east.

Several city streets crossed the project site. It was a requirement of the City and County of Denver to maintain at least one north/south through street during construction. Wewatta Street is the eastern most cross street and Chestnut Place is the western most. To facilitate construction from west to east, Wewatta was maintained during the first phase of bus terminal and LRT construction. This allowed the underground bus terminal to be fully constructed, waterproofed and backfilled, as well as Chestnut Street to be constructed over the new bus terminal.

Figure 8: First stage construction. North is to the top right, the new LRT station is to the upper left and the existing LRT station is at the bottom right.

With the western portion of the box constructed and backfilled, the LRT switch was performed, on time, and demolition of the existing at grade LRT and AMTRAK train stations commenced. Traffic was switched to Chestnut Place and the existing Wewatta Street was demolished and bus terminal construction progressed to the east.

Figure 9: DUS shoring wall in the background, Rail bridge foundation construction in the foreground.

At the east end, adjacent to the historic station, an extensive shotcrete tieback shoring wall was required to support the historic station. Due to the historical significance of the existing structure, minimizing construction and long term impacts to the station was imperative. Final excavation and shoring wall construction progressed simultaneously until the shoring wall reached its final height of 24 feet and bus terminal construction could progress up to the shotcrete facing.

Figure 10: Second stage construction, North is to the Top Left, the historic station can be seen to the right.

Figure 11: Final Stage construction near completion, with fully erected CRT canopies.

FOUNDATIONS AND SUBSTRUCTURE

Foundations utilized on the project consisted of multiple types. Drilled shaft, spread footing, micro-pile and soil and rock tie backs were all utilized in various locations. The underground bus terminal is supported predominantly by a reinforced concrete floating slab foundation, referred to as the base slab. The base slab consisted of a 4 foot thick reinforced concrete footing that transitioned into a 3 foot thick slab in areas not subject to bus wheel loading. The thickness allowed the slab to resist loading from applied lateral soil loads and surcharges, axial loads from the superstructure and soil overburden, as well as vehicular loading both at grade and directly upon the base slab. Additionally, the thickness was required to ensure the structure had sufficient mass to resist potential buoyant forces applied by the presence of ground water. Typical exterior walls, interior walls and intermediate columns were cast-in-place and framed into the base slab and provided full support for the precast superstructure.

Figure 12: Cast in place wall construction, exterior wall shown with forms in the back-ground.

Figure 13: Cast-in-place column with steel corbels.

At the CRT platform, five rail lines cross over the underground bus terminal. Due to the heavy rail loading, a cooper E-80 for AMTRAK and an E-50 equivalent for RTD Commuter lines, the design team opted to isolate these bridges from the base slab by utilizing drilled caisson foundations, and independent abutments and multi-column substructures. This isolation required a gap between base slab and drilled caisson, which presented a unique detailing issue and potential fatal flaw in the waterproofing system. Therefore, redundant waterproofing systems were installed that allowed for differential movement over the life of the structure.

What was unique about the east end of the project was the integration of the Train Hall Canopies over the CRT Platforms. The train hall was a tube steel arch structure supported on deep foundations. The deep foundations required post-tensioned rock anchor tie backs to allow for future construction of the surrounding building sites. The tie backs replaced the support typically generated by the passive pressure of the soil, which would be removed during adjacent building excavation.

BUS TERMINAL STRUCTURE

The underground bus terminal structural elements consist primarily of concrete. Concrete is an effective material for many reasons, but can often prove costly and time consuming, when skilled labor is required to build the forms and when cure times and quality control delay construction progress. As part of the design-build process, the contractor and designer are always looking for ways to save time and money, without sacrificing quality. Accelerated precast construction is one of the ways proposed by the design-builder to reduce cost and shorten schedule activity durations.

Three separate girder types are used to form the majority of the bus terminal roof system, precast prestressed bent caps were utilized to support the superstructure system, and the top deck was formed using partial depth precast prestressed deck panels. Additional precast mildly-reinforced beams are used for framing openings throughout the project, primarily at skylights, elevators and stair openings.

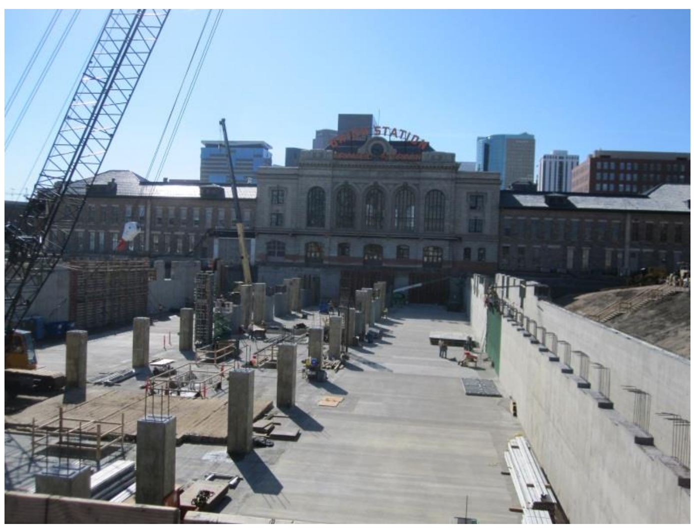

Figure 14: Final Stage construction prior to setting precast, looking east at this Historic Station.

Supported by the interior precast caps and exterior CIP walls, the terminal roof system consists of a combination of precast elements: box beams, double tee beams and precast deck panels. The roof system is approximately 150 feet by 1,100 feet (165,000sf). Precast elements helped facilitate the roof construction and provided the necessary capacity to support construction loading and the soil overburden planned for the pedestrian plaza area above. Box beams were used predominantly over the main bus terminal footprint and double tee beams were used over the mechanical areas. Precast panels were used throughout the box beam sections to complete the roof deck system.

In total, over 400 major precast elements make up the underground terminal roof system, which include 60 bent caps, 261 box girders and 35 double tee girders, and over 100,000 square feet of partial depth precast prestressed deck panels. The entire structure was then wrapped in waterproofing to provide a complete system capable of withstanding a 75 year design life, consistent with AASHTO bridge requirements.

Precast Bent Caps

Accelerated precast construction was investigated to replace the cast-in place (CIP) concrete bent caps with precast units. Using precast elements removed pier cap construction from the construction critical path by eliminating the need to tie reinforcing cages, build forms, and allow cure time to occur on site.

Figure 15: In place precast bent cap at the CRT platforms, final placement shown on cast-in-place columns.

The originally proposed CIP bent caps were detailed to be continuous over several column supports to increase effectiveness and a fixed connection at the column to cap interface was preferred. In order to facilitate precast construction the column to cap connection detail required revision, a pin connection was utilized to simplify setting the precast element. Thus, the precast cap sections were re-designed as simple span units and voids were detailed to accept the pin/key detail at the top of column. The simple span design reduced some effectiveness and required additional prestressing, but ultimately the construction schedule time savings proved worthwhile and saved the project months.

Figure 16: Erection of the first precast bent cap, looking east the historic DUS and Denver skyline in the back ground.

Due to the high demand imposed by soil overburdens in excess of six feet, it was not possible to prestress the short simple span bent caps in such a way that internal stresses were controlled in throughout the construction process. Traditional methods for stress control, harping and debonding, did not prove effective, so specialty options had to be considered. Temporary post-tensioning, in the form of end bearing mono-strand was utilized. Mono-strand was cast into the section and carefully aligned so that each mono-strand ran through block-outs on the top exterior corner of the bent cap. This allowed the bent caps to be set adjacent (end to end) to one another along the length of the terminal, girders and the bus terminal roof to be constructed, and the temporary prestressing quickly released and abandoned in place prior to allowing live loads on the structure.

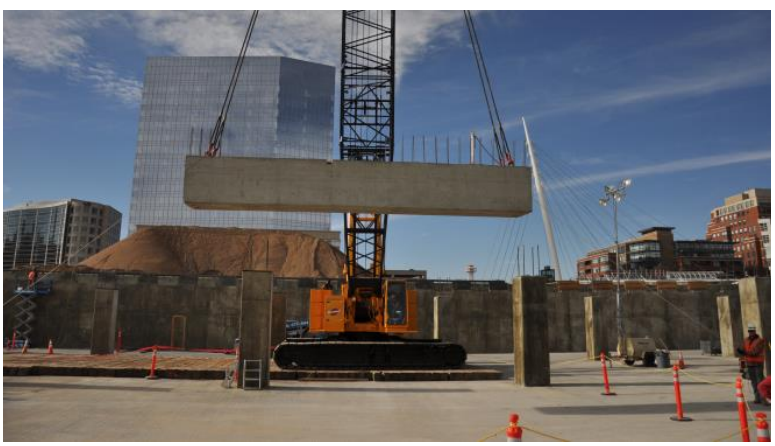

Figure 17: Erection of the first precast bent cap, looking south Millennium Bridge can be seen to the right of the cap.

The precast bent caps formed the interior pier lines within the underground structure and supported the precast box girders which made up the majority of the roof system. The typical project bent cap was approximately 30 feet long and had a square 48 inch cross section. The bent caps were prestressed using 0.6” strands, and mildly reinforced for shear and splitting forces. A total of 1,500 linear feet of precast bent caps were used, a total of 60 precast segments.

Figure 18: Bent cap erection staging, DUS can be seen in the background (Looking East).

Precast Girders

Three separate types of precast girders made of up the majority of the underground bus terminal roof systems. These girder sections consisted of double tees, box girders and tub girders.

42 inch deep precast prestressed double tee girders were utilized in maintenance and mechanicals rooms on the west and north ends of the underground terminal. The double tees were installed as simple spans, and utilized only in locations where cover and vehicle accessibility was limited in order to ensure design capacity of the sections. Double tee girders were set side-by-side to allow for a quick composite deck pour and to ensure worker safety and accessibility. Spans ranged from 21 feet, to as long as 65 feet, and in order to accommodate the angular geometry many of the units were cast with tapered top flanges and at varying angles. In total, 2,000 linear feet of precast double tees were used, totaling 35 pieces.

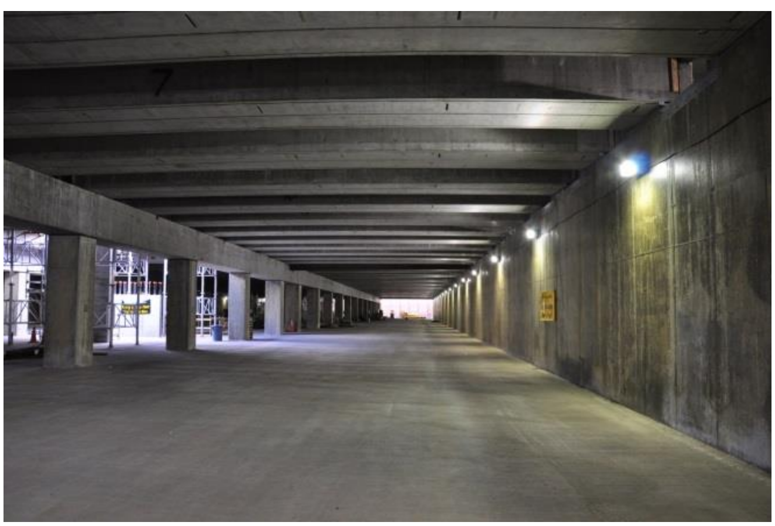

Figure 19: Bus lane inside of fully enclosed bus terminal, precast box girders can been seen above, precast bent caps to the left and cast-in-place walls on the right.

The majority of the underground terminal was constructed using precast prestressed spread box girders. A total of 260 box girders were used on the project, resulting in just over 12,150 linear feet. A standard shape, 60 inches wide by 30 inches deep with 6 inch walls, was used throughout the project. Generally, the girders were spaced at 10 foot on center, designed as simple spans, and set directly on top of cast-in-place stem walls or precast bent caps. Span ranges were from 15 feet over the bus entrance and exit to 68 feet in the mechanical rooms.

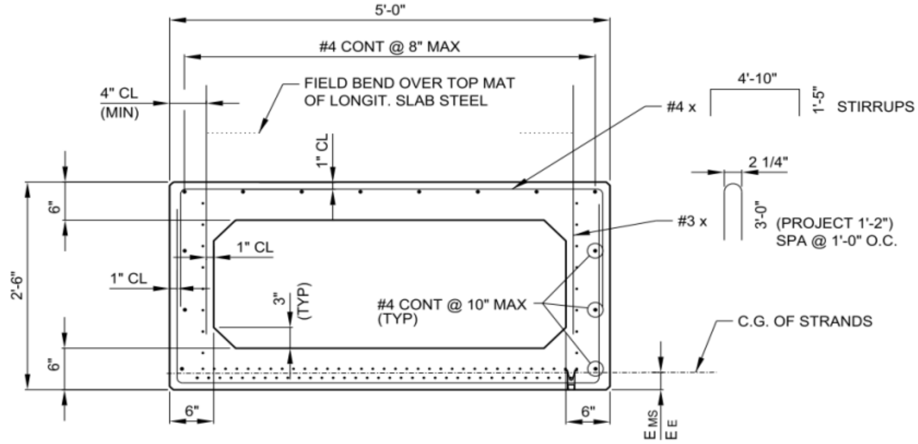

Figure 20: Typical project Box Girder

Unistrut C-channel inserts were provided along the corners of all girders to provide locations to attach utilities, and minimize post installed attachment to the precast elements. Additionally, the space between adjacent girders was sealed off with sheet metal, attached to the Unistrut to create continuous ventilation ducts designed to ventilate and exhaust bus emissions to and from the facility (Figure 21 and 22). Within the underground terminal, light gauge framing and drywall finishes were also attached to the unistrut.

Figure 21: Unistrut inserts on box girders, formed ventilation ducts can be seen between girders.

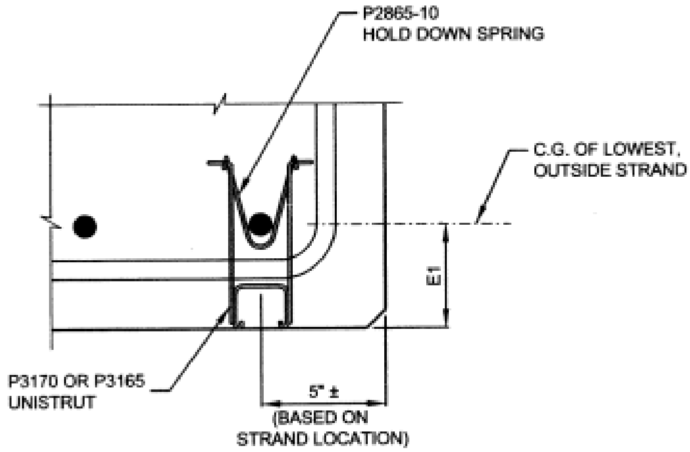

Figure 22: Unistrut inserts in all precast beams

In addition to the box girders, tub girders were used to isolate wet utilities from the water tight underground structure. Tub girders were used to create step downs in the top of the deck, where the large diameter utility could be recessed, accessed from above for maintenance, and remain outside of the enclosed space (Figure 23). These tub girders trenches where integrated into the underground terminal roof system by using special detailing to connect precast deck panels and the CIP roof slab to the girder top flanges and allow for waterproofing to be continuously applied along the inside face of the girder section.

Figure 23: Tub Girder utility trench with deck formwork to the left and right.

Precast Deck System

All precast girders on the project were designed to take advantage of composite construction. A composite 8 inch deck slab formed the top of the bus terminal roof system. In order to speed construction of the 165,000 square foot roof system, partial depth precast-prestressed deck panels were utilized. Precast deck panels were placed on foam pads and sealed against the box girders, tub girders, or walls and a cast-in-place slab was then cast continuously over the entire roof. The panels were cast with a roughened top surface which allowed them to become composite with the CIP portion of the slab without the need for projected reinforcing.

Figure 24: Precast box girders with partial depth precast-prestressed deck panels.

The typical deck panels were 8 feet long by 3 inches deep, with widths of approximately 6 feet. Along the length of the ventilation plenum, a 5 inch deep by 13 foot 6 inch panels spanned across the entire opening to create the roof, and was cast with a 5 inch topping slab creating a composite slab bridge, eliminating the need for additional framing in the area. In the CRT area of the bus terminal, the use of precast panels was limited and isolated locations needed to be fully formed on false work or placed on stay-in-place steel forms. Varying girder spacing, girder types, as well as architectural integration required many special case details.

Figure 25: Construction Cross section showing precast panels on Box Girders, with a portion of cast deck beyond.

COMMUTER RAIL AND AMTRAK BRIDGES

A total of five rail lines cross over the underground bus terminal in the CRT area. These five lines are carried by three separate bridges all supported by CDOT standard BT girders. The three bridges posed many design challenges for the design team, specifically limited access for maintenance after construction, overhead clearance within the underground bus terminal, isolation from the bus terminal, and waterproofing.

In order to address future maintenance of the bridges it was determined that the structures would be designed as simple span-made-continuous with integral abutments. Simple span-made-continuous offers the complete elimination of bearings at intermediate piers and also offers the advantage of a continuous girder which helps to minimize structure depth, but does require special considerations during design and heavier reinforcement in the bridge deck. Similarly, integral abutments eliminate the need for bearings and allow for the full structure to be buried outside of the limits of the bus terminal. Additional considerations to limit the over-all structure depth and maintain clearance within the bus terminal included side-by-side girders and direct fixation at the commuter rail lines.

Figure 26: CRT train bridge for a single track, with clipped BT girder in place.

Figure 27: AMTRAK train bridges with full BT girder, CRT bridge can be seen beyond.

The bridges were completely isolated from the bus terminal to eliminate concerns of differential movement due to the heavier live loads. Drilled caissons supported independent columns which penetrated through the bus terminal base slab. Additionally, wall type abutments were built outside of the bus terminal walls and sealed to limit water infiltration. Live load deflections required that the bridge be separated from the platform slabs above grade which lead to additional joint detailing and flashing details. Waterproofing was addressed by providing a redundant system at the base slab that was completely replaceable at the interior and spray on waterproofing membranes applied to the top of the bridge decks.

Commuter Rail Bridges

Two commuter rail bridges were constructed over the underground bus terminal, one bridge supported two tracks and the other supported a single track structure. The bridges were designed to AREMA standards using a Cooper E50 loading to allow for CRT vehicles which had yet to be selected by RTD at the time of design. Three tightly spaced clipped CDOT BT-42 girders were used under each track and a cast-in-place composite slab completed the deck. Clipped BT-42 girders closely resemble an I-girder and are produced by blocking out the girder top flange to match the width of the bottom flange. While not as efficient as a standard BT shape, the section allows for tight girder spacing which was required to minimize structure depth. Due to the additional reinforcement requirements of the direct fixation plinths and tight girder spacing, precast deck panels were not used on these structures.

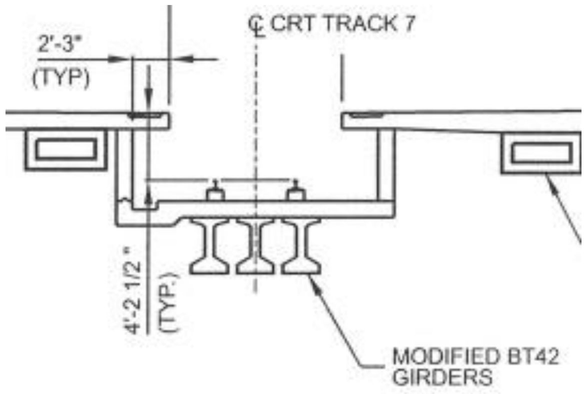

Figure 28: Single CRT Bridge, with BT42 Girders

AMTRAK Rail Bridges

A two track heavy rail bridge was constructed over the underground bus terminal to support AMTRAK operations. The bridge was designed to AREMA standards using a Cooper E80 loading and was checked as two independent superstructures with a service access platform spanning between the two tracks. Three tightly spaced CDOT BT-63 girders were used under each track and a cast-in-place composite slab completed the deck. Due to the tight girder spacing, precast deck panels were not used on this structure.

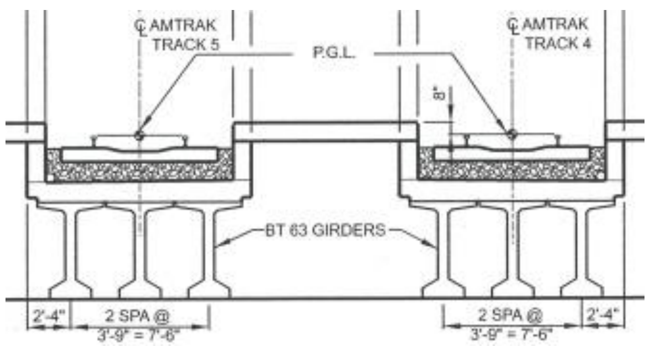

Figure 29: AMTRAK bridge with Adjacent BT 63 Girders

CRT PASSENGER PLATFORMS AND PLATFORM WALLS

CRT passenger platforms are constructed similarly to the rest of the underground bus terminal. However, due to the elimination of the large soil overburdens and vehicular loading, significantly larger girder spacing was possible. Two precast prestressed box girders were utilized for 39 foot wide platforms which allowed for intermediate framing between the girder to provide space for stairs, elevators, and large cast-in-place diaphragms which supported overhead canopies. A 12 inch composite deck, cast on precast panels between girders was used for the pedestrian platform surface. The structural slab was protected by a waterproofing membrane and 3 inch of lightweight topping concrete.

To the north of the underground terminal, nearly 900 feet of platform was constructed that has the ability to service 8 trains simultaneously. Platform stem walls were built using precast MSE panels that were ultimately framed into the platform slab. Over 6,300 linear feet of precast panels were used, with heights ranging from 4 feet minimum to a maximum of 8 feet. The use of precast panels allowed the contractor to eliminate wall footings or the need to place false work into the track lanes, which allowed for wall and track bed construction to progress simultaneously, significantly speeding platform construction.

ARCHITECTURAL PRECAST CONCRETE

While structural precast concrete was a major part of the underground structure, architectural precast concrete was used heavily in above ground plaza areas. Integration of form, function and durability made concrete the ideal choice for use in architecturally designed vent towers and planter segments. Architectural concrete posed a significant challenge to the bus station design team as setting the elements would require cranes to be used directly on top of bus terminal roof. Special design checks for strength, and careful survey control of outrigger locations had to be put into place for each crane pick location.

Figure 30: Precast Vent Tower during Erection

Figure 31: Precast vent towers at the precast plant after casting.

Figure 32: Precast vent towers at completed LRT station, looking north-east.

The precast vent towers stand almost 20 feet above the LRT station plazas and range from 12 feet to 20 feet in diameter. The towers are architecturally integrated into the surroundings by adjusting angles and shapes to complement the nearby building and pedestrian bridges. Three vent towers were placed, each consisting of six precast segments that were connected by welded connections on site. Precast planters, were segmented and set into place to form large tear drop shapes. The planters provided much needed greenery to the concrete landscape, but also provided seating areas and helped to channel pedestrian traffic between the LRT and Bus Terminal.

PROJECT PROGRESS

To date the project progress has been excellent with the design-construct team hitting all major deadlines. Budget and schedule successes are largely due to the efficient use of precast concrete elements. The facility celebrated its grand opening on May 9th, 2014, which is almost exactly 4 years after construction began. Other notable dates are listed below:

1. AMTRAK cutover – February 1st, 2011 (To Temporary Station)
2. LRT Opening Day – April 26th, 2012
3. AMTRAK Opening Day – February 27th, 2014
4. Underground Bus Terminal and CRT opening – May 9th, 2014
5. Historic Building Renovation – expected in summer of 2014

CONCLUSIONS

The application of accelerated bridge construction methods using precast-prestressed concrete allowed for the successful completion of the Denver Union Station Project. The complexity of the Denver Union Station project allowed for the use of standard forms of bridge and building precast concrete, including bulb tee girders, box girders, MSE panel walls, bent caps, as well as the unique use of precast concrete for architectural designs as with the precast vent towers. As the project fully opens to the public and RTD continues to expand their transportation offering, Denver Union Station will once again become the center of transportation within the Denver-Metro Area.

Figure 33: Completed CRT canopies fully lit at night.