Report No. UMTA-MA-06-0025-78-2

RAPID TRANSIT SUBWAYS - GUIDELINES FOR ENGINEERING NEW INSTALLATIONS FOR REDUCED MAINTENANCE

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JANUARY 1978
GUIDELINES

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
Office of Technology Development and Deployment
Office of Rail Technology
Washington DC 20590

Technical Report Documentation Page

1. Report No. UMTA-MA-06-0025-78-2	2. Government Accession No.	3. Recipient's Catalog No. PB279453
4. Title and Subtitle RAPID TRANSIT SUBWAYS – GUIDELINES FOR ENGINEERING NEW INSTALLATIONS FOR REDUCED MAINTENANCE		5. Report Date JANUARY 1978
		6. Performing Organization Code
7. Author(s) James Birkmyer		8. Performing Organization Report No. DOT-TSC-UMTA-78-2
9. Performing Organization Name and Address BECHTEL INCORPORATED* FIFTY BEALE STREET SAN FRANCISCO, CA 94119		10. Work Unit No. (TRAIS) UM804/R8723
		11. Contract or Grant No. DOT-TSC-1078
12. Sponsoring Agency Name and Address U.S. DEPARTMENT OF TRANSPORTATION URBAN MASS TRANSPORTATION ADMINISTRATION OFFICE OF TECHNOLOGY DEVELOPMENT AND DEPLOYMENT OFFICE OF RAIL TECHNOLOGY WASHING, DC 20590		13. Type of Report and Period Covered Guidelines July 1975-March 1977
		14. Sponsoring Agency Code

15. Supplementary Notes

*UNDER CONTRACT TO: U.S. DEPARTMENT OF TRANSPORTATION TRANSPORTATION SYSTEMS CENTER KENDALL SQUARE CAMBRIDGE, MA 02142

16. Abstract

Economic design of new subways requires optimization of installation and maintenance costs of all the major constituent items. A prerequisite for this is an awareness of the rigorous environmental and other conditions imposed on the subway.

Changing ground pressures crack structures, and this results in water seepages that deteriorate both the structure and the installed items.

Durable watertight structures are obtained by using appropriate structural systems, material specifications, construction details, and waterproofing systems. Cathodic protection provides an economic protection against corrosion of metallic items in aggressive soil conditions.

Ventilation and pump structures should be planned for ease of access and maintenance. Vents flush with street or sidewalk increase the dirt load and maintenance; above-surface alternatives should be evaluated.

Escalators are high total cost items and operate under especially arduous conditions. Maintenance costs are reduced by using heavy duty components, adequate monitoring systems, and by designing the housing and machine room to permit ready maintenance and inspection. Automatic lubrication or sealed bearings also reduce maintenance.

Elevators, ventilation equipment, and pumps and their housings should be engineered and specified to maximize durability of component and minimize maintenance on a similar basis to escalators. Passenger elevators should be planned to also move maintenance equipment and materials.

Satisfactory architectural finishes should be selected for durability and ease of cleaning as well as for appearance.

Stations should be planned for adequate monitoring of all spaces and for good illumination to reduce vandalism and to enhance public safety.

Effective maintenance depends on ready accesses and provisions for movement of equipment and materials in the various sections of the subway. Station entrances, the portals, and ventilation and pump shafts should be designed accordingly.

Guidelines and justification of good design practice for these and related subjects are presented.

17. Key Words Service conditions, interacting variables, waterproofing systems, concrete for durability, tunnel linings, monitoring corrosion, corrosion protection, cathodic protection, escalators, elevators, pumps, lighting, architectural planning and finishes, maintenance accesses and facilities	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED		22. Price A06 - A01

Form DOT F 1700.7 (8–72) Reproduction of completed page authorized

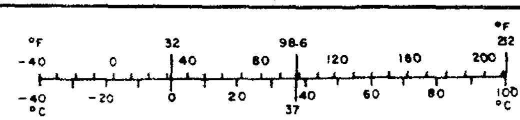
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

These "Rapid Transit Subways - Guidelines for Engineering New Installations to Reduced Maintenance" are the result of evaluating design philosophies and consequent maintenance problems and practices of several transit properties in this country and abroad. The objective is to provide engineers and architects with concise guidelines to optimize capital expenditures against maintenance costs. It is recommended that the design staff for a new installation include the engineer who will be responsible for its maintenance and cleanliness.

Subways vary widely in size, capacity, geology, construction materials, systems, and techniques. However, it is believed that in each similar economic solutions can be obtained by using rational engineering and comparative cost evaluation techniques. It must be emphasized that these guidelines do not supercede nor take precedence over codes, laws, and ordinances of municipalities or states in which the operating property is located.

Construction and maintenance of the basic structure are of prime consideration. Settlement and water leaks make a maintenance program both costly and discouraging. The architectural or cosmetic treatment of the public areas has to be both pleasing and easily maintained. The vertical and horizontal transportation systems within the station must be dependable and ready to serve the rider on the way to his destination. The trackway pumps and ventilation fans, unseen by the public, must perform reliably in their functions of keeping the property warm, dry, ventilated, and safe on all occasions.

It is hoped that these guidelines will assist both in upgrading the quality and in reducing the total costs of transit systems and thereby providing acceptable economic transportation for people within metropolitan areas.

The sponsor of this study was The Office of Rail Technology, Office of Technology Development and Deployment, Urban Mass Transportation Administration of the U.S. Department of Transportation. It is part of the Coordinated Department of Transportation Tunneling Program.

This work was performed under contract to the Transportation System Center (TSC) Cambridge Massachusetts. The contract was awarded under TSC's Urban Rail Supporting Technology Program with Mr. Gerald R. Saulnier of the Office of Ground Systems as technical monitor. The author wishes to thank UMTA, the sponsor and Mr. G. Saulnier of TSC for the assistance and advice provided during the execution of the work.

Early in the work schedule, the American Public Transit Association (APTA) formed a Maintenance Guideline Committee, the members of which comprised the Maintenance Superintendents of Massachusetts Bay Transportation Authority, Chicago Transit Authority, New York City Transit Authority, New York Port Authority, Trans-Hudson Corporation, and Washington Metropolitan Area Transit Authority. Under the chairmanship of TDC, the committee defined maintenance areas of particular interest to ongoing operating properties. The committee also provided considerable maintenance data from represented properties and valuable constructive critiques of the Guidelines as they were being written.

Bechtel's consultants for the work were Mr. E. E. McPhail, Manager of Plant Maintenance, Toronto Transit Commission and the Maintenance Superintendents of the London Transport Executive. Both consultants drew deeply from their considerable experiences in maintaining their subways and greatly assisted in formulating many of the Guidelines.

Other transit property managements who cooperated most helpfully in this work by making available both their maintenance engineering staff for onsite discussions and by providing their maintenance data, were San Francisco-BART, Paris-RAPT, Stockholm-SL, Brussels-STIB, Berlin-BVG, Hamburg-HHA, Munich-SV.

Several maintenance equipment manufacturers and contractors provided useful data about their particular equipment or operations. These included the San Francisco offices of Otis Elevator Company, American Colloid Company, the Tile Council of America, and the National Terrazo and Mosaic Association, Inc.

For the assistance provided by these transit properties, organizations, and manufacturers, the author wishes to extend his thanks and especially to the various staff who, in spite of busy work schedules, gave their time freely to provide the information sought.

Publishers of technical material who kindly gave permission for reproducing some of their material (or referencing it) include American Concrete Institute, the Stamat Publishing Company, the Institution of Civil Engineers (London), and the Institution of Structural Engineers (London).

GUIDELINES FOR NEW STRUCTURES

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Section 1

SUMMARY

These Guidelines have been formulated to provide good planning criteria and engineering practices to optimize the installation costs against maintenance costs of the various structures, architectural finishes, and fixed mechanical/electric equipment that comprise an underground transit complex.

For such an undertaking, assumptions must be made about a number of fundamental conditions such as the physical boundaries, environment of the structures and certain factors that will vary during the lifespan of the structure. The factors include cost of money, inflation, economic relationships between labor and machine operations, and other time-dependent data. Generally, the particular conditions and factors upon which each guideline's recommendation is based is stated in Section 2 or as a qualification to the particular guideline.

SECTION 2 — SERVICE CONDITIONS AND GENERAL CRITERIA

The function of a subway structure is unique. The trackway contains the train, rails, electrical power conductor rail, a miscellany of sensitive electronic and electrical equipment, and other support services. The station structures house escalators, elevators, fare collection and other supportive mechanical and electrical equipment, and a variety of architectural finishes. All of these items require considerable maintenance, the scheduling and performance of which are often severely restricted by the presence of trains in the trackway and patrons in the stations. Guidelines are presented for assessing service conditions and interacting variables.

The service life of a subway installation is expected to exceed 150 years; the components and finishes may have to be replaced several times over this period.

The subway complex often exists in an aggressive environment; chemically charged groundwater and shifting ground loads take their toll on the structures, leakage and moisture on the installed items, and vandalizing patrons on the architectural finishes. All of these occurrences shorten the useful service life of a subway component. When formulating design criteria, the impact of all of these factors (which often interact) must be assessed and evaluated for all important items.

SECTION 3 – STRUCTURES

Causes of deterioration in underground structures are groundwater, chemical action, and stray electrical currents. These effects can be largely mitigated if the structures are made substantially watertight by good design and construction practices and by use of durable materials. Guidelines are provided to cover most conditions.

The following are relevant to achieving desirable objectives:

- design stresses in relation to reduceing cracking and inflow of water in several types of structures,
- good practice details for providing watertightness of various types of concrete joints,
- several aspects of importance such as the formulation of the concrete mix, placing and curing it, and other factors necessary to maximize the durability of reinforced concrete, and
- membrane waterproofing systems, materials, and protections.

Tunneled Structures

Tunneled structures may have two types of lining; both have somewhat differing requirements for the essential waterproofing. Guidelines are included for both types are as follows:

- Cast-in-place linings require attention to concrete joint details and waterproofing systems, and
- Segmented concrete and metallic linings have materials, details, and manufacturing requirements of various systems; various waterproofing methods must be used to obtain satisfactory water tightness.

Cossosion Protection

Exposed and embedded structural and miscellaneous steel and reinforcing steel are all subject to corrosion, and guidelines are provided for several types of desirable protection, including:

- protective coatings for structural, miscellaneous, and reinforcing steel,
- monitoring methods for corrosion in reinforcement and steel segmented tunnel lining, and
- design of cathodic protection systems.

Drainage Systems and Pump Structures

These include the collection, drainage, and disposal of water entering the subway from various sources. Guidelines are provided for sizing and designing the drainage systems to minimize maintenance; pumps structures should be located and arranged for ready access by the maintenance staff.

Ventilation Structures

The following design items are important to maintenance of the track ventilation structures:

- Position of the surface vent: the alternative locations of street surface level or in a structure in the sidewal or behind the property lines may have a major effect upon the degree of cleaning and drainage required, and

- Access for maintenance, drainage and provisions for cleaning: all are important to the degree of efficiency of the maintenance process.

The guidelines define the various provisions that should be made in the design to cater effectively for all these aspects.

SECTION 4 – MECHANICAL AND ELECTRICAL EQUIPMENT AND LIGHTING

Fixed mechanical and electrical equipment includes escalators, elevators, pumps, and ventilation fans. The guidelines for all of these items concentrate on incorporating design features that will extend the service life of the component and minimize its maintenance requirements.

For the individual items, the following additional specifics are included:

- Escalators: Accesses for maintenance; speed and running controls; mechanical and visual safety,
- Elevators: Planning for use in the station maintenance process and in emergency situations, evaluation of hydraulic versus traction types; reduction of vandalism,
- Pumps: Estimating water flows and sizing pumps and pumps sumps; alternative procedures for dealing with flooding situations; pump types and material specifications, and
- Ventilation equipment: Selecting equipment based on service conditions, appropriate quality, and space for maintenance,

Lighting Systems

The more important items affecting the selection and design of lighting systems in the underground complex concern safety, visual effects, and both installation and maintenance costs. In these respects specific guidelines are provided covering the determination of satisfactory illumination intensities and the interrelationship between lighting and the selection of finishes and ceiling systems.

SECTION 5 – ARCHITECTURAL PLANNING AND FINISHES

The maintenance costs and safety of a station and its architectural finishes are affected both by the layout and the selected finishes and installation details. Selection of the finishes should be based on comparative economic evaluations of installed versus maintenance costs, and guidelines have been provided in the major areas to establish the necessary parameters for evaluation.

The layout and planning of the station area should emphasize the aspects and details that will reduce vandalism, enhance safety, and simplify the cleaning operation.

The critical aspects of floor finish installation include interraction of the floor topping with services and the structure, expansion joints, and floor-to-wall details.

The desirable characteristics for floor finishes must be determined as well as varying durability and ease of maintenance among commonly used materials.

Stair treads must be repaired or replaced frequently. One approach to the problem is to provide readily replaceable treads in precast concrete or other material.

Wall finishes may be applied directly to the structure or separated from it by a false wall. Each system requires different details. If direct application is used, care is required in the installation to prevent structural cracks being propagated through the finish, and with false walls, provision must be made for ventilation and inspection of the structure behind. Wall finishes should be selected not only for appearance but for resistance against vandalism and durability.

Ceiling finishes also may be applied directly to the structure or suspended, and similar precautionary measures should be exercised during installation to prevent structure crack propagation and to provide ventilation and inspection of the structure. Several hung acoustic ceiling systems are recommended for evaluation.

As a guide to economic evaluation of finish materials and systems, refer to Section 6 of the "Rapid Transit Subway - Maintenance and Engineering Report."

SECTION 6 – MAINTENANCE ACCESSES AND FACILITIES

The three accesses from the surface to the subway are the stairs, escalators, and elevators of the station and through the portals; ventilation and pump shafts; and emergency exits of the trackway.

Guidelines are provided for planning and providing special details in such accesses to allow maintenance of the underground complex.

Section 2

SERVICE CONDITIONS AND GENERAL CRITERIA

The various operations within an underground transit system impose unique conditions on its structures. Besides the rail track and power conductor rails, the trainway contains an assortment of metallic hardware, cables, and often sensitive electrical equipment that must be supported and maintained. Wayside equipment, such as pumps, ventilation fans, and drainage systems are important supporting subsystems in the train operation and must function reliably. Closely spaced train schedules and the presence of the conductor rail impose restraints on the scheduling and maintenance of both the trainway and wayside items.

Passenger related equipment (escalators, elevators, fare systems, monitoring devices) also requires maintenance, and it is desirable that the stations be architecturally attractive as well as functionally efficient for thousands of patrons per day. Station maintenance is constrained by the presence of passengers in the station.

Guideline 2-1 — Service Conditions

Before engineering design criteria are established, a full appraisal should be made of the fundamental service factors. Some of the most important are described in the following paragraphs.

Service Life. The service life of underground transit facilities may be anticipated as 150 years or more; therefore, criteria must plan for maintaining and replacing many of the elements in the facilities.

External Environment. An underground structure has not only to support the loads of soil, water, and surface surcharges, but its materials frequently may be under constant and continuing attack from chemicals in the soil and water and from stray electrical currents. Furthermore, the soil load and surcharges may vary over the years, and these changing pressures may cause the structure to distort and crack; thus increasing its vulnerability to electrochemical attack.

Stray Electrical Currents. Most rapid transit trains are powered by direct electric current furnished by a conductor rail mounted on the track ties or structure base; the return current is transmitted through running rails. (London Transport is an exception in that it uses an additional conductor rail for the negative return.) Moisture and dirt, especially metallic dust, are always present in such systems and result in constant current leakage. This leakage or stray current can pass through transit structures (either metallic-lined tunnels or reinforced concrete cut-and-cover) into the groundwater to instigate electrochemical attack on both the transit structures and their adjacent structures and utilities.

This situation, coupled with the adverse effects to be expected from the external environment, creates a potentially costly maintenance problem that can, however, be avoided or minimized by appropriate engineering design.

External Physical Constraints. Surface traffic, groundwater, and adjacent structures frequently impede access to the underground structures from the outside, making it costly, difficult, and, in some cases, totally impractical to effect repairs from the outside.

Internal Physical Constraints. Maintenance of the trackway structure is constrained by the presence of trains, equipment, cables, and other items within the trackway. Station structure maintenance is constrained by the presence of passengers. These factors compound scheduling problems and increase the cost of the work. Hours of revenue service often extend through most of a 24-hour day, year round.

Mechanical and Electrical Equipment. Such items of equipment as escalators and elevators must be operated throughout most, if not all, of the hours of revenue service. The service demands made on them and their use and abuse by the public are much greater than in other commercial installations. Trackway pumping and ventilation equipment may be in constant operation, intermittent, or as standby for emergencies. Whatever the service, the installations are generally in damp, dirty, and aggressive environments.

Architectural Finishes. The density of passenger traffic in a heavily patronized station over most of a 24-hour day greatly exceeds that of any other private or public facility. Patrons enter the stations directly from the sidewalk and, according to its condition and to the season, carry in dust, mud, sand and salt (from snow removal), etc., on their feet. Thus, the floors, stairs, and escalators may receive heavy dirt loads during major periods of the year.

Rapid transit serves all elements of the population, and this inevitably includes a vandalism-prone portion, including youths and children, who are awaiting a chance to deface or destroy reachable walls, ceilings, seats, and other items.

Both of these situations are endemic to rapid transit properties and, in addition to efficient passenger flow, are the major factors to influence the choice of architectural finishes and station layout. Use of appropriate materials (and equally important, avoidance of unsuitable ones) for station finishes can help minimize maintenance costs. Layouts that permit maximum surveillance by the station staff and that place vulnerable material outside of easy access by the public are equally important.

Justification:

The conditions to which rapid transit property is subject must be recognized and defined to enable the development of economic engineering design criteria. The important differences between the service conditions of underground transit structures and of other structures must be appreciated if a satisfactory design is to be achieved.

Guideline 2-2 — Evaluation of Interacting Variables Affecting Maintenance

When service conditions have been defined, design criteria for each component of the underground system should be developed through an evaluation of installation costs versus maintenance and replacement costs. These evaluations must include examination of the several interacting design options against physical variables to determine both maintenance costs and procedures. Illustrative of the more important components and considerations in their evaluations are listed below:

1. Structural systems and quality of materials,
2. Materials and systems for waterproofing the structures; evaluation of economic trade-off between installation of complete membrane waterproofing against increased cost of maintaining a structure that is not or is only partially waterproofed (if the structures are completely waterproofed, it is assumed that stray currents are effectively barred from leaving the structure),
3. In conjunction with (2), avoiding stray currents by using alternative power modes,
4. In conjunction with (2), eliminating stray current effects by cathodic protection,
5. For escalators and elevators, specifying heavy duty components, monitoring performance, emphasizing safety details, and exercising surveillance to reduce vandalism,
6. For pumps and ventilation fans, specifying heavy duty components and a self-oiling system and employing remote monitoring,

7. For architectural finishes, selecting materials of durable quality of good cleaning qualities and installed in systems that are readily replaceable; standardizing materials and stockpiling replacements to simplify replacement during service, and
8. Determining the demands of the foregoing on maintenance organizations, facilities, equipment, and supplies.

Justification:

Evaluation of these interacting variables will permit developing design criteria that will optimize capital cost against cost of maintaining the several components that compose an underground system.

Section 3

STRUCTURES

A major cause of deterioration of underground structures and of much of the fixed equipment within them is water or dampness, usually in combination with chemical action and stray currents. If a structure is completely waterproofed, e.g., by a membrane all around it, and the membrane is nondielectric (as most are), maintenance problems from these sources essentially would disappear. Of course, such problems would not arise if the ground were dry or if the structure were above the groundwater table; however, an internal drainage system would still be needed to handle precipitation, broken water pipes, wash water, etc.

With proper design and construction, many structures can be made substantially watertight, even in bad ground conditions with high water tables. Prevention of structure failure or distress is, of course, axiomatic to the satisfactory performance, durability, and watertightness of the underground structure. Therefore, the engineer must carefully assess the ground characteristics and the effects of both the short- and long-term varying pressures and movements upon the structural system he selects. Evaluation must also be made of future modified structure loads resulting from changing groundwater elevations and increasing ground movements caused by future adjacent construction operations — excavation, pile driving and vibration, dewatering, etc.

The following guidelines aim at minimizing the effects of all these actions.

CUT-AND-COVER STRUCTURES

The main elements that affect maintenance of cut-and-cover structures are waterproofing, the structural design system and stress capacity, design of joints, and concrete durability.

Guideline 3-1 — Minimum Waterproofing

The roofs of cut-and-cover concrete structures should be protected from dampness or water ingress with an applied waterproofing system.

Justification:

This recommendation assumes constant moisture in the soil, even if the roof is above the groundwater tables, and that in the station areas architectural ceilings will either be fixed directly to, or hung from, the soffit of the roof slab; metal unistruts, brackets, bolts, and other items that support pipes, cables, lights, etc., will be incorporated in the soffits of both the station and the trackway. Water that collects on horizontal roofs, even in small quantities, will eventually percolate through the concrete to dampen the soffits, or will seep through cracks, and sooner or later the embedded metal and the suspended items will deteriorate. Installation cost of a roof waterproofing is relatively small.

Guideline 3-2 — Design and Stresses in Structure Systems

The three most commonly used systems in reinforced concrete are rigid frame or box, jack arch, and articulated structures. Recommendations for some good practice design procedures of these are contained in the following paragraphs.

Rigid Frame Structures. Relative to ground movement, these structures are virtually transversely rigid (or stiff), and they act as stiff beams in the longitudinal direction. The following procedures are recommended for inclusion in the design of the structures:

- In determining the external loading for the transverse design, assess and allow for differential side and vertical loads that may develop during the service life of the structure,
- When ground of variable compressibility is encountered, check the structure for its competence to span compressible areas as a longitudinal beam,
- In ground of variable compressibility where joints are introduced in the longitudinal direction of a structure, provide adequate vertical (and if an area of seismic activity, horizontal) shear transfer details,
- When the structures are in contact with corrosive soil and water, it is desirable to adopt design criteria that will limit the stress under the design loads in the reinforcing steel and, consequently, the width of stress cracks in concrete. Under most conditions, intermediate-grade steel (rather than high tensile), with ACI recommended working stresses, should be satisfactory. Where possible, smaller diameter bars, rather than larger, should be used to permit wider distribution of cracks and to reduce crack size, and
- The percentage of longitudinal (or distribution) reinforcement in the structure elements should be increased above the ACI minimum requirements, to reduce transverse cracking in the longitudinal direction. It is recommended that this percentage be doubled.

Justification:

During the life of a structure, the soil loads around it may be changed by adjacent construction activity, excavations, pile installations, and dewatering. These may particularly change the differential loading and increase the stresses in the external corners of the structures. Such increases, although they may not be structurally dangerous, will increase the incidence of cracking and the rate of structural deterioration. Present knowledge indicates that the extent and size of cracks in concrete that is exposed to corrosive soil and water are likely to cause long-term deterioration of the structure. Deterioration, therefore, can be partially controlled by limiting the size of cracks and the stress placed on the reinforcement. Limiting crack size requires correct assessment of the ground loading criteria (which may often constitute the total design load); stress in the reinforcement may often be accomplished by avoiding high tensile steels, i.e. by using intermediate grades.

Jack Arch Structures. A jack arch system comprises steel beams, generally 5 feet apart, spanned by concrete arches, and may be used either for the roof only or for exterior walls as well. In both cases the steelwork is usually designed as freely supported and intended to carry the entire structure load. The bottom slab, or invert, is normally reinforced concrete. The following recommendations are made for designing this type of structure:

- External waterproofing must fully protect areas where the roof beam ends terminate; where steel is used in the walls, these should be fully waterproofed, especially at the terminations.
- When this type of structure is used, particularly for the walls and in ground of variable compressibility, the structure must be analyzed for effects of longitudinal bending caused by differential settling.
- For fireproofing, it is advisable to completely encase the steel members in concrete.

Justification:

Concrete bonds poorly to the flat surfaces of structural steel. Structural movements and concrete shrinkage tend to break this bond and permit the entry of moisture, resulting in corrosion and deterioration. The beam seatings — areas of high local stresses — are particularly vulnerable to this situation, hence, the importance of a good external water-proofing system. A jack arch structure generally tends to have weak longitudinal "beam action" because only one external layer of longitudinal reinforcement can be placed on the face of the concrete resulting in a structure of low longitudinal shear resistance. This shear resistance is particularly poor in the walls, and differential ground settlement may cause severe concrete cracking or shear failures.

Articulated Structures. This system generally incorporates slurry concrete walls or secant (intersecting drilled piles) concrete pile walls. The inverts are normal cast-in-place concrete, and the roofs may be either cast-in-place or prestressed concrete units. Structurally, the junctions of the floor and roof with the walls act as pinned connections. Although continuity may exist in roof and floor slabs over any central supports, this structural form has considerable transverse flexibility. Because of the additional embedded depth of the walls into undisturbed ground below the invert slab, longitudinal stiffness may not be a problem in ground of varying compressibility. Walls generally prove to be watertight, particularly if installed with bentonite slurry.

For designing such structures, it is recommended that particular care be devoted to developing flexible waterproofing seals between the horizontal slabs and the walls, especially if structural distortion from ground movements is likely.

Justification:

Apart from the desirability of preventing water from entering the structures, dowels or reinforcement are normally provided at the slab and wall joints, and these should be adequately protected against corrosion. In corrosive situations, stainless steel should be considered for these items. Joint sealants should have sufficient flexibility to remain effective when movements occur.

Guideline 3-3 – Expansion, Construction, and Control Joints

Expansion Joints. In general, an underground concrete structure does not need expansion joints because the concrete, as it hardens, tends to shrink more than it will expand from any temperature increases that may occur during its service life.

It is recommended that expansion joints, which provide a definite gap between the concrete sections, not be used. Control (contraction) or construction joints will suffice.

Construction Joints. Typically, these are used in two situations: longitudinally in the walls above the invert slabs, and sometimes below the roof slab; and transversely at the termination of the concrete section placements.

- Longitudinal Joints. Three types of longitudinal joints are illustrated in Figure 3-1. Detail B, rather than Detail A, should be used. In most situations, however, water stops are not needed within the structural element. Detail C would be more satisfactory and economical than Detail B.

  Justification:

  The basic difficulties in making water stops work effectively, particularly when they are located at the bottom of a wall where access for vibrators is restricted, are (1) compacting the concrete properly around them and into the chevrons and (2) ensuring that the upper section is adequately secured so that it is not pushed horizontally when the wall concrete is placed. In nearly all cases the shear key, in Detail A, is not needed and is an unnecessary cost complicating the placing of the water stop.

  Where the use of bentonite is acceptable, the construction simplicity of Detail C makes it predictably reliable.

- Transverse Joints. These joints are required in the bottom and top slabs and in the vertical walls at the end of each concrete section pour. Recommended details for these joints are shown in Figure 3-2

  Justification:

  These details are frequently used. However, because water stops are placed either horizontally in the floor and roof slabs or vertically in the walls, and although concrete can be placed and compacted around these joints more reliably than around longitudinal joints, care must be exercised in obtaining compaction on the undersides of the horizontal surfaces.

  Bentonite strip water seals, as shown in Figure 3-1, Detail C, are difficult to place satisfactorily under the bottom slab joint, but can readily be used in the walls and top slab. To maximize shear key resistance, it is important to use equal dimensions measured from the water stop, avoiding a plane of weakness as the details indicate in Figure 3-2.

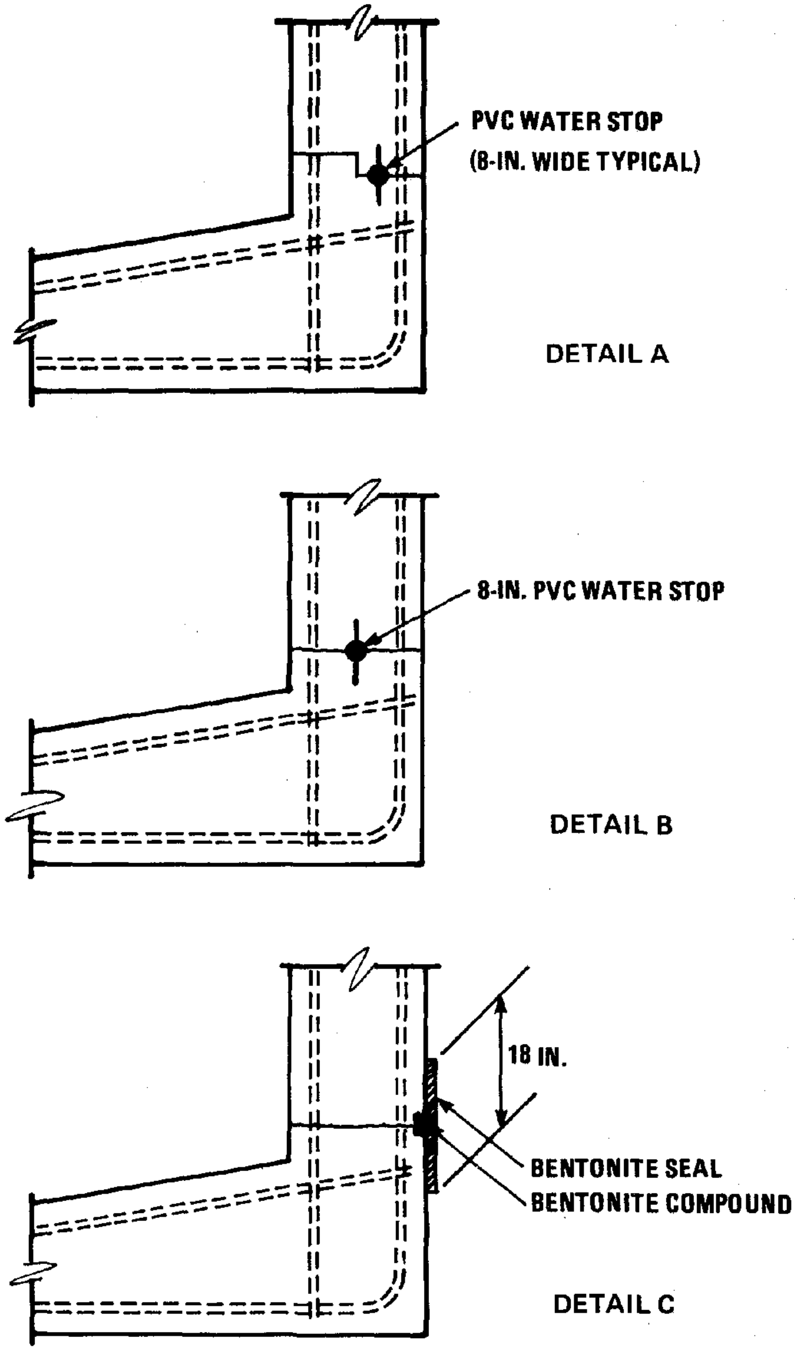
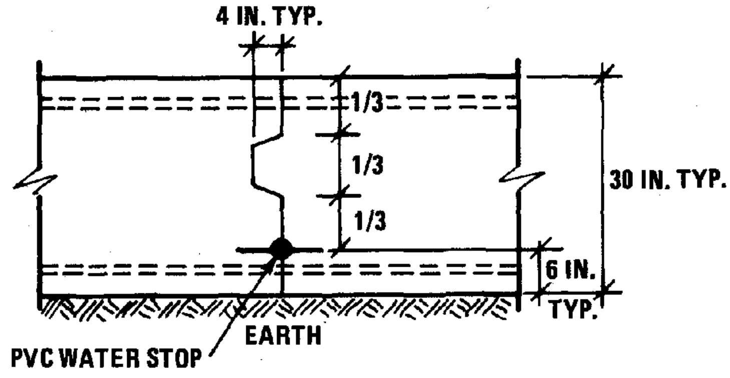
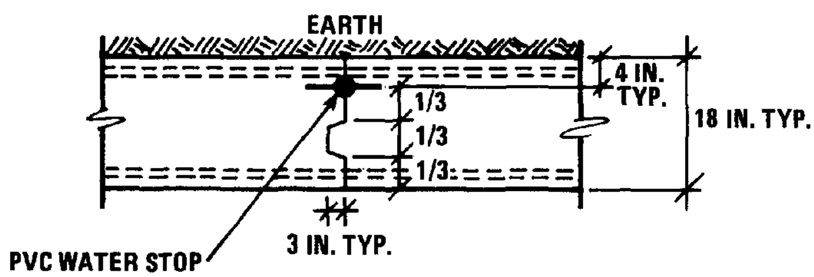


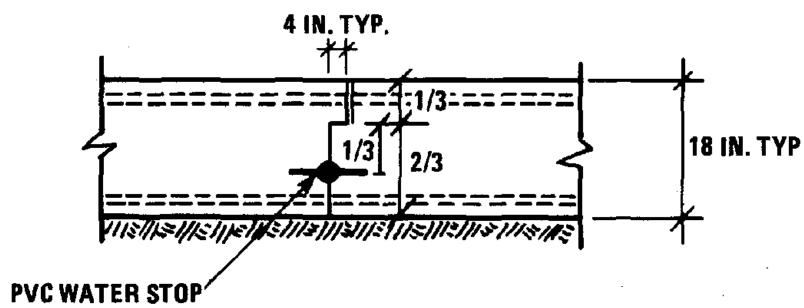
Figure 3-1 CONSTRUCTION JOINT DETAILS



DETAIL A – INVERT JOINT



DETAIL B – ROOF JOINT



DETAIL C WALL JOINT

Figure 3-2 TRANSVERSE JOINTS

Control Joints. This type of joint is sometimes placed in walls and roofs to permit the shrinkage cracks in the concrete to occur in one streight plane, which then can be sealed against water ingress. The cracks self-form along the planes of weakness as shrinkage occurs.

It is recommended that, where used, these joints be placed not more than 15 feet apart and be constructed as shown in Figure 3-3. The principal requirements of such a joint are as follows:

- The combined depth of the chases formed in both faces of the section should be approximately 25 percent of the section thickness.
- The longitudinal reinforcing steel should stop on one side of the joint and a bond breaker be applied to the steel extending past it.
- The earth face groove should be sealed.

Justification:

Control joints often effectively control concrete cracking and water seepage.

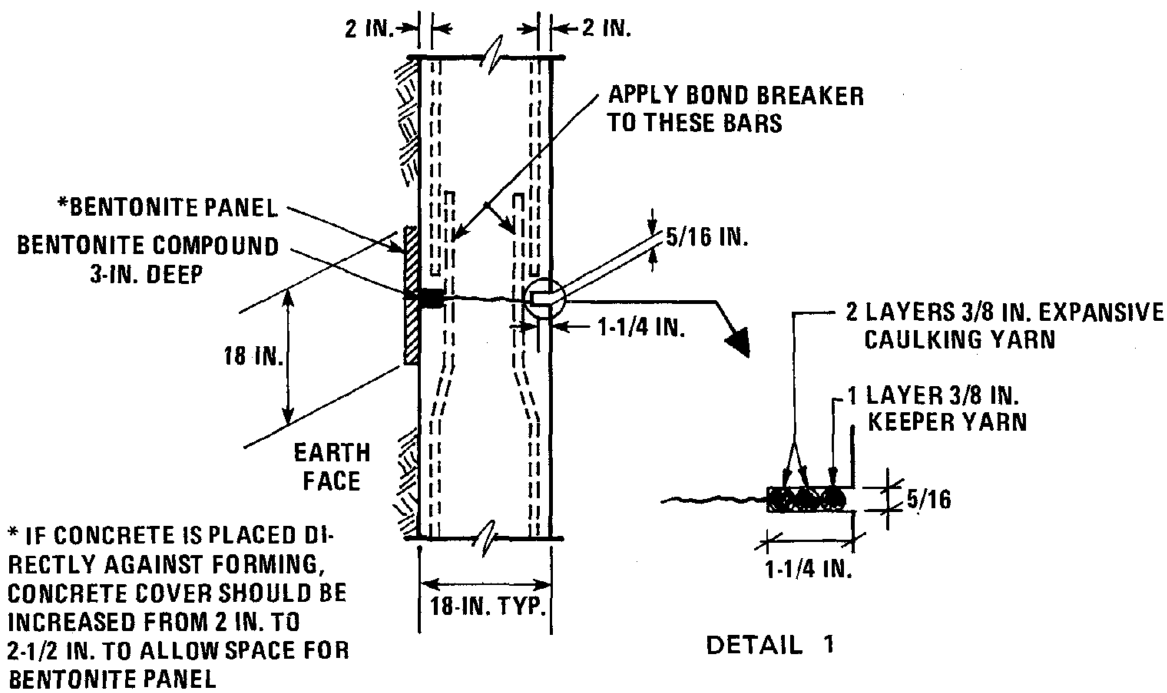


Figure 3-3 CONTROL JOINT

Guideline 3-4 — Concrete for Durability

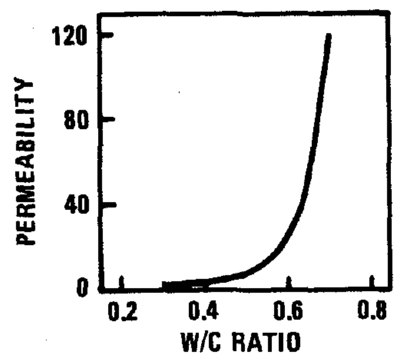
The four principal factors that determine the durability of concrete are materials, proportioning and mixing, temperature control during placing, and curing. Generally, ACI and ASTM standards should be followed. In addition, the following recommendations are particularly oriented to producing durable concrete for the often unique conditions encountered in subway construction.

- Cement: Portland cement ASTM, C150 Type 2, has proven low-shrink characteristics (Ref. 4.41, ACISP 49) and also exhibits low heat of hydration. Where the ground and groundwater contain excessive amounts of sulfates, the cement should be modified to Type 5.
- Materials: Aggregates should be nonalkaline reactive with low water absorption characteristics; no chlorine additives should be used. Workability admixtures conforming to ASTM C495 may be used to reduce water-cement ratios.
- Concrete Mix: The water-to-cement ratio should be as low as practical for placing and workability. A ratio of 0.4 should be satisfactory for placing concrete in most subway structural sections, but in no case should it exceed 0.45.
- Temperature: The temperature of the concrete at the time of placing should be kept as low as possible, particularly in warm weather; if necessary, shaved ice can be added to the mixing water to reduce the temperature.
- Curing: The concrete forms should be removed as soon as possible and the concrete cured by a continuous water mist spray. Horizontal slabs should be protected from the drying and warming effects of hot sun.

Justification:

The prime requirements for durable concrete are that it be dense, well compacted, and crack-free to provide both resistance against chemical attack from aggressive groundwater and impermeability for the protection of the reinforcing steel. The guides recommended above will provide a satisfactory concrete.

The influence of a low water-to-concrete ratio in reducing permeability is indicated in Figure 3-4.



EFFECT OF WATER-TO-CEMENT RATIO ON PERMEABILITY OF HYDRATED PASTE TO WATER 10^{-12} CM/SEC*

Figure 3-4 WATER-TO-CEMENT RATIO

The effect of the length of its curing time on the permeability of concrete, which is of particular importance in the outer layer covering the reinforcement, is shown in Table 3-1. The surface layer of the concrete dries more rapidly than the interior of the section, and, as indicated, unless the surface is kept moist for at least 7 days, a satisfactorily low coefficient of permeability will not be achieved.

Table 3-1

RELATION OF CURING TIME TO PERMEABILITY*

Days of Curing	Coefficient of Permeability
Fresh Paste	1,150,000,000
1	36,300,000
2	2,050,000
3	191,000
4	23,000
5	5,900
7	1,380
12	195
24	46

*Source: Corrosive Metals in Concrete, ACI Publication SP-49

Continuous mist spray has the advantage over a curing membrane of reducing temperature buildup in the concrete during cement hydration as well as of controlling the drying shrinkage.

A third factor in obtaining impermeable concrete is minimizing shrinkage and temperature cracks. This can be assisted by using a low-shrink cement, such as Type 2; by using suitable workability admixtures; and by controlling the temperature at placing.

Guideline 3-5 — Reinforcement Cover

It is recommended that the dimensions required by the Uniform Building Code for concrete cover be used: namely, 3 inches where the concrete is deposited directly against the ground surface and 2 inches where the concrete is formed but will be directly in contact with the ground. In slurry wall construction, 4 inches should be provided.

Justification:

The additional inch of concrete cover is required when it is placed directly on the ground because the bottom inch will probably mix with a certain amount of soil. For slurry wall concrete, 4 inches are deemed advisable to prevent contamination of the outer surface of the concrete with bentonite. It thus provides insurance that at least 2 inches of concrete will protect the reinforcement. Figure 3-5, although based on a water-to-cement ratio of 0.5 and 1-1/2 inches of cover, justifies this recommendation.

Guideline 3-6 — Waterproofing Systems

Three principal waterproofing systems are recommended for economic evaluation. The systems are:

- Over the roof,
- Over the roof and down the walls, and
- Completely around the structure; i.e., roof, walls, and invert.

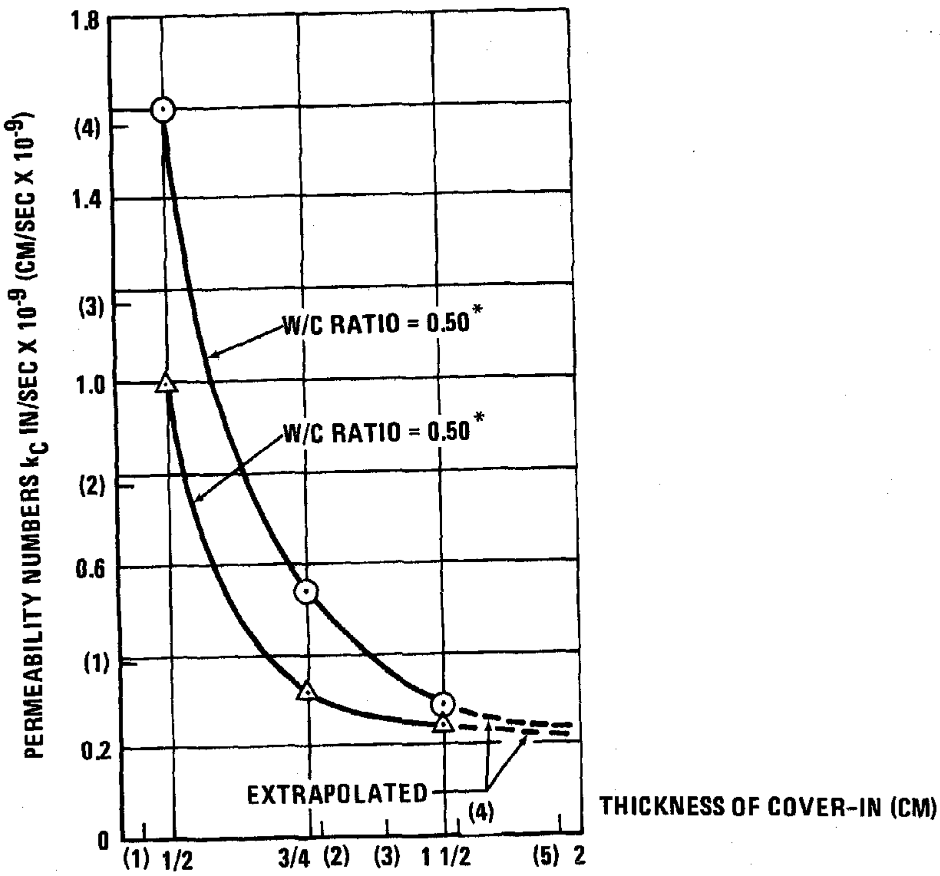


Figure 3-5 THICKNESS OF COVER AND PERMEABILITY

The station structure and the track structure should be evaluated separately.

Justification:

The evaluations should include a comparison of the installed costs of the three different systems against the reduced maintenance cost of items such as: the structure in respect to concrete corrosion and deterioration, the operation and maintenance of the drainage and pumping system, the effects of stray currents both on the subway structure and others including utilities outside the subway, the trackway supported components, and the architectural finishes.

*Source: Corrosive Metals in Concrete, ACI Publication SP-49 (two different tests)

Figure 3-6 shows a typical twin-cell cut-and-cover trackway. The same general details and waterproofing systems will apply to most cut-and-cover station structures. Figures 3-7, 3-8, and 3-9 show details of the three systems of waterproofing. Figure 3-10 indicates an alternative construction method for Systems 2 and 3.

A detailed discussion on waterproofing systems and materials is given in Section 7 of Rapid Transit Subway-Maintenance and Engineering Guidelines Report.

Guideline 3-7 — Waterproofing Materials

Three principal types of materials should be evaluated for the waterproofing system. The material types are as follows:

- bentonite sandwich panels,
- sheet membranes of either plastic or synthetic rubber, and
- multiple membranes of nonfuming coal tar enamel with fiberglass reinforcing mat.

Justification:

For a description of the three types of materials, refer to Rapid Transit Subways - Maintenance and Engineering Report. Points of particular importance to consider include the following:

- Bentonite. A low-cost material which, although only in service a relatively short time, appears to give very satisfactory results. The practicality of using it beneath the bottom slab of a structure to provide the all-around waterproofing shown in System 3 has not yet been demonstrated. Drawbacks include the facts that bentonite does not provide a barrier for stray currents leaving or entering the structure and that it cannot be used in some saline water conditions.
- Plastic and Rubber Sheet Membranes. These appear to be long-lived if carefully installed and protected. During installation, the relatively thin sheets must be protected from puncture, and the splices between the sheets must be completely watertight. Any such deficiencies will allow water to migrate and enter the

structure in places remote from the source, thereby making detection of source and repairs difficult. The uncured-butyl-backed polyethylene appears to be much less vulnerable to water migration from the above possible deficiencies than are single-sheet materials.

- Multiple-Ply Built-Up Coal Tar Membranes. Coal tar has demonstrated longevity of more than 100 years and appears to be inert when attacked by any chemical salts in the ground. The multilayered staggered-lap installation ensures that the membrane obtained is integral. Its relative thickness also provides protection against accidental puncture during and after installation.

Guideline 3-8 — Waterproofing Installation Methods

Appropriate installation methods must be developed for each system to be evaluated. These methods should include protective barriers. Typical details of the methods are shown for each system in Figures 3-7, 3-8, 3-9, and 3-10.

Justification:

Two methods are shown for installing the membrane against the structure walls. In one, the membrane is applied against the concrete outer form (or excavation support) and the concrete is placed against it. In the second, a working space is provided to allow the membrane to be applied directly to the structure, and a protective covering is installed before backfilling. In general, the latter method is more satisfactory (and, perhaps, is the only way that some of the membranes can be used), but it requires more excavation and backfilling and more street decking, when required, than the other methods. It is, therefore, more costly.

The following details apply to the three systems illustrated in Figures 3-7, 3-8, and 3-9.

- Bentonite Panels. As the only protective barrier required on the roof is sand, this and other aspects of its installation make this system less costly than the other systems. Plastic bentonite is used for filling spaces in contraction and expansion joints and reentrant corners. Figure 3-9 does not apply to bentonite.

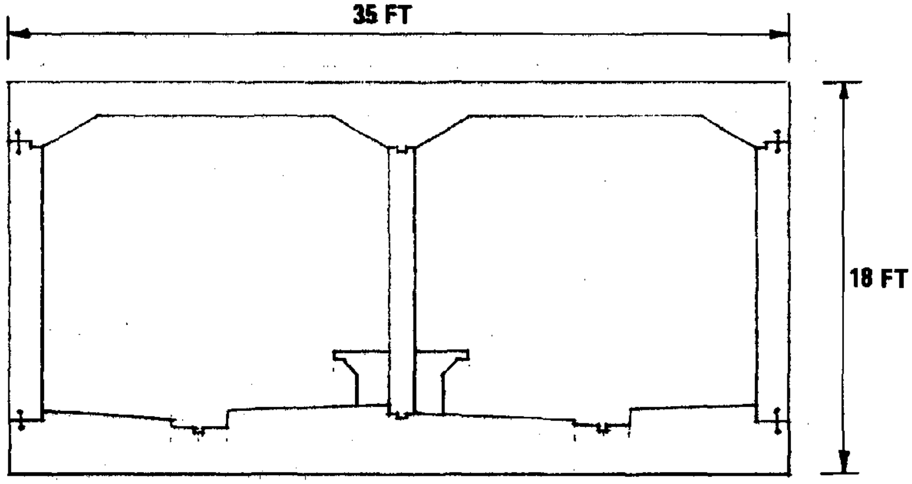


Figure 3-6. TYPICAL CUT-AND-COVER TWIN-CELL TRACKWAY STRUCTURE

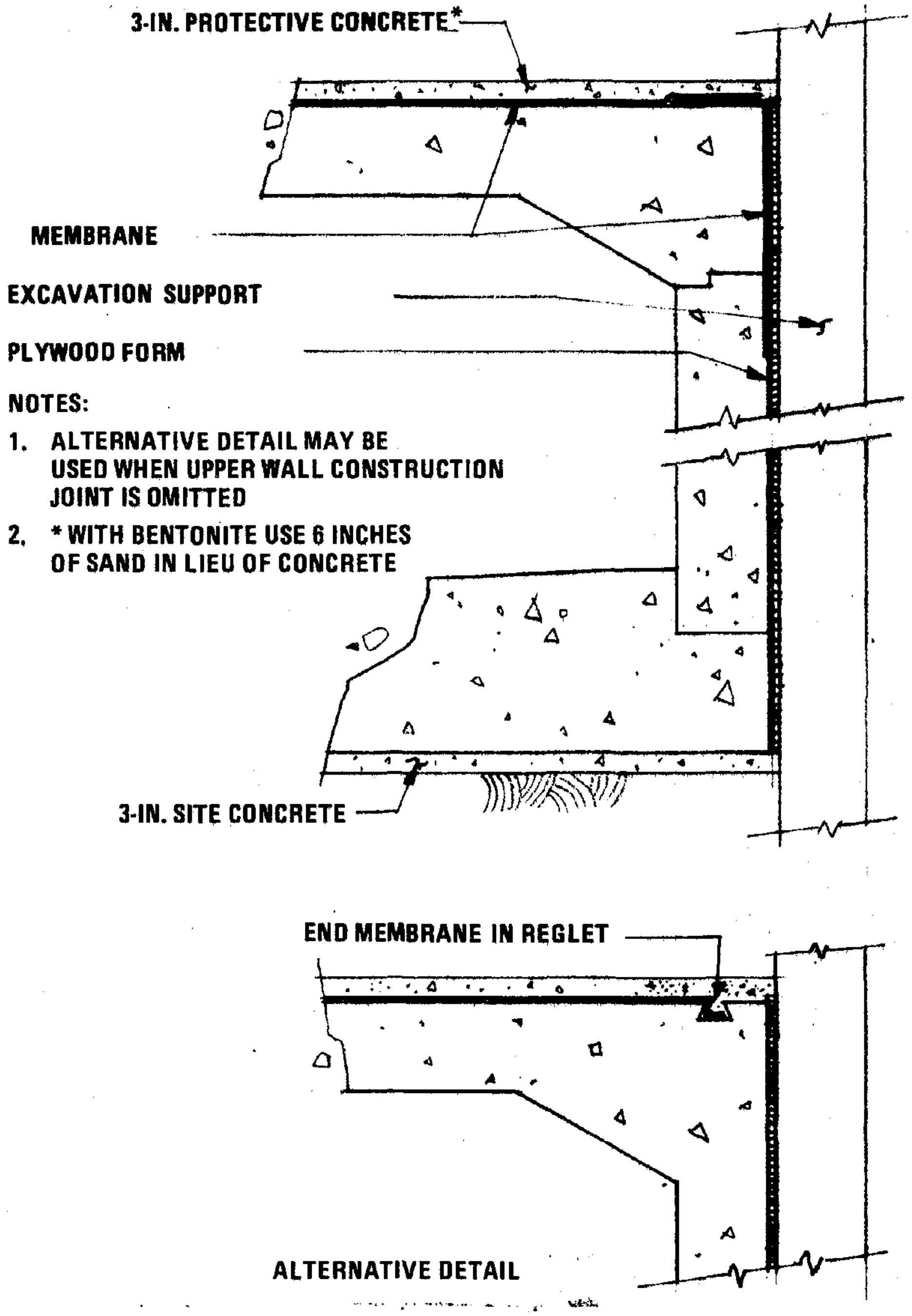
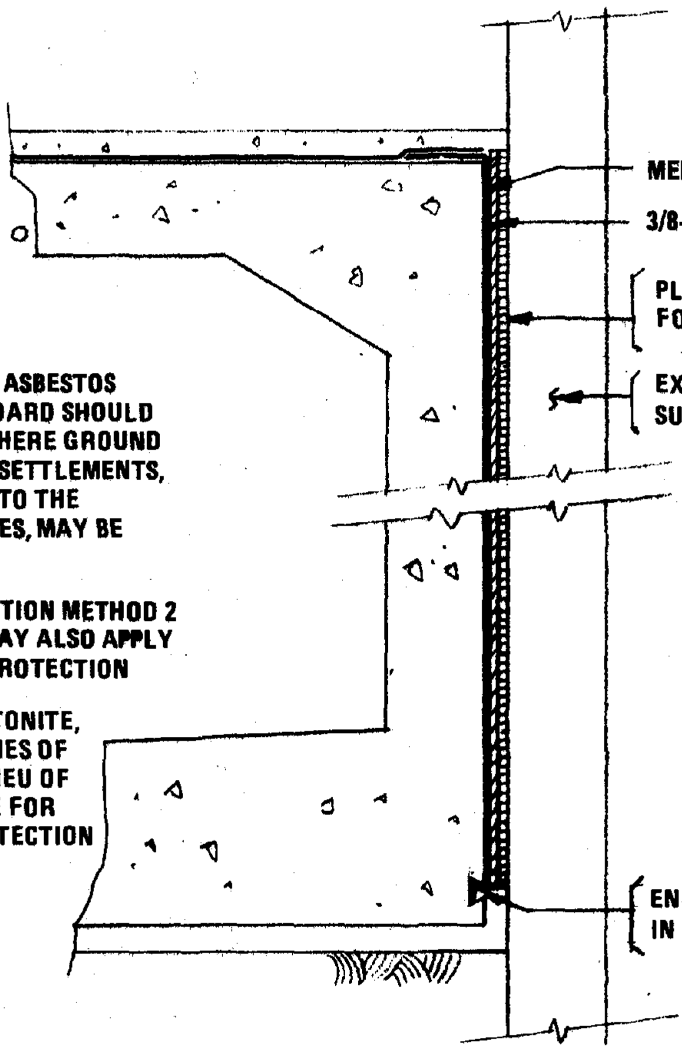


Figure 3-7 WATERPROOFING OVER ROOF – SYSTEM 1



NOTES:

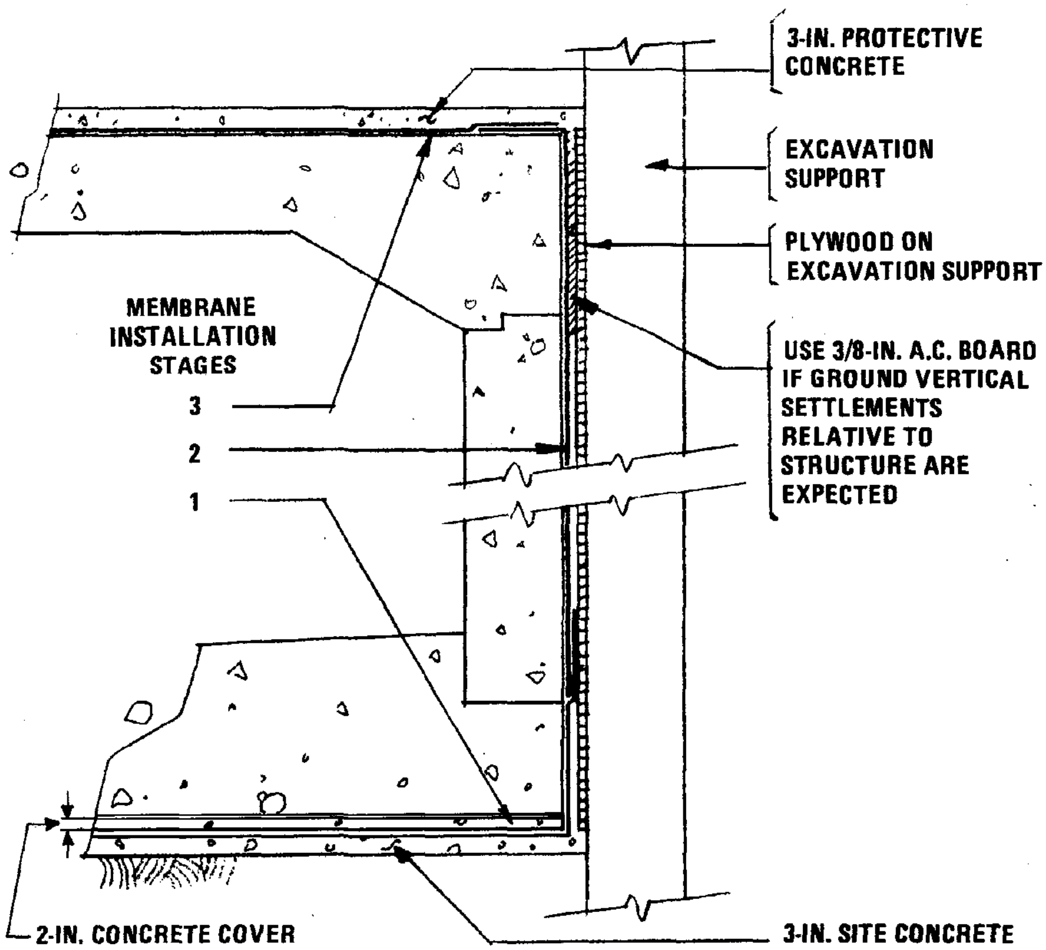
(1) THE 3/8-IN. ASBESTOS CEMENT BOARD SHOULD BE USED WHERE GROUND VERTICAL SETTLEMENTS, RELATIVE TO THE STRUCTURES, MAY BE EXPECTED.

(2) CONSTRUCTION METHOD 2 FIG. 3-10 MAY ALSO APPLY TO WALL PROTECTION

(3) WITH BENTONITE, USE 6 INCHES OF SAND IN LIEU OF CONCRETE FOR ROOF PROTECTION

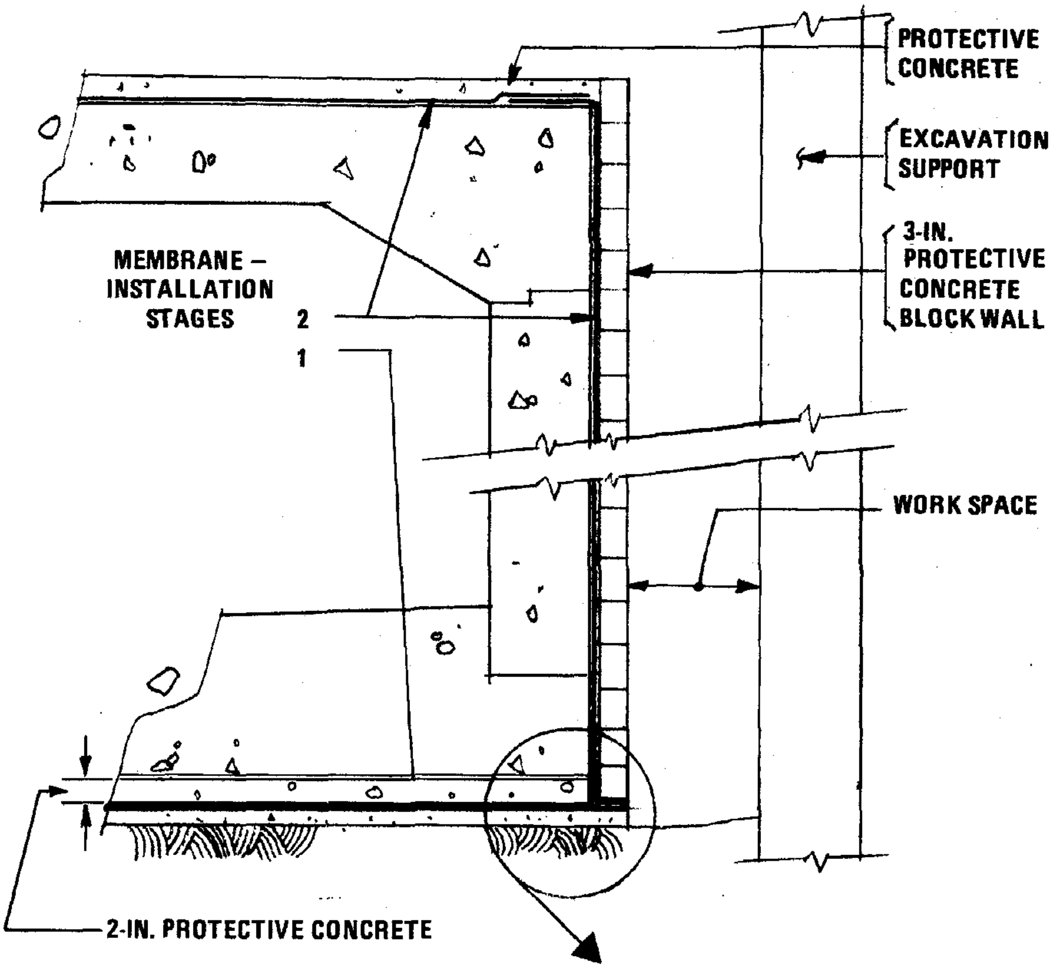
CONSTRUCTION METHOD 1 – MEMBRANE APPLIED TO CONSTRUCTION FORM

Figure 3-8 WATERPROOFING OVER ROOF, DOWN WALL – SYSTEM 2



CONSTRUCTION METHOD 1 – MEMBRANE APPLIED TO CONSTRUCTION FORM

Figure 3-9 WATERPROOFING ALL AROUND – SYSTEM 3, METHOD 1

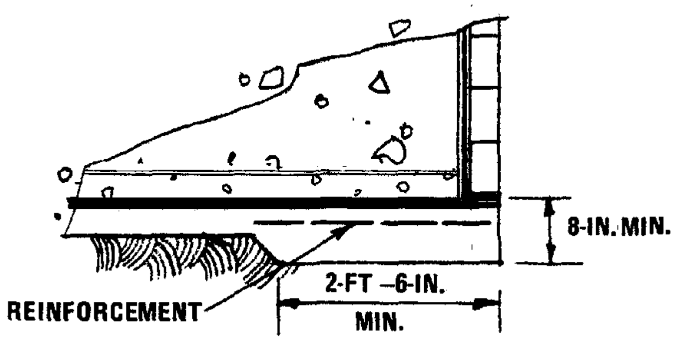


CONSTRUCTION METHOD 2

SHOULD BE USED WHEN GROUND VERTICAL SETTLEMENT RELATIVE TO STRUCTURE IS EXPECTED

NOTE:

This method may be used for System 2.



DETAIL

CONSTRUCTION METHOD 2 – MEMBRANE APPLIED DIRECTLY TO WALL

Figure 3-10 WATERPROOFING ALL AROUND – SYSTEM 3, METHOD 2

- Plastic Sheets and Built-Up Membranes. Protection requirements for these two materials are essentially the same. It will be noted in Figure 3-9 that a protective barrier has been provided over the invert membrane for protection during placement of the heavy reinforcing steel. This protective barrier has not been shown for the walls where the concrete is placed against the excavation shoring, but, in certain circumstances (particularly with plastic membranes), this should be considered.
- For an all-around waterproofing system, penetrations by such items as electrical conduits, water pipes, and drainage systems must all be properly sealed.

TUNNELED STRUCTURES

As in cut-and-cover structures, the major generant of maintenance is the ingress of water.

Guideline 3-9 — Cast-in-Place Concrete Linings

Cast-in-place concrete tunnel linings should receive the same attention as cut-and-cover structures so that a dense, crack-free, durable concrete is achieved. Specifically, adequate reinforcement in the longitudinal direction should be provided (at least double the minimum ACI requirements for shrinkage), temperature control in the green concrete should be observed, construction joints should be formed against properly designed stop ends, and sealed joints should be provided.

Where the tunneling is through ground or rock that is subject to readjustment from ground stresses or movements, measurement of the temporary tunnel supports should be taken at regular intervals, and, where practical, the concrete lining should not be placed until the movements are minimal.

Justification:

The recommendations are directed toward minimizing the water inflow into the tunnel and creating a low-maintenance-cost structure. Major water leakage comes through circumferential cracks caused by shrinkage; therefore, low-shrinkage concrete should be used.

Guideline 3-10 — Segmented Concrete Linings

Lining design should be based on Report DOT-TSC-OST-77-7,* Systems Study of Precast Concrete Tunnel Liners. Incorporation of the following criteria in the design of linings will reduce maintenance requirements.

- low-modulus, lightweight, high-strength concrete,
- a flexible segment-joint-sealing system that can accommodate movement
- Establishment and insurance of fine tolerances during manufacture
- Maintenance of tight circumferential and radial joints for watertightness in bad ground conditions
- segment faces detailed to prevent edge bearings which give rise to spalling.

Justification:

The first factor, low-modulus concrete, allows tunnel linings to bend more readily to accommodate ground movements without cracking. The other factors are principally directed at attaining watertightness. Fine tolerances between the segment faces and detailing the faces correctly also will prevent spalling and cracking under the high loads of the construction shield and the permanent ground forces.

Guideline 3-11 — Expanded Segmented Linings

In a dry, homogeneous ground that has a sufficient stand-up time to permit excavation with a tailless shield, a system of expanded precast concrete tunnel lining may be considered. With such a system, the segmented lining is placed directly against the exposed ground behind the shield and expanded tightly against it. The expansion is usually accomplished by packing wedge segments longitudinally between the lining segments. Refer to DOT-TSC-OST-77-7 for a discussion of such designs.

Justification:

Several economic advantages are obtained in this system. The principal savings are as follows:

- Omitting the fastening system (bolts) speeds ring erection, and the cost of the bolts themselves is saved,
- Because the lining is expanded directly against the ground, the tail space does not have to be grouted, thus saving labor and materials, and
- Manufacturing cost of the segments is reduced.

For this lining system, the ground must be predominantly free from water. The water sealing may be limited to installation of caulking in areas where seepages occur.

Guideline 3-12 — Segmented Metallic Linings

In firm ground, the lining should be designed as "flexible"; in soft, squeezing ground, the design should be rigid. High-strength bolts should be employed to attain tight segment joints. Protection against corrosion should be provided with inorganic zinc silicate coatings on the inside and faying faces and coal tar epoxy enamel on the ground face. Strict tolerances should also be established for the faying faces, bolt holes, etc., and ensured during manufacture.

Justification:

The flexible lining design uses a minimum of material and is, therefore, an economical system in firm ground. In soft or squeezing ground, "stiff" design is required to limit the distortion of the lining. High-strength bolts provide a tight interface between the segments and the rings that helps maintain the integrity of the sealant system during the service life of the tunnel. The protective coating system described should protect the lining satisfactorily against corrosion in average aggressive environments. For a discussion of this subject, see DOT-TSC-OST-77-7

Guideline 3-13 — Waterproofing Systems

Three principal systems may be used for waterproofing tunnels: the grout in the tail space, gaskets, and caulking.

System 1: Tail Space Grouting. The space between the outside of the lining and the ground should be filled as quickly as possible to provide an integral annular ring of grout. The grout should be designed to provide almost immediate support between the lining and the ground as well as a considerable measure of impermeability.

System 2: Gaskets. Continuous elastomeric gaskets should be provided around the four faces of each segment. The gaskets should not be thicker than needed to create a seal, and should be of a material with sufficient elasticity to maintain its competence during movements of the segment joints.

System 3: Caulking Systems. The four faces of the segments should be grooved for installation of a caulking system.

Justification:

System 1. A properly formulated and introduced tail space grout will create the first and often major barrier to water penetration and reduce the amount of water reaching the tunnel lining. Composition of such grout includes various proportions of cement, bentonite, fly ash, sand, and additives that provide flowability. The grouting must be accompanied by an effective shield tail seal. Several effective seals have recently been developed, particularly in conjunction with bentonite slurry face tunneling machines. Another requirement, particularly when the ground has a poor stand-up time, is to introduce the grout as soon as the shield starts to move forward, thus avoiding collapse of the ground into the void at the crown of the tunnel and preventing the introduction of an integral annular ring of grout. Typical details of shield tail seals that have been used are indicated in Figure 3-11. It should be noted that all the seals are in sections with holding bolts that permit replacement when damaged.

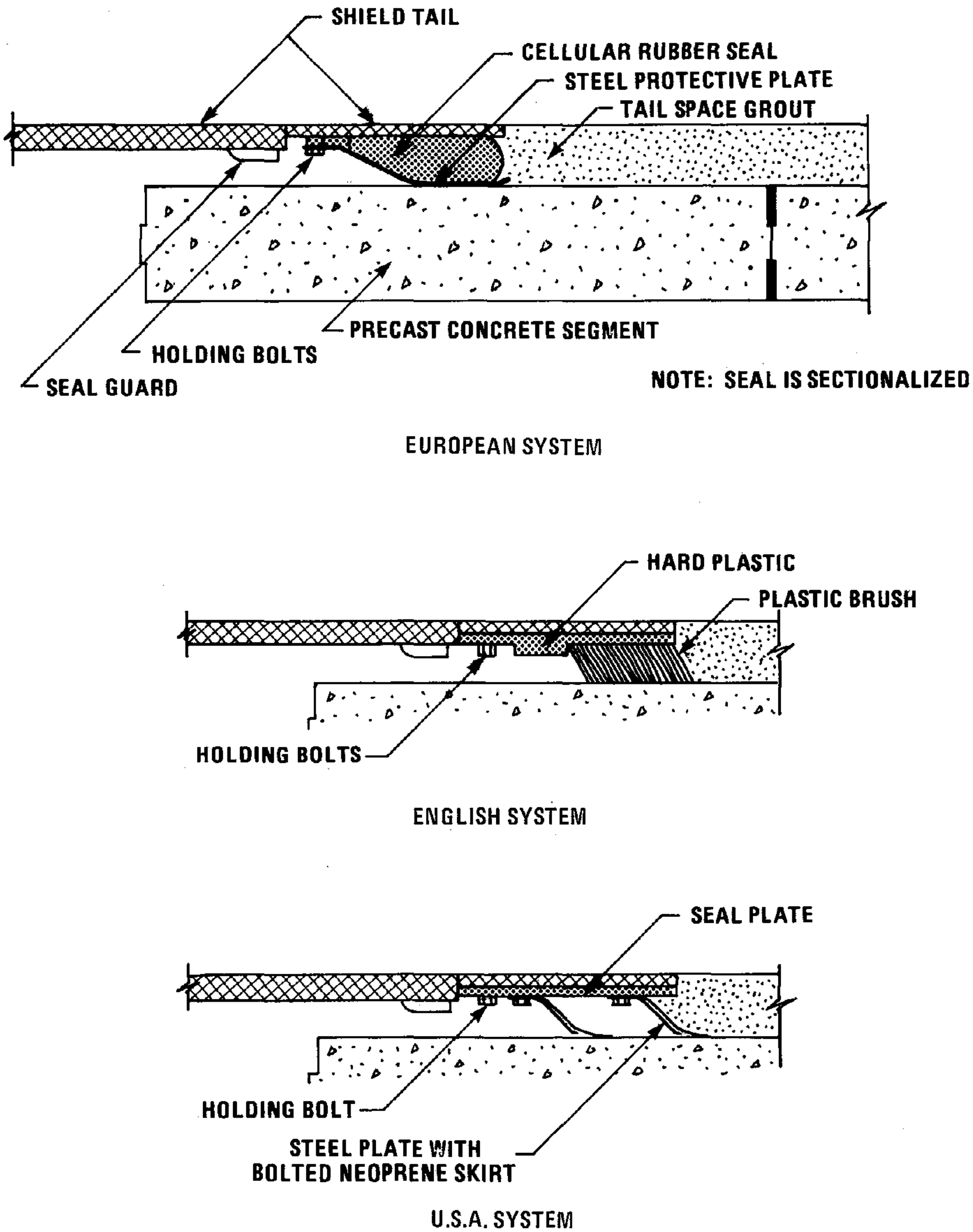


Figure 3-11 TYPICAL TUNNEL SHIELD TAIL SPACE GROUT SEALS

System 2. Theoretically, gaskets around the segment faces should prevent water seepage. In the design of such seals for a shield-driven tunnel, the different requirements for the circumferential faces and for the radial faces must be considered. During erection of the lining, the circumferential faces will sustain high pressures from the shoving jacks of the tunnel shield face. These pressures may be as high as 1,700 psi, but of short duration. The radial faces must transmit the compressive forces in the ring generated from the soil it supports. These pressures are long-term and may average 1,000 psi, but because of the bending and flexing of the ring, pressures may double along one edge and drop to zero on the other edge. Material and physical requirements for the gasket material are discussed in DOT-TSC-OST-77-7.

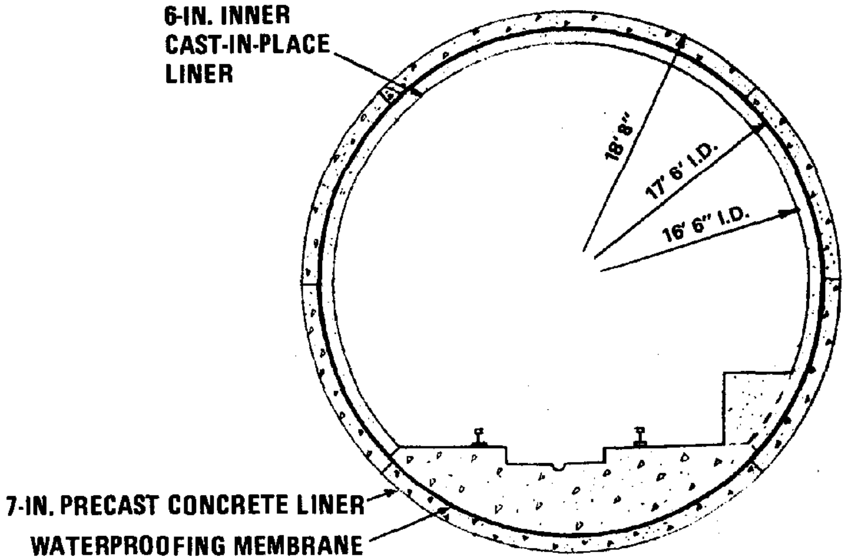
System 3. Caulking grooves in the segment faces are an inexpensive provision for stopping leaks. These leaks may be caused by failure of the other two sealing systems. DOT-TSC-OST-77-7 contains a discussion of caulking materials and systems.

Guideline 3-14 – Membrane Waterproofing for Concrete Tunnels

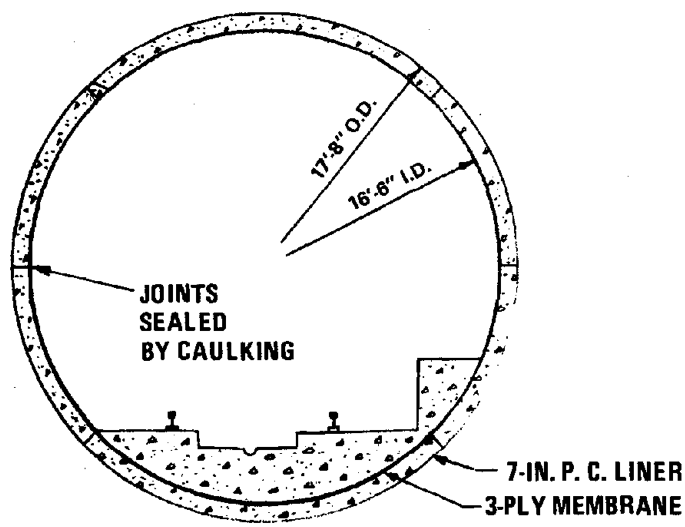
A cost evaluation should be made of providing inner membrane waterproofing for concrete tunnels. Such an evaluation should compare the costs of two tunnels: one with a single lining and the other with a membrane applied to the inside of a primary lining and held in place with a secondary lining designed to resist the full water pressure. Such alternatives are shown in Figure 3-12.

Justification:

The same rationale applies as was used in the evaluation in Guideline 3-6. During the years the tunnel will be in service, leakage will occur from time to time if the tunnel is not completely waterproofed with a continuous membrane. An example of an installed cost comparison between a precast concrete primary lined tunnel and one with a membrane and backup



WATERPROOFED WITH 3-PLY MEMBRANE AND
6-IN. CONCRETE INNER LINING – SYSTEM 2



GASKETED AND SEALED JOINTS – SYSTEM 1

Figure 3-12 TRACK TUNNEL WATERPROOFING SYSTEMS secondary concrete lining is provided in Section 6 of the Rapid Transit Subways and Engineering Report. It will be noted that an appreciable cost increase over that of the primary lined tunnel can be anticipated.

CORROSION PROTECTION

The guidelines in this subsection discuss corrosion protection which is needed in one form or another for all exposed steel in underground structures. Structural steel and miscellaneous steel, partly embedded in concrete and partly exposed to corrosive conditions, require special protection at the interface between the concrete and the steel.

Where conditions are severely corrosive, a comprehensive economic evaluation should be made of the several alternative protective systems available for the embedded reinforcement. These systems include total membrane waterproofing coverage, cathodic protection of the reinforcing steel, and protective coating of the reinforcing steel. In many situations, protective coating of the reinforcing steel may be limited to secondary structures contiguous to the main subway structure that are difficult to waterproof, or to those reinforcing bars in the external face of the main structure that will be under high stress.

Guideline 3-15 — Protective Coatings for Structural and Miscellaneous Steel

Method 1. Where the steel is partly embedded and partly exposed to corrosive conditions and is subject to abrasion, it should be both galvanized and epoxy-coated.

Justification:

Examples of these situations include the following:

- miscellaneous steelwork in emergency exits and in ventilation shafts that open to the street or sidewalk and that are subject to weather damage and calcium chloride and
- steelwork in pump sumps.

Galvanizing provides good protection against many forms of corrosive environments but can be penetrated by chloride ions, particularly at the interface of the concrete and the steel. A protective epoxy coating will prevent this penetration as well as provide insulation from stray electric current attack. The galvanizing will protect the metal from abrasion (particularly such items as walkways, gratings, ladder rungs, hatchway covers, and frames) after the epoxy coating has broken down.

Method 2. Where the conditions are only lightly corrosive (i.e., wet or damp) but no chlorides or acids are present, a 3-mil thick inorganic zinc silicate may be substituted for the galvanizing in Method 1. The zinc silicate may also be supplemented by an epoxy coating if stray electric currents are anticipated.

Justification:

Inorganic zinc silicate does not resist abrasion as well as zinc and, because of its lesser thickness, has a reduced sacrificial life. However, for the conditions stated, it will provide satisfactory protection for less cost.

Guideline 3-16 — Protective Coatings for Reinforcing Steel

For the situations discussed at the beginning of this subsection on corrosion protection, reinforcing steel may be coated with a powder-applied epoxy 7 mils (±2 mils) thick.

Justification:

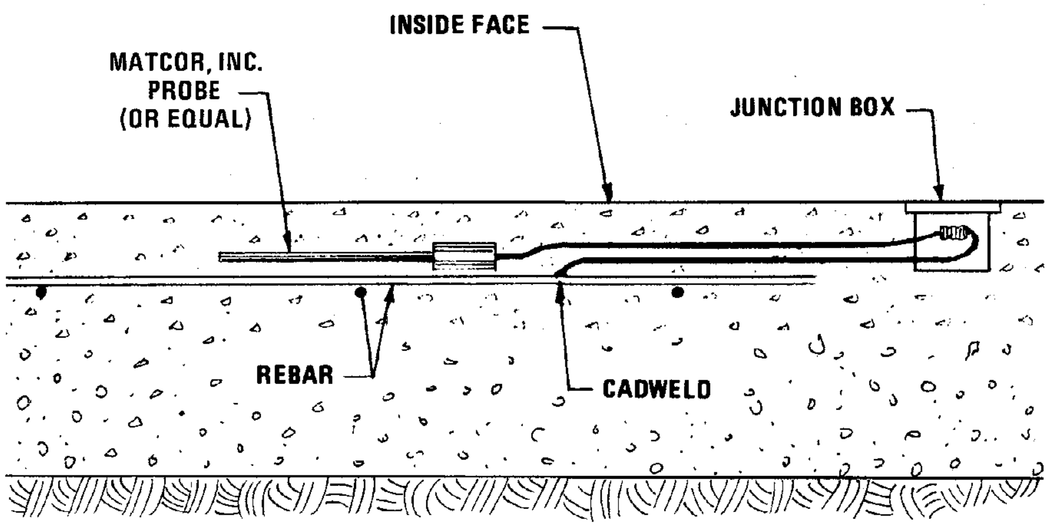
An evaluation of performance and application methods of the epoxy coating is contained in ACI Publication SP-49. The coating will insulate the reinforcing steel from the penetration of chloride ions, stray currents, and other corrosive agents. The coating will provide a satisfactory bond between the reinforcing steel and the concrete. The coating is relatively tough, and it appears that, with certain precautions, the bars may be bent to normal radii without damaging the coating. Cut ends may be protected by liquid, field-applied coatings, as can repairs to areas that may be damaged during transportation and erection. Obviously, a certain amount of care must be taken during both these operations to avoid rough handling, and rigorous inspection of the coating and its repair, if necessary, must be made when the steel has been placed, but before the concrete is poured. Epoxy coating applied before bending will approximately double the base cost of a typical range of reinforcing steel.

Guideline 3-17 — Monitoring Corrosion of Reinforcing Steel

In unstable ground and corrosive environments, a corrosion monitoring system should be installed for reinforced concrete structures (including cut-and-cover, cast-in-place, and segmented lined tunnels) that are not protected by a full membrane. Details of such a system are shown in Figure 3-13.

Justification:

Where ground conditions are determined to be corrosive, a prudent and economical approach is to establish a number of reinforcement monitoring stations in the especially critical areas. This approach assumes that when corrosion is detected, it can be remedied by installing a cathodic protection system and requires bonding the earth face layer of reinforcing bars together by tack welding. Typical costs and details of such bonding are referred to on Figure 3-13 and permit the installation cost of such a monitoring system to be estimated. Installation of typical cathodic protection systems is discussed in Guideline 3-19.



SECTIONAL PLAN OF WALL

NOTE:
1. LOCATE THE PROBE AS CLOSE AS POSSIBLE TO THE REBAR WITHOUT TOUCHING IT.
2. CADWELD THE GREEN GROUND CABLE TO THE REBAR.
3. COIL THE PLUG AND SLACK CABLE IN THE JUNCTION BOX OR RECEPTACLE.
4. SEE GUIDELINES REPORT SECTION 5 FOR DISCUSSION OF DETAILS OF TYPICAL INSTALLATION

Figure 3-13 CORROSION MONITORING INSTALLATION

The reinforcement in precast concrete linings must be electrically bonded by tack welding, and the segments must be bonded together as described for steel segment lined tunnels, Guideline 3-18.

At present, detecting deterioration of the earth face of reinforced concrete structures from the inside by nondestructive testing does not appear feasible. Alternative methods appear to be either core drilling from the inside or excavating and exposing the concrete from the outside. However, if the reinforcement monitoring indicates no corrosion, the concrete outside it may be assumed to be in satisfactory condition.

Guideline 3-18 — Monitoring Corrosion of Steel Segment Lined Tunnels

For steel-lined tunnels located in corrosive soil, it is recommended that the condition of the exterior surface of the lining be monitored by ultrasonic thickness-measuring devices.

Justification:

As for the reinforced concrete monitoring system, it is assumed that if corrosion is detected (by a reduction in thickness of the outside steel skin), it can be arrested by installing a cathodic protection system. If such an installation is required, the segments must be electrically connected by bonding bars between the segments. During tunnel construction, those segments in the invert that will become inaccessible when the concrete track support and walkway are built must be bonded before the concrete is placed. The accessible segments above the concrete may be bonded at the time the cathodic system is required.

It is extremely difficult to establish a priori that properly back-grouted steel linings with good protective coatings on the exterior face will be attacked by corrosive agents. In most situations, the measures described above will provide an economical compromise solution.

CATHODIC PROTECTION SYSTEMS

In the design and installation of a cathodic protection system, the following factors must be examined:

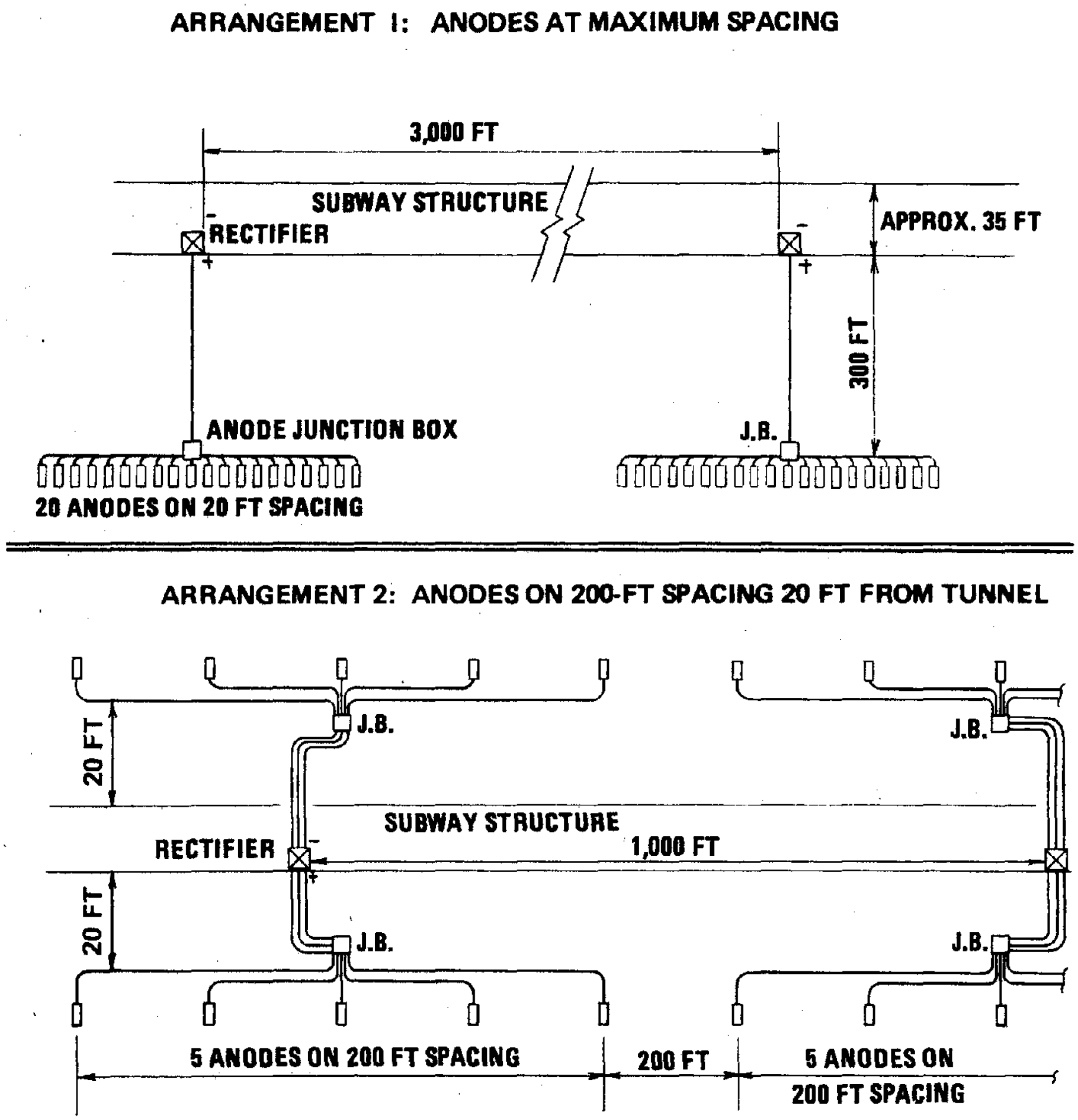
- The quantity of metal in the structure to be protected; reinforcing steel in concrete structures and steel or cast iron in tunnels,
- The severity of corrosive conditions,
- The resistivity of the soil, and
- The outside physical constraints on the installation of the system, such as existing structures, utilities, and other installations along the subway route.

The protection system requires a power source, rectification to dc current, transformation to the desired voltage, sacrificial anodes installed in the ground adjacent to the subway structures, and, as mentioned in Guideline 3-16, bonding of the metallic items in the structures to be protected.

Guideline 3-19 — Design of Cathodic Protection

Within the scope of these guidelines, it is possible to highlight only some of the more important factors for consideration.

- As a guide for layout and typical components, Figure 3-14 indicates two arrangements and spacings of the sacrificial anodes: a 3,000-foot spacing 300 feet from one side of the structure, and a 200-foot spacing on the outer side of the structure and 20 feet from it.
- A selection of either will probably be determined by the limitations imposed by the existing structures and utilities alongside the subway. Other things being equal, it appears that the arrangement with the 3,000-foot anode spacing is the more economical one. When the total cost of each system is evaluated, consideration should be given to maintenance and replacement. An illustration of such an evaluation is provided in the Rapid Transit Subways - Maintenance and Engineering Report.



NOTE:
SEE APPENDIX FOR COST ESTIMATE
OF TYPICAL INSTALLATIONS.

Figure 3-14 CATHODIC PROTECTION LAYOUT AND COMPONENTS

Justification:

There are appreciable cost variations between the two possible arrangements of the anode banks. It is important to evaluate all the factors that determine the spacing. The physical installation of the anodes and the electric cables connected to the subway may be the largest variable factor because of the presence, and probably imprecisely known locations, of existing utilities within the city streets. Excavations for this purpose may have to be undertaken manually.

The possible effects of the electric currents generated by the cathodic protection system itself on the street utilities and external structures must also be taken into account in the evaluation.

DRAINAGE SYSTEMS AND PUMP STRUCTURES

Guideline 3-20 – Drainage Systems

Layout of the subway drainage collection system and design of the details should be based not only on normal good engineering practice, but on careful consideration of the following items:

- Design measures should ensure that major flooding of the subway will not occur through station entrances, ventilation or other shafts, and portals. Such measures may include raising entrance thresholds and shaft surface terminations above possible surface flood levels and providing suitable berms and drainage ditches at portals.
- The system should be sized for anticipated seepages, inflows from ventilation shaft gratings, louvers, emergency exits and portals, station entrances, and any other accesses from the surface. It should also be sized to handle wash water from station cleaning operations and from the wet track cleaning system, if used. In addition, the incidence and extent of accidental or unusual flooding situations, such as burst water pipes, firefighting, or torrential downpours, should be assessed to determine whether allowance should be made in the permanent pumping installation for these infrequent (presumably) large volumes of water or whether a supplementary emergency system should be established.

- Catch basins should be located as near as possible to the source of water inflow; e.g., across or just inside of the portal faces, at the low point between stations, or at the end of station platforms if appreciable wash water is expected. Fan shafts that terminate at street surface may require separate drainage. Grating bars should run parallel to the direction of the water flow, with back sills to collect paper and other debris. Gratings should be positively secured against uplift but also readily removable.
- The drainage piping system should be designed so that, as far as possible, it will remove the type of dust and dirt generated in the subway system; i.e., metallic and concrete dust with a certain amount of oil and grease. Metallic pipe should receive a first-class corrosion coating, such as coal tar enamel, on the inside; all pipes of the subway construction should be encased in concrete. Where movement may be expected, the concrete should be reinforced. The casing should be structurally continuous with the catch basin and the pump sump to minimize the risk of fractures from soil movements at these locations. Clean-outs should be located where they are easily accessible for operation of cleaning rods.

Justification:

The drainage system of a subway is a vital support service. A correct design that will ensure its functioning for the particular water flows, chemical conditions, and solids that it must transport will pay handsome dividends in reduced maintenance costs. Major lengths of the piping system are normally below the structure and, therefore, extremely difficult to replace or repair at any time during the expected service life of the subway property. Top-quality installation and materials for the drainage system should be considered mandatory. Facilities for handling emergency flooding situations will be discussed in the guidelines for electrical and mechanical equipment.

Guideline 3-21 — Pump Structures

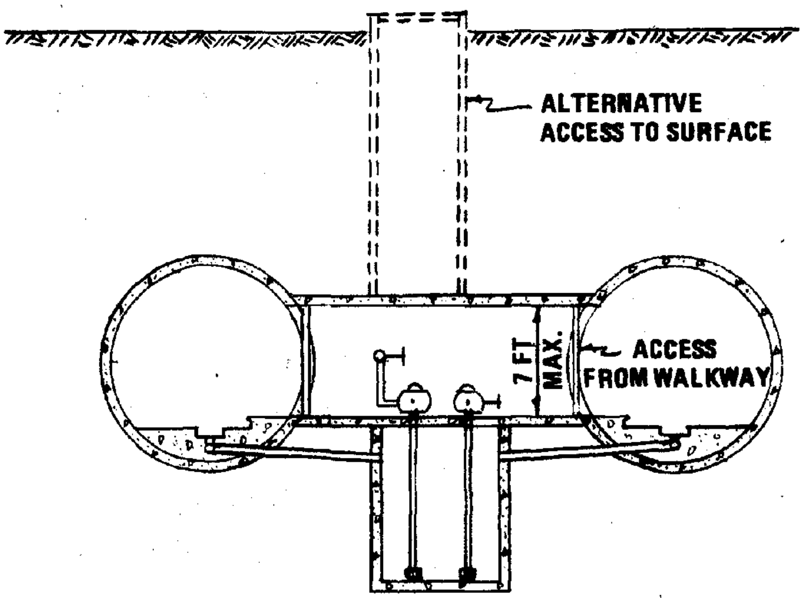
Wherever possible, pump structures should be accessible from the trackways so that inspection and maintenance can be performed during the train revenue service periods.

Justification:

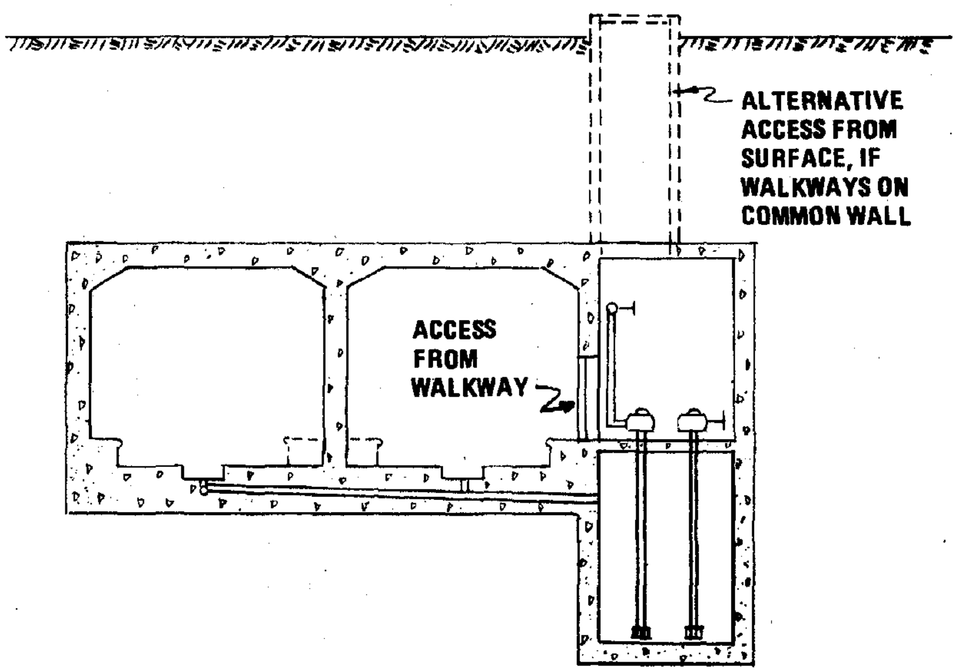
Trackway pump installations (and often the station drainage connection system located in the low points in the trackway) and accesses are determined by the type of trackway structure. Typical structure accesses for the intermediate subway track locations are illustrated in Figure 3-15 (a). For tunnel trackway structures, the pumps can be placed between the two tunnels and accessed from the station center platform via the track walkways.

Figure 3-15 (b) shows an arrangement for a cut-and-cover two-cell box structure where the pump structure must be placed along the outside wall. If the stations have side platforms, the trackway service walkways can be located along the outside walls to give easy access to the pump structure. If, however, the station has center platforms, walkways will be built along the central dividing wall with access to the pump structure across the track and probably over the conductor rail. In this situation, where possible, it is desirable to provide access from the surface by extending the structure as required.

In many instances, pump structure accesses can be combined with the ventilation shafts. The maintenance and inspection programs become more flexible and economical if they can be performed independently of the train revenue schedule.



(a) SINGLE-TRACKWAY TUNNELS



(b) CUT-AND COVER TWO-CELL BOX

Figure 3-15 PUMP STRUCTURES AND ACCESSES

VENTILATION STRUCTURES

This subsection covers trackway ventilation structures. Ventilation may consist of one or more interrelating systems, but it generally requires vertical shafts from the trackway structure to the surface.

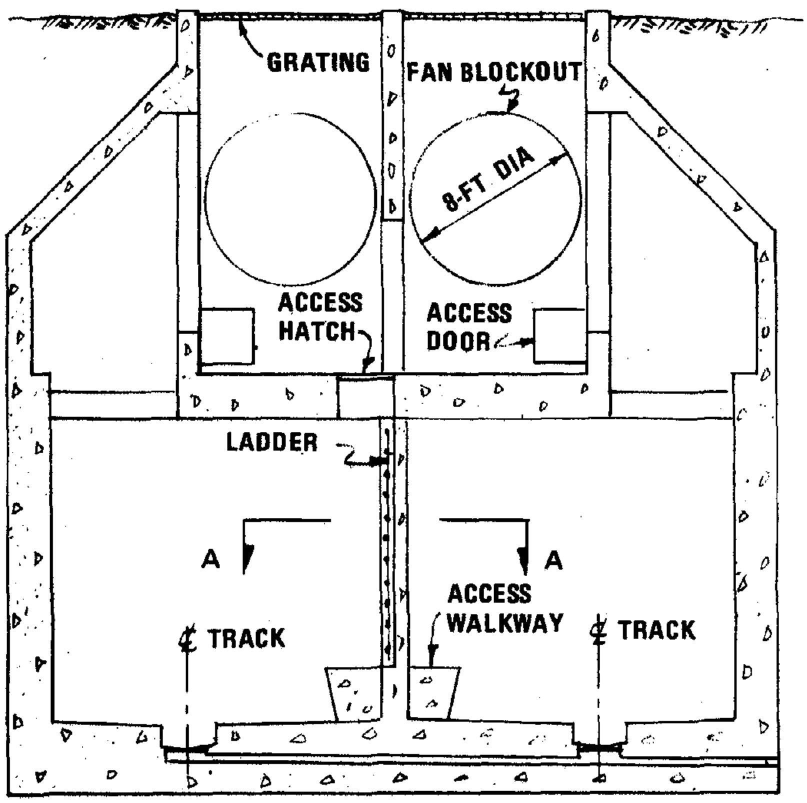
The shafts usually are sized to an area of approximately 50 percent of that of the trackway. Often they are located at the ends of the station and at one intermediate point between the stations. Fans for positive ventilation may be provided at all the locations, but often only at the intermediate point. In the latter case, fans may extract only (either seasonally or continuously) to remove the heat generated by the train operation, but they should also be reversible for emergency smoke control.

A fan shaft often includes emergency exits from the trackway to the surface and, at low points in the line, combines with the drainage pumping facility.

Location and design of the vent shaft's surface termination are important for a number of reasons, as will be discussed in the following guidelines. Three major positions are the roadway or sidewalk, above the sidewalk level, or behind property lines (usually elevated above the ground). Figures 3-16, 3-17, and 3-18 show alternative arrangements of ventilation system terminations.

Guideline 3-22 — Position of Surface Vent

An evaluation should be made of the following alternatives: placing the vent at street or sidewalk level, extending it above the sidewalk level (if space permits), and placing it behind the street property line. Maintenance costs will form an important part of the evaluation.



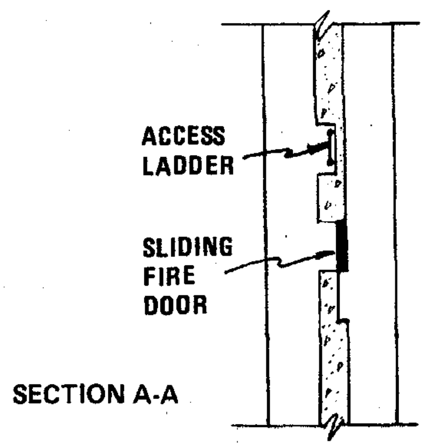


Figure 3-16 VENTILATION STRUCTURE TERMINATION AND ACCESS – TWIN CELL

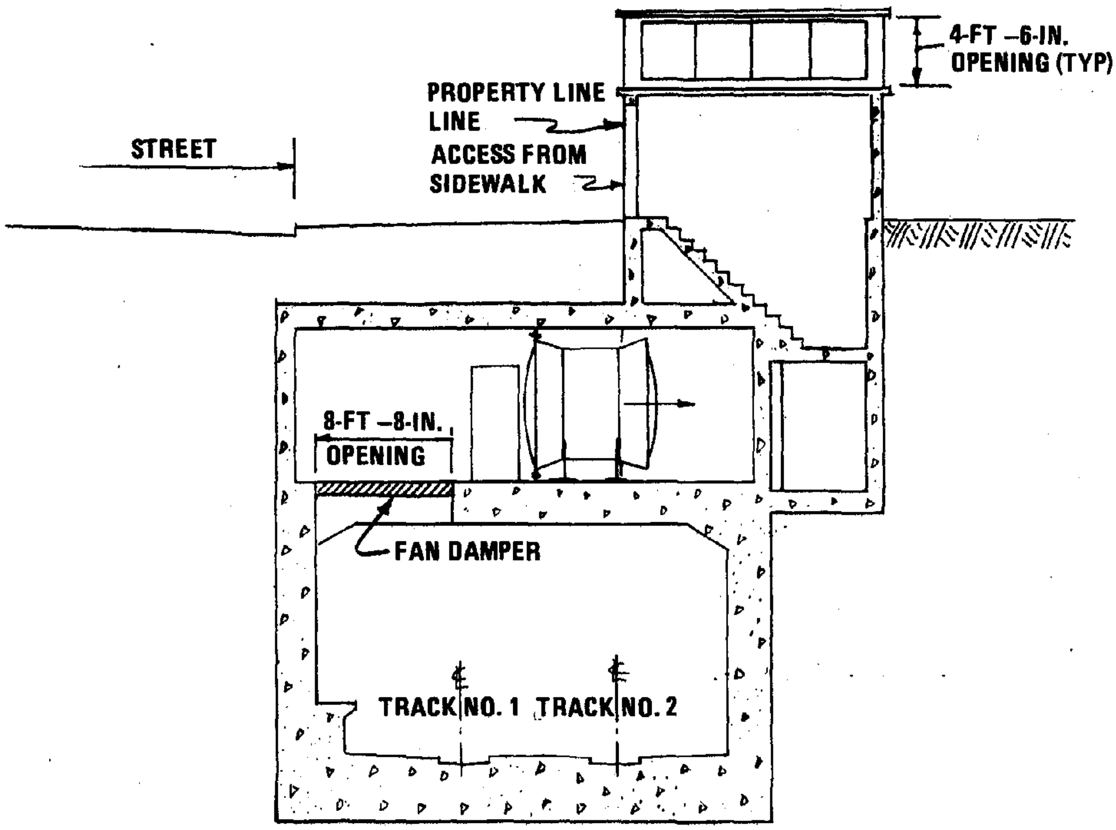


Figure 3-17 VENTILATION STRUCTURE TERMINATIONS AND ACCESSES – SINGLE CELL

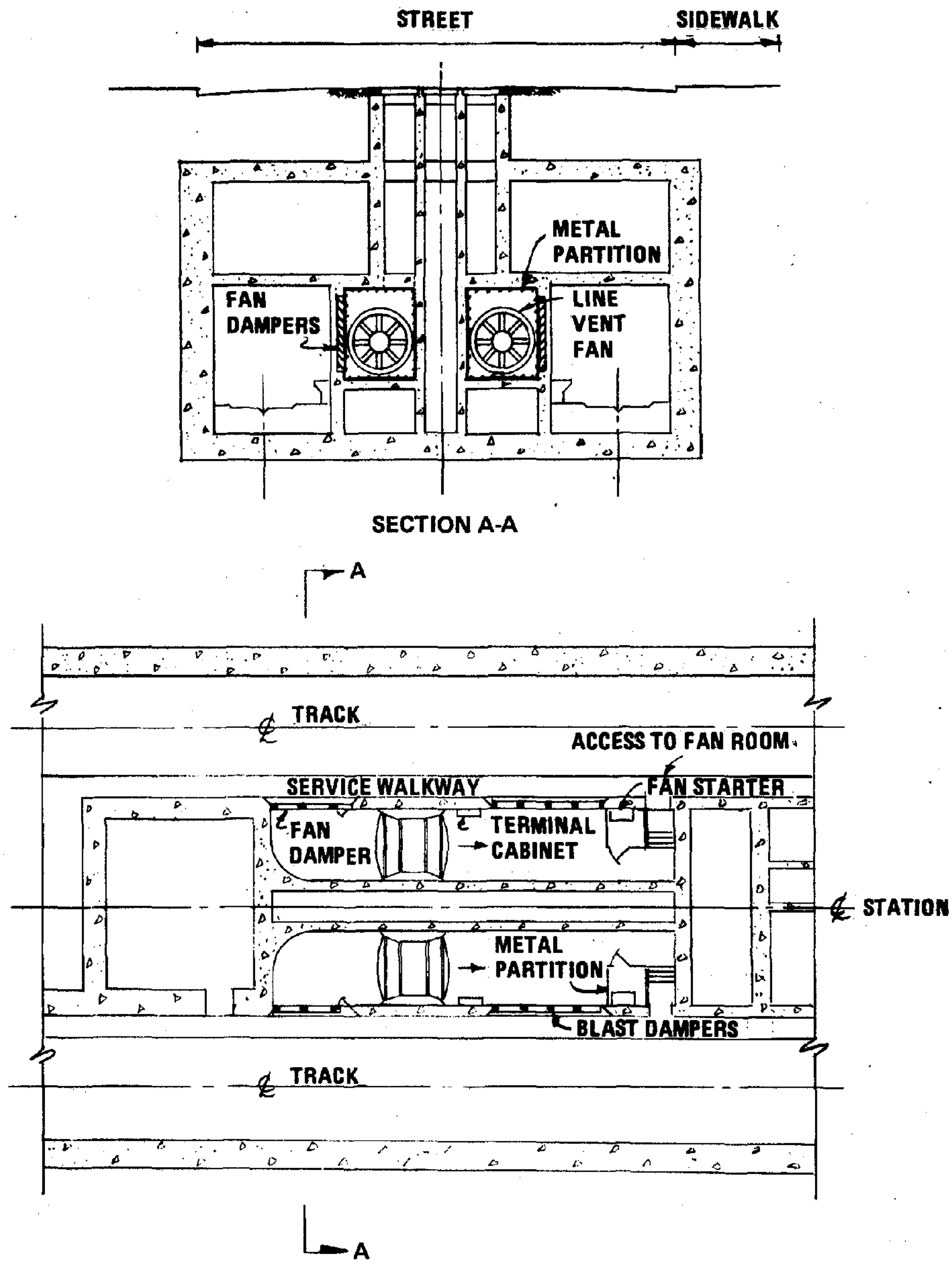


Figure 3-18 VENTILATION SYSTEM ARRANGEMENT – TWIN BOX SECTION

Justification:

Installation costs of the alternative vent termination locations can vary widely, particularly if additional property has to be acquired to place the vent behind the property line. Factors to be considered in the evaluation should include the following:

- Acoustics. If the fans are to be operated continuously or only in periods of hot weather, elevating the shaft above the surface has considerable advantages, particularly in residential areas.
- Flooding. In certain situations, the vent grille at street or sidewalk level will involve additional precautions and costs to guard against flooding and accidental spillage of flammable liquids.
- Dust and Air Pollution. Street- and sidewalk-level vents collect dirt and debris, particularly where they serve as pressure relief only, and such material can be drawn into the trackway. In any case, additional maintenance costs will be involved in cleaning the shaftways and sumps. Noxious fumes from automobile exhausts and other forms of air pollution may also be introduced into the trackway system.
- Maintenance of Miscellaneous Metal. Placing the vent grille above the ground surface, particularly if the grille can be placed vertically, will minimize the amount of water entering the shaft and will result in lessened maintenance costs of the metal ductwork and other miscellaneous iron and steel items. Among these are the hatchways and other items needed when the ventilation shafts also serve as emergency exits.

Guideline 3-23 — Access for Maintenance

It is recommended that accesses for maintenance of the ventilation shaft and its equipment be provided at the trackway level, as well as at the surface, where possible.

Justification:

Most ventilation shaft systems, even when they vent the structures at the top or roof, provide for drainage at the bottom of the shaft.

Also, either mechanically operated or dynamically controlled movable louvers may be provided in the trackway wall. All these are maintenance items at this level. In addition, the shafts require cleaning at intervals, and it may be convenient to wash or brush accumulated dust and debris from the walls and horizontal surfaces to the bottom of the shaft, where they can be conveniently collected at track level.

The ventilation shafts are open to the adjacent walls of twin-tunnel track structures and can be accessed from the service walkways.

In the case of a twin-cell, cut-and-cover structure with side-platform stations, the openings are on the outside of the walls. Again, access can be from the service walkways. If, however, the station is of center platform design, the service walkways will be along the common wall. In this case, the vent opens to the trackway roof, and it is often possible to provide access by ladder through the common wall; this is recommended. Details of the various trackway ventilation terminations are indicated in Figures 3-16 and 3-17.

Guideline 3-24 – Drainage and Maintenance Requirements

Where the ventilation shaft terminates at street or sidewalk level, drainage should not discharge directly into the trainway. Provision should be made to collect dirt and debris at a high level, and, if it is not possible to discharge the drainage directly into the street disposal system, catch basins with adequate oil separators should be provided.

Justification:

Spilling flammable liquids is always possible in busy streets, and the trackway should be protected against such accidents. In addition, if the dust and debris from the street are brought down to track drainage, the system may become plugged, particularly in periods of low rainfall. Provision for drainage must, of course, be made at the base of the ventilation shaft to handle seepage and cleaning water flows.

Guideline 3-25 – Provision for Cleaning

It is recommended that provisions be made for the efficient cleaning of ventilation shafts.

Justification:

Experience indicates that all ventilation shafts require cleaning from time to time. The frequency and magnitude of this operation depend on a number of factors relating to the location of the vent at the surface, the way the fans extract (continuously or not), the quantity of dust generated in the trackway, and the trackway cleaning system and frequency. In existing transit properties, the cleaning frequency of ventilation shafts seems to vary from monthly intervals, where the vents are located at street surface, to 5 or 7 years, where the vents are above street level.

Provisions for minimizing the cleaning effort include:

- Contouring the surfaces of the shaft, equipment, and miscellaneous metal to reduce dust-catching surfaces and corners,
- Providing smooth, slick concrete surfaces, including concrete sealers,
- Planning for ready access to all surfaces and areas by means of ladders, platforms, or moving scaffolds,
- Considering cleaning by high-pressure water sprays and designing the drainage system accordingly, and
- Planning for debris removal from the surface or at track level.

Section 4

MECHANICAL AND ELECTRICAL EQUIPMENT AND LIGHTING

The four main items of fixed mechanical and electrical equipment are escalators, elevators, pumps, and fans (discussion of the latter is limited to trackway ventilation fans). A fifth important electrical item is the lighting system. The scope of this subsection is limited to points of major value in planning economical maintenance programs and is by no means intended as a complete coverage or specification. The design and manufacturer of escalators and elevators is covered by the American National Standard Safety Code ANSI A17.1 for Elevators, Dumbwaiters, Escalators, and Moving Sidewalks.

ESCALATORS

Of all the fixed mechanical equipment, escalators typically represent the largest capital investment and the highest maintenance cost, and they are an extremely important functional link in efficiently moving passengers between the trains and the surface. Conditions of service for transit system escalators are much more severe than for general commercial applications: these escalators may operate more than 18 hours a day 7 days a week with heavy loading during peak hours, be capable of regular reversal to accommodate traffic flow, and must be reliable because of the limited time available for maintenance.

Guideline 4-1 — Design Specifications

The following considerations are recommended for incorporation in the design specifications for escalators:

1. Separating the main drive motor from the escalator truss and providing maintenance access from a machine room at the head of the escalator and down the incline,
2. Designing the chain lower carriage to maintain an automatic constant tension adjustment for the main drive chain wear. The carriage and idler sprockets should be one assembly and mounted so as to prevent skewing,
3. Heavy duty step chains should be provided with large, well lubricated wearing surfaces that provide long service,
4. Wherever possible, fitting components with life-packed bearings,
5. Where (4) is not applicable, including a well designed automatic lubrication system, with a lubricant reservoir, for all fixed part bearings.
6. Designing the main chain track radius at no less than 12 feet at upper curve and 8 feet at lower curve (not including the radii around the gears) for speeds of 150 ft/min. These dimensions may be reduced by 3 feet for lower speeds.
7. Installing a fault-finding system for all components subject to breakdown, the information to be displayed in the station attendant's booth as well as indicated by appropriate lights in the machine room
8. Reinforcing with nylon and using stainless steel core for hand rails exposed to weather

Some of these features are illustrated in Figure 4-1.

Justification:

These items are considered of major importance in obtaining a durable, low-maintenance-cost escalator best suited for the heavy duty service

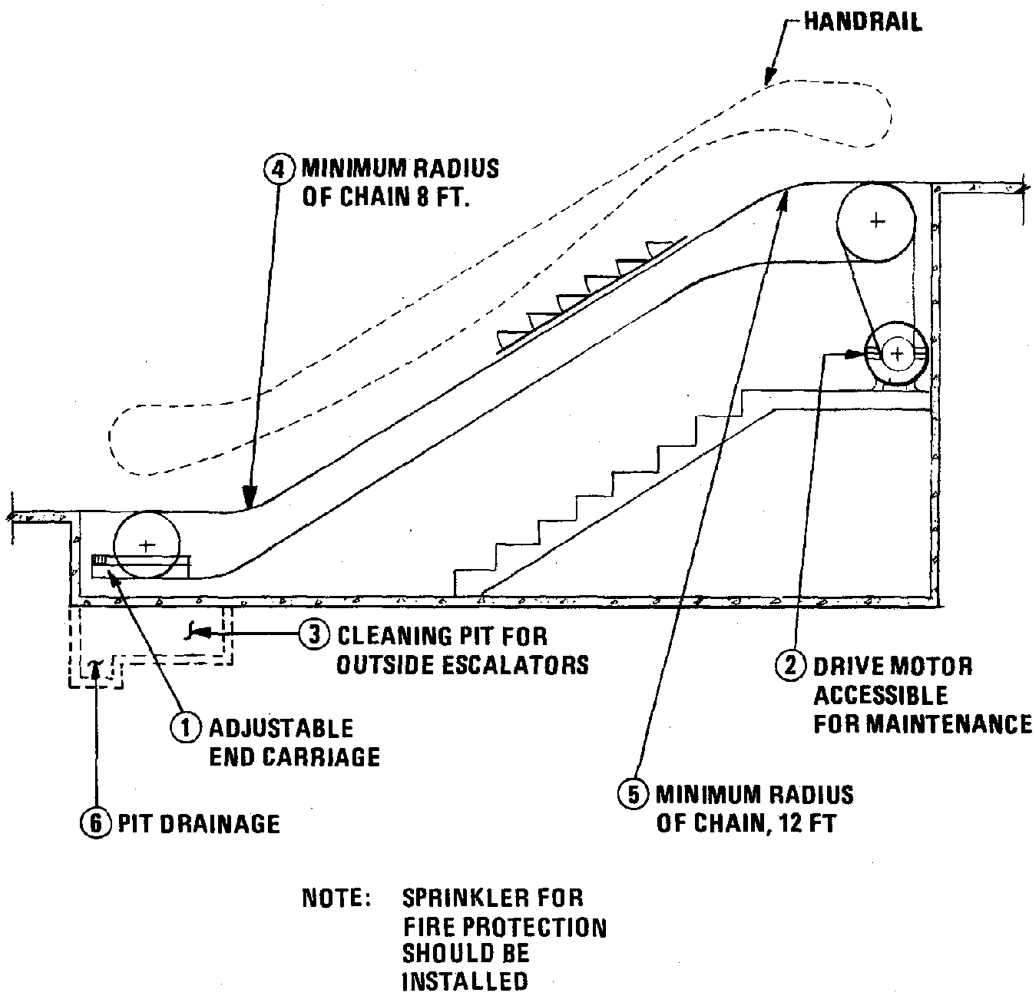


Figure 4-1 ESCALATOR

required for station subway use. The following justifications correspond to the numbered recommendations:

1. Providing a machine room at the head of the escalator with easy access to the main drive motor and mechanism greatly eases maintenance and reduces the incidence of interruption in the escalator service. Access down the incline permits inspection and maintenance in this area while the escalator is in service.

2. The automatic adjustment and constant tension of the lower carriage, or chain bearing, not only reduces maintenance effort, but also tends to reduce the wear on the bearings.

3. Heavy duty step chains not only greatly extend the periods between replacement but also reduce the incidence of gaps developing between the steps and creating dangerous conditions.

4. Minimum radii of 12 feet and 8 feet at upper and lower curves for the main chain return reduces the tension on the chain and the wear on the bearing pins.

5. Sealed bearings reduce maintenance and damage from over or under lubrication.

6. The automatic lubrication system reduces the cost of maintenance and if well designed ensures that the bearings are properly lubricated at all times. However, excess lubrication may damage the bearings and call for use of drip trays which may increase the risk of fire.

7. Independent fault monitoring by the station attendant permits the identification of a fault and relaying of the information to the maintenance department, thus increasing maintenance efficiency and reducing the amount of down time.

8. Hand rails are an expensive maintenance item, typically taking two or three days to replace; use of stainless steel has proven to increase the life and reduce stretches and the incidence of breaks.

Guideline 4-2 – Speeds

Speed of an escalator may be based on its height. The transit systems surveyed in the U.S. or abroad exhibited three standard speeds: 90 feet per minute, 120 feet per minute, and (abroad) 150 per minute. These speeds often correspond to heights of 25 feet, 50 feet, and more than 50 feet.

Justification:

The trip time often governs the desirable speed of the elevator; hence the longer escalators generally are operated faster than the shorter ones. The survey did not determine that more accidents occurred entering and leaving the escalator when it moved at the higher speeds.

Guideline 4-3 — Running Control

Alternative controls of escalator speeds for various conditions of location and passenger density should be evaluated against power consumption and maintenance.

Justification:

The extent of maintenance and component replacements for an escalator depends on the mileage (i.e., speed x time) imposed on it. Very frequent stopping, starting, and reversing will accelerate wear on the components including brakes, motors, and controls. In most stations, some escalators are used infrequently during a significant portion of the revenue service day, and, in the interests of saving mileage, there are two choices for operation:

- Stop the escalator when not in use; it may then be started by passenger actuated treadle or electric beam.
- Program the escalator with two passenger carrying speeds; it will operate at the higher speed during peak traffic periods and at the lower speed during off peaks. It should stop completely before changing speeds.

The former appears economical when periods of nonuse are frequently more than 15 mintues. The latter is preferable when the nonuse period is generally less than 15 minutes. The latter also permits valuable flexibility in crowd control in peak periods; i.e., crowding on platforms can be reduced by running the escalator at the lower or higher speeds (according whether the elevator is delivering to or receiving from platforms).

Guideline 4-4 — Mechanical Safety

The following specifications are recommended for safe operation of escalators:

- Maximum gap tolerances between treads, risers, and combs and between tread and skirts are established by code; these should never be exceeded.
- Brake design must include accurate adjustment to achieve satisfatorily smooth stops.
- Handrails should be so designed that the possibility of fingers being trapped between moving and stationary parts is minimized.
- If a handrail breaks, the driving mechanism should automatically shut off.
- Emergency stops and starts should be gradual rather than sudden.

Justification:

A frequent cause of mishaps on escalators is clothing being caught between the moving tread and stationary parts; the incidence of this type of occurrence depends upon the gap between the fixed and moving parts. The same reasons apply to the design of handrails. Sudden stops and starts obviously could injure passengers; emergency control mechanisms should ensure gradual commencement and cessation of movement.

Guideline 4-5 — Visual Safety

The following recommendations should be incorporated into the design. for lighting escalator areas:

- Eliminate glare on escalator treads and combs by using less reflective materials and by employing proper lighting design.

- Intensify lighting at the top and bottom of the escalator.
- Highlight side and nosings of the treads by yellow or other colored paints. Note: the paint must be maintained or, in the event of accident, this could become a legal point of claim.

Justification:

Under certain lighting conditions, highly reflective materials can cause dizziness, confusion, and accidents, particularly on high escalators. Stainless steel and aluminum appear to be the usual materials in treads and combs and become highly polished with use; however, the glare effect can be minimized by correct placement of lights and by highlighting paint.

Entry to and exit from the escalator require the most concentration from the passenger, and intensified lighting in these areas considerably reduces passenger hesitation thus avoiding congestion while speeding and smoothing the traffic flow.

Painting, particularly of the nosing, is a maintenance activity; the same result could probably be achieved by incorporating a readily replaceable plastic nosing strip.

Guideline 4-6 — Monitoring and Maintenance

The following instrumentation is recommended for incorporation in the design to assist in timely maintenance:

- Instrumentation to gather continuous energy consumption data and to record programmed stops and starts
- Instrumentation to record emergency stops, and
- Television surveillance of operating conditions.

Justification:

Energy consumption charts in conjunction with records of programmed stops and starts will provide valuable information for establishing the wear-and-tear rate on the escalator. This information will permit adjustment of the stop and start program to minimize energy consumption and maintenance. In the interest of economy, such instrumentation may be limited to representative escalator installations.

Misuse of the emergency stop button is a source of additional cost and lack of availability in escalator operation. Television surveillance in conjunction with station attendant monitoring can reduce this cost as well as control vandalism and help determine escalator loading conditions and appropriate actions to control them.

Guideline 4-7 — Planning for Maintenance and Cleaning

In laying out areas containing escalators, provisions should be made to allow ample access to the escalator chamber to facilitate maintenance and cleaning. Preferably, such an area should be separated from the public area. Platforms, steps, and ramps should be designed to permit easy access to all parts of the machinery and to allow easy withdrawal of components. Dust collection trays should be arranged for cleaning either by brushing or high-pressure water spray. In the latter case, supply and drainage facilities must be allowed for. Concrete surfaces should be smooth and sealed to permit easy cleaning and to eliminate concrete dust generation. Reentrant corners should be chamfered or rounded.

Justification:

Escalator maintenance and cleaning are major cost items and are labor intensive. Inspection maintenance should be performed at frequent intervals and, therefore, easy accessibility to all items involved should be included in the design.

By their design, escalator treads act as shoe cleaners; therefore, large quantities of dirt and dust fall into the under-escalator housing. Dust and debris collection and removal are an essential part of the total cleaning operation.

ELEVATORS

Elevators in subway stations are either for the use of the general patronage or the handicapped only. They may also serve to transport injured or otherwise incapacitated patrons or transit staff, maintenance equipment and material, fare collection money, and consumable supplies. These latter functions are becoming increasingly more important to the operations and maintenance of a station, and will be the subject of the guidelines which follow.

Guideline 4-8 – Size, Capacity, and Arrangement

In addition to moving patrons, elevators should be of size and capacity to transport the following:

- A stretcher case with attendants.
- All regularly used maintenance equipment, material, and consumable supplies, and
- Fare collection money (if appropriate).

In addition, the elevators should serve all station levels and the street and, where practicable, provision for surface vehicle access should be considered.

Justification:

Accidents can occur anytime anywhere (including in the train) in the subway system, and for such events it is highly desirable to have elevators sized to accommodate stretcher cases and attendants for transport to the surface.

As discussed in Rapid Transit Subways - Maintenance Guidelines, the most efficient maintenance procedures for a station may depend upon whether or not elevator transportation is available. Therefore, elevator design should be evaluated for assistance in station maintenance as well as for the other functions noted.

The provision of access for surface vehicles aids the street transportation related to both of the above functions.

The National Elevator Industry, Inc. (New York) Publication, Standard Elevator Layouts, provides considerable detailed information on standard layouts, and other data, for installing traction (rope) and hydraulic passenger and freight elevators.

Guideline 4-9 — Evaluation of Elevator Type

A comparative cost evaluation should be made between electric traction and hydraulic elevators. The following major items should be considered:

- installation costs,
- installation space requirements and
- maintenance costs.

Justification:

Each elevator type has different advantages in repect to installation and maintenance costs according to the particular installation. The most pertinent variable factors are:

- Height of Travel and Geology. Hydraulic elevators require a ram length from the bottom of the overrun pit equal to the height of travel plus about seven feet: e.g., a typical station with the roof 8 feet below street level would require a ram cylinder length of 40 to 45 feet. Such a cylinder can be installed economically by drilling into good ground, such as firm clay. In rock or waterbearing sand, the economics are quite different.

- Space Requirements. A traction elevator requires a larger machine room than a hydraulic elevator. For the traction type, placing the machine room directly over the top of the hoisting is economical; however, this is generally not acceptable for a subway station. The hydraulic machine room need not be located in any particular relationship to the shaftway, which permits flexibility in planning.
- Power. Hydraulic elevators consume more power than do traction ones.
- Equipment Installation and Maintenance Costs. For typical stations and reasonable geology, the cost of equipment and installation is somewhat less for hydraulic elevators. In addition, the average maintenance costs for hydraulic types appear to be approximately 50 percent of those for traction.

Guideline 4-10 – Reliability and Monitoring

Where the elevators are to be operated by the general public, car control mechanisms should be as simple as possible and readily maintainable. Monitoring devices should display fault details in the attendants' booths as well as in the machine room.

Justification

However well maintained, elevator malfunctions (often through door mechanism failures) will occur from time to time. When elevators stick, it is crucial that the situation be corrected as expeditiously as possible and the passengers freed. If the attendant knows the cause of the fault, he may be in a position to correct it himself; at least he can describe details of the fault to the maintenance team and prepare them before they arrive on the scene.

Guideline 4-11 – Car Vandalism

The car should be designed to resist vandalism and have finishes that resist defacement. Shatterproof glazing in one or two sides may be useful to permit monitoring.

Justification:

These recommendations are important if the general public will use the elevators. Using hard, slick finishes inside the car will reduce maintenance. Passengers are being monitored through use of car side glazing in Stockholm.

Guideline 4-12 – Planning for Maintenance and Cleaning

As for escalators, machine rooms should be planned so that all parts of the equipment to be maintained are readily accessible. Lifting beams or other devices should be installed in the appropriate locations for replacing heavy components. Pit floors and machine room floors (where the latter are in contact with the ground) should be waterproofed and provided with drainage.

Justification:

As for escalators, elevator maintenance is important and relatively frequent. All of the above recommendations will reduce the maintenance cost.

PUMPS

Sizing pumps and sumps for a new transit system requires consideration of many factors, some of which are outlined in Guideline 3-18, Drainage Systems. Anticipated sources and quantities of water that must be removed from a subway structure (not including station facility drainage) are discussed in the following paragraphs.

- Seepage. Specifications for some new systems do not allow the seepage rate to exceed 2×10^{-5} gpm per square foot of surface. For the average single track structure, this amounts to approximately 1 to 1.5 gpm per 1,000 feet of length.
- Wash Water. The quantity of water used in washing the trackway and stations (if a wet system is adopted) can be estimated according to the methods employed.

For instance, a trackway washing car discharges 50 gpm over a period of an hour and a half. Periodic washing down of station floors, platforms, walls, etc., may amount to 10 to 15 gpm. It must be determined if these two operations will take place concurrently.

- Broken Water Pipes or Hydrants. The amount of water lost can readily be determined; roughly, a 2-inch pipe under pressure of 100 psi will discharge approximately 100 gpm.
- Accidental Flooding. Water from such a source will vary considerably according to the location and elevation relative to the ground surface of ventilation gratings and emergency exits and portals; each must be assessed on its own merits. Catch basins and gratings must be designed of sufficient size to prevent clogging.

In selecting the number and size of pumps for locations where a steady flow of water is anticipated from seepage and wash water, two pumps seem to be sufficient and, if they are not of equal capacity, one of them should have the capacity to handle twice the design normal flow. The other may be sized to handle the more or less frequent larger flows such as those from trainway washing or accidental flooding. Durability of the pumps should be ensured by selecting material suitable for the pH of the water to be pumped.

Guideline 4-13 – Sizing of Pumps

The following considerations should help determine the size of the pumps:

1. A minimum of two pumps should be provided, and each should have the capacity to handle twice the expected quantity of water from seepage, routine station washing, and, as appropriate, rain water from portal, ventilation, and emergency exit drainage.
2. One pump should be sized for the criteria in (1) and the second sized for the criteria in (1) plus water from the train tunnel washing process and a certain amount of flooding.

3. Provision should be made to add pumping capacity to take care of emergencies such as broken water pipes or exceptional flooding.

4. Using portable pumps should be considered as an alternative to (3).

Justification:

The above recommendations provide only a rough guide; special conditions at some pumping locations may require a different approach. Providing two pumps in each location is generally accepted practice to assure reliability in the case of breakdown. In some properties, Item 4 is found to satisfactorily reduce fixed installation and operating costs.

Guideline 4-14 — Pump Type and Specification

Turbine line shaft pumps, duplex type, are recommended for most situations. Generally heads over 100 feet are not encountered and single stage pumps are satisfactory. Power is normally 440 volt ac. Emergency alternative power sources should be provided.

According to whether the water to be pumped is above or below pH of 6 the following materials are recommended for maximum longevity.

	Recommended Material	
Item	pH<6	pH>6
Volute	Bronze	Stainless steel
Impeller	Bronze	Stainless steel
Shaft	Stainless steel	Stainless steel
Liner	Bronze	Stainless steel
Strainer	Bronze	Stainless steel
Column, flanged	Stainless steel	Stainless steel
Discharge pipe, flanged	Stainless steel	Stainless steel
Bearing	Graphalloy	Graphalloy
Bearing housing	Bronze	Stainless steel
Thrust bearing	Sealed[a]	Sealed[a]
Bearing lube, automatic	Individual lube[a]	Individual lube[a]

(a) Sump pump, oil lubrication for lineshaft pump

Justification:

The recommended pump types appear to have proved to be reliable and to require a minimum of maintenance. Using the recommended materials and lubrication system will allow economical upkeep.

Guideline 4-15 — Emergency Conditions

Two alternative power sources should be provided for emergencies. In addition, provision should be made for portable emergency pumps, provided either by the transit owner or by arrangement with the local fire department.

Justification:

Prevention of flooding of the subway structures is of prime importance. Such flooding is likely to occur at periods of violent storms which, in turn, tend to interrupt power supplies; hence, the importance of reliable alternative sources. These may include alternative external power sources or standby diesel generators which are normally located in the stations next to the pumping location. Such standby plants also provide emergency power to the station facilities when required. Provision for installation of emergency pumps is generally inexpensive, largely being a matter of access and a connection to the piping system, but essential insurance for maintaining the operation and safety of the system in the extreme flooding conditions.

Guideline 4-16 — Sizing of the Pump Sump

The size of the pump sump is predicated on the sources of water inflow and the size of the pumps. For day-to-day removal of seepage and wash water, an economical range of pumping should be considered to be between three times a day per pump with minimum pumping periods of ten minutes each and eight times a day with a one-hour pumping periods.

Justification:

The above ranges indicate acceptable cycling and pumping times for the maintenance and durability of the pump. The final selection of pump size can be made only after all the water-generating sources have been evaluated and the diversity factors estimated.

Guideline 4-17 – Pump Sump Layout

The pump sump, together with a catch basin, should be laid out as shown in Figure 4-2.

Justification:

A catch basin is provided to intercept the drainage and to settle the solids before they enter the sump pump; it should have at least a 1-hour retention capacity. Such a catch basin would prolong the periods between sump clean up and would protect the pumps from abrasion by the solids. The local sump in the pump chamber itself will permit the use of a portable submersible sump pump for dewatering the chamber for self-cleanout and maintenance upon the pump and impeller. It is envisaged that the solids will be removed manually into drums for disposal.

Guideline 4-18 – Water Level Control and Monitoring

Water levels should be controlled by mercury switches, and a maximum water level float switch should be provided and connected to the appropriate services control center. It is also recommended that the cycling of the pumps and power consumption be recorded.

Justification:

The mercury switch water level controls appear to be reliable and fairly maintenance free. Emergency high level alarms are essential and must be incorporated as part of the overall transit safety system.

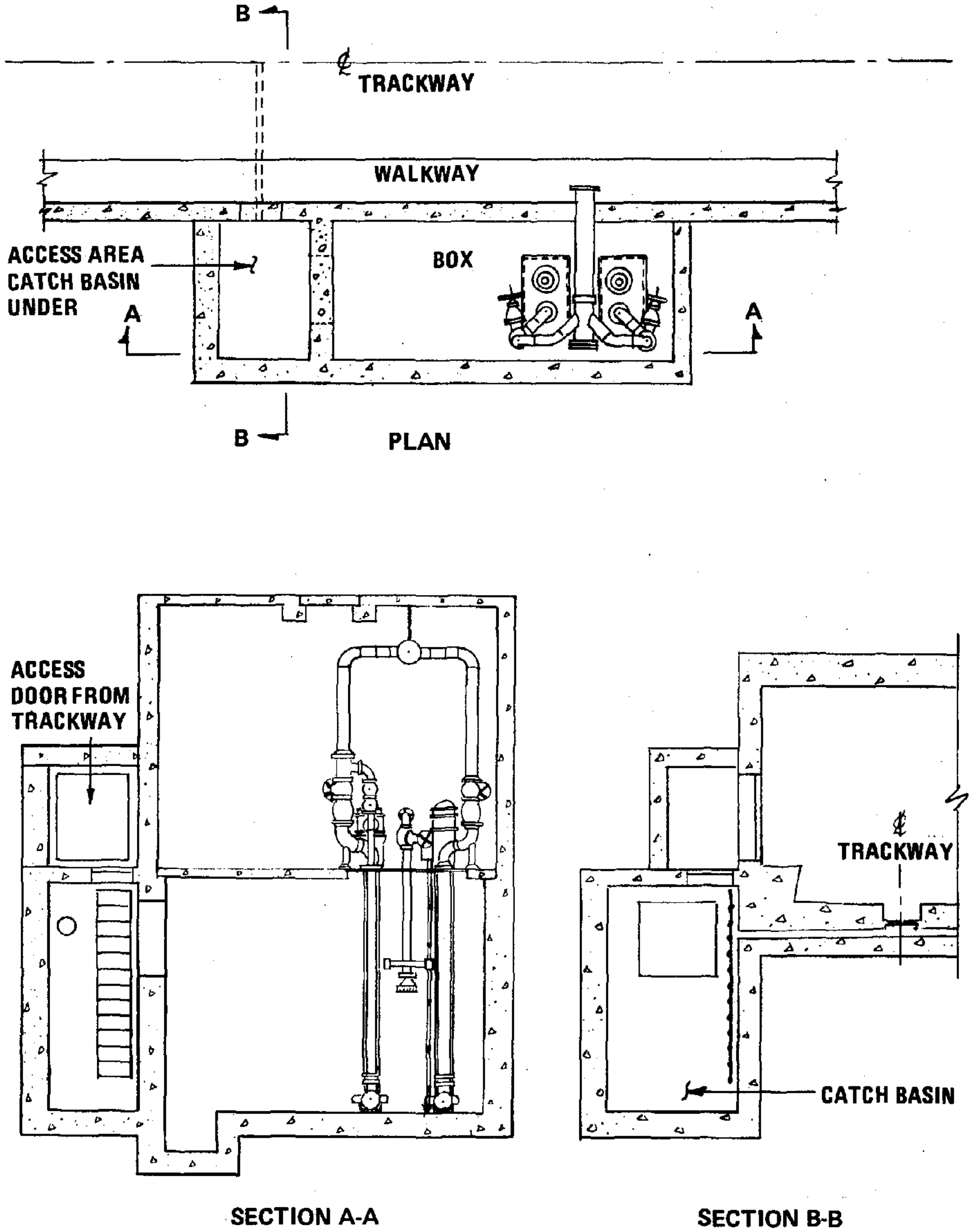


Figure 4-2 PUMP ROOM

Recording the actual service of the pumps, or at least those in the more important drainage locations, provides a method both of detecting unusual water flows and also of obtaining more efficient maintenance procedures and extending the life of the equipment.

Guideline 4-19 – Protection of Piping

It is recommended that dielectric insulating joints be installed between the pump discharge pipe and the waste main (if of ferrous material) and that the shaft pump discharge head and pipe be epoxy coated, both inside and outside.

Justification:

Experience indicates that both of these actions are effective in reducing corrosion and pitting of the piping.

VENTILATION EQUIPMENT

According to the particular environmental conditions in a transit property trackway, ventilation fans may be operated on a seasonal basis, or, occasionally, continuously around the clock to remove excess heat from the train operation and for smoke and heat control in emergencies; or they may be operated for the latter emergencies only. Also, the fans generally must be reversible for emergency control of heat and smoke.

Detailed guidelines for selecting ventilation equipment are superfluous here because of this wide range of possible service conditions and the fact that the subject is fairly exhaustively covered in Subway Environmental Design Guide Handbook, Vol. 1, Principles and Applications, prepared for the Department of Transportation, Urban Mass Transit Administration, Office of Technology Development and Deployment, Washington, D. C. However, guidelines in this subsection present some general principles for designing and specifying ventilation equipment that will provide long-term satisfactory performance for low maintenance effort.

Guideline 4-20 – Design Basis

It is recommended that the subject matter discussed in Subway Environmental Design Handbook (Section 4.2, Environmental Control Equipment) be used as the basis for formulating the design criteria for the ventilation fans and equipment.

The conditions of service for each particular installation should be thoroughly investigated, and the optimum equipment for long-term minimum maintenance selected.

Justification:

The following aspects will have a major influence in the equipment selection:

- Because of their relatively lesser demand for expensive underground space, axial flow fans (rather than centrifugal) are normally selected.
- For equipment to be operated during train service, a major design loading comprises reversing pressures and oscillating pressure pulses generated by the train as it approaches and leaves the ventilation shafts. If the pressures might cause the fan to stall (even if it is designed for the conditions), the life of the various components such as bearings and drives will be shortened and maintenance costs increased.

  At least one property (London, which operates continuous tunnel ventilation) employs gravity louvers that close the track level ports of the intermediate ventilation shafts as the trains pass, thereby avoiding the condition. When such louvers are used either they must be mechanized to open when the fans are reversed or a bypass provided.
- All the equipment components should be designed to operate in the highest temperatures anticipated (such as from a burning train). Such components include fan belts, motors, electrical controls, and wiring.

Guideline 4-21 – Quality of Ventilation Equipment

All equipment should be of the highest quality and heavy duty, particularly if extensive operation is expected. The provision of debris screens and filters at the air intakes should be considered.

Justification:

Trackway ventilation equipment often is in a damp, humid environment. When the equipment is operating, dust and debris from the trackway will be drawn past it into the fan rooms. In situations where trackways will not be regularly and systematically maintained, the installation of debris screens and, perhaps, filters, may be warranted to reduce accumulation of dust and dirt in the shafts. Environmental pollution may also become a factor.

Heavy duty components – including bearings which should be sealed as far as possible and electrical items which should be completely watertight, obviously will reduce maintenance requirements.

LIGHTING

The lighting system in subway structures is important for several reasons, the more pertinent of which are:

- Safety: good illumination helps prevent accidents, particularly at stairs and elevators and train platform edges. Adequate lighting in general public areas allows station attendants to effectively monitor the area and deters physical attack or robbery. In machine rooms and other work areas, adequate lighting is necessary both for safety and for performing the work that is undertaken in these areas.
- Visual effects: well designed illumination can enhance the aesthetic effects of the station finishes, and
- Cost: installation, operation, and maintenance costs are directly proportional to the number of fixtures and type of lighting selected.

The major portion of the underground complex lighting system is in the public areas of the stations, and the lighting arrangement and design will be largely influenced by the station finishes and ceiling systems. Because of the numerous possible combinations of these variables, only guidelines of general good practice will be presented for designing lighting systems that are economical to install, operate, and maintain.

In general, most transit properties are lit by fluorescent rather than incandescent fixtures because of economy in power and maintenance and the more uniform illumination provided.

Guideline 4-22 — Illumination Intensity

Minimum illumination of all areas (excluding trackways between stations) should conform with the recommendations given in the Illuminating Engineering Society's Handbook. Critical areas, such as entrances interfacing with the street, station platforms, top and bottom of stairs and escalators, all should be highlighted. In addition, standby emergency lighting of one footcandle should be provided. For trackways between stations, general lighting of 40 watt rapid start fluorescent lamps at 50-foot centers is satisfactory as a minimum.

Justification:

These standards have provided safe and adequate lighting for the newer installations in the United States. An appreciably lower level of illumination was observed in the stations of European properties; e.g., London, Munich, Stockholm, and although apparently satisfactory in respect to safety, by American standards the stations appeared somewhat gloomy.

Guideline 4-23 — Compensatory Illumination Level

When determining illumination intensity, an evaluation should be made of the economics of extending the (group) replacement period by providing additional lighting to compensate for a percentage of burnouts and loss of illumination through age deterioration.

Justification:

Many transit properties find group lamp replacement the most cost effective method. The replacement policy should be determined at the time of lighting design.

In this case, a study relating all costs — installation, power, cleaning, maintenance (including replacement) — to the minimum desirable illumination level will reveal the economics of this provision (Stockholm designs for 15 percent burnout prior to relamping). The visual effects of uneven and flickering (from fluorescent fixtures) illumination resulting from this policy is also part of this evaluation.

Guideline 4-24 — Interrelationship of Lighting and Finishes

The possibilities of effecting visual changes of finishes by the use of varying lighting colors and patterns in different stations should be evaluated.

Justification:

The same tile and other finish material can take on appreciably different visual appearances when illuminated in different colors and patterns. This highlighting approach provides an economical method of attaining the desirable objective of standardizing station finishes, therefore reducing installation and replacement costs and still obtaining different appearances among (or within the same) stations. Paris Metro adopted this approach in renovating the Metro stations. This is illustrated in Figure 4-3.

Guideline 4-25 — Economic Lighting Systems

Lighting systems should be evaluated that optimize installation, illumination efficiency, operation, and maintenance systems.

Justification:

Two such systems are illustrated as examples in Figure 4-4. Both feature direct lighting from more or less continuous runs of bare fluorescent lamps through open hung ceilings and reflected lighting off the underside of the structure above. The lighting is economic in first cost and, not having covers, is easily maintained.

System 1 has an advantage over System 2 in that the lamps are directly accessible, but the illumination is less uniform. System 2 requires removing ceiling panels for access to the lamps.

Guideline 4-26 – Arrange Lamp Access for Easy Maintenance

Lamps should be located so they are readily accessible for maintenance.

Justification:

Maintenance costs are increased if the lights cannot be reached conveniently. An example of bad practice is lights placed over the platform trackway requiring maintenance work to be done in restricted work periods. and with special equipment. Lights placed in high ceilings also may require both special equipment and extra labor for maintenance.

Guideline 4-27 – Water-Resistant Fixtures

An appreciation of both the underground environment and cleaning methods to be adopted for station finishes and trackway should be made when designing the lamp fixtures.

Justification:

In some properties, the most efficient method for cleaning the station walls and ceilings and the trackway is by high pressure water spray. If such a procedure is adopted, the lamp fixtures must be enclosed and gasketed.

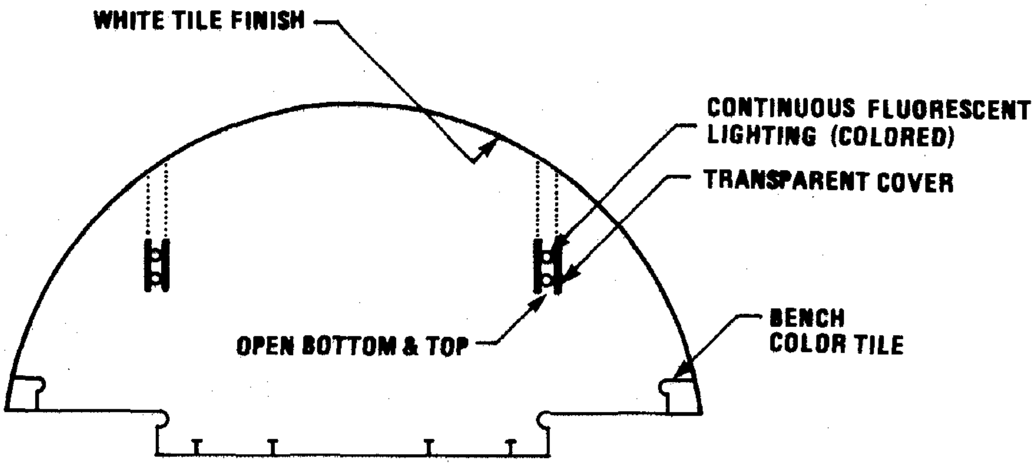


Figure 4-3 STATION ILLUMINATION – PARIS METRO

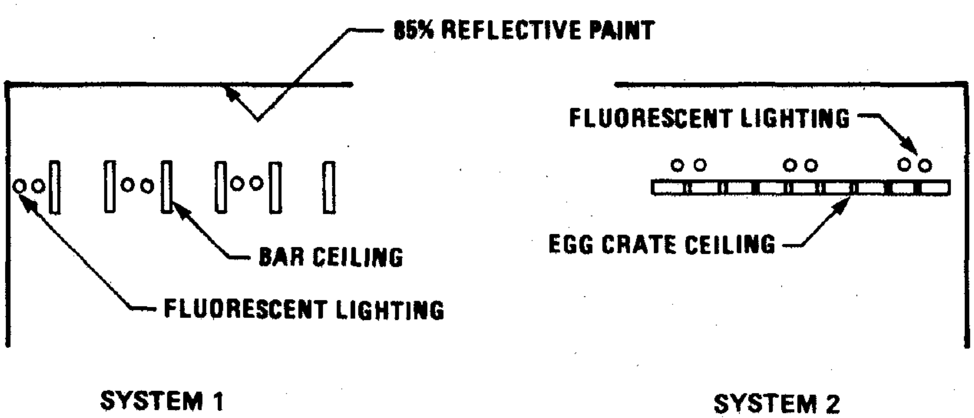


Figure 4-4 STATION ILLUMINATION TYPICAL OPEN CEILING

Very often the environment is damp at station entrances, in the trackway, and in the appurtenant structures; therefore, it is desirable to install enclosed and gasketed and corrosion-resistant (or outdoor type) fixtures.

Guideline 4-28 – Fluorescent Lighting Specification

It is recommended that specifications should require the lighting to be F40 T12RS (rapid start) for ceilings of average height.

Justification:

This specification provides ballast protection in the event of lamp failure, good lamp life, and a low lumen depreciation (over life of lamp).

Section 5

ARCHITECTURAL PLANNING AND FINISHES

This section examines architectural layouts and the selection and installation of architectural finishes in the light of optimizing installation (or first) costs against maintenance costs.

To optimize the selection of each finish item discussed, a property owner should perform an economic analysis based on the unit cost and other factors applicable to local conditions. As noted previously, the life span of the structures of most properties may be more than 150 years, and during that time most items will have to be replaced several times. This should influence the economic analysis.

LAYOUT AND PLANNING

As well as efficient station operation and passenger flow, layout planning should have three main objectives: to prevent vandalism, to enhance safety, and to optimize the cleaning process.

Guideline 5-1 — Layout to Minimize Vandalism

All public areas should be arranged so that they are readily observable at all times by station attendants. Screened areas for vending machines and telephone booths should be avoided. Areas out of direct vision of station attendants should be monitored by television.

Justification:

Secluded areas always tend to attract loiterers who, in most large urban areas, seem to have an irresistable urge to deface public property. By observing the above planning recommendations, the extent of vandalism can be greatly reduced, if not avoided altogether.

Guideline 5-2 — Dimensions and Other Planning Aspects to Avoid Vandalism

Finished ceilings should be at least 9 feet above floor level and the requirements for suspended signs must be accounted for in determining the actual height. Walls of vulnerable material should be protected from direct contact with the public by railings; glass, unless reinforced, should be avoided.

Justification:

Experience with most properties indicates that ceilings, signs, etc., generally out of reach of the public will not be defaced. Lights also generally seem to be safe at this height. A single railing approximately 2 feet from the wall will generally protect it from defacement. Glass seems to invite destruction; while reinforcement will not always prevent this from occurring, it will, at least, prevent shattering.

Guideline 5-3 — Planning for Safety

Different aspects of safety should be studied concurrently and integrated during the planning of the station. These aspects include arrangement of entrances (particularly locating doors to avoid conflicts between passengers during periods of two-directional traffic); adequate crush space at head and foot of stairs and escalators; intensified lighting in critical areas such as the head and foot of stairs, turnstiles, directional signs, and platform edges; layouts that allow easy surveillance of all areas by the station attendants supplemented, as necessary, by closed-circuit TV monitoring to enhance passenger safety against attack; selection of non-slip floor and stair finishes and escalator treads, particularly in areas likely to be wet during inclement weather.

Justification:

The above items represent a check list of some of the major factors that affect passenger safety. The value of adopting such recommendations is generally self-evident; some of them will be discussed in more detail.

Guideline 5-4 — Layouts for Ease of Cleaning

Wherever possible, an uninterrupted floor space should be maintained. Floor mounted items such as directional signs, light standards, seats, waste containers, etc., should either be wall mounted or ceiling hung. Rounded corners, both reentrant and external, are desirable as are well designed baseboard and floor-to-wall gutter details.

Justification:

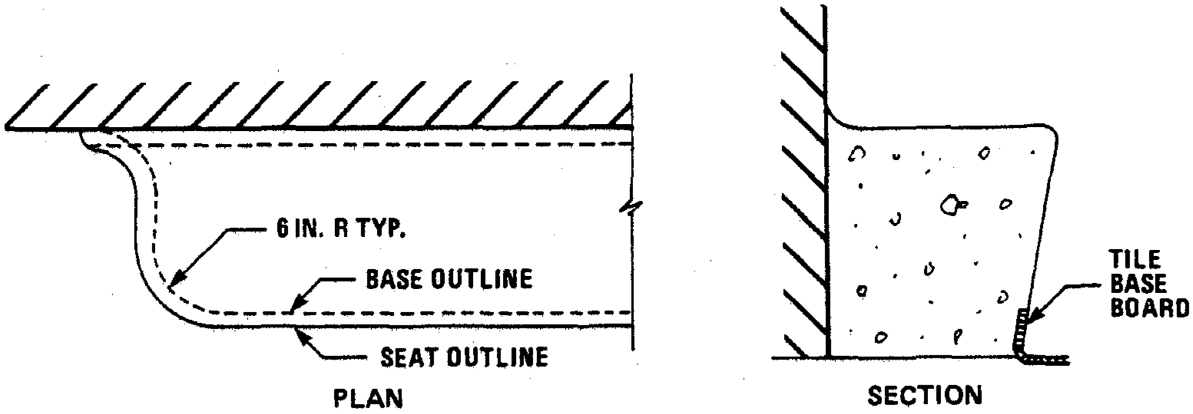
For many layouts, cleaning costs represent the major portion of the total maintenance cost. With the increasing cost of labor, there is a correspondingly greater interest in mechanizing floor cleaning operations. The floor area should, therefore, be designed to allow maximum cleaning by machines and to minimize the necessity for manual cleaning. Some typical details of several items that make machine cleaning easy or have otherwise proved satisfactory for maintenance are shown in Figure 5-1.

FLOOR FINISHES

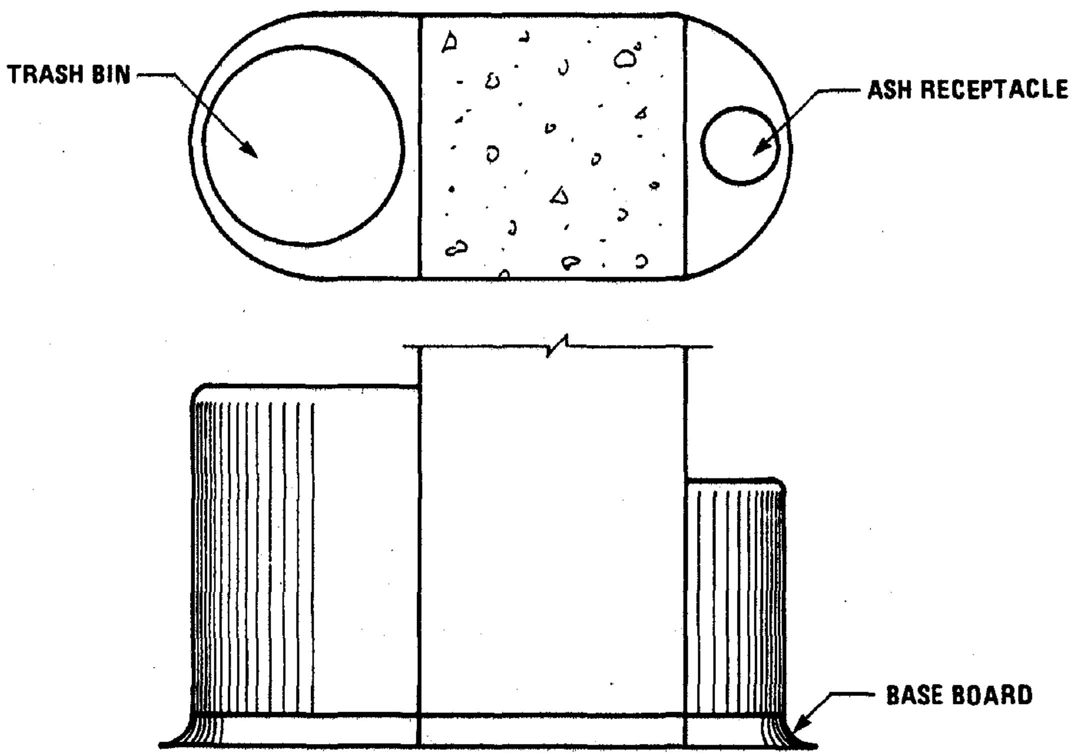
The three main categories of floor surfaces are:

1. Hard — including quarry tile, paver brick, and terrazzo concrete,
2. Resilient — including asbestos and vinyl tile and rubber tile or sheet, and
3. Soft — of which carpet is typical. Because of the exceptionally heavy wear and dirty conditions in subway stations, only the first two categories are appropriate for use on floors.

Only the materials in Category 1 will be discussed in the following guidelines.



WALL BENCHES
DETAIL 1



COLUMN DETAILS
DETAIL 2

Figure 5-1 FLOOR-MOUNTED ITEMS DESIGNED FOR EASE OF MAINTENANCE

Important concerns in selecting a floor surface material are durability, appearance under the various conditions of service, cleanability, ease and availability of replacement, and nonslip or safety characteristics. Installation of the floor surface must interface with underlying electrical and mechanical services and with the floor structure itself. In this latter aspect in new transit systems, electric communication cables are required to serve the turnstiles, the fare collection machines, the information booth, and, perhaps, vending machines and other items. These cables are often placed between the structural floor and the finished floor surface.

Guideline 5-5 — Interaction of Floor Topping with Services and Structure

The following recommendations concern the placing of floor topping.

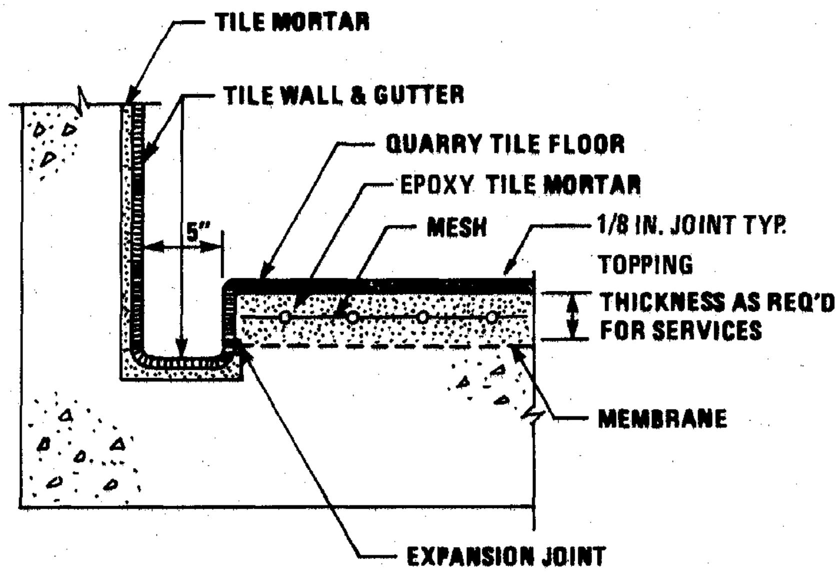
- Make allowance in the thickness of the floor topping to accommodate service conduits
- Provide at least 1-1/2 inches of topping over the conduits; some engineers recommend 3 inches or, where possible, placing service conduits in the structural floor
- Provide a bond breaker between the topping and the structural floor
- Reinforce the topping adequately

Justification:

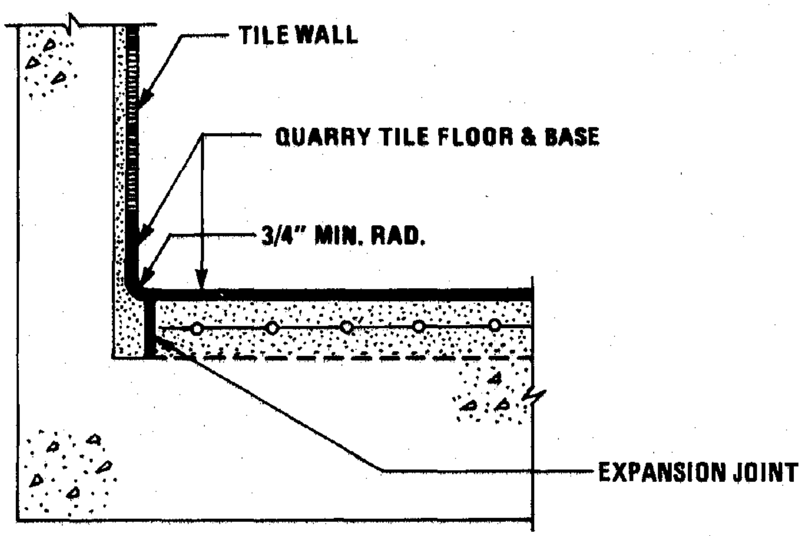
If the concrete topping is sufficiently thick over the service conduits and is adequately reinforced, it will not crack through and mar the finish. All concrete structures crack to some degree, and the bond breaker will prevent cracks from being propagated through the topping and finish. The reinforcement will also help prevent cracking.

Guideline 5-6 — Allowance for Expansion Joints — Access to Conduits

Expansion joints are desirable near junctions with walls and where the structure changes character; i.e., at thresholds, as well as at the normally recommended spacing for large areas. Such expansion joints should be carried up from the floor structure through the topping and the tile course. Typical details of these joints are shown in Figure 5-2.



DETAIL 1
FLOOR TO WALL WITH GUTTER;
STAIRS TO WALL SIMILAR



DETAIL 2
FLOOR TO WALL WITHOUT GUTTER

Figure 5-2 FLOOR WALL DETAILS – TILE WALLS

Conduit runs should be organized into compact banks and, where possible, parallel to the finish courses and the position of the conduit run identified.

Justification:

To avoid cracking of the surface, expansion joints must be incorporated to allow free movement by the reinforced concrete topping (to the capacity of the reinforcement). In doing so, care must be taken to avoid anchor points at turnstiles or information booths. Over the service life of the station, access to the service conduits or addition of new ones may be required. If these are identified and are parallel to the courses of the finished surface, access will be greatly facilitated.

Guideline 5-7 — Installation Details for Tile Floors

It is recommended that the details shown in Figure 5-2 guide tile installation. Further details of good practice and specifications for installations are contained in Handbook for Ceramic Tile Installation, Tile Council of America, Inc. For tile materials, Recommended Specifications for Ceramic Tile, also from the Tile Council.

Justification:

The 1/8-inch mortar joint between the tiles permits cutting out and replacing defective tiles with the minimum chance of damaging adjacent tiles. The thin epoxy mortar bed may be removed and replaced and will harden sufficiently rapidly to permit the floor to be returned to service a few hours after the repair has been made. The referenced documents are a useful source of basic design and specification information.

Guideline 5-8 — Selection of Floor Finish

Recommended floor materials for evaluation include quarry tile, paver brick, precast terrazzo tile, and monolithic or cast-in-place terrazzo. A present-worth economic cost analysis should be made to aid in selection (see Rapid Transit Subways - Maintenance and Engineering Report, Section 6). Such a study should also consider the possibility of using materials of different durability according to the expected intensity of service at particular locations. If tiles are selected, additional quantities should be ordered and stored at the station to facilitate future replacement.

Justification:

The three materials (and two systems for terrazzo) represent the most commonly used and generally satisfactory floor finish materials in a large number of transit properties. (An exception to this is the asphalt widely used in Paris and Berlin, and because its use in the U. S. might appear to be limited, it is discussed in the Rapid Transit Subways-Maintenance and Engineering Report only.) The three materials differ widely in durability, tractability, and appearance. Individual materials may vary widely in quality according to specifications and manufacture. This discussion assumes that each type is top quality in its kind. A general description of the types, their composition, durability, and additional factors to be considered in the selection follows.

Quarry Tile. This is a fine grained clay tile about one-half inch thick with an extruded die face which produces a relatively smooth surface. Hard wearing abrasive material such as carborundum or aluminum oxide can be incorporated into the surface, and water absorption is very low — 5 percent or less. Additionally, these tiles have demonstrated extremely good wearing qualities. They are nonslip, easy to clean, and obtainable in a variety of colors and sizes.

Paver Brick or Tile. Paver brick is manufactured from a coarser grained clay of lesser water content. Traditionally, the heavy duty brick is 1-1/2 inches thick, but recently, a paver tile 5/8-inch thick has been developed with a fused, hard, mat grained surface and is said to be extremely durable. Paver bricks and tiles do not incorporate abrasives, but their surfaces are rough compared with the quarry tile. Color is generally a darkish red brown.

Terrazzo. This is produced as a concrete — cement and aggregates. The cement and fine aggregate (sand) are various colors; e.g., white, pink, and the large aggregate is a variety of colored crushed rock. The exposed surface is finished by grinding. In subway stations, terrazzo is used in the form of precast tiles or slabs of various sizes and thicknesses, or it is placed monolithically and divided into panels of various sizes by divider strips. Terrazzo is popular because of its ornamental appearance. Useful design and specification material about terrazzo appears in Catalogue 9.19 d/Na, The National Terrazzo and Mosaic Co. Assn. Inc.

Cleaning. Generally, the smoother and harder the surface, the less effort is required for cleaning. On this basis, quarry tile, terrazzo, and paver brick, in that order, have the most desirable cleaning characteristics.

Additional Inventories. After a period of time, matching replacement tiles are hard to find. To avoid mismatching, an adequate amount of extra tiles should be ordered originally and stored at appropriate stations.

Durability and Maintenance. In a rapid transit station, specific areas will receive considerably more wear than others. This can be seen by following the probable passenger flow through a typical station as shown in Figure 5-3. The areas are marked 1, 2, and 3, representing intensive, medium, and low wear. The justifications for these allocations are as follows: all people have to enter the station via the stairs or escalators to the mezzanine; they all must proceed through the fare gates to the escalators or stairs serving the platforms and through a corridor, perhaps, to the platform itself. On leaving the platform, the same course must be followed in reverse to reach the street. All passengers must traverse this relatively narrow corridor that is, therefore, subjected to the heaviest wear of any part of the station. Within this corridor, spaces where people change pace or stop and start, such as the head and foot of the stairs and fare gates, will receive additional wear. Areas 2 will

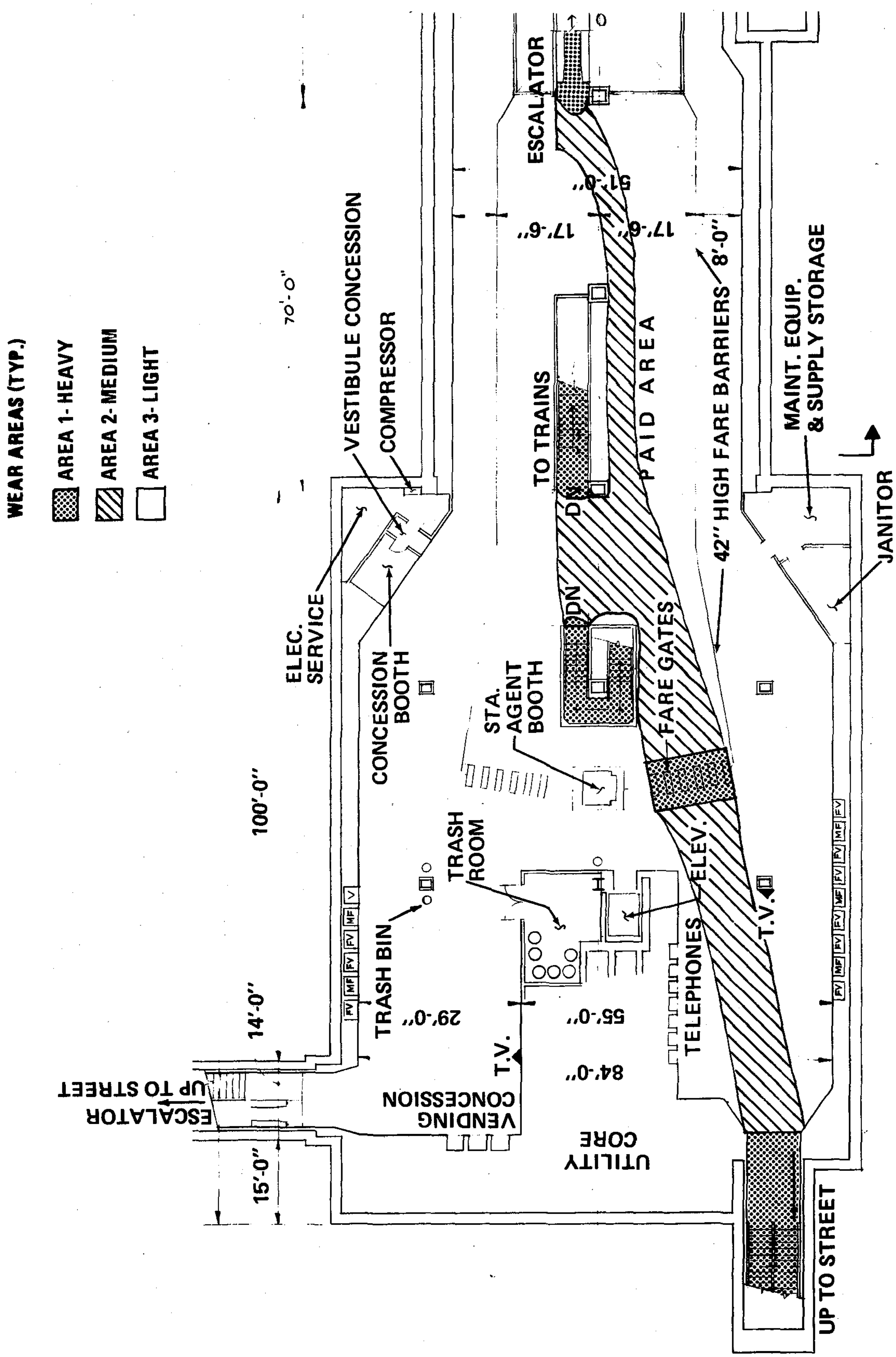


Figure 5-3 STATION PART MEZZANINE PLAN

be subject to medium wear; these include ticket and concession areas, which only a proportion of the people will use, and the general platform area which, because of its size, will receive a lesser concentration of traffic. However, the platform areas where passengers enter and alight from the train will receive heavy wear. Areas 3, generally, are the corridors, which may be quite extensive, and the free area linking the various fare gates. A small proportion of the passengers use these corridors and wear may be considered light.

It can be seen, therefore, that because of wear patterns there may be justification on the grounds of installed cost for using two or more different qualities of floor finish. Whatever is used, replacement of the floor finish at the gates and at the foot of stairs will be required more frequently than other places and the design should prepare for this.

Desirable Characteristics of Individual Materials. The selection of color is important for two reasons: the amount of cleaning required to maintain good appearance and the ability to match replacement material. Dark terrazzo or a monotone red quarry tile readily show up certain types of dust and debris. Very light finish terrazzos, marbles, etc., are easily stained and heel marked. Therefore, tiled finishes should be of varigated pattern of medium density color. Terrazzos with darkish colored large aggregate and lightish cement sand are good in this respect. The large aggregate seems to maintain a better appearance than small chips; it is also easier to walk on.

Terrazzo Tiles vs Monolithic. The big advantage of tiles over monolithic is the speed of installation during repair and replacement. The monolithic system requires several days for the breaking out, placing, and grinding before the floor can be put back into service. Precast terrazzo often comes in 12 x 12 or 18 x 18 tiles about an inch thick, with slightly rounded edges.

Stairs

If stairs are the principal access to the mezzanine or platform, their safety and maintenance design is particularly important. The treads should be replaceable; treads and systems recommended in the following guidelines have performed satisfactorily in a number of transit properties. Rubber treads, which have been introduced only recently in Boston, appear to have an interesting potential.

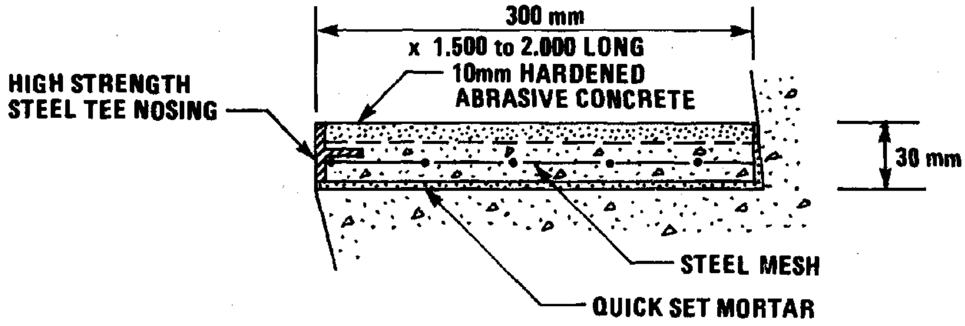
Guideline 5-9 — Tread Materials and Systems

The following materials should be evaluated: precast concrete of special formulation incorporating abrasives, metal nosings, granite slabs, and quarry tile with rounded nosings. Two designs and one using rubber are shown in Figure 5-4. Extra original treads should be purchased and stored for future replacement.

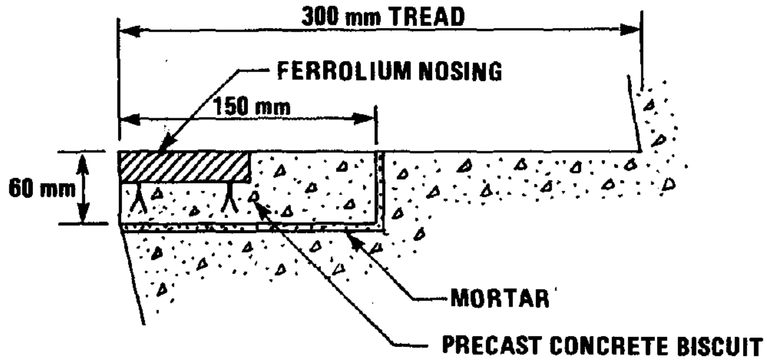
Justification:

Precast Concrete. The treads shown in Figure 5-4 for Paris and London are used apparently successfully in those cities. The abrasive in the concrete provides slip resistance and the special formulation of the concrete increases durability. Properly formulated and manufactured quarry tiles have demonstrated longevity under the heavy service imposed on stairways. They are slip proof and of good appearance. If replacement is required, the procedure is the same as for floors, and, with the use of epoxy mortars, the use of the stair can be quickly resumed. The rationale for storing treads is the same as for tiles.

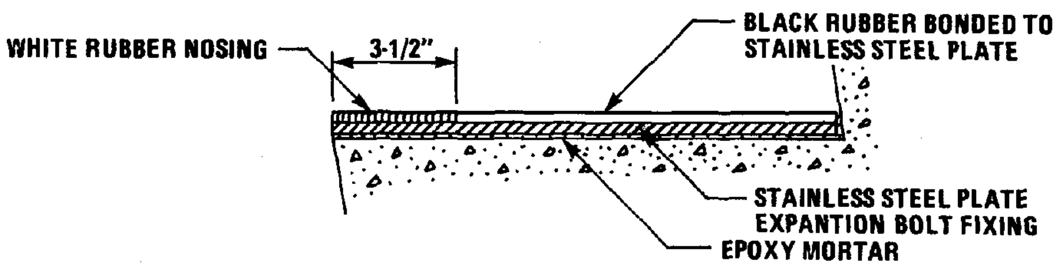
Granite Slabs. Rough cut granite slabs an inch and a half thick are probably the most durable and slip proof of all materials. Slabs approximately 3 feet long can readily be replaced if necessary. They are expensive, however, and difficult to clean, and unless cleaned, their appearance is poor.



PRECAST CONCRETE – PARIS



FERROLIUM NOSING/PRECAST CONCRETE – LONDON



RUBBER/STAINLESS STEEL TREAD – BOSTON

Figure 5-4 PREFABRICATED STAIR TREADS

Terrazzo. The previously discussed materials and systems which produce good wear and chip, and slip resistance particularly in wet situations, are recommended over terrazzo owing to difficulty in effecting repairs, monolithic tread and (riser) construction should be avoided. Heavy duty, paver bricks will chip at the nosings if they are not rounded.

Guideline 5-10 — Stair to Wall Detail

A rounded gutter should be formed at all stair-to-wall intersections as indicated in Figure 5-2, Detail 1.

Justification:

This detail is important for both appearance and cleaning. For stairways open to the weather it also assists in drainage of water from the tread and from the walls.

WALLS

There are generally two systems of supporting the wall finish. One is directly on the structure wall, i.e., concrete; the other is on a false wall with an airspace between it and the structure. With the first system, it is important that the structural wall be essentially watertight and that structural cracks are not transmitted through the wall finish. In the second system, which presupposes some water seepage through the structural wall, provision should be made for removable wall panels to enable periodic inspection of the structural wall. The following guidelines recommend materials that have demonstrated satisfactory performance in several existing transit properties.

Guideline 5-11 — Wall Materials Applied Directly to Structure

It is recommended that the following materials be evaluated: hard-glaze ceramic tiles, terracotta, and mosaic. To prevent structural cracks being propagated through the finished material, a flexible or plastic mortar should be employed. See Guideline 5-7 for design and specification details.

Justification:

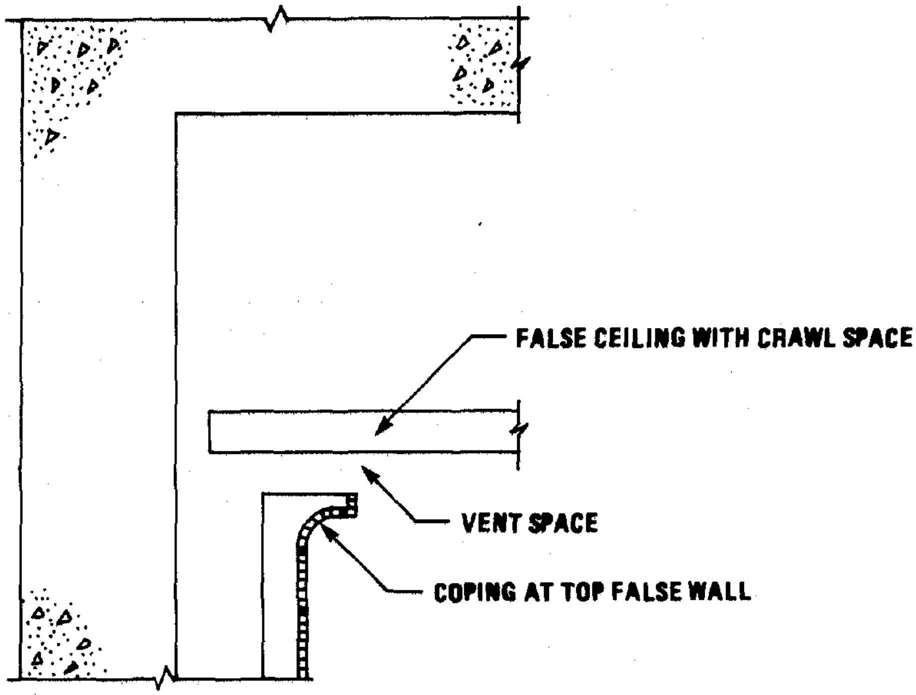
Hard-glaze ceramic tiles with the usual size of 6 inches long by 3 inches wide, are easy to clean. Structural cracking, if propagated through the mortar, will tend to follow the bedding planes rather than crack through the tile.

Terracotta tiles are normally larger than hard-glaze tiles, typically 12 inches long by 8 inches wide, of a semiglazed surface finish, and somewhat more difficult to clean than the hard-glaze type. Because of their larger size, they tend to suffer more from structure cracking.

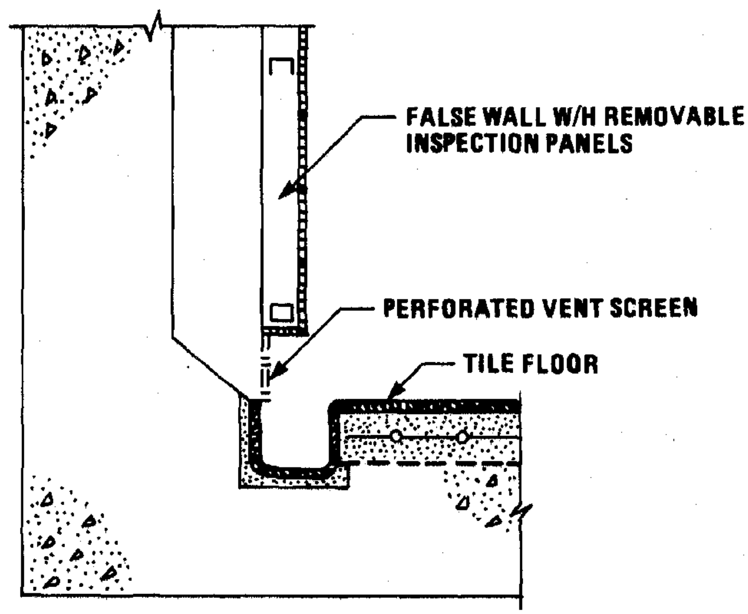
Mosaics, which often come assembled on 12-inch-square backing sheets, are fixed to a previously applied rendering over the structural concrete with epoxy adhesives. The bedding joints, normally about a sixteenth of an inch wide, are then filled with mortar. Unless the adhesive is correctly formulated and the workmanship is first class, the mosaics may work loose, or be pried free by vandals, over a period of time. However, replacement is fairly easy. The hard-glaze surface finish is easy to clean, although the mortar bedding, if white, as it often is, is difficult, particularly if defaced by spray guns. The resistance of mosaic against structural cracking, because of its small size, is very good.

Guideline 5-12 – False Wall Systems

It is recommended that false walls be designed to provide adequate air flow between the back of the wall and the structure, and that components of the wall, such as ties and battens, be fully protected against corrosion. It is further recommended that where the structural wall in the mezzanine is used as a cableway, an inspection walkway be provided behind the false wall, or allowance be made for movable panels at regular intervals to permit periodic inspection, both of the structural and false walls and cables. Suggested details of the main components, including drainage, of such walls are indicated in Figure 5-5.



DETAIL 2 FALSE WALL TO CEILING



DETAIL 1 FLOOR TO FALSE WALL

Figure 5-5 FALSE WALL SYSTEMS

Justification:

Dampness or seepage through the structural wall over a period of time will produce adverse effects upon the false wall, unless proper provisions for ventilation and against corrosion are made. Also the rate of seepage may increase over the years. The extent and location must be identified so that remedial measures can be taken as needed, and this requires removable false walls or inspection panels.

Guideline 5-13 — Finish Materials for False Walls

For false walls with removable panels, finish materials should be limited to ceramic mosaics or metallic panels such as stainless steel or aluminum. Alternatively, a combination of glazed brick with reusable metal panels interspersed could be used. Where the wall is inaccessible to the public, as in the trainway opposite the platform, painted or enameled finish asbestos board is a suitable material.

Justification:

The above recommended materials combine to produce a lightweight, relatively flexible, durable false wall system suitable for the purposes already discussed.

Guidelines 5-14 — Metallic Finishes

It is recommended that all stainless steel and aluminum panels (preferably anodyzed and with a duranodic finish), railings, skirtings, and pillars be provided with a brushed finish. Aluminum anodyzed bronze or other colors also appears satisfactory.

Justification:

Light polished metal soon becomes dull and poor in appearance from fingerprints when the public comes in contact with it and can require a considerable cleaning effort if its appearance is to be maintained. A heavily brushed finish will greatly reduce the cleaning requirement. Anodyzed surfaces, if bright, appear to be fairly resistant to finger-printing and defacement.

CEILINGS AND CEILING FINISHES

The principal functions of ceiling finishes are appearance and acoustical. As for walls, the finish may be applied directly to the structural concrete or it may be hung from the structure, i.e., a false ceiling. In this latter case, for the same reasons given for walls, provision should be made for periodic inspection of the structure. Where noise suppression is important, such a structural profile as barrel vault or waffle will greatly reduce the noise, and less reliance need to be placed on the finish material. The design of false ceilings must prevent oscillation or other undesirable movements from air pressures created by the trains.

Guideline 5-15 — Ceiling Materials Applied Directly to Structure

- Paint for waffle ceilings,
- Ceramic tiles or painted acoustic plaster for barrel vault ceilings, and
- Painted acoustic plaster for flat slab and beam ceilings

Justification:

The above recommendations are predicated on the fact that the structures are designed for minimum head room on the ground of economy and also that sound waterproofing of the roof has been achieved. Painted ceilings require redoing every 5 to 7 years but are not necessarily uneconomical. Their appearance can be pleasant, particularly in combination with a good structural soffit design. Where used in trainway areas, sound suppression should be obtained from treatment of the walls or track bed.

Ceramic tiles are poor acoustically but appear to be satisfactory in tunneled trainway platforms or vaulted ceiling construction, in combination with acoustic treatment of walls or perhaps floors. Maintenance, including cleaning costs, is low.

Painted acoustic plaster provides a measure of noise suppression, and is relatively economical to clean and maintain. Not recommended, on the grounds of uneconomic maintenance and cleaning, are acoustic treatments such as sprayed-on asbestos or directly applied acoustic material with spaced, plastic, or aluminum channels.

Guideline 5-16 — Suspended Ceilings

It is recommended that suspended ceilings be designed with a space of at least 24 inches below the structural ceiling and that crawlways be provided for periodic inspection. The space should be ventilated. With open suspended ceilings, provision for the crawlway may be omitted; however, the elements of the ceiling should be readily detachable to permit access to the structural ceiling.

Justification:

Over the service life of the structure, leaks can be expected and their effects and remedy must be provided for; hence the importance of the above inspection and access provisions.

Guideline 5-17 — Suspended Ceiling Systems

It is recommended that the following systems be evaluated:

- Solid system, aluminum channel backed with acoustic board,
- Acoustic plaster, painted,
- Open system, waffle pattern with aluminum bars,
- Baffle system, extruded aluminum bars, and
- Baffle system, painted asbestos cement.

Justification:

The above systems appear satisfactory in respect to maintenance and cleaning. The open type suspended ceiling with aluminum baffles, or bars in egg-crate form, would appear to require minimum maintenance and cleaning, and the baffle system has the added advantage of simplifying the housing of the lighting system. This is discussed further in Section 4. Any soft acoustic material is undesirable because it catches dust, retains moisture, and is difficult to clean. For the same reason, perforated metallic acoustic panels or asbestos panels are undesirable.

Guideline 5-18 — Selecting Architectural Finishes

In selecting architectural finishes, the installation costs should be optimized against maintenance costs.

Justification:

The maintenance costs in a station are often largely influenced by the type and details of the finishes used. An economic evaluation of the various interacting factors discussed in this section will aid in optimizing the selections.

Section 6

MAINTENANCE ACCESSES AND FACILITIES

Access to the subway from the surface is from three general locations:

- Through the station entrances via stairs, escalators, and elevators,
- Through the portals to the underground trackway structures, and
- From the ventilation and pump shafts and emergency exits.

Generally, these accesses are designed for their own particular function and not for the maintenance of the subway system. The following guidelines recommend various measures that may be undertaken in the planning and design of the accesses to facilitate the maintenance operations.

An additional item affecting maintenance in the trackway is the location of the track crossovers for turnbacks or for single tracking of the trains under emergency conditions. Such crossovers, especially in the subway, are a major cost item, and therefore their location is determined by the operations function rather than convenience for maintenance. However, their position and spacing must be often taken into account in scheduling the use of the accesses for a particular maintenance operation.

Guideline 6-1 – Access to Trackway for Maintenance Vehicles

Where train operations permit (revenue service not continuous) and where there is an appreciable distance between the portals and the storage locations of the maintenance vehicles, it is recommended that entry access for the road/track maintenance vehicles (where used) be made at grade as near as possible to the portal.

Justification:

In many cases, these at-grade track entries provide valuable flexibility for scheduling maintenance operations, particularly if they can be advantageously sited with the track crossovers. Where revenue service operates more or less around the clock, the near portal accesses permit fast entry onto one track which can be freed for maintenance purposes by single tracking on the other. Such wayside entires to the track do, of course, require stringent scheduling of the train movements and safety training of the maintenance crews to completely ensure safety.

Guideline 6-2 — Walkways for Maintenance

Maintenance sidewalks should be provided throughout the system's trackways.

Justification:

The importance for such sidewalks was discussed in preceding sections of these guidelines in connection with maintenance of the pump and ventilation structures and equipment. The same walkways are required for emergency exits for passengers. They also provide safety for track walkers, inspectors, and for some types of routine structure maintenance.

The walkways are placed on the wall of a trainway, remote from the conductor rail, and where this changes sides, such as at turnouts or alternating side platform and center platform stations, crosswalks are provided at track level connecting the two sides.

Access is gained to the walkways from the station platform and from the surface through the ventilation, pump, and emergency exit shafts.

Guideline 6-3 — Shaft Access to Trackway

Where shafts for pumps, ventilation, and emergency exits terminate in a sidewalk or behind street property lines, it is recommended that the surface accesses be planned for the various maintenance activities. Provision should be made for telpher bars.

Justification:

The extent of these provisions depends upon the location of the ventilation equipment and the accessibility of the ventilation equipment and pumps for maintenance at track level. Accesses at surface level permit flexibility of maintenance scheduling and also provide additional entries to the trackway for personnel and light equipment and for the supporting power supplies, e.g., compressed air and, perhaps, electric power. Telpher hoisting bars are useful for a variety of maintenance operations such as supporting scaffolds and lifting machines where mobile cranes are not available.

Guideline 6-4 — Station Elevators for Maintenance Purposes

Where elevators are provided for the handicapped, they should be of a size and capacity to transport all planned mechanical cleaning equipment and supplies as well as any frequently used maintenance equipment and material. The elevators should serve all major floor levels and be accessible to trucks at street level.

Justification:

As discussed in the guidelines for station cleaning, the ability to move cleaning equipment vertically determines the method selected. The trend towards mechanical cleaning equipment is increasing, and suitably designed elevators permit its maximum use. Moving equipment and material through the different levels of a station by stair or escalator is time consuming and generally will damage them, unless specific precautions are observed. Handling baled trash and debris is also simplified by using an elevator.

Guideline 6-5 — Stairs and Escalators

Where stairs or escalators must be used for transporting maintenance equipment and materials, it is recommended that one or two of either item be specially designated for such use. Properly designed protective stair skids and escalator cradles should be used for transporting all sizable equipment and material.

Escalators may be used within limits to transport items such as mechanical floor cleaners, providing devices are designed to spread the load over two or three treads. A 48-inch wide tread normally is designed for 300 pounds, and it is feasible to supply a device to carry the load on to these treads.

Justification:

Recognizing the vulnerability of most stair nosings to mechanical damage when maintenance equipment and material are carried on the stairway will do much to prevent damage and to preserve a good appearance. If the recommended precautions are observed, transport of equipment by escalator is acceptable.

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