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Reconstruction Of The Dewey Square Tunnel

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Summary

This paper discusses preliminary design and construction staging plans to reconstruct the existing Dewey Square Tunnel in Boston as a part of the Massachusetts Highway Department (MHD) Central Artery Project. This highway tunnel, part of the existing Central Artery I-93 alignment, is to be upgraded to satisfy current highway standards. The design includes extensive structural modifications and a program of inspection and material testing of the existing tunnel.

1.0 Introduction

The existing Dewey Square Tunnel (DST) is a six-lane, 701 meters (2300 feet) long, two barrel highway tunnel in downtown Boston. It was constructed in the early 1950's by the cut-and-cover method, and forms the southern downtown link of the existing Central Artery (I-93).

The overall MHD's Central Artery/Tunnel (CA/T) project is a large transportation improvement project which includes removing the existing elevated artery and replacing it with a new, wider downtown expressway tunnel. Part of this effort requires the renovation of the existing DST and the addition of a 131 meters (430 feet) long tunnel extension to the existing south portal. The existing six lane DST currently serves both northbound and southbound traffic. The reconstructed DST will carry southbound traffic only. Refer to Figure 1 for a plan view of the existing traffic flow.

The existing DST, one link in the overall highway alignment, features 1950's design standards which are now unacceptable as a part of the upgraded highway system. For example, the southbound lanes have a 48.3 km/hr (30 mph) design speed due to a tight horizontal curve and a limited sight distance. The roadway super-elevation is only 1.5%, and there is no additional vertical clearance inside the tunnel to allow a roadway cross slope for higher design speed.

Initially, conceptual highway plans focused on two overall schemes to address these problems:

- Reuse of the existing tunnel with as few modifications as possible,
- Demolish and replace the existing tunnel with a new tunnel.

Both schemes had drawbacks. In the first option, the MHD and the Federal Highway Administration (FWHA) were reluctant to accept the existing tunnel "as is", since billions of dollars were being spent elsewhere to build the CA/T to current AASHTO Interstate Standards. The second scheme satisfied the agencies concerns but would have required preparation of a new Environmental Impact Statement (with a resulting delay to the project of several years), and over $100 million dollars in additional construction costs.

Due to difficulties with options 1 and 2, a third option was examined. This idea focused on the renovation of the existing tunnel. Overall, the existing tunnel exterior envelope will be maintained. However, the existing center wall will be shifted to the west to create two main traffic flows, three lanes for the I-93 Southbound and one or two lanes for the I-90 Collector. In addition, a divider wall between the I-93 Southbound traffic and a Northbound on-ramp (Ramp RT) will be provided. This renovation will achieve current AASHTO design criteria in the tunnel, resulting in improved vertical clearance, improved sight distances, and horizontal roadway curves with larger radii, thus improving roadway safety.

2.0 Construction Staging and Structural Analysis

The basic tunnel section is comprised of structural steel frames at 1.5 meter (5 feet) on center with a reinforced concrete encasement for the base slab, exterior and interior walls. The exposed steel roof beam supports a reinforced concrete slab above. The frames geometry and member sizes vary throughout the tunnel. The existing structural geometry will be revised, when the center column is relocated.

The existing DST renovation and the new 131 meters (430 feet) tunnel extension will be phased in two parts to maintain 2 to 3 southbound lanes within the tunnel at all times. Figure 2 illustrates the typical tunnel cross section and phases of construction.

The sequential procedure for modeling of the existing DST frame sections is as follows:

- Create a computer model of the existing geometry, member properties, and loading to determine the existing 'locked-in' stresses and deflections. The invert base slab with an embedded wide flange beam was modeled as a composite section, whereas the roof and wall column sections are non-composite.
- Install the new support columns based upon the revised tunnel alignment.
- Remove the existing center support column.
- Revise the geometry, apply new loading combinations, and reanalyze.
- Determine the existing corner connection capacity for each load combination and compare this limiting value with the fixed end moment from the frame analysis.

- Limit the capacity of the corner connections to this moment limit value and reanalyze the frame, if required. This analysis is an interactive process and has to be continued until convergence is achieved.
- Compare the final member stresses to the existing member capacities and design reinforcement as required.
- Document all stresses and deformations for the final configuration.

We have performed the preliminary analysis using both the STAAD-III and the ANSYS finite element programs, with the results being in consistent agreement. The ANSYS program will be used for the final analysis since the program can perform the convergence procedure automatically.

The results from analysis described above indicate some overstress of the roof beams and the base slab at areas of maximum moments. This overstress typically occurs in areas where the existing tunnel has the maximum width. At areas of roof beam overstress, structural steel reinforcement can be added to the exposed beam. However, strengthening of the invert base slab, consisting of a steel beam encased in concrete, is more complex. Two methods currently under review include:

1. Reinforce the top compressed flange of the beam,
2. Reducing the design negative moment by creating a moment connection between the invert beam and the support column.

3.0 Highway Realignment and Traffic Staging

The tunnel currently features a minimum 4.3 meter (14'-3") clearance from the top of the roadway to the bottom of roof beams. A new clearance of 4.4 meter (14'-6") plus additional space for the super-elevation is needed.

The traffic staging design was based on these points:

- Major work begins only after northbound traffic is diverted to a new tunnel under Atlantic Avenue.
- At least three lanes of southbound traffic flow at all times.
- The reconstruction work is done in two phases. In phase 1, three lanes of southbound traffic are diverted into the existing northbound barrel to provide a work zone in the existing southbound barrel and the area of the new tunnel extension. During the second phase, two lanes of the southbound traffic are diverted into the reconstructed southbound barrel and one lane is placed on the surface (see Figure 2). This will allow for the completion of the existing tunnel renovation and the new tunnel extension.

Software was developed to help complete the layout design. A tunnel profile generator was prepared to help set the alignment. CADD tunnel profiles are generated from a tunnel geometry database and superimposed upon the existing tunnel geometry. To determine which alignment fits in the available space and which doesn't, the geometry database is adjusted and profiles regenerated.

4.0 Tunnel Inspection and Evaluation

In order for the design to work as planned, it was necessary to verify the condition of the existing tunnel. Previous inspections indicated that the tunnel was generally in good condition. In order to proceed with the design, a three phased inspection program was developed and implemented.

The first inspection phase consisted of a visual examination of the entire tunnel and the development of a detailed work plan for the final inspection. This visual inspection consisted of the concrete roof slab, concrete walls, and roadway invert slab. Concrete deterioration including spalls, cracks, and delamination along with visible reinforcing steel corrosion were cataloged by location in a database program. The steel roof beams, although exposed to view, were not easily accessible and were not inspected during this phase. The roof beams had accumulated 40 years of soot from automobile exhaust, much of it a by-product of leaded gasoline. This hazardous lead material needed to be removed prior to handling and examination of the roof beams.

The second inspection phase included sampling and testing of steel coupons from the roof beams, and concrete cores from the existing walls and roadway invert slab. The results indicate that the structural strength is equal to or greater than that specified by the original design drawings.

The first two phases of inspection were used in preliminary design. The third inspection program was developed for use in final design. This phase of inspection featured some of the same elements as phase two, but to a much larger extent. Test pits were created to remove concrete and inspect connections between girders and columns and to retrieve steel coupons, rivets, and bolts for testing. Preliminary results from this ongoing testing program indicate that the existing tunnel is in good condition. The tunnel's major structural elements are shown to be capable of resisting future loading conditions.

Acknowledgments

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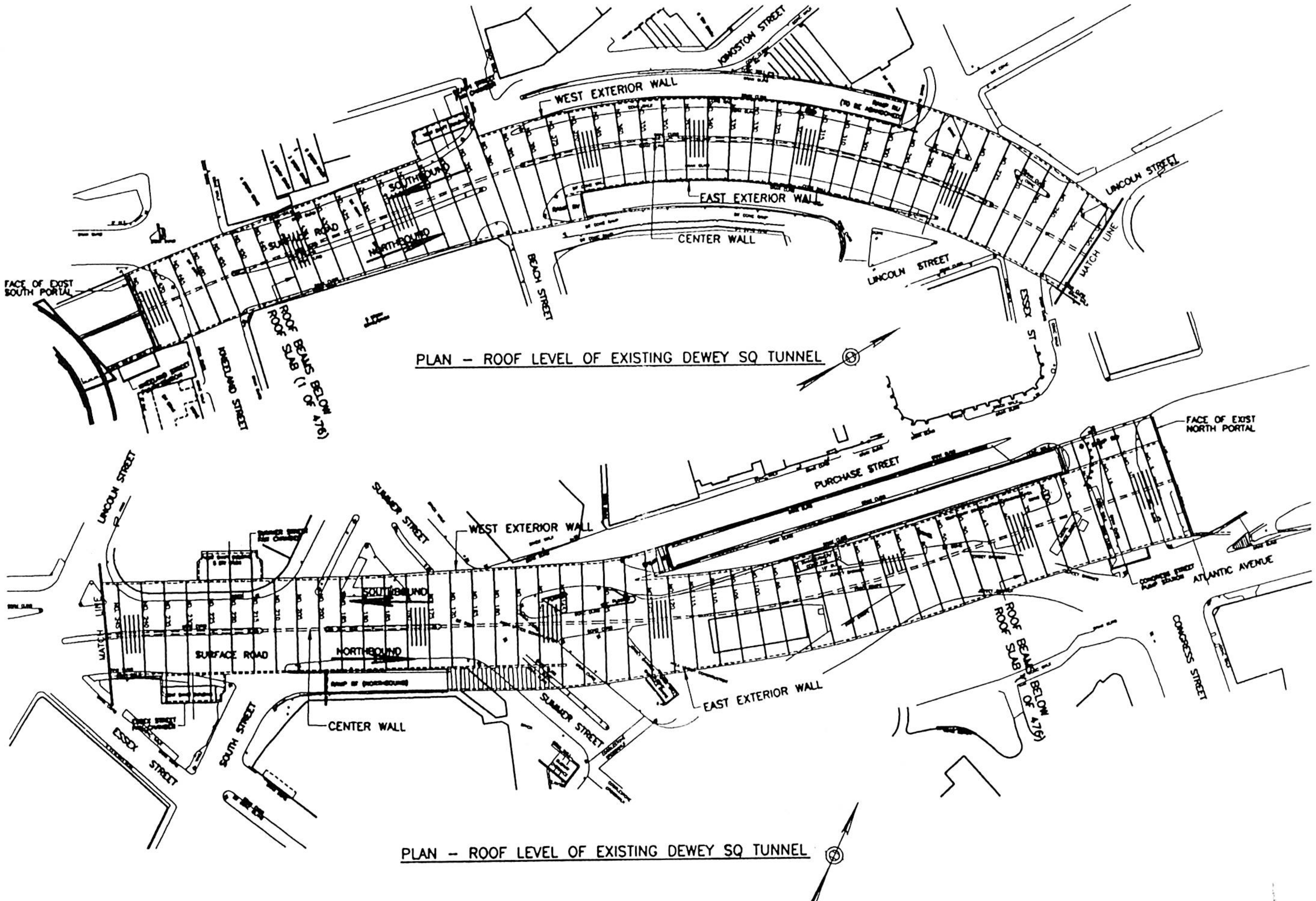
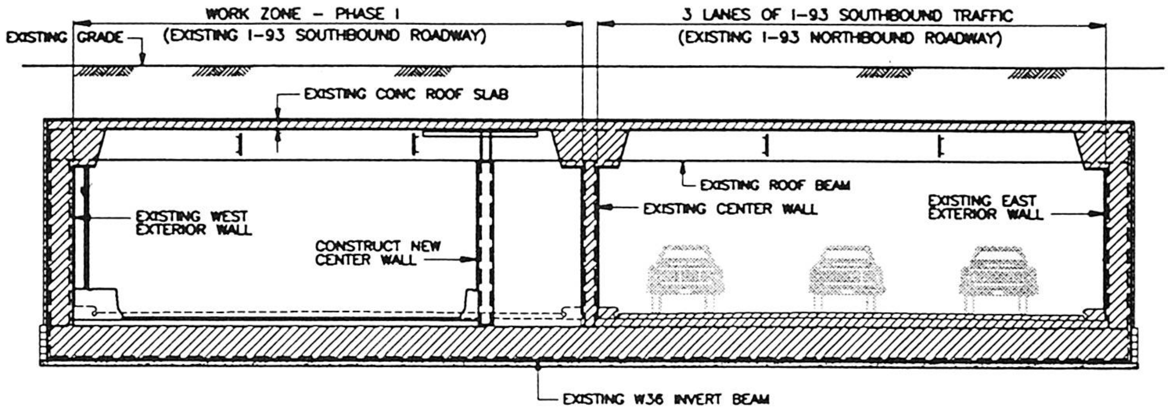

WEST EXTERIOR WALL
KINGSTON STREET
SOUTHBOUND
SURFACE ROAD
NORTHBOUND
EAST EXTERIOR WALL
CENTER WALL
LINCOLN STREET
MATCH LINE
FACE OF EXIST SOUTH PORTAL
BEACH STREET
LINCOLN STREET
ESSEX ST
ROOF BEAMS BELOW ROOF SLAB (1 OF 476)
KNEELAND STREET
PLAN - ROOF LEVEL OF EXISTING DEWEY SQ TUNNEL
FACE OF EXIST NORTH PORTAL
PURCHASE STREET
LINCOLN STREET
SUMMER STREET
WEST EXTERIOR WALL
SOUTHBOUND
MATCH LINE
SURFACE ROAD
NORTHBOUND
CENTER WALL
SOUTH STREET
ESSEX STREET
SUMMER STREET
EAST EXTERIOR WALL
ROOF BEAMS BELOW ROOF SLAB (1 OF 476)
ATLANTIC AVENUE
CONGRESS STREET
PLAN - ROOF LEVEL OF EXISTING DEWEY SQ TUNNEL

FIGURE 1

EXISTING DEWEY SQUARE TUNNEL RENOVATION

PHASE I CONSTRUCTION



PHASE II CONSTRUCTION

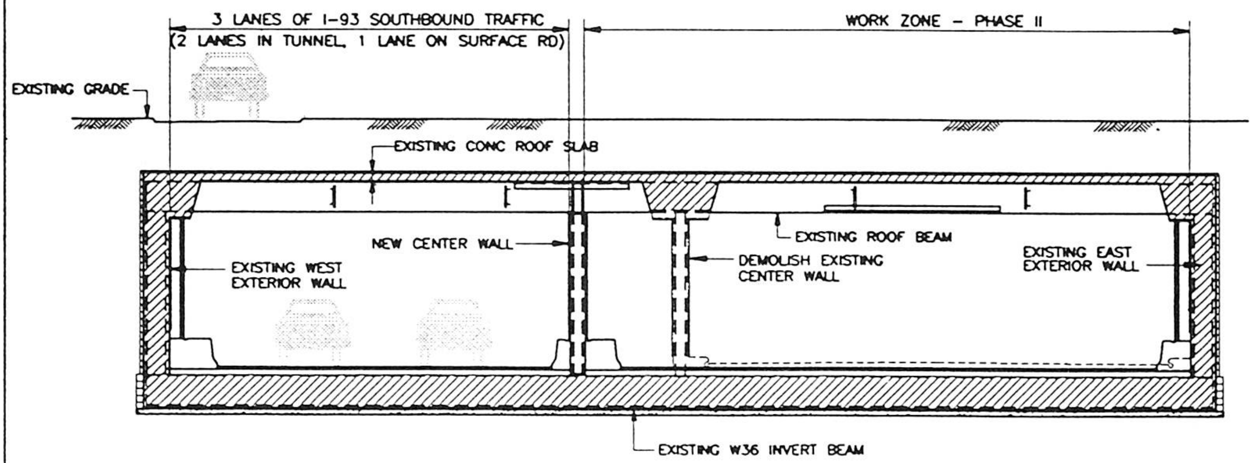


FIGURE 2