Design and Construction of the Second Street Bridge and Transit Center, Cincinnati, Ohio

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1. BRIDGE DESIGN REQUIREMENTS

The Second Street Bridge was constructed as a part of the I-71 Ft Washington Way reconstruction project. The bridge responded to a number of unique design requirements.

From an urban design perspective, the Second Street Bridge was a key element of the I-71 Ft Washington Way (FWW) reconstruction project and the City of Cincinnati's plan to connect downtown with the sports complex and the Ohio River waterfront. Prior to the FWW project, I-71 was located in a depressed section, and created a physical barrier between the business district and the river. One of the main goals of the FWW reconstruction was the extension of the existing north-south downtown street system to the waterfront across I-71, and the reclamation of waterfront areas. Second Street is the southern boundary of the FWW project, and a significant element in the overall plan (See Figure 1).

Fig. 1 – FWW I-71 Reconstruction Second Street Bridge on Far Side of Depressed Highway Section

It was originally envisioned that Second Street would be located on grade, directly adjacent to the floodwall that protects I-71 from the Ohio River. This decision was revisited during the development of the Ft Washington Way project, when it was decided to place Second Street on structure for a four-block 2,070 foot long section. The space beneath the Second Street bridge, being grade separated from the street grid and directly adjacent to the downtown core, became a critical east-west corridor for current and proposed transit systems and the location for an intermodal transit plaza (See Figure 2). In addition, the close proximity to the new sports complex consisting of Paul Brown Stadium, Cinergy Field, the new Reds Ballpark, and Firstar Center

Transit Center beneath street level and commercial development to the south side.

made the space beneath the bridge a staging area for transport to sporting and other major waterfront events. As an indicator of the anticipated volume of traffic at the transit plaza, it is anticipated that 90,000 people could use the facility for transportation to sporting events. While the space beneath the bridge is being developed as a regional bus center, current plans envision a potential future conversion to an intercity rail line station under Second Street.

Fig. 3 – Rendered split section of Second Street showing LRT at street level with transit center on lower level.

Design elements that emphasized the connection of the city with the waterfront were incorporated into the Fort Washington Way project design. These included an urban forest, an enhanced architectural character of the street fixtures and furniture, and use of distinctive finishes, colors, and textures between Second and Third Streets (See Figures 3 and 4). Visually, the bridge deck surface resembles a major downtown street with a distinctive architectural character. As a result, the deck and superstructure contained many complex details not typically encountered on the most bridges. In addition to being a local street, Second Street is a collector distributor road on the south side of the depressed I-71 main line. Traffic entering downtown from the I-75 and I-71 northbound, and exiting downtown onto I-71 northbound use the five lanes on the Second Street deck. Ramp structures, located at each end of Second Street bridge, complete these connections.

Fig. 4 – FWW depressed section. Second Street Bridge in foreground.

Multistory commercial development, museums, parking and other uses, including the National Underground Railroad Freedom Center, were planned directly adjacent to the south side of Second Street, and their primary access point was at the Second Street bridge deck level. However, the column locations and loads for planned buildings were unknown at the time of the Second Street Bridge design. The Second Street bridge columns were positioned to not preclude future column placement for the adjacent development, allow for transit center operations beneath the bridge, and be structurally independent of adjacent planned buildings and elevated streets (See Figure

5). As a result, the column lines were located approximately 13 feet from the edges of the bridge deck.

On most projects, bridge aesthetics addresses the distinct forms and features of a bridge when seen in the landscape. In the case of Second Street, the bridge was deliberately designed to be invisible as possible. The urban design concept required the top surface of the bridge deck to blend into the surrounding streetscape and have no distinct identity as a bridge. The microsilica deck overlay was colored black to simulate the asphalt used adjacent streets and brick pavers were placed in the deck, and camouflaged the structure. Unlike most bridge projects, the primary aesthetic feature of the Second Street Bridge was the form and finish of the superstructure, the ceiling for the transit center (See Figure 6).

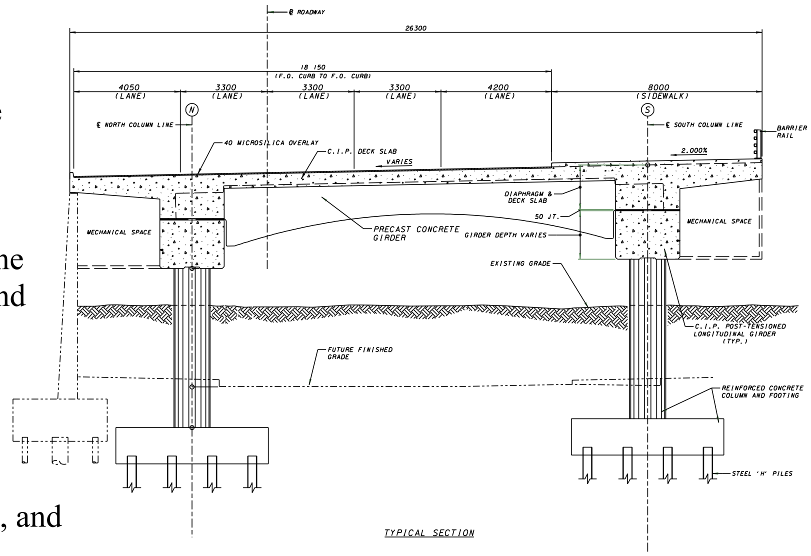


Fig. 5 – Cross section of Second Street Bridge.

In addition to aesthetics, the design of the bridge superstructure considered incorporation of mechanical ventilation systems, life safety systems, and vertical circulation (elevators and stairwells) to the street level. Since the transit center below the bridge deck would be functioning on a permanent basis, the design of the bridge deck needed to be durable. In the extreme event that localized replacement of the deck was required, the design needed to allow this to occur with minimum disruption to the transit operations.

The Preliminary Engineering study for a Cincinnati light rail system identified elevated Second Street as a promising alignment for a light rail line. While the specific geometrics of the light rail line alignment were not identified in the study, the bridge design needed to proceed and incorporate provisions for both highway and two tracks of light rail. Since the position of the rail line was not known at the time of bridge design, it was decided to design the Second Street superstructure for installation of light rail anywhere on the deck. In addition, the bridge deck details needed to be able to allow for installation of rails flush with the street level after the bridge construction was completed. Project-specific bridge deck details were developed.

Fig. 6 – View of superstructure during construction

From a cost perspective, the Second Street Bridge needed to be constructed within a limited budget. Placing the street on a 178,00 square foot on structure rather than on embankment required a cost effective structural system that could respond to multiple project requirements. The structure needed to be as repetitive as possible in order to take advantage of economies of scale for both design and construction. Prefabrication of bridge components to the maximum extent possible was seen as advantageous since the site was very congested and other contractors were working in close proximity. The bid price of approximately $90 / sf compared well with other types of conventional bridge construction in the Cincinnati market, and confirmed the validity of this approach.

From a schedule perspective, the construction schedules for both the adjacent Paul Brown Stadium and the Ft Washington Way contracts required a completion date of August of 2000. The decision to change Second Street to a structure was made in early 1999. This resulted in a very limited time window to complete the design, obtain bids, and complete construction. Standardization and prefabrication of components assisted in meeting this extremely tight project schedule.

2. STRUCTURAL SCHEME

Both concrete and steel structural schemes were investigated for the Second Street Bridge. Concrete was primarily chosen for the following reasons:

- Speed of construction. The limited construction schedule did not allow sufficient time for fabrication of a steel superstructure. Local precasters had demonstrated that they could deliver the required quality and quantity of precast sections within the available schedule.
- Lower relative cost of concrete bridges as demonstrated by previous contracts bid on the FWW project.
- Fire resistance for a critical elevated street and potential high occupancy station area. No visually objectionable fireproofing was required for a concrete bridge superstructure.
- Adaptability and robustness of a concrete superstucture to accommodate future light rail installation.
- Concrete best met the architectural requirements of the Transit Center

The selected three-bay structural scheme consisted of two longitudinal post-tensioned concrete girders with a center-to-center dimension of 56.7 feet. Transverse precast concrete floorbeams transversely spanned the center bay between the longitudinal girders. The outer bays were constructed with post-tensioned concrete cantilever slabs.

The 2070 foot long bridge structure was divided into nine concrete frames with expansion joints located at each joint between the frames. The frame length was established as a function of: the existing street grid dimensions; thermal, creep and other superstructure movements; and the overall objective of standardizing the frame construction details to the maximum extent possible. Two general types of frames were defined: four "block" units and five "intersection" units. Bus dimensions and other station requirements determined the typical 70-foot longitudinal column spacing within

Fig. 7 – Post tensioning bridge plates at end of longitudinal girder frame blockout.

the frames. Standardization also provided for a fast track design to meet the demanding design schedule.

Column and footing reinforcing was standardized into a minimum number of types. All column cage lengths were made to a constant length to allow for prefabrication of reinforcing bar cages, and simplicity and interchangeability from the contractor's perspective. Circular columns were used to provide for simplicity in formwork and to fit into the overall architectural concept for the transit center.

Since the longitudinal girders supported the transverse framing on a 70 foot typical longitudinal bay, they were post-tensioned. The post-tensioning was stressed from end to end of each frame. Short reinforced concrete "blockout" portions were provided within frames to allow for stressing jack clearances and provide the contractor with maximum flexibility in stressing of the frames (See Figure 7).

During design, brief consideration was given to long-line precasting the longitudinal girders and erecting them in segmental cantilevers from the columns. While this approach would have eliminated the need for falsework, it would also have required transport and erection of large heavy segments. In addition, precast segmental construction was not widely utilized in the project area at the time that Second Street was under design. For these reasons, the decision was made to design and detail the structure as a cast-in-place structure post-tensioned end to end of the frames.

The transverse precast concrete floorbeams are the primary visual feature of the bridge underside. Early architectural sketches depicted a concrete barrel vault roof over the transit center. This type of structure, while feasible, would not have met the required schedule or construction budget. As an alternative, a custom arched girder section was developed for this project. Architectural studies demonstrated that the ached girders achieved a barrel vault effect when viewed along the transit center axis, one of the primary ways that one would view the structure. In addition, the use of a series of girders provided modular spaces between the girders for suppression systems, and other required installation of overhead lights, fire features. As the attached figures demonstrate, the resulting ceiling provides visual interest. (See Fig. 8 & 9)

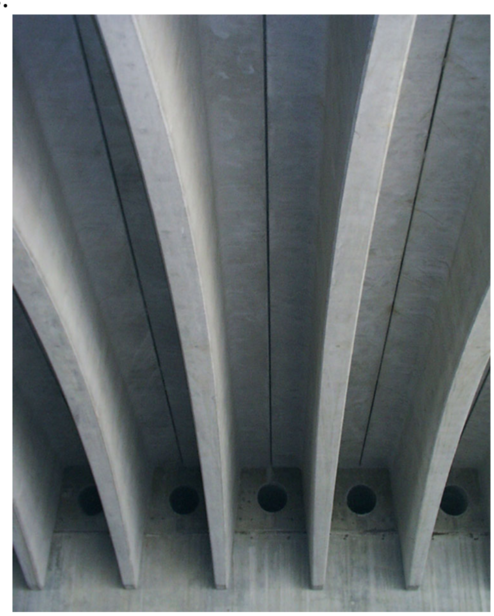


Fig. 8 – Detail of floorbeams at connection to longitudinal girder. Note holes in diaphragm for ventilation system.

Fig. 9 – Barrel vault effect of completed structure

The floorbeams were detailed as a standardized precast element with no dimensional variations between pieces. This simplified formwork and allowed for rapid production and delivery of precast components. The transverse post-tensioning in the deck cantilevers required a duct to be placed in each prestressed concrete girders for this second stage prestressing. The design drawings were developed for both a post-tensioned and a prestensioned girder option to provide flexibility to the precaster.

One important feature of construction was the elimination of the need for deck slab forms in the center bay. Deck forms between girder flanges are relatively time consuming to place. It was determined that the use of a wide top flange with a narrow gap at the transverse joints would eliminate the need for deck forms and produce an improved appearance relative to a deck with exposed potions of the deck underside.

The floorbeam spacing was determined primarily by structural requirements. The Second Street Bridge was designed to support traffic loads, pedestrian loads on the wide sidewalks on the south side of the deck, and light rail vehicles. The floorbeams were designed to support light rail at any location on the deck. Dead loads for the deck slab were larger than typically encountered for a bridge deck for the same reason. The future light rail installation could occur at any plan location, and the deck thickness needed to accommodate this. For these reasons, the typical floorbeam spacing was fixed at 5.16 feet and the deck slab thickness was 18 inches.

A final component of the system is the cast-in-place integral diaphragms for the transverse precast girders. The utility space for the transit center was located under the cantilevered slabs. Openings were required in the diaphragm for the air handling system to ventilate the "tunnel" under the bridge. The diaphragms also served as mounting locations for intersection signal poles and light poles.

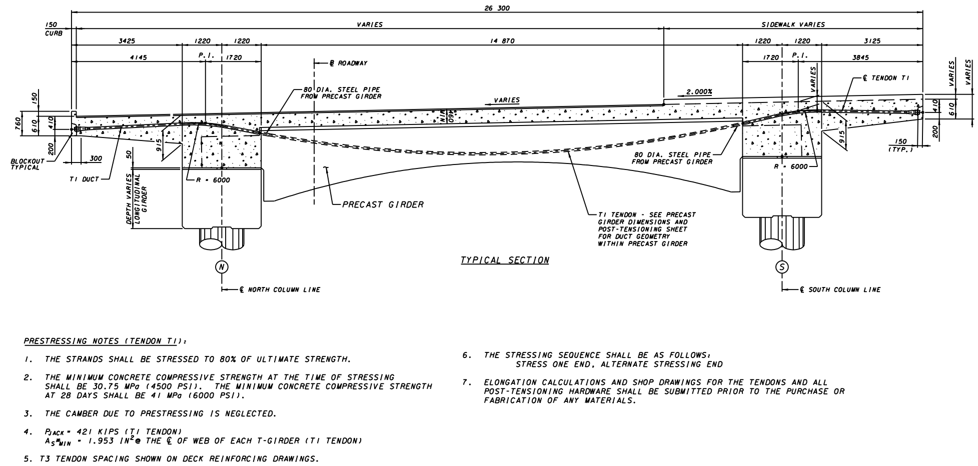


Fig. 9A – Cross Section of deck showing second stage post-tensioning

3. SELECTED STRUCTURAL DESIGN ISSUES

Vibration was a concern in the design of the bridge superstucture. Since the bridge needed to convey future light rail traffic as well as highway traffic and pedestrians, the perception of objectionable vibrations needed to be avoided. An analysis was prepared on the deck system. It was determined that the unloaded natural frequencies of the deck were greater than the 2.5 to 3 Hz threshold value for objectionable vibration.

Collision forces were investigated for five-foot diameter typical columns. The 400 Kip collision load from the AASHTO LRFD code was applied to the design of the columns to account for bus and future rail transit vehicles.

Detailing of the dapped end girders was an area that required close examination. Due to the change in cross section introduced by the arched stem, and the introduction of two stage prestressing in the floorbeams, there were questions regarding potential horizontal cracking at the face of the dapped end transition. A finite element analysis was performed to determine a probable range of stresses at this location. Reinforcing details were developed to address the potential cracking issue.

During the initial design of the superstructure, the designers assumed that the floorbeams would be fabricated as double T sections. This was assumed to be the most stable shape for transport and erection. Fabricator input during design lead to a revision in this approach. The double T sections were changed to single T sections to allow for reduced shipping and erection weight.

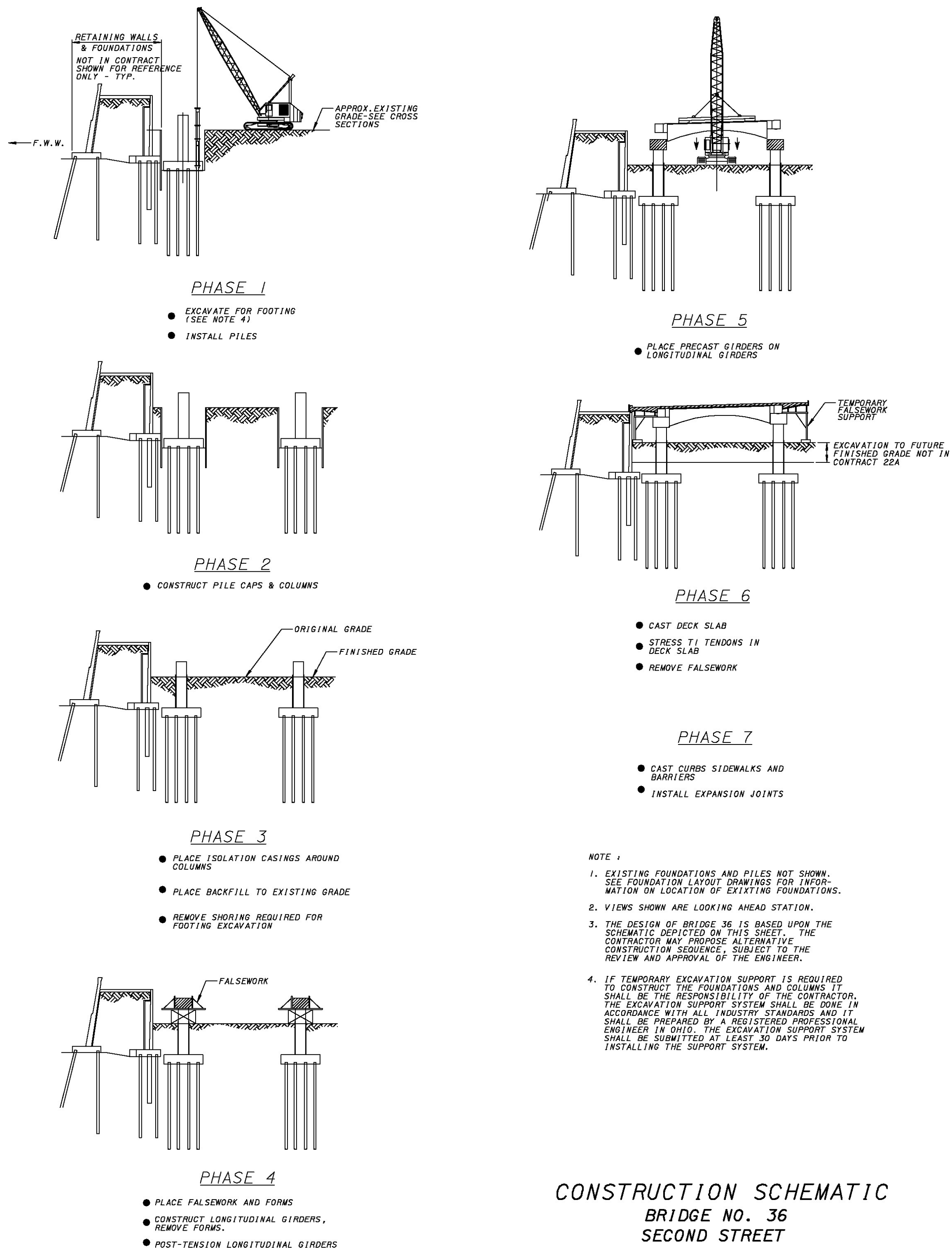
4. BRIDGE CONSTRUCTION

The Ft Washington Way project utilized a close collaboration between the project construction management team and the design engineering team. This process was beneficial in the Second Street bridge design in following:

- Construction input resulted in the development of a realistic construction sequence being assumed for the design
- It resulted in the examination of potential construction methods that are appropriate to the schedule and budget given the experience of local contractors.
- The process insured that the interface points between the multiple on-going contracts were considered in the design, and adjustments to the scheme made where appropriate.
- The resident engineer was a member of the design team and understood the critical features of the design that needed to be implemented in the field. This was particularly helpful in development of special provisions.

The Second Street bid documents contained an assumed sequence of construction to allow for the intent of the design to be clearly represented to the contractor. This is a relatively common drawing in bid documents for complex concrete bridges, such as segmental box girders. Due to the complexity and unique features of this bridge, this type of drawing was warranted. The contractor's actual construction sequence closely followed the scheme depicted in the bid drawings (See Figure 10 next page).

Fig. 10 – Construction sequence drawings for bridge



Schedule was critical to the design and construction of the Second Street Bridge. The adjacent Paul Brown Stadium was under construction at the same time as Second Street. Completion of the stadium was set at August 2000, and the adjacent Second Street was a primary access for vehicle and pedestrian traffic to and from the Stadium. This schedule constraint established the completion date of the west portion of the Second Street Bridge.

In order to meet this construction schedule, the detailed design of the bridge was compressed to a six-month schedule. This design schedule included evaluation of design concepts, selection of a preferred alternative, and preparation of construction documents. In addition, design of the bridge needed to address interface points from adjacent contracts that were also in various stages of design completion, as well as the architectural requirements of the transit center that were in a very preliminary stage of completion. A fast-track design approach was adopted to meet the challenging schedule.

Fig. 11 - Floor beam erection

Construction was planned to proceed from west to east, and complete the portion adjacent to Paul Brown Stadium first. It was envisioned that the division of the bridge into separate frames allowed the contractor a large degree of flexibility in scheduling their weekly or monthly work activities should localized obstacles be encountered. Since the components were repetitious along the length of the bridge, it was assumed that once the crews had mastered the activities associated with one feature of construction, peak production rates could be achieved in a short time (See Figures 11 & 12).

Fig. 12 – Floorbeams erected awaiting deck slab casting

The Second Street site was surrounded by other major on-going construction activities. To the north was the I-71 main line reconstruction, to the east and west was the construction of ramps that connected Second Street to I-71, and to the south were multiple construction contracts associated with Paul Brown Stadium and associated development. The net effect was to place the Second Street construction activities in a tightly constrained site, which required close coordination with adjacent contractors.

The detailed construction activities and sequence were the following:

- Excavate foundation pits, place steel piles, place footing and column rebar, place footing concrete, place column concrete.
- Erect falsework for longitudinal girders. Place forms, rebar and PT ducts. Place concrete. Stress girders. Grout
- Erect floorbeams
- Place forms for deck overhangs. Place rebar and PT ducts for deck. Place deck concrete. Stress transverse tendons. Grout.
- Place sidewalks and curbing. Place deck overlay.

Milestone dates were:
The contract was awarded in October, 1999
Construction of the foundations began in October, 1999
Construction of the prestressed concrete longitudinal girders began in January, 2000
Erection of the precast floorbeams began in March, 2000
Casting of the deck slab began in May, 2000
Second Street Bridge was open to traffic in August 2000.