THE SOUTH COVE TUNNEL PROJECT, BOSTON, MASSACHUSETTS

By

ZOLTAN A. STACHO*

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SYNOPSIS

This paper outlines the design aspects of a new subway structure in downtown Boston, which forms part of the Massachusetts Bay Transportation Authority's Southwest Corridor extension. It also draws attention to a variety of construction techniques to be employed on the project.

DESCRIPTION

The Boston Redevelopment Authority's urban renewal program for the South Cove area got off to a good start earlier this year. One has only to take a short stroll around the downtown theater district to notice that several of the older buildings have already been demolished. The $200 million South Cove Urban Renewal program includes new high-rise complexes for the Tufts New England Medical Center, and extensions to the Don Bosco Technical High School, as well as other residential, commercial and institutional buildings. There will also be extensive alterations to the existing subsurface utility system and to the existing street network.

The MBTA's proposed Southwest Corridor extension cuts straight across the heart of this future development and, expected to be completed by 1975, it will allow the obsolete Washington Street Elevated to be demolished in its entirety. This new extension will replace and extend service between the Washington Street tunnel and Forest Hills with an improved, high performance transit facility, and will provide patrons with a speedier, more comfortable, and safer journey.

The new subway structure will start at a connection to the existing

*P. E., Project Manager, Parsons, Brinckerhoff, Quade & Douglas, Inc.

Washington Street tunnel at Kneeland Street and will run in a southwest direction and dip below the Massachusetts Turnpike Extension before linking up with the New York, New Haven and Hartford Railroad tracks at grade, east of Back Bay Station. There are six railroad tracks now in operation which parallel the Massachusetts Turnpike Extension. To the north are the two Penn-Central Railroad tracks, while the four to the south are used by the New York, New Haven and Hartford Railroad. The new rapid transit route will occupy the middle two sets of the existing New York, New Haven & Hartford Railroad tracks. Eventually, this route will extend to Route 128 in Dedham, operating on railroad right-of-way and on the Southwest Expressway median for some distance. The Expressway is now being designed and is scheduled for construction within the next few years. (Figure 1.)

The proposed South Cove Tunnel project, though little over a half-mile long, presented numerous technical problems which will have to be overcome. These problems will be solved by means of a potpourri of construction techniques, which will be discussed later. In the construction of the subway at the northerly end, a 1,450-foot cut and cover section will be constructed. To avoid disrupting traffic on the Massachusetts Turnpike Extension, a 350-foot length of twin bored-tunnel structure will be driven under it. To allow a 725-foot open-cut operation on the section of bored-tunnel connecting to the at-grade tracks, south of the Turnpike, the existing Arlington-Tremont Street Bridge will be demolished. This skew structure will be replaced by a reinforced-concrete substructure and steel girders with concrete deck, after the open cut section is installed. The bridge will be rebuilt in stages so that it will be open at all times, thus keeping interference to traffic to a minimum. (Figure 2).

The project also includes a passenger station located in the heart of downtown Boston, adjacent to the proposed Tufts New England Medical Center and Don Bosco Technical High School. It was designed by architectural affiliates of Parsons, Brinckerhoff, Quade & Douglas, Inc., Lord & Den Hartog, and will be constructed of reinforced concrete and structural steel. The station will extend southwards from Washington Street to the existing Broadway.

DESIGN CONSIDERATIONS

Site

All properties adjacent to the proposed route will have been demolished before construction starts, with one exception — the Don Bosco

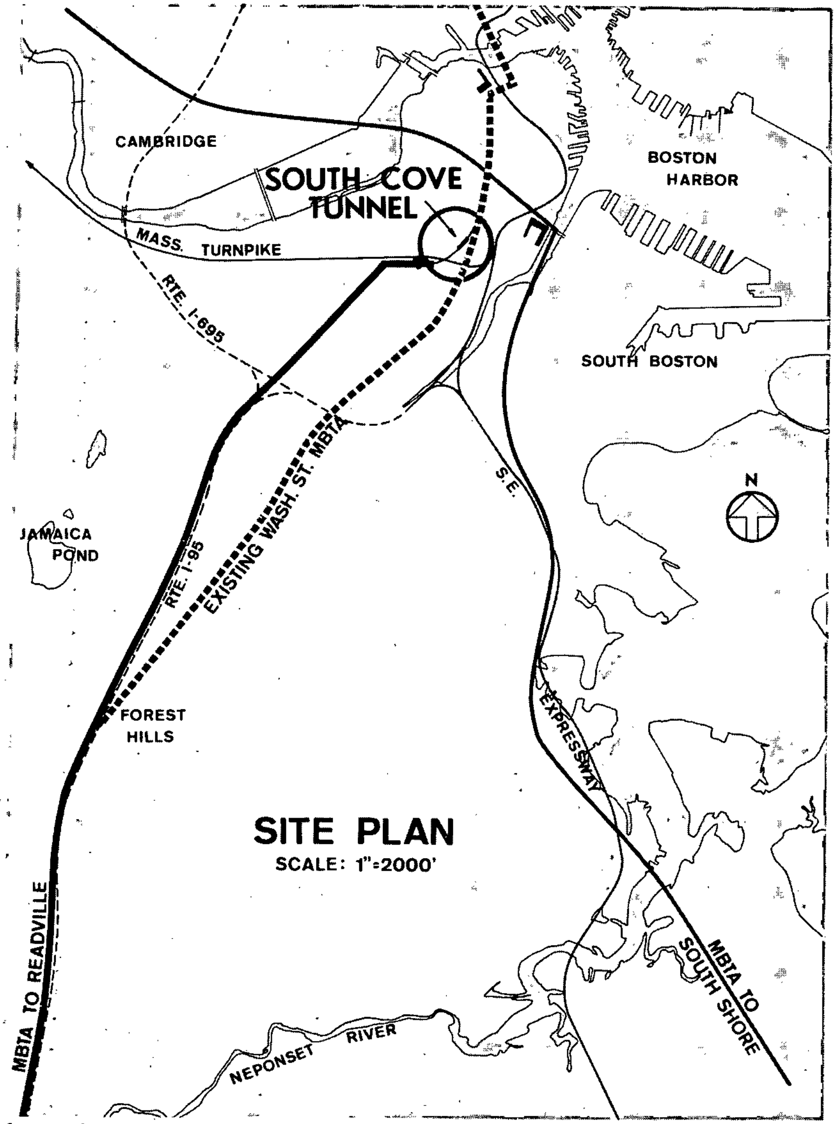

Fig. 1. — The site of the South Cove Tunnel Project — a first stage improvement to the MBTA's Southwest Corridor extension. This new line, expected to be completed by 1975, will replace and extend service between Washington Street tunnel and Forest Hills, and will allow the existing Washington Street elevated to be demolished. The new route will ultimately extend to Route 128 in Dedham.

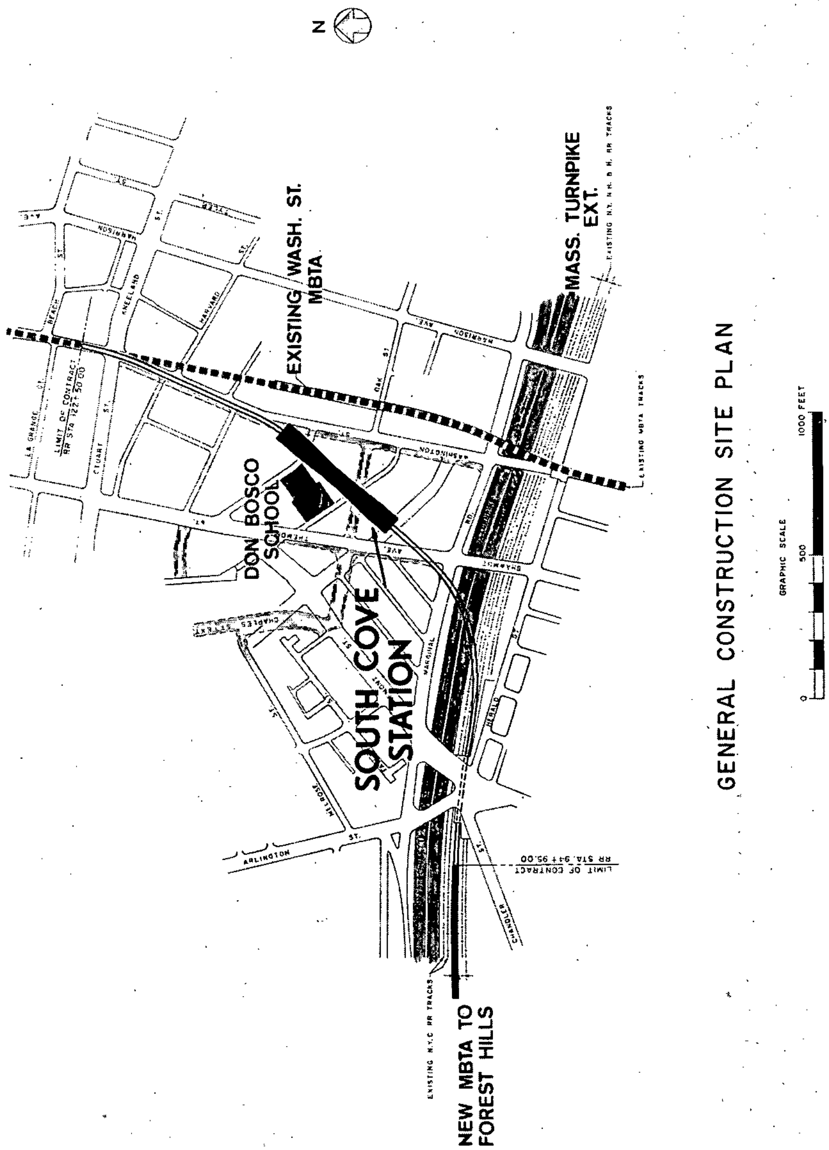

Fig. 2. — Construction site plan shows the half-mile long tunnel as it passes within inches of the proposed addition to the Don Bosco Technical High School and then under the Massachusetts Turnpike Extension. The existing Arlington-Tremont Street bridge will be demolished to allow open-cut operations to be carried out on a 725-foot section. The bridge will be replaced after the open-cut section is installed. The new South Cove passenger station will have side platforms 410 feet long.

Technical High School which is to remain. Even after fine maneuvering of the alignment in this vicinity, it was evident that some method of excavation support would be necessary. Underpinning, though entirely feasible, was ruled out on the grounds of cost. Instead, bentonite slurry cut-off walls were specified.

From the north end of the project to the Turnpike, a cut and cover construction method was specified for reasons that will be discussed later.

In order to permit the operations of trains between the new South Cove subway station and the at-grade tracks, *any* new structure must cross the Massachusetts Turnpike Extension. The Massachusetts Turnpike Authority has confirmed that non-interference to surface traffic is vital to the efficient operation of this highway. An elevated crossing is not practicable at this location, since the short distance between the south end of the proposed passenger station and the north side of the Turnpike will not allow the necessary change in elevation. Therefore, only a bored tunnel crossing was considered.

Soil Conditions

A plan based upon the Bonner map of 1722, together with the Fuller Whitney revisions of 1814, shows that the tunnel will pass under the Turnpike in an area once occupied by the old Back Bay shoreline; this was confirmed by the soupy organic silt stratum encountered during exploratory borings. This area was later filled — relatively recently in fact, probably a little over a 100 years ago — with material obtained from pits in Roxbury, Dorchester and Brighton.

Soil borings along the tunnel route established the fact that over a large portion of the site a hotchpotch of miscellaneous fill exists. There is a thin layer of fill in the area which was formerly below water. Under this is a layer of silt and organic silt, occasionally with layers of peat. This silt layer is thin at the Turnpike crossing but towards the west it reaches a thickness of about 20 feet. Under the silts occur the clays characteristic of the Boston area; soft blue at the bottom, and the stiffer, highly preconsolidated yellow at the top.

To the north of the Turnpike, the surface layer is granular fill, 5 to 10 feet thick, beneath which are yellow and blue clays. The borings reached refusal at elevations varying from about -20 at the southern end of the project to $+50$ at the northern end (Datum USC and GS $+$ 100). There were no rock cores taken but the underlying rock is apparently a grey shale. A thin layer of mixed material containing clay, sand, gravel, and shale fragments is generally present between the bottom of the blue clay and the elevation at which refusal was reached. (Figure 3.)

The properties of cohesive soil strata were examined in detail by means of laboratory tests on undisturbed samples.

Alignment and Profile

There was no need to make a route location study prior to final design, since a report * prepared in July 1964 for the Massachusetts Bay Transportation Authority had already recommended a route and this location was accepted. However, refinement of the alignment and profile together with the computer solution of geometric problems were required. The distance between the existing Essex Street and the proposed South Cove stations is approximately 800 feet, therefore speed was not a critical factor. The minimum track radius is 526 feet, all curves having spiral transitions at each end of the curve. (Figures 4 and 5.) Maximum superelevation is 6 inches with linear transition. Maximum grade is 4% with the grade in the station area being 0.50%. Minimum length of vertical curve is 150 feet. The track is standard gauge. The car type will be MBTA's Number 11 car, 65 feet long, with 45 feet truck centers, 9 feet 6¾ inches wide. For this car a clearance envelope was developed and the rolling and yawing motion of the car was taken into consideration. (Figure 6.) A six car train length was used for design.

Loads on subway structure

Vertical: Dead load consists of the weight of the complete structure and of the supported backfill. Surcharge for roadway and sidewalk live loads applied at the ground surface, both over and adjacent to the subway, was considered as a static uniform load of 600 pounds per square foot for a depth of cover of five feet or less. This loading decreases uniformly at a rate of 40 pounds per square foot per foot increase in depth until the depth of cover of 20 feet or greater, where no surcharge live load was considered. At the existing Washington Street and at the Massachusetts Turnpike an alternative loading for depths of cover of three feet or less was considered, consisting of the Standard AASHO HS 20-44 truck load. In the areas where proposed building columns will be supported directly on the roof of the subway station and line structure, actual column loads were used for design. At

*Report on Proposed Extension of Main Line Rapid Transit Facilities over the New York, New Haven and Hartford Railroad from Washington Street Tunnel to Route 128 in Dedham by De Leuw Cather & Company.

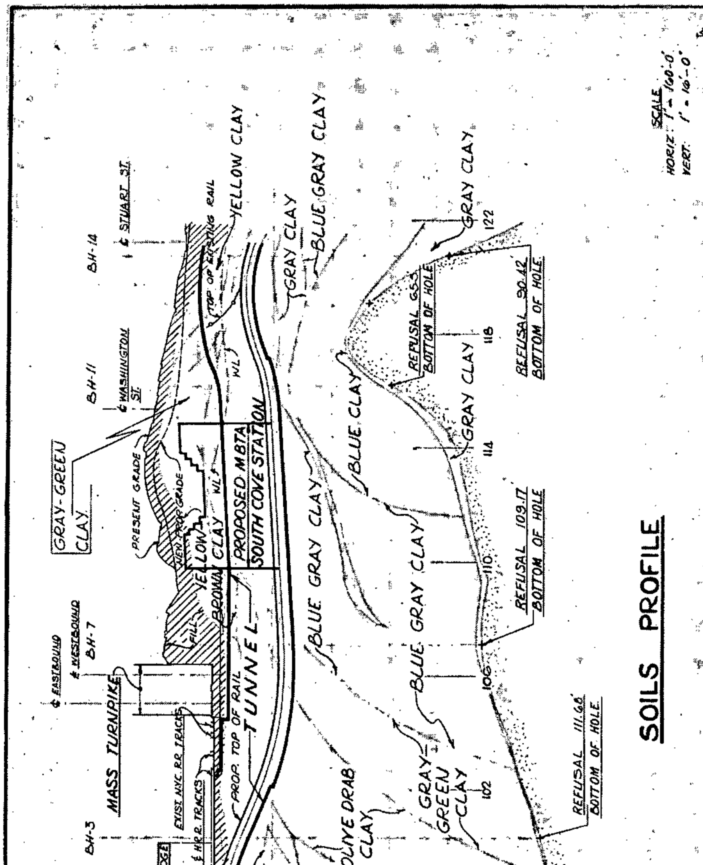

Fig. 3. — Soils profile shows the area through which the tunnel will be constructed. A layer of miscellaneous fill covers a large portion of the site, under which occur the silts, occasionally with peat. Beneath the silts are the characteristically Boston clays — soft blue at the bottom, stiffer yellow at the top.

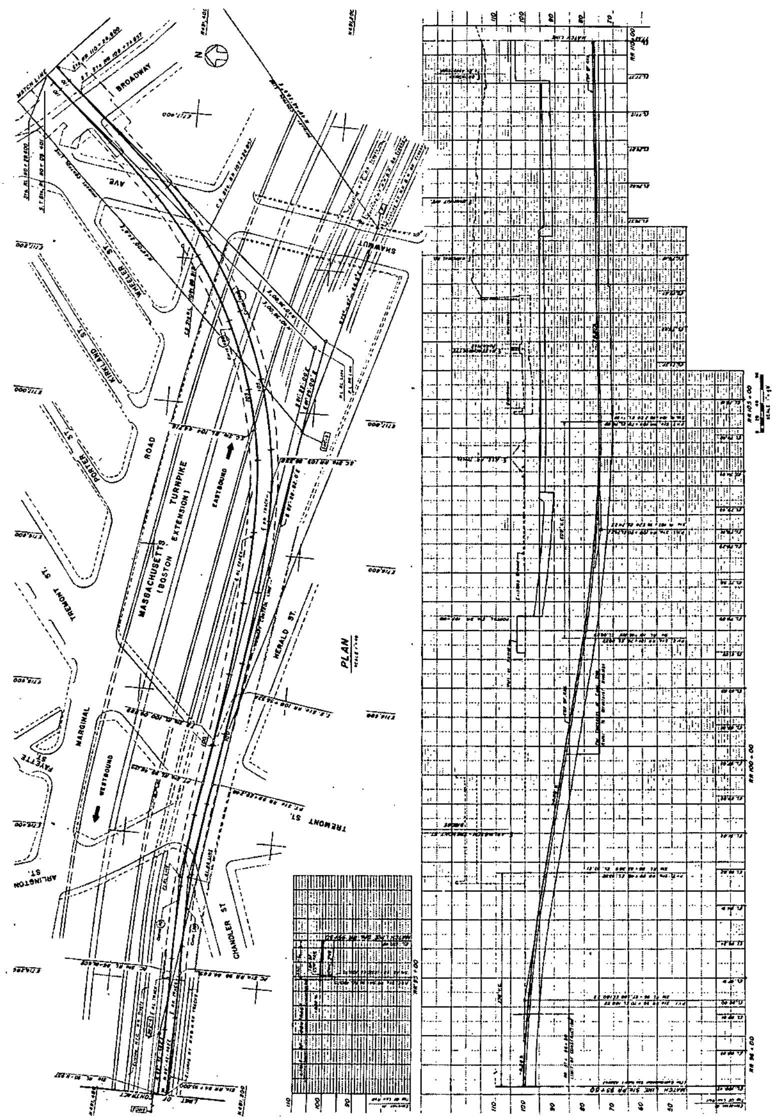

Fig. 4. — Construction plan and profile show how the tunnel will be built right beneath the South Cove area streets as well as the Massachusetts Turnpike. Minimum track radius is 526 feet with all curves having spiral transitions. Maximum gradient is 4 per cent with the grade in the station area being 0.50 per cent. See also Figure 5.

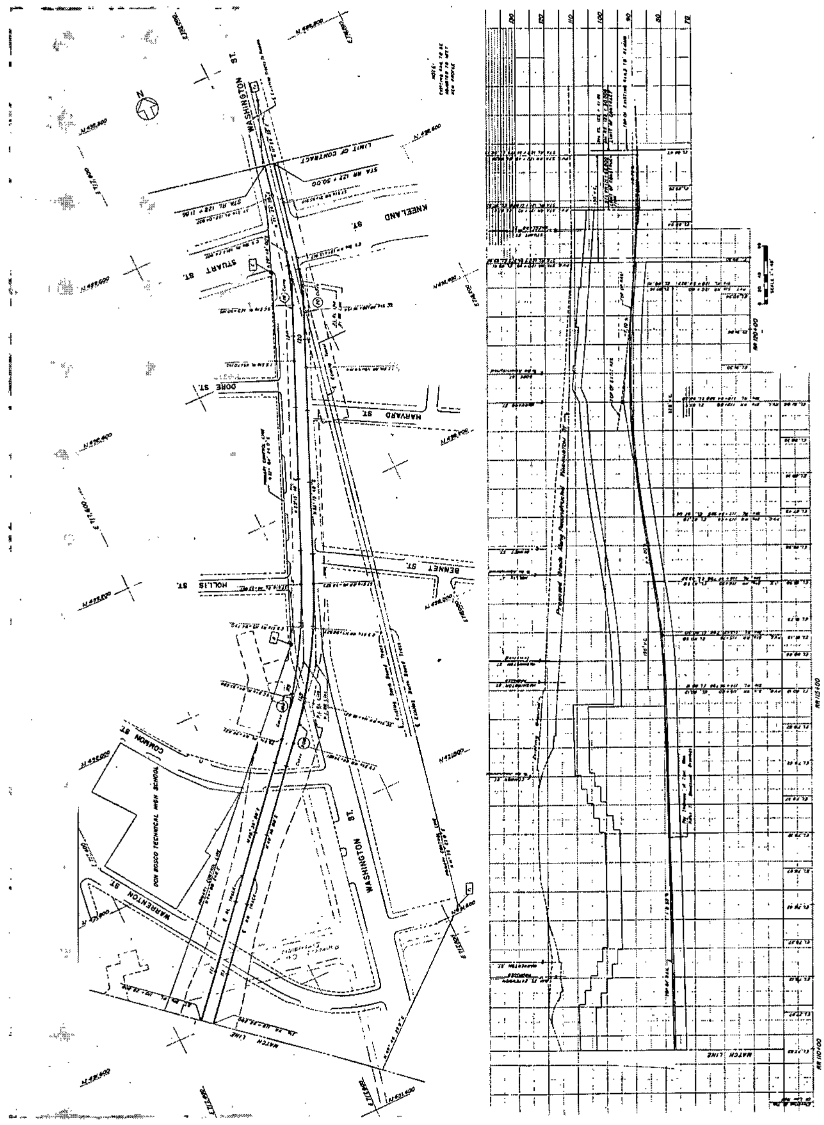

Fig. 5. — Construction plan and profile show how the tunnel will be built right beneath the South Cove area streets as well as the Massachusetts Turnpike. Minimum track radius is 526 feet with all curves having spiral transitions. Maximum gradient is 4 per cent with the grade in the station area being 0.50 per cent. See also Figure 4.

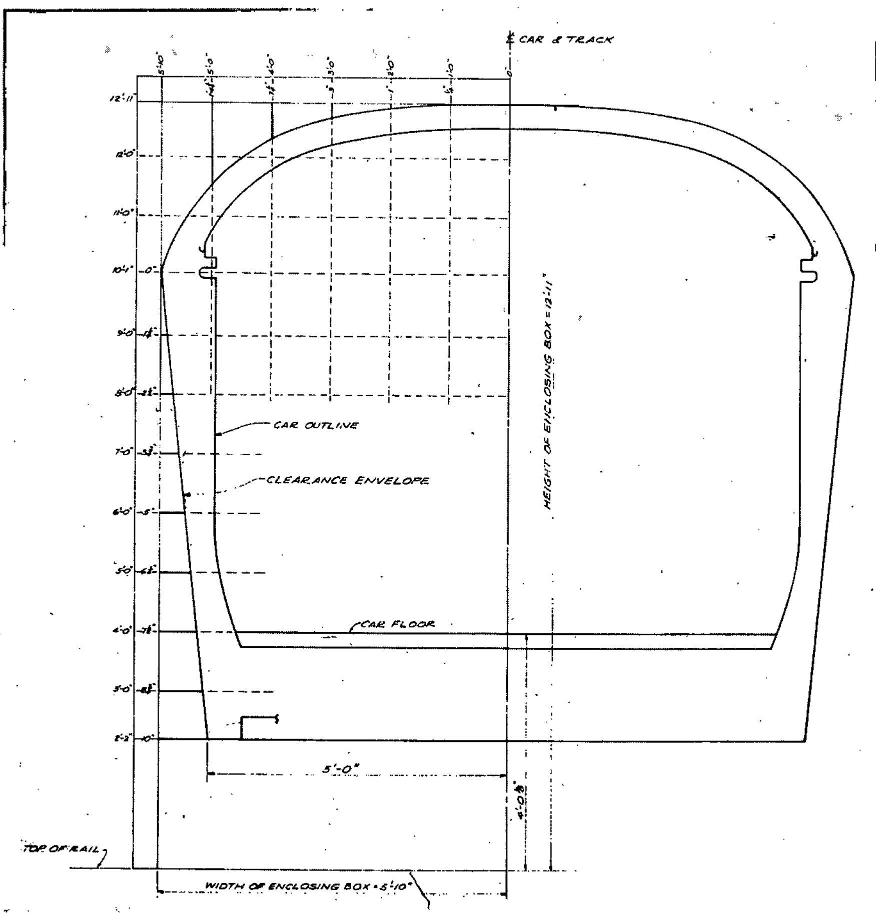

Fig. 6. — This clearance envelope was developed for the MBTA's 65-foot long Number 11 car. The car's rolling and yawing motion, were taken into account.

the railroad tracks an alternative Cooper, E-72 loading for depths of cover three feet or less was considered.

Horizontal: The standard expression for lateral pressure of cohesive soil

$$P_{horizontal} = P_{vertical} - 2C$$

was not considered applicable. With the value of 1000 pounds per square foot cohesion taken for design, the above expression would yield values of zero lateral soil pressure. There is a distinct possibility that soil pressure will be exerted on the structure after a long period of time due to progressive straining of the adjacent clay.

The lateral design pressure of

$$P_{horizontal} = 0.4 \times P_{vertical}$$

was applied, which is consistent with the cohesive soil and the relatively rigid nature of the permanent structure, which limits the deformation of the pressure-producing soil. Over and above the soil pressure, hydrostatic pressure was exerted on the structure below ground water. The lateral pressure due to live load surcharge on the ground surface was also included using the following expression

$$P_{horizontal} = 0.4 \times q$$

where q = live load surcharge adjacent to permanent structure (600 pounds per square foot or AASHO HS20-44 or Cooper E-72, whichever is greater). The existing Don Bosco High School building exerts a lateral pressure as well. All existing footings within the zone of influence were taken into consideration using the design foundation load as surcharge live load. In addition to the vertical and horizontal loads, the structure was checked for buoyancy.

Loads on temporary construction structures

In order to assure that all prospective bidders should use the same design criteria for the support of excavation, recommended lateral pressure diagrams were included with the contract documents. For the arching — active case, where the flexible wall is restrained rigidly at several points along its height, such as in a braced trench, the shape of the pressure diagram is trapezoidal. This pressure diagram has been established by means of measurements. For a cohesive soil the maximum lateral pressure is given by the expression

$$P_{lateral} = P_{vertical} - 4C \text{ or } P = \sigma h - 4C$$

where C = cohesion of the soil. However, in this case, introduction of four times the cohesion would yield zero lateral soil pressure in some instances and, as this is not realistic even for temporary structures, it is proposed to consider a trapezoid of slightly different shape.

As the existing railroad immediately adjacent to the sheeting is to be kept in operation during construction, a live load surcharge was incorporated in computing total lateral pressure. With no railroad contributing live load surcharge during construction, the vertical surcharge due to traffic and/or construction equipment will be considered. (Figure 7.)

It must be noted that the stability of the deep excavation was analyzed, to establish the safety of the deep excavation against failure.

Support of existing buildings

In the vicinity of the proposed tunnel the Don Bosco High School structure will remain and will be affected by the excavation for the station area.

Several methods of providing support for this building during construction were studied but only two basic approaches were considered worthy of further evaluation:

1. Underpinning.
2. Providing preloaded cross lot bracing in conjunction with a continuous bulkhead placed adjacent to the building.

In considering the underpinning alternative, the zone of influence was defined by a slip line extending from the bottom of the excavation at 1½ horizontal to 1 vertical. Any footings occurring within this zone were considered as being susceptible to displacement if not properly supported. The design, therefore, required the installing of underpinning members in order to transmit building loads to firm soil stratum outside the zone of influence. Because of the nature of the soils and the fact that the shear strength was found to diminish with depth, it was considered necessary to extend the underpinning members to bedrock. This criterion clearly implied the use of underpinning piles to be jacked under the footings in small lengths. Detailed investigation and cost analysis, however, pointed out that such a scheme, although totally feasible, would be very costly.

The provision of a bulkhead used in conjunction with preloaded cross lot bracing seemed to offer the best solution for providing adequate support. In order to be economical such a bulkhead would have to eliminate the underpinning completely.

The means of construction of the bulkhead were narrowed down to ei-

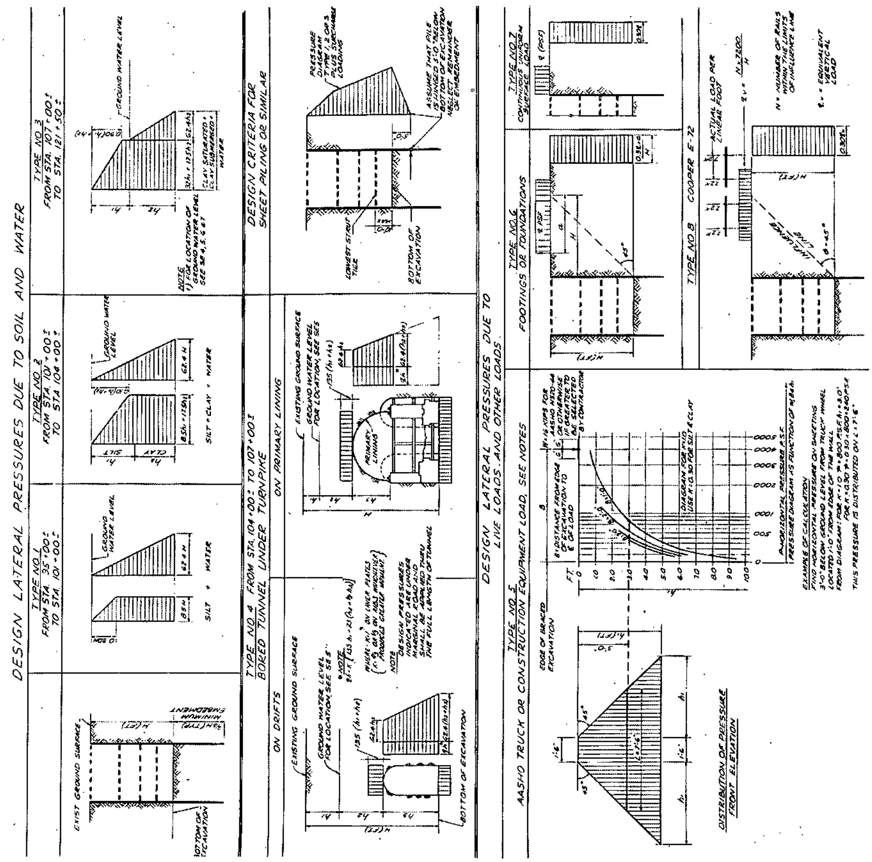

Fig. 7. — Lateral pressure diagrams were developed for dead loads due to soil and hydrostatic pressures and for live loads. For the support of excavation to temporary construction structures, recommended pressure diagrams were included with the contract documents so that prospective bidders might use the same design criteria.

ther continuous structural steel sheet piling or a reinforced concrete wall installed by the slurry trench method.

Experience has shown that the latter method may be used safely and economically to support existing buildings without the need for any underpinning whatsoever. The wall provides a rigid watertight bulkhead which totally eliminates the loss of ground resulting from both horizontal deflection and from the migration of soil particles through the vertical bulkhead, and therefore provides for the complete stability of the adjacent foundation.

Structural steel sheet piling if properly installed and braced would provide a similar form of support but would be subject to horizontal movement due to the inherent flexibility of the material; that is, if it were to be installed using a spacing of wales and struts that would be practicable and compatible with the contractor's space requirements.

With this method of support, inward movements of the sheet piling would result in some loss of ground under the Don Bosco High School which would lead to differential settlements of this building. The tremie concrete wall, however, due to its inherent stiffness and mass, will eliminate this type of deflection and will maintain the foundations at their existing levels.

Therefore, the tremie concrete wall alternative was adopted.

Support of proposed buildings

The Don Bosco High School Extension and Quincy School building to be erected as part of the urban renewal project will be so located that building columns will physically be in contact with the proposed subway section.

In the case of both the Don Bosco and Quincy schools, the column loads can be supported directly on the proposed subway station roof with loads transmitted through the station walls to the invert slab; the slab is made stiff enough to distribute the loads to the underlying soils and, as the total pressure thereby induced on the soils is less than that existing due to overburden, only very minor settlements are expected. As at this time details of the loading from the Quincy School is not known, provision was made to receive a uniform surcharge on the station roof of 1000 psf directly under the proposed school structure.

Other proposed buildings included in the South Cove redevelopment scheme are in the very early planning stages. It was assumed that the foundations for these buildings will not be placed on the subway structure and loads arising therefrom will not in any way be transmitted to the subway structure.

Station

A comparative study of two schemes, the two side platforms scheme, as opposed to the one center island platform scheme, was made. From this preliminary study it was concluded that the side platform scheme be adopted for the following reasons:

— Compatability with all other existing side platform stations on the "Orange Line".

— The greater ability to handle larger projected patron traffic volumes.

— Shorter overall station length, taken from end of lobby to end of lobby, which in turn decreases the corridor lengths.

— Overall superior patron circulation.

— Greater patron safety and comfort.

— Cost estimates indicated that costs were approximately the same for both schemes.

In order to create a sequence of spatial experiences for the patron, both on the mezzanine and platform, it was decided to expand the volume of space towards both ends of the station. This volume increase also minimized the piston effect of a train entering the station. This concept was achieved by a gradual simultaneous stepping of the ceiling and walls. It must be noted that a freer curvilinear transition and a more rigid diagonal scheme, both in plan and elevation, were considered but were found undesirable from both a structural and architectural point of view.

Waterproofing

Several methods of waterproofing were investigated and a conclusion was reached that, with structures that are permanently located below ground watertable, there is no foolproof method of insuring a totally dry structure other than the method referred to as "Brick and Mastic". The costs associated with waterproofing in this manner are extremely high. Therefore, the following criteria were adopted:

For line structures no waterproofing membrane will be provided. A richer concrete mix was specified for the walls and slabs by using densifying agents and waterstops at all construction joints. In the event that major leaks occur, the leaks will be stopped by various injection methods.

For the station roof, a membrane will be provided consisting of either 1/16 inch thick butyl rubber or 1/4 inch thick bentonite panels protected by a three inch thick course of lean concrete. This membrane will extend down the walls to a depth approximately one foot below the last construction joint in the wall. A richer concrete mix for the walls and slabs and waterstops at all construction joints was specified. An "air gap" will be provided between the structural walls and finishes so that any leakage that occurs will be collected in channels behind the finishes and drained away to the sump. If leakage occurs at the grade slab, any inflow of water will be drained away through the drainage facilities.

Ventilation

In order to establish design criteria for the new project, the effectiveness of the present ventilation system in the MBTA's "Orange Line", between the new portal near the junction of the New York, New Haven and Hartford Railroad and the Penn-Central Railroad to the new portal in Charlestown, was studied. Appropriate criteria were established and general conclusions and recommendations made.

As the ventilation of subways is considered a very serious problem, the study was quite extensive. In the following paragraphs the study findings, criteria and design recommendations are discussed in detail:

A field survey was made to establish locations and dimensions of all existing ventilation shafts as well as the dimensions of stations and tunnels so as to provide a basis for evaluating the capacity and condition of all emergency ventilation fans.

Information provided by the MBTA on the subway system was studied and analyzed. This information included plans of the system and operating details on the number of trains per hour, number of cars per train, and on train schedules, speed, load factors, and system power losses plotted as a function of time.

To analyze temperatures in the system, heat losses from trains, passengers, lighting, and auxiliary power were quantified, and an evaluation of the total sytem heat gain was made under the "worst case" operating condition which occurs during an evening rush period on a hot day in July. This total system heat gain was equated with the total heat flow out of the system, and the resultant system temperatures, piston effect air flow rates, and the capability of the existing emergency ventilation system were established and analyzed. Train heat losses were determined by integrating the area under the power loss versus time curves.

The two cooling media available to remove heat from the subway system are the earth surrounding the system which acts as a "heat sink", and outside air which is forced through the system by the piston effect of moving trains or by fans. Heat leaving the system through both media was determined and analyzed.

The rate of heat flow out of the system into the ground was found by evaluating the heat sink effect of the earth surrounding the subway tunnel. A method originally developed by the National Bureau of Standards for determining the heat sink effect upon air flowing in underground ducts was modified and employed in this analysis.

Ventilation air requirements were determined by calculating the air flow required to keep air temperatures in the system within specified limits under the "worst case" condition, and taking into account system heat losses to the "sink".

The amount of ventilating air required to limit the temperature rise in the system was compared with the normal rate of ventilation provided by the piston effect of moving trains in the subway. A computer program, developed for the BART system in San Francisco by Parsons, Brinckerhoff, Quade & Douglas, was used to evaluate this piston effect.

A computer analysis of the emergency ventilation system was also made. In this analysis, it was assumed that trains were stalled in different locations, and that various emergency conditions existed. Input data included the findings of the computer study, used to evaluate piston effect, as well as fan capacities and probable performance characteristics.

The findings were as follows:

— In all but one line section of the subway, air flow resulting from piston effect is sufficient, even during an evening rush hour in July, to maintain temperatures equal to or less than the outside ambient air temperature, and to provide a reasonable rate of air change.

— In subway stations, the air flow rates from piston effect do not provide enough air to maintain a tolerable environment for patrons during extremely hot weather. Additional mechanical ventilation is required to limit the temperature rise on station platforms above ambient air temperatures when these are at summer highs. The additional fan capacity required per station will vary from 10 to 20 million cubic feet per hour depending on whether the station handles traffic in only one or in both directions.

— The emergency ventilation system in the existing subway segment studied is inadequate. In general, it will not exhaust smoke or supply fresh air at an appropriate rate during fire fighting operations, nor will it clear underground sections of smoke rapidly enough to permit early restoration of normal services.

— The maximum system heat gain coincident with maximum outside air temperature occurs during a 4:00 to 6:00 p.m. rush hour in July.

— Train heat losses account for approximately 90 percent of the total subway system heat gain. These include heat losses from braking, starting, lights, controls, power lines, and air conditioning.

— Heat losses from train braking accounts for about 50 percent of the total train heat loss and occurs almost entirely within stations.

Criteria used to arrive at the above findings are as follows:

— Temperatures in stations and in line sections during an evening rush hour should not be more than 3° F above outside air temperature when this is 91° F, or more than 10° F above outside air temperature when this is 60° F.

— Two to three air changes per hour are required to adequately expel odors and haze from the subway during rush hour traffic.

— Emergency ventilation should be provided which is capable of purging smoke and fumes from an affected subway segment in four minutes or less, with air velocity not exceeding 15 miles per hour in the annular space around trains where there are walkways.

As a result of the study, it was recommended that in the South Cove Tunnel project reversible axial flow fans be provided in fan rooms located at each end of the station.

These fans will be capable of supplying or removing air to or from the subway system as required. The fans will be controlled locally from the fan room or remotely from the train starter's room in South Cove Station. Activation of the fans will operate the appropriate dampers allowing the fans to supply fresh air or remove smoke or heat laden air from the system.

Rail Supports

Studies were conducted to evaluate rail fasteners and to determine their suitability for use in the subway structure. Though the rail installation and traction power design was not a part of this contract, it was mandatory to establish a design criterion for rail installation. The existing MBTA system has a "tie and ballast" installation with standard wood ties and short "unwelded" rails. In subways and on aerial structures this is not considered a modern method for rapid transit facilities. At the time when the design was prepared, the MBTA had no established criterion for rail fastening methods. It was very important to establish such a design criterion which would suit any kind of rail installation in the future, other than tie and ballast installation.

Two basic techniques were studied for establishing a design criterion:

1) Half ties embedded in concrete. With this method the half ties are placed on the final grade slab. To keep them permanently in place they are properly aligned and shimmed and concreted in.

2) Second pour technique.

With this method the structural grade slab is constructed with a longitudinal continuous slot under the rails and steel rebar "hairpins" provided. The rail with fasteners is aligned both vertically and horizontally, and the concrete is placed under the fasteners to keep the rails in place.

With either technique, any type of rail fastener can be used. It was also assumed that continuous welded rail will be installed, in order to decrease the sound and vibration level to the minimum. Since no resolution could be reached at that time, it was recommended that the subway structure should be detailed so that either technique could be used. The grade slab inverts were designed and detailed accordingly.

CONSTRUCTION TECHNIQUES

Cut and Cover Section

It was carefully studied whether or not economic tunnelling could be applied outside of the station area. It was found that at the north end of the project, where the existing structure meets the new line, cut and cover is unavoidable. The subway in the area adjacent to this cut will be at a shallow depth below ground, thereby making tunnelling operations expensive, if not unfeasible. There were no doubts about the station, consequently from the south end of the station the cut-and-cover method was proposed as far as the north end of the project. Further studies were conducted with regard to method of construction south of the station. As previously discussed, there was no question that tunnelling be used under the Massachusetts Turnpike. The only question was where the transition should occur between tunnelling and cut-and-cover. A decision was soon reached after the Boston Redevelopment Authority requested the MBTA that, between the Turnpike and the Station, the subway structure should be able to support future buildings. To comply with this request, the limit of the cut-and-cover section at the south end was set at Marginal Road. Thus, a cut-and-cover section was recommended from this point to the north end of the project.

With regard to decking, several detours were recommended around the cut-and-cover area, thus decreasing the requirements for decking to a minimum.

It was specified that the sides of excavation be maintained and secured by a system of supports which consists of vertical sheet piling or other approved methods of support, secured in place by means of bracing which may include wales, braces, struts, shoring anchors and similar members. A system of supports based on the use of soldier piles and horizontal lagging was not allowed. This restriction was recommended by the soils engineer after analyzing the slope stability of the soil. Furthermore, it was also specified that the sheeting be driven to a depth below the invert of the excavation to 2/3 of the depth of the excavation, in order to increase the factor of safety. The design criteria for the design of temporary structures were previously discussed.

Adjacent to the Don Bosco High School the sheeting will be replaced by a reinforced concrete wall installed by the slurry trench method, for reasons discussed above. It was specified that the transverse bracing system at the Don Bosco High School area be preloaded. Preloading of the bracing will be performed by using steel wedges, jacking or other approved means. The preloading is to be maintained at all times. In order to assure proper preloading, bracing load measuring instrumentation will be provided. The strain gages are to be of the vibrating wire type, weather resistant, suitable for permanent encasement in concrete and be mounted in pairs on opposite sides of webs of bracing members. Reading of the recording instruments will be done systematically. In addition to the instrumentation by the contractor, an independent instrumentation will be provided by The Department of Civil Engineering of the Massachusetts Institute of Technology.

It was assumed that, due to the low permeability of the soil, dewatering will not be a serious problem. It was intended that the prevailing ground water level adjacent to the work be maintained, and ground water recharged if required. Surface drainage will be diverted away from the excavations. Observation wells will be installed to assure compliance with the requirement that the prevailing ground water level be maintained.

In the areas where utilities are to remain, hand excavation was specified. As excavation proceeds, a supporting system will be installed. The last five-foot depth of excavation to final grade will be excavated in panels not exceeding 50 feet in width. The last five-foot depth of excavation will not be made unless the bottom structural grade slab concrete is placed within 30 days after such excavation is made. Unauthorized over-excavation will be replaced by compacted backfill or concrete. When it becomes necessary to remove any section of the supporting system when placing concrete, it will be done only after the load is transferred to the permanent structure. Backfill will be placed after walls and roofs of the structure have been placed and the concrete has developed a strength not less than 80% of the specified compressive strength. Material for backfilling was specified. It is intended to remove sheeting after backfilling operations.

The Bored Tunnel

Extensive study was conducted with regard to desirable methods of tunnel construction. Consideration was given to an underpinning method which would utilize the Turnpike slab as the roof of the structure. Unfortunately, this would have involved tedious hand mining techniques which are not desirable from the schedule and cost point of view.

It was recommended that the reinforced twin tunnels under the Turnpike be constructed in free air, utilizing a roof shield which will be propelled forward by hydraulic jacks to support the soft material of the crown. Because of the vertical alignment — a critical factor in the design — inadequate overburden over the crown of the tunnel mitigated against the use of compressed air: one-foot six-inches was specified as the maximum distance between the top of the tunnel and the underside of the Turnpike roadway slab. With this recommendation the following sequence of construction was proposed: (Figure 8)

1) Starting from a shaft, drive drifts nos. 1 and 2 by heading and bench method with roof poling plates. Use ribs and lagging in drift nos. 1 and 2, respectively, construct reinforced-concrete side and center wall pedestals. Anchor wall plates on the concrete pedestals.

2) Set up the half shield in the shaft and break away. With the shield riding on the wall plates drive heading A, erect ribs and gasketed liner plates (Figure 9) and grout. Heading A is to be driven to the open shaft in the track area. While heading A is being advanced, drift no. 3 can be driven from the open cut and east side-wall constructed.

3) After completion of heading A and drift no. 3, the shield can be turned to drive heading B north towards the station. During the driving of heading B, the arch concreting and low pressure grouting in heading A can be undertaken.

4) Excavate the remaining bench in tunnel A while concreting the arch and grouting in heading B.

5) After completion of the reinforced concrete arch in tunnel B, excavate the remaining bench and pour the invert concrete as outlined for tunnel A.

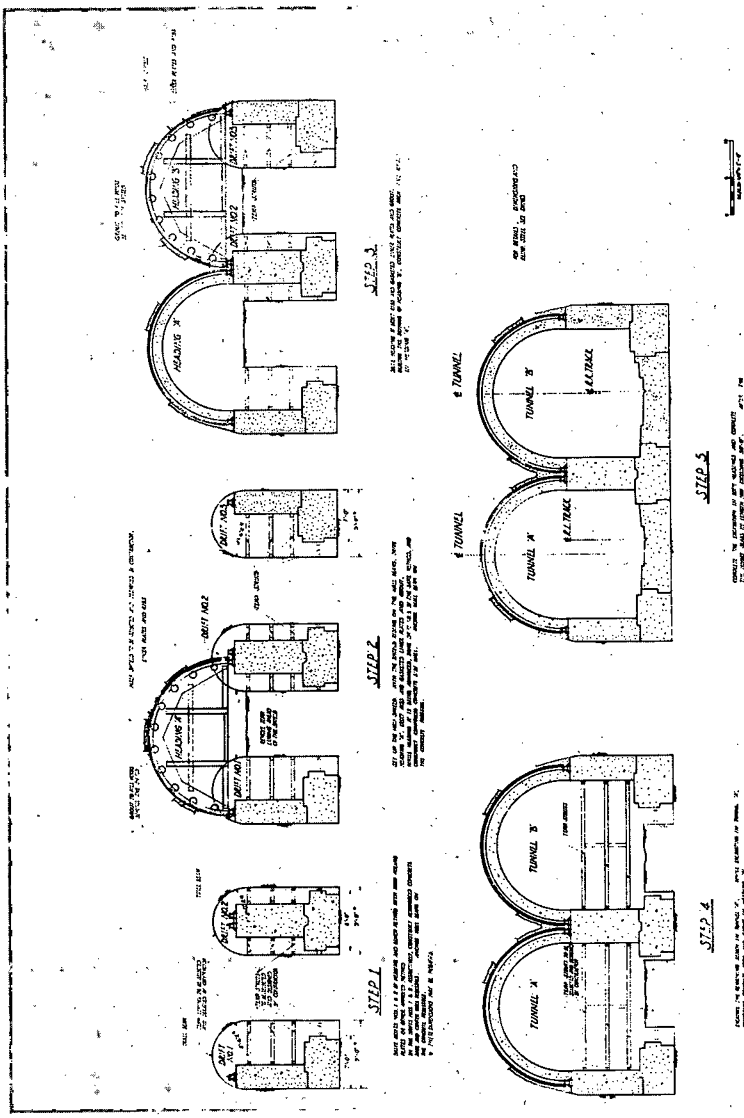

Fig. 8. — Cross-sectional view shows the step-by-step procedure in the construction of the tunnel structure. The permanent vertical walls of the tunnel will be constructed within three parallel drifts which will form the guideways over which the roof shield will be advanced.

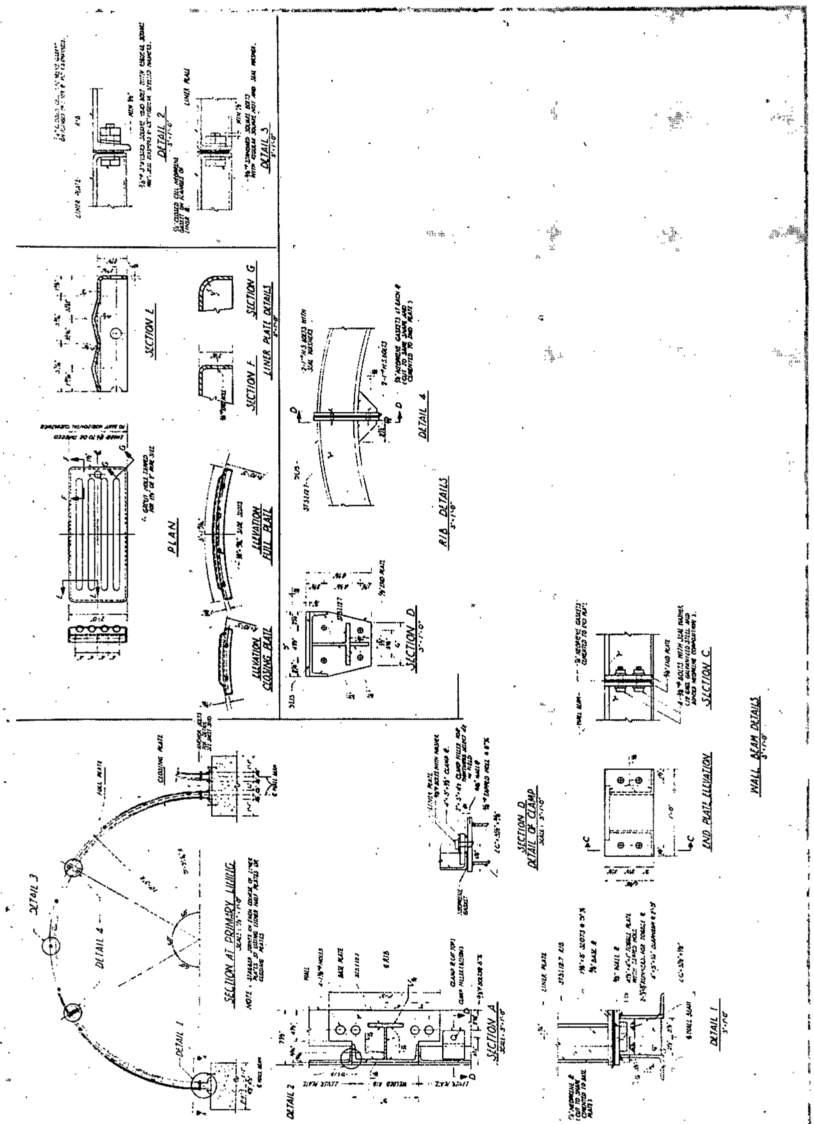

Fig. 9. — As soon as the first heading is driven, with the shield riding on the wall plates, gasketed liner plates and ribs will be erected. The details are shown here.

It was specified that an attempt should be made to stabilize the roadway fill and the silt. Ground freezing was thought to be impracticable and costly.

Station Structure

The station structure will be constructed by cut-and-cover method as previously discussed. It will be a reinforced-concrete structure except for the roof, which will be a composite ceiling system. This system is predicated upon structural requirements. The roof will carry heavy building loads from the proposed Don Bosco High School. A 20-foot on center steel column system will support a deep plate girder "spine" with a one-way composite ceiling system of 5-foot on center beams spanning between the plate girder and concrete exterior walls.

Concrete fireproofing for all structural steel was specified in order to conform to all local and national building codes, and good long-term maintenance provisions. Although a subway station in Boston is not governed by these codes, fireproofing is recommended as a desirable public safety standard. (Figure 10.)

In order to reduce the effect of ground water seepage into the station, the top of the lowest portion of the structure, which falls in the central area of the station, was raised to an elevation somewhere above the existing water table.

Ventilation shafts leading up to the surface located beyond each end of the station were specified, based on the design criteria discussed earlier. These serve the purposes of comfort cooling, ventilation, emergency-ventilation and the reduction of the piston effect created by the train as it enters the station from the confined space of the trainway by drawing out the excess air pressure. The space under the platform will be used for ventilation. Openings between the trainway and this space were provided through which air, heat, odors and miscellaneous small particles such as brake shoe dust will be removed through the fans and ventilation shafts. The increased cubic footage at each end of the station will also aid in minimizing the piston effect.

All exposed concrete work in ceilings, walls and columns will be an unpainted, smooth finish, with a light gray cement for maximum reflectivity of the fluorescent lighting system.

All platform, mezzanine, lobby and corridor floors will be brown quarry tile. Safety strips at platform edges will be yellow quarry tile. All walls and partitions will be medium gray glazed structural tile and the head

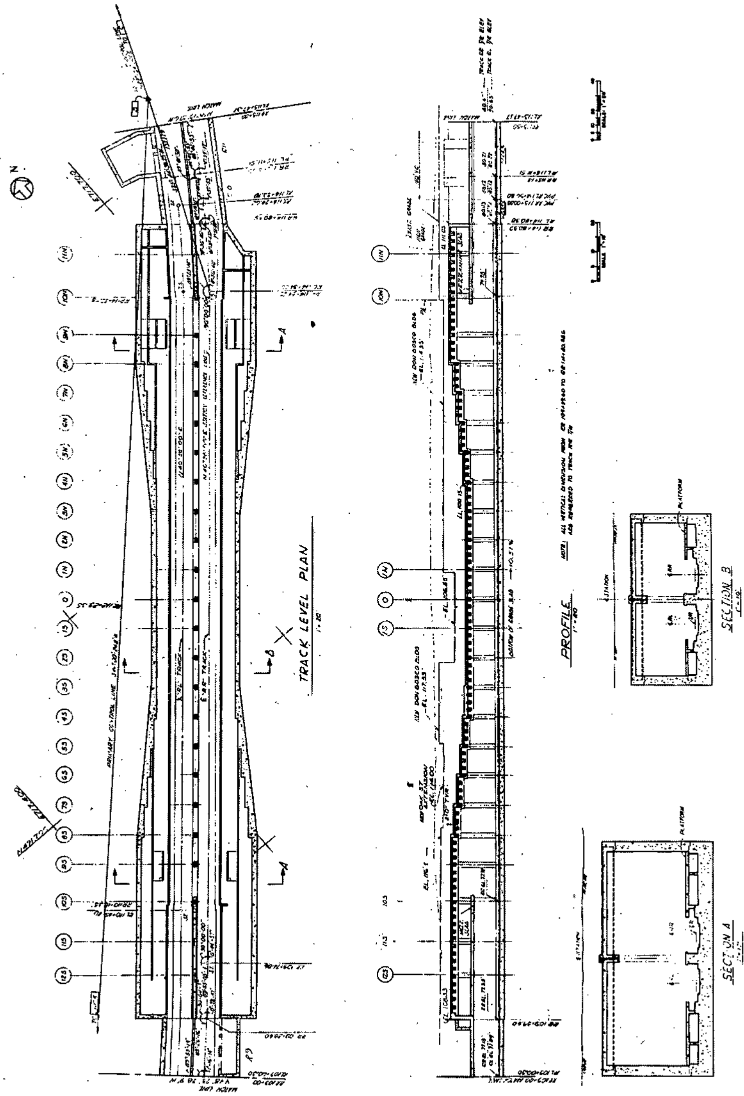

Fig. 10. — The station structure will be constructed by cut-and-cover methods and will be of reinforced-concrete except for the roof which will be a composite ceiling system. The more than usual volume of space at each end of the platforms will aid in minimizing the piston effect associated with trains as they enter a station from a tunnel.

houses exposed concrete, so as to match the color and texture of related building complexes.

In order to comply with the waterproofing criteria discussed previously, cavities will be provided between the concrete exterior walls and the glazed structural tile interior walls so as to provide for ground water seepage runoff, and waterproofing on the top of the structure. Acoustical treatment will not be provided at this time; but in the space beneath the platform, where treatment will be most beneficial, provisions were made for future acoustical treatment.

Concrete Cut Off Wall Installed By Slurry Trench Process

From the various design considerations discussed before a reinforced tremie concrete wall will be installed by the slurry-trench process along the line of, and immediately exterior to, the subway structure on both sides of the excavation adjacent to the Don Bosco High School. The wall is to be separated from, and not incorporated in, the permanent subway structure. Materials, equipment and construction methods to be used were specified. It is not intended to go into details with regard to this method, except that some information may be of interest. The slurry properties will be determined by tests described in the American Petroleum Institute Standard 13 B, "Standard Procedure for Testing Drilling Fluids". The specific gravity of the slurry will not be less than 1.05 nor more than 1.10. Sand content will not exceed 5% at any time. Tremie concrete will be 3000 psi, using 10% additional cement, 3/4-inch maximum size coarse aggregate, retarding-densifier admixture and a slump between 7 and 9 inches.

In order to provide for protection of the building, construction of the wall will have limitations as follows:

— Within the 50-foot length of wall closest to the Don Bosco Technical High School, the maximum width of slots will be 10 feet. Elsewhere the maximum width of slots will be 20 feet. (Figure 11.)

— Within any 50-foot length of wall, no more than two excavated slots will be left slurry-filled without tremie concrete in place. In addition, there will be at least one unexcavated slot, or tremie concrete filled slot, between the two excavated slots. Placement of tremie concrete will be started in the excavated slot within twelve hours of completion of excavating the slot and proceed continuously until completion of concreting.

— Before starting the slurry trench excavation, the Contractor will submit for approval, the slot distribution he intends to use, in accordance with the

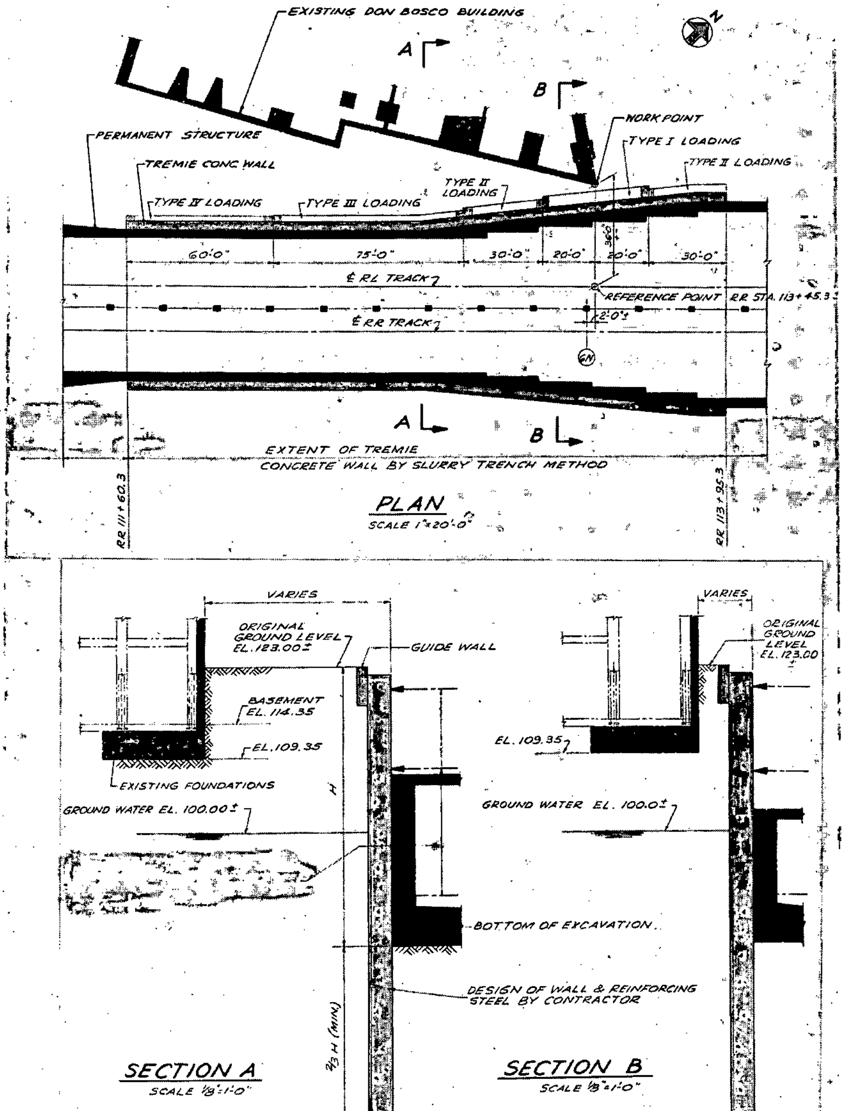

Fig. 11. — The reinforced tremie concrete cut-off walls for supporting the excavation adjacent to the Don Bosco High School will be installed by means of the bentonite slurry-trench method. 3000 p.s.i. tremie concrete will be used to displace bentonite slurry previously placed around reinforcing steel cages in the excavated slots. Within the 50-foot length of wall closest to the school, the maximum width of slot will be 10 feet.

limitations outlined above. After approval, the slot limits will be clearly marked on the guide trench. The system of guiding the slot excavating equipment will be such as to make it possible to excavate the slot within the marked limits.

— A Slot Inspection Tool will be designed and furnished by the Contractor. The inspection tool will be capable of showing that the slots are fully excavated to the full depth and that the ends of concrete panels already poured are clean.

— Concreting equipment will be capable of placing the tremie concrete at the bottom of the slots and up through the full height of the slot. Concrete may be placed by gravity flow or by pumping.

— The slots will be maintained full of slurry during excavation operations and until the tremie concrete placement is essentially completed. Precautions will be taken to prevent any sudden loss of bentonite slurry from the trench, and any loss, if it occurs, will immediately be replenished with slurry. The slurry will be circulated or agitated during excavating operations and immediately prior to concreting. However, the slurry requirements will be maintained at all times, including non-working periods and stoppages; and circulation or agitation shall, if necessary, be continuous to meet these requirements.

After the slot has been excavated to the required depth and inspected and cleaned, prefabricated reinforcing steel cages will be lowered into the slot and correctly positioned. Excavated slots between bulkheads will be filled with concrete placed by the tremie method. The slurry level will be maintained within two feet of the top of the slot during concrete placement. Casings or other shapes used for bulkheads and for forming keys in concrete will be extracted when concrete has taken its initial set.

The Contractor will be responsible for determining that the quantity of concrete deposited is not less than the volume of wall occupied thereby.

Utilities

The Contractor is responsible for maintaining and supporting all utilities affected during the prosecution of his work. Generally, this is a very serious problem. To avoid complications, all schedules and work efforts were carefully coordinated in advance. Under a separate contract for the Boston Redevelopment Authority, a utility relocation plan of public utilities was prepared by Chas. T. Main Inc., Engineers, and was made part of the subway construction contract. The private utility companies are in the process of relocating all utilities in the vicinity of the construction. With this advance planning and scheduling it is hoped that either no utilities, or just a few lines of minor importance, will stay within the limits of excavation. However, at the intersection of Stuart-Kneeland and Washington Streets this is not the case. The maze of combined sewers, telephone, telegraph, gas, water (high and low pressure), electric and steam lines will be supported and maintained at all times in coordination with the private utility companies. It must be noted also that in this area, soldier piles and lagging for excavation support is to be allowed. (Figure 12.)

Maintenance, Support and Protection of Existing MBTA Facilities

The MBTA's trains will be in daily operation during the performance of the work in the existing tunnel. It is required that all demolition and new construction work be done without interruption or change in the regular schedule of train operations. The passenger trains operate continuously on weekdays between the hours of 5:15 a.m. to 1:00 a.m., and on Sundays between the hours of 6:00 a.m. to 1:00 a.m. Occasionally work trains operate through these areas during the hours when passenger trains do not operate. At the location of construction affected by the passenger train operations, a large percentage of the work will be performed during the hours when passenger trains do not operate. In addition, temporary shields and partitions will be provided on the inside portion of the existing structure to be demolished, for the protection of persons and equipment. No explosives will be used for demolition.

STAGING

The South Cove Tunnel Project will cost about $18.5 million, and will be built in three separate stages, spread over a four-and-a-half to five-year period.

The first contract covers the construction of about 1,500 feet of cut-and-cover subway section including the passenger station, a connection to the existing Washington Street tunnel, and the bentonite slurry cut-off walls to the Technical High School. Bids were taken on September 10, 1968, for this first stage and the contract was awarded to Peter Kiewit Sons' Co. for a sum of approximately $11.6 million; a bid, gratifyingly enough, just about 5% over the engineering estimate. The first contract is scheduled to last 2 1/2 years.

The second contract will cover the construction of the bored tunnel under the Turnpike, the open cut section and the Tremont-Arlington Street bridge. The third, the architectural fit and finish work, will include station

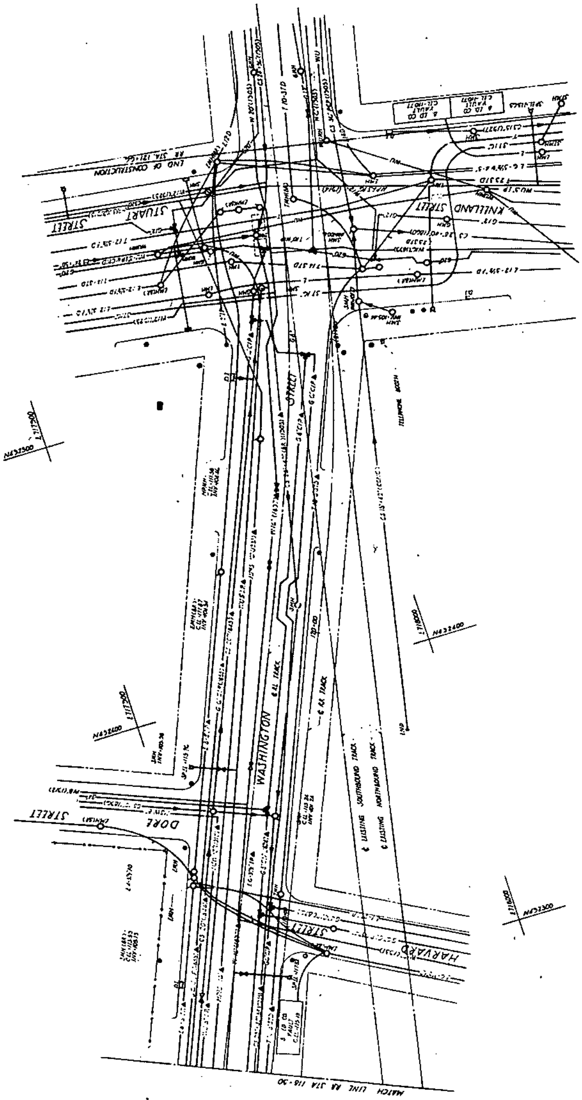

Fig. 12. — A maze of utilities exist at the Stuart-Kneeland and Washington Street intersection. These utilities will be supported and maintained at all times in coördination with the private utility companies.

escalators, ventilation and electrical works. In addition, after completion of all construction of the Southwest Corridor, one contract for the entire line will cover the track installation, and a separate contract will cover the traction power installation.

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