CRITERIA
STRUCTURAL

CUT-AND-COVER UNDERGROUND STRUCTURES

CONTENTS

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1. SCOPE

The criteria set forth in this Section govern the static load design of all cut-and-cover underground structures with the exception of pile foundations, which are covered in Facility Design, Criteria, Structural, Foundations. The cut-and-cover underground structures include subways, cross-passages, sump pump structures, stations, ventilation structures, and other structures of similar nature.

The design of building components such as stairs, elevators and escalators etc. within the cut-and-cover underground passenger stations and live loads on cut-and-cover underground passenger station platforms shall be in accordance with Facility Design, Criteria, Structural, Passenger Stations and Buildings.

2. APPLICABLE CODES

The design of structures within the scope of this Section shall be in accordance with the provisions set forth in these Criteria and shall also meet the requirements of the CBDS, CBC, ACI, AISC and AWS, except where such requirements are in conflict with these Criteria.

3. STRUCTURAL SYSTEM

Structural system for cut-and-cover line structures shall be single and/or multi-cell reinforced concrete box structures, with walls and slabs acting one-way in the transverse direction to form a continuous frame. Temporary excavation support systems shall not be used as whole or part of the permanent walls. Expansion or contraction joints are required at locations of major change in structural sections such as from line structure to station. All construction joints shall have continuous reinforcing steel, non-metallic waterstops and sealants.

Driven steel or concrete piles, cast-in-place drilled hole piles, and prestressed or non-prestressed soil anchors are not allowed for resisting uplift or flotation.

4. LOADS AND FORCES

4.1. General

All components of underground structures shall be proportioned to withstand the applicable loads and forces described in Facility Design Criteria, Structural, Aerial Structures. The load factors and design shall be in accordance with Article 4.11 specified herein.

4.2. Zone of Influence

For temporary effects during construction to the existing BART's structures, the Temporary Zone of Influence is defined as the area above a positive Line of Influence which is a line from the critical point of substructure at a slope of 1 1/2 horizontal to positive 1 vertical (line sloping towards ground level) or the area below a negative Line of Influence which is a line from the critical point of substructure at a slope of 1 1/2 horizontal to negative 1 vertical (line sloping away from ground level).

The Geotechnical Engineer for the proposed structure has to determine the permanent effects/influence to the existing BART's structures based upon the soil conditions in the vicinity of the proposed structures and the existing BART's structures. Particular attention shall be paid to liquefiable soil, expansive soil, soil classified as Site Class E or F in accordance with ASCE 7 and lateral spreading, etc. Under these soil conditions, the slope of the Permanent Zone of Influence shall be determined by the Geotechnical Engineer, but shall not be steeper than the slope of the Temporary Zone of Influence as specified above.

4.3. Future Traffic Loads

An area surcharge applied at the ground surface both over and adjacent to underground structures is to simulate possible roadway and sidewalk live loads. This surcharge is also intended to simulate conditions during future construction activities adjacent to the underground structures. Such construction may result in permanent loads, or in temporary loads from construction equipment, from the stockpiling of construction materials, or from the deposition of excavated earth. It is also possible that loads such as those from hauling trucks, may be applied inadvertently to the underground structures due to their innate inconspicuousness.

An area surcharge shall be applied at the ground surface both over and adjacent to underground structures. The vertical surcharge shall be considered as a static uniform load applied at the ground surface as follows:

a. 600 psf for $x < 5$
b. 600-40(x-5) psf for $5 \leq x \leq 20$
c. 0 for $x > 20$

x = Vertical distance from the top of subway roof to ground surface, in feet.

The above surcharge shall not be applied, when

a. The alternative traffic loading specified in Article 4.4 is applied, or when
b. A specific, applicable building surcharge as described in Articles 4.5 and 4.6 is applied.

Recommended coefficients for horizontal surcharge loading shall be presented in the Final Geotechnical Engineering Report.

The surcharge shall be applied to all underground structures, line and stations, unless (1) positive and recognizable means are provided at the ground surface to ensure that the above types of loading cannot occur and (2) the District specifically permits, in writing, the application of a surcharge of lesser magnitude.

4.4. Alternative Traffic Loading

For the underground structures beneath or adjacent to operating railroads, both the vertical and lateral surcharge shall be based on Cooper's E-80 railroad surcharge loadings. Refer to the standards of the subject railway.

For the underground structures adjacent to existing State bridge overcrossings, both the vertical and lateral surcharge shall be based on the operating loads from the Contractor's equipment with a minimum surcharge loadings equivalent to a 100-ton crawler crane.

For underground structures beneath highways, city streets or planned roadways, the applied vehicular live load shall be based on the HL-93 loading according to the CBDS. For underground structures which are not anticipated to be beneath railroads, overcrossings, highways, streets, or roadways, the applied live load shall be based on no less than HL-93 loading according to the CBDS. The distribution of this live load shall be in accordance with the following:

a. Fill height less than two feet - live load shall be applied as concentrated loads directly to the top of the slab.

b. Fill height greater than two feet - concentrated live loads shall be distributed over a square area, the sides of which shall equal 1.75 times the depth of the fill.

c. When distribution areas overlap, the total load shall be uniformly distributed over an area defined by the outside limits of the individual areas.

For design of the top slab of underground structures supporting the alternative traffic loading, impact loading (I) shall conform to the following:

0 ft. to 1.0 ft. fill height	I	=	30 percent of LL
1.0 ft. to 2.0 ft. fill height	I	=	20 percent of LL
2.0 ft. to 3.0 ft. fill height	I	=	10 percent of LL
more than 3.0 ft. fill height	I	=	0 percent of LL

The fill height shall be measured from the top of ground or pavement to the top of the underground structure.

4.5. Existing Structures

- Existing structures that are to remain in place above underground structures shall either be underpinned in such a manner as to avoid increased load on the underground section, or the section shall be designed to support the structure directly. Non-BART structures may be supported directly on BART structures only with specific approval in writing by the District.

- Underground structures shall be designed for additional loading from existing adjacent buildings or structures unless they are permanently underpinned or have foundations to below the zone of influence. A building shall be considered to be adjacent to the underground structures when it is within the Temporary or Permanent Zone of Influence as specified herein Article 4.2.

- Each existing structure shall be considered individually. In the absence of specific data, for a given height of building and type of occupancy, applicable foundation loads shall be computed according to the CBC and the additional uniform lateral pressure on that portion of the subway sidewall below the elevation of the building foundation shall be distributed as shown on the preliminary engineering drawings. If distribution is not indicated on the preliminary engineering drawings, Designer shall determine distribution.

4.6. Future Structures

4.6.1. Clearance

Structures over or adjacent to BART's subway structures shall be designed and constructed so as not to impose any temporary or permanent adverse effects on subway. The minimum clearance between any parts of the adjacent BART structures to exterior face of substructures shall be the larger of the Temporary and Permanent Zone of Influences, the Operating Envelope as specified in Facility Design, Criteria, Structural, Aerial Structures, Article 7.9, Operating Envelope, and 7 feet 6 inches. In addition, the substructures shall be located such that the lateral loads from the foundations of the structures shall not impact the BART structures. Minimum cover of 8 feet shall be maintained wherever possible.

4.6.2. Surcharge

In general, cut-and-cover subway structures were designed with an area surcharge applied at the ground surface both over and adjacent to the structures. The area surcharge was considered static uniform load with the following value:

D (ft)	Additional Average Vertical Loading (psf)
D>20	0
5<D<20	800-40D
D<5	600

Where **D** is the vertical distance from the top of the subway roof to the ground surface.

4.6.3. Steel-lined Tunnels

In general, steel-lined tunnels were designed to support the weight of 35 feet of earth above the roof of the tunnel. Whenever the actual depth of cover is less than this amount, construction may be added imposing an additional average vertical loading of 120 pounds per square foot for each foot of depth of reduced cover. Where basements are excavated, the allowable additional average vertical loading can be

increased to the extent that it is balanced by the weight of the removed material. The effects of soil rebound in such cases shall be fully analyzed.

4.6.4. Shoring

Shoring is required for excavations in the Zone of Influence. Zone of Influence is defined herein Article 4.2.

See Facility Design, Criteria, Structural, Aerial Structures, Article 7.2, Shoring, for seismic and wind load requirements for temporary structures. In this case, the BART structure to be supported by shoring shall be treated as temporary structure and the duration is the period that the BART structure be shored for the construction of the adjacent structure.

4.6.5. At-Rest Soil Condition

Shoring shall be required to maintain at-rest soil condition and monitored for movement.

4.6.6. Soil Redistribution

Soil redistribution caused by temporary shoring or permanent foundation system shall be analyzed.

4.6.7. Dewatering

Dewatering shall be monitored for changes in groundwater level. Recharging will be required if existing groundwater level is expected to drop more than 2 feet.

4.6.8. Piles Predrilled

Piles shall be predrilled to a minimum of 10 feet below the Line of Influence. Piles shall be driven in a sequence away from BART structures. No pile will be allowed between steel-lined tunnels.

4.6.9. Vibration During Pile Driving and Soil Compaction (Vibro Compaction etc.)

Subway structures shall be monitored for vibration and settlement caused by the operations of the construction equipment including but not limited to pile driving and soil compaction (vibro-compaction, etc.).

The Peak Particle Velocity (PPV) in the vertical direction as measured from the closest BART structures to the construction equipment shall not exceed 1.0 in/sec (transient source) and 0.5 in/sec (continuous/frequent intermittent source). For structures supporting BART tracks, the BART tracks movement shall be limited to a maximum of 1/4 inch per 30 feet of length in both horizontal and vertical directions. For other structures, the settlement shall not exceed 0.3 inches.

4.6.10. Hand Excavation

Excavation shall be done with extreme care to prevent damage to the waterproofing membrane and the structure itself. Hand excavation shall be performed for the final one foot above the subway roof.

Refer to Article 4 of Facility Design, Criteria, Structural, Foundations for requirements regarding construction adjacent to existing and BART structures.

4.7. Earth Pressure

4.7.1. Vertical Earth Pressure. Depth of cover shall be measured from the ground surface or roadway crown, or from the street grade, whichever is higher, to the top of subway surface. Saturated densities of soils shall be used to determine the vertical earth pressure. Recommended values shall be presented in the Final Geotechnical Engineering Report.

4.7.2. Lateral Earth Pressure. See Facility Design, Criteria, Structural, Earth Retaining Structures. For the purpose of these criteria, cut-and-cover subway box sections are defined as structures with stiff walls, which are restrained at the top so that the amount of deflection required to develop active pressure is not possible.

4.8. Hydrostatic Pressure (Buoyancy)

The effects of hydrostatic uplift pressure shall be considered whenever ground water is present. The hydrostatic uplift pressure is a function of the height of water table above the foundation plane, and shall be assumed uniformly distributed across the width of the foundation in proportion to the depth of the base slab below the design ground water table

Structures shall be checked for both with and without buoyancy to determine the governing design condition. Maximum design flood levels are indicated in the Hydrology Report. If Hydrology Report is not part of the preliminary engineering documents provided by the District, Designer (or its Geotechnical Engineer) shall research, determine applicable levels and submit the report to BART Engineering for approval.

4.9. Flotation

4.9.1. General

For design flood levels and flood zone, see the Hydrology Report, if applicable.

Cut-and-cover structures subject to ground water table and/or located within the flood zone shall be checked and provided with adequate resistance to flotation.

No permanent dewatering system shall be assumed for the design of underground cut-and-cover structures.

4.9.2. Factor of Safety

- The structure shall have a minimum factor of safety against flotation at any construction stage of 1.03, excluding any benefit from skin friction.
- The structure, when complete, shall have a minimum factor of safety against flotation at up to the 100-year flood level of 1.07 excluding skin frictional effects.

- The structure, when complete, shall have a minimum factor of safety against flotation at the 500-year flood level of 1.00 excluding skin frictional effects.

- The dead weight of the structure used in the flotation calculations for the underground structures shall exclude the weight of:

  1. Any building above the structure,
  2. Any live load internal or external to the structure,
  3. Any loads which may not be effective at the time, and
  4. 2 feet of backfill over the roof except when checking against the 100-year and 500-year flood levels.

4.10. Earthquake Forces

See Facility Design, Criteria, Structural, Seismic Design, for the requirements for seismic design of underground structures.

Temporary structures in contact with the permanent structures and to be left in-place shall be designed as permanent structures under earthquake loadings.

4.11. Load Factors

The cut-and-cover underground structures shall be designed for the following static loading conditions:

1. $U = 1.2 (D + T) + 1.6L + 1.6H$

2. $U = 1.2 (D + T) + 1.6L + 1.6H + 1.6B$

Where
- U = Minimum required strength to resist factored loads or related internal moments and forces.
- D = Dead loads including structural components and non-structural components, gravity load of soil, water in soil, and structures directly supported on the subway structure.
- L = Live loads including BART system live load, impact due to moving trains, centrifugal force, longitudinal force where applicable, vertical aerial surcharge at the ground surface to simulate the roadway and sidewalk live loads, and all other miscellaneous live loads as specified.
- H = Lateral loads due to horizontal pressure of soil, design groundwater in soil, horizontal surcharge from the surface live loads and additional pressure from existing adjacent buildings or structures.
- B = Vertical hydrostatic pressure (Buoyancy)

T = Cumulative effect of temperature, creep, shrinkage, differential settlement, and shrinkage-compensating concrete.

3. All factors in the loading combinations specified in these Load Factors shall be changed to 1.0 when design groundwater load is replaced by load due to 500-year flood.

4. Design flood loadings shall not be combined with seismic load.

5. The cut-and-cover underground structures shall be designed in accordance with the ACI 318 strength design method.

4.12. Subway Walkway Cover Live Loads

Stationary and hinged cover assemblies shall be designed for a minimum uniform live load of 100 pounds per square foot or a concentrated live load of 1,000 pounds over a 2 feet by 2 feet area. Deflection at center of span under 100 pounds per square foot uniform live load shall not be more than 1/8 inch. Hinged cover material shall comply with NFPA 130 requirements.

4.13. Live Loads and Equipment Loads for Ventilation Structures

See Criteria, Structural, Passenger Stations and Buildings, for roof and floor live loads and equipment loads for ventilation structures.

4.14. Reports, Plans, and Procedures

Refer to the applicable submittal requirements as specified in Article 4 of Facility Design, Criteria, Structural, Foundations to BART for review and approval

5. WATERPROOFING OF UNDERGROUND STRUCTURES

5.1. General

Roofs, walls, and floors (base slabs) of all underground structures including stations, auxiliary spaces except as otherwise noted, cut-and-cover subways, and tunnels shall be waterproofed. To ensure adequate inspection and long term performance, no blind side waterproofing shall be used.

Provisions shall be made to collect and drain water potentially seeping through the roof, walls, or floor whether such structure components are waterproofed or not. The design leakage shall assume a maximum of 0.2 gallons per minute per 250 feet of single track line structure, or per 10,000 square feet of continuous interior surface.

5.2. Station Structures

5.2.1. **Roofs.** Station roofs shall be completely waterproofed. Waterproofing and the boundary condition details at reglets and flashings shall be provided.

5.2.2. **Walls.** Exterior station walls shall be completely waterproofed. Mezzanine walls enclosing public areas and entrance walls shall be furred out, and provisions shall be made for collecting and draining seepage through these walls. The depth of the furring shall be governed by the space required for the placing of fare collection and other equipment, and architectural requirements, such as the minimum thickness of the wall finish. The fastening of the finish to the wall shall be such that water can drain off the walls freely and that it will not corrode the fasteners.

5.2.3. **Floor Slabs.** For station floor slabs, no special waterproofing provisions shall be made where the water can drain freely into the floor drainage system, and where such a leakage and drainage is not objectionable from a corrosion, operational or visual standpoint.

Drainage shall be provided at public areas of the station floor slab.

5.2.4. **Base Slabs.** Waterproofing shall be applied under station base slab.

5.2.5. **Appendages.** Differential vertical movements of the station body and its appendages, such as wings or entrances at shafts, due to ground re-expansion as a result of returning of ground water, may cause cracks at joints and other locations. Special attention shall be given to design detailing to mitigate this problem. Where such movements cannot be avoided, properly designed waterproof joints between such appendages and the station body shall be provided.

5.3. Line Structures

5.3.1. **Subway Box.** Exterior membrane waterproofing shall be applied to the outside of the cut-and-cover subway box and the base slab. The waterproofing from the roof shall extend to the sides of the box, 12 inches below the bottom of the roof slab. Waterproofing details including but not limited to interface between wall and roof/base slab shall be shown on the Contract Drawings. Any seepage through the walls or the floor shall be carried away by the track drainage.

5.3.2. **Transition Structure.** For subway daylight transition structures, where U-sections with exposed sidewalls are used, special attention shall be given to controlling shrinkage cracks in sidewalls between construction joints.

5.4. Electrical Rooms

Electrical rooms include spaces that house train control facilities, substation facilities, switchgear, ventilation fans, pumps, and other electrical equipment.

5.4.1. **Train Control and Auxiliary Equipment Rooms.** Rooms or spaces shall be completely waterproofed, including all wall and roof surfaces in contact with earth. Floor drains shall be provided. Refer to Facility Design, Criteria, Mechanical, for floor drains.

5.4.2. Substations, Switchgear, Fan Rooms, and Similar Equipment Rooms. Rooms or spaces shall have roof surfaces in contact with earth waterproofed. Floor drains shall be provided as required in Facility Design, Criteria, Mechanical.

5.4.3. Pump Rooms. Floor drains shall be provided to prevent the accumulation of seepage as required in Facility Design, Criteria, Mechanical.

5.5. Waterstops and Sealants

Waterstops and sealants shall be used in all construction joints in exterior walls, floors, and roofs.

5.6. Bentonite and Other Waterproofing Materials

Bentonite waterproofing shall not be used where the site is exposed to infiltration of seawater, which may inhibit formation of the bentonite gel or cause long term deterioration. In such locations, butyl or built-up membranes may be used, and injection shall be limited to epoxy type materials.

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