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RAPID TRANSIT TUNNEL DIMENSIONS IN THE UNITED STATES: A BRIEF SUMMARY

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FINAL REPORT

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16. Abstract

Inside dimensions and shapes of existing and planned rapid transit tunnels in the United States are identified. Included is a discussion of those factors involved in deriving the inside dimensions of a tunnel and methods of calculation of circular tunnel diameters. Background information is provided for use in discussions concerning the need for standardization of tunnel dimensions.

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PREFACE

The objective of this work is to summarize data on tunnel sizes and shapes and to identify the factors involved in sizing tunnels. The information contained in the report was compiled by the Mechanical Engineering Division of the Transportation Systems Center under the sponsorship of the Office for Systems Development and Technology, Office of the Secretary.

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1. INTRODUCTION

This report identifies inside dimensions of existing and planned rapid transit tunnels in the United States. Tables 1 and 2 list those existing and proposed transit systems surveyed. Background information is provided to consider the need for standardization of tunnel dimensions. The varying number of sizes of tunnels within a transit system as well as among transit systems is documented.

Historically, transit systems have been custom designed for each city. As a result, dimensions of stations, vehicles, and tunnels have varied considerably from system to system and within systems. The degree to which these customized designs might lead to increased costs is a very important subject for further study, although not treated in this survey.

The range of inside dimensions for circular and non-circular tunnel shapes is shown in Table 3.

1.1 CIRCULAR TUNNELS

Circular-bored subway tunnels in the United States range in inside diameter from 15'3" to 20'5" (Table 3). This is a result of varying transit vehicle cross-sections, varying running clearances, varying super-elevations, and other parameter variations defined below in Section 3. The accomodation of these parameter variations results in customized designs which in turn lead to added capital costs.

1.2 NON-CIRCULAR TUNNELS

The range of inside dimensions for non-circular tunnels in the U.S. is outlined in Table 3. As with circular tunnels this is a result of the variation of vehicle cross-sections and other tunnel parameters. Figure 1 identifies the non-circular tunnel shapes included in Table 3.

Cut and cover tunnel dimensions, unlike bored tunnels, are

TABLE 1. EXISTING SUBWAY TUNNELS

City	Tunnel Shape[1]	Tunnel Size			Minimum Lateral Curve Radius (ft)	Design Speed (mph)	Remarks
		H	W	ID			
Boston	Rectangular	14'9"	15'6"		47'	40	Boylston St. - Single Track
	"	14'6"	13'		47'	40	Beacon Hill - Single Track
	"	14'	22'3"		47'	40	Tremont St. - Double Track
	"	14'	28'		75'	43	East Boston - Double Track
	"	14'8-1/2"	25'		500'	50	Main St., Cambridge - Double Track
	Horseshoe	16'	23'		47'	40	Tremont St. - Double Track
	"	17'8"	23'8"		75'	43	East Boston - Double Track
	"	20'	28'		47'	40	Beacon Hill - Double Track
	Basket Handle	17'2-1/4"	25'		500'	50	Main St., Cambridge - Double Track
	"	17'9-1/4"	28'		500'	50	Dorchester - Double Track
	Arch	17'6"	25'4"		90'	38	Washington St. - Double Track
	Circular			18'8"	500'	50	Dorchester - Single Track
Chicago	Rectangular	13'4"	14'		275'	55	Milwaukee Kimball - Single Track
	"	15'	30'				Double Track
	Horseshoe	15'9"	17'6"				State St. - Single Track
	"	19'	21'				Milwaukee Dearborn
	Circular			20'5"			Single Track

[1] See Figure 1
Source: Refs. 7 through 19.

TABLE 1. EXISTING SUBWAY TUNNELS (CONTINUED)

City	Tunnel Shape[1]	Tunnel Size			Minimum Lateral Curve Radius (ft)	Design Speed (mph)	Remarks
		H	W	ID			
Cleveland	Rectangular	15'	30'			35	Double Track
New York	Rectangular	13'2"	28'-1/2"		178	50	Double Track
(NYCTA)	"	14'6"	24'6"				Double Track
	Horseshoe	16'	29'6"				Twin horseshoe tunnels 14'6" center spacing - Double Track
	Circular			18'9"			
(PATCO) Camden, NJ	Rectangular	13'9"	27'3"		125	40	Double Track
(PATH) NY-NJ	Circular			15'3"	90	40	Single Track
Philadelphia	Rectangular	14'5-1/2"	13'3"				Market St. - Single Track
	"	13'-1/2"	14'2"		140	42	Broad St. - Single Track
	"	13'6-1/2"	28'2"		140	42	Broad St. - Double Track
	"	14'5-1/2"	48'6"		105	42	West Market St. - 4 Tracks
San Francisco	Rectangular	13'	14'9"		500	80	Single Track
		13'6"	27'				Double Track
	Circular			16'6"			Radius of Curvature = Tangent to 1500' - Single Track
				17'0"			Radius of Curvature = 1499' to 500' - Single Track

TABLE 2. PLANNED SUBWAY TUNNELS

City*	Tunnel Shape[2]	Tunnel Size			Remarks	Min Rad of Curve (ft)
		H	W	ID		
Atlanta	Rectangular	13'	14'6"		Single Track	
	"	13'	15' to 20'6"		Varies* - Per cell, 2 cell block	
	Horseshoe	15'	17'		Single Track	
		or				
	"	14'5"	16'6"			
Baltimore	Anticipation of eventual connection of the Baltimore system with the Washington System has lead to similar design criteria. See Washington for sizes.					
Boston	Rectangular	14'9"	27'		Tanget-width varies* Haymarket North extension - Double Track	450
	Circular			18'0"	Overlapping Double Tubes	
Buffalo	Rectangular	13'	14'		Single Track	
	"	13'	29'		Double Track	
	Circular			16'0"	Single Track	
Chicago (Central Area Transit Project)	Rectangular	12'9"	14'4"		Single Track	90
	Arch	15'6" to 16'7"	15' to 17'2"		Varies*	

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[2] See Figure 1

*Varies as a function of superelevation, track radius of curvature and location of safety walk.

Source: Refs. 3,7,8,9, and 20 through 25.

TABLE 2. PLANNED SUBWAY TUNNELS (CONTINUED)

City	Tunnel Shape	Tunnel Size			Remarks	Min Rad Of Curve	Des sp
		H	W	ID			
Chicago (Cont.)	Circular			17' to 19'8"	Varies*		
Los Angeles	Rectangular	12'	12'		Single Track		
	"	12'	25"		Double Track		
	Circular			16'2" to 17'6"	Varies*- also varies with vehicle length - not yet decided		
Minneapolis	Circular			14'0"			
New York (NYCTA)	Circular			15'6"	Free air methods	850	
				15'9"	Compressed air method		
Philadelphia	Horseshoe	14'3-1/4"	18'		Broad St. extension Single Track	140	
Washington	Rectangular	12'	13'9"- 17'6"		Varies*- Single Track	755	75
	Horseshoe	14'2-1/2"	14'-5/8"		Single Track		
	Basket Handle	17'	26'4-1/2" to 34'3-3/8"		Varies*- Double Track		
	Arch	13'10-1/2"	13'8-7/8" to 15'6-3/8"		Varies* - Single Track		
	Circular			16'6"	Prefabricated segmental liners - Single Track		
				16'8"	Cast-in-place liners - Single Track		

TABLE 3. RANGE OF TUNNEL INSIDE DIMENSIONS

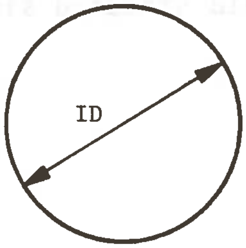
Type*	Single Track						Double Track			
	H		W		ID		H		W	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Circular					14' 0"	20' 5"				
Non-Circular										
Rectangular	12' 0"	14' 9"	12'	20' 6"			12' 0"	15' 0"	22' 3"	30' 0"
Horseshoe	14' 2"	19' 0"	14' 1"	21' 0"			16' 0"	20' 0"	23' 0"	29' 6"
Arch	13' 10"	16' 7"	13' 9"	17' 2"			17' 0"	17' 9"	25' 0"	34' 3"
Basket Handle	NR		NR				17' 6"	**	25' 4"	**

*See Figure 1

NR - None recorded in this survey

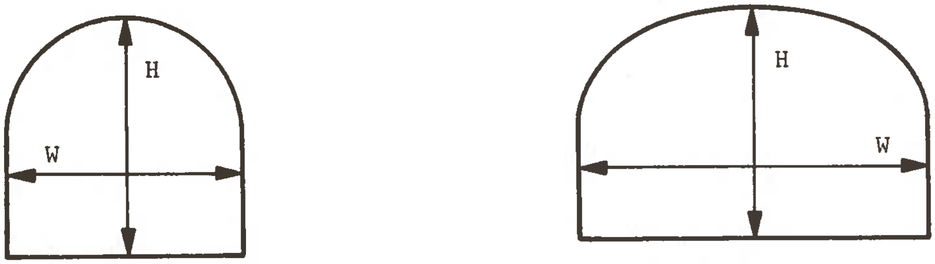
**Only one tunnel recorded in this survey.

CIRCULAR



NON-CIRCULAR

a) RECTANGULAR b) HORSESHOE



c) ARCH d) BASKET HANDLE

Figure 1. Tunnel Sections (Ref. 5 & 6)

dependent on street width, utility density, and other site dependent factors in addition to tunnel parameters. Nevertheless, the tunnel parameters identified in Section 3 must be accounted for in deriving the inside dimensions of all tunnels. Standardization of these parameters could yield standard sizes.

2. METHOD OF STUDY

The inside dimensions and shapes of existing and proposed tunnels for each transit system in the United States have been recorded and compiled into Tables 1 and 2. An analysis of these data appears in Section 5.

Data on existing tunnels were gathered from reports, design criteria, telephone conversations, and correspondence. Data on proposed tunnels were gathered in the same manner. However, since some transit systems are still in the early planning stages, tunnel size and shape have not yet been established. References 1 and 2 provide information on cities planning to construct rapid transit tunnels.

3. IDENTIFICATION OF FACTORS IN SIZING TUNNELS

In deriving the inside dimension of a tunnel, the vehicle clearance envelope and the tunnel clearance envelope are defined under the varying conditions of vehicle movements, locations of the walkway, superelevation, and radii of track curvature. The vehicle clearance envelope is defined as the space occupied by the dynamic outline of the design vehicle plus an added running tolerance around the dynamic outline. The tunnel clearance envelope comprises the remaining factors, which are specified by type of tunnel cross-section.

3.1 VEHICLE CLEARANCE ENVELOPE

The vehicle clearance envelope comprises the following factors:

3.1.1 Dynamic Outline

Dynamic Outline is that derived from the vehicle static outline (vehicle cross-section) plus the following car body movements:

Lateral Movement

Lateral movement of wheels
Car body against stops
Car construction tolerance
Truck construction tolerance
Truck assembly tolerance
Wheel wear
Railwear

Vertical Upward

Track construction tolerance
Car construction tolerance
Car body camber
Bounce against stops
Vertical track curvature

Vertical Downward

Wheel wear
Rail wear
Air springs against stops
Primary springs against stops
Vertical track curvature

Roll

Specific degree of roll after a specific amount of lateral movement.

Figure 2 shows the dynamic outline, which is the combined effect of these factors.

3.1.2 Middle Ordinate Displacement

For varying curve radii, graphs are formulated giving track radius of curvature vs. displacements for mid-car and end-car overhang (see Figure 3). A most convincing reason for increasing the minimum radius of curvature is to reduce the tunnel diameter. However, it is realized that site-dependent factors often restrict the minimum radius.

3.1.3 Effect of Superelevation

The width of the design vehicle dynamic outline on superelevated track, exclusive of the values for mid-ordinate displacement and end-car overhang, is called the dynamic width. This width includes the dynamic width toward curve center, DW_T, and the dynamic width away from curve center, DW_A (see Figures 4 and 5). These values are measured horizontally from the centerline of track to the widest point on the design vehicle dynamic outline. Graphs are formulated giving superelevation vs. DW_T and DW_A (see Figure 6).

The effect of superelevation is considered independently in determining the vehicle clearance envelope and has been taken into account in establishing the dimensional clearances for the various construction sections.

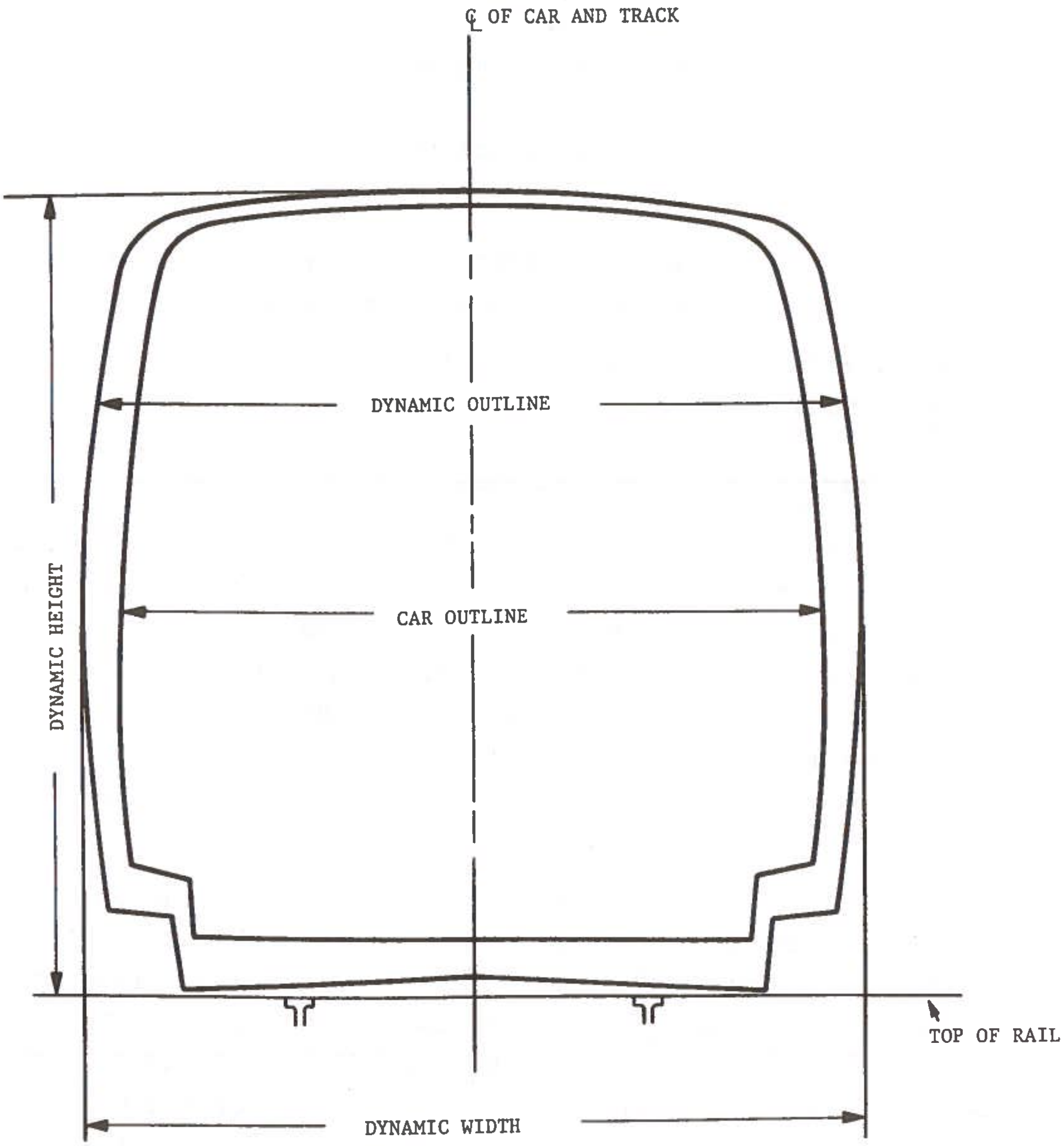
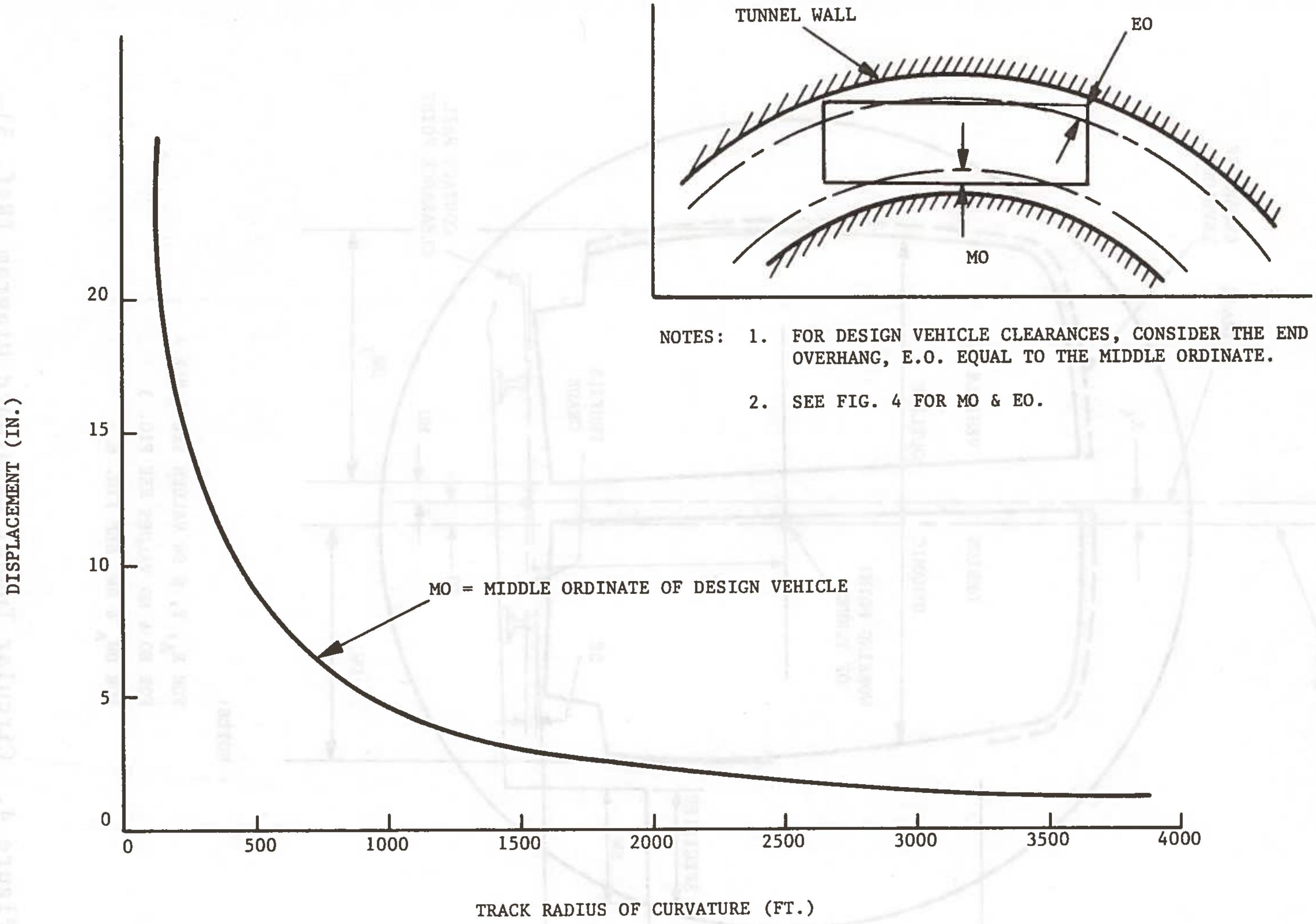


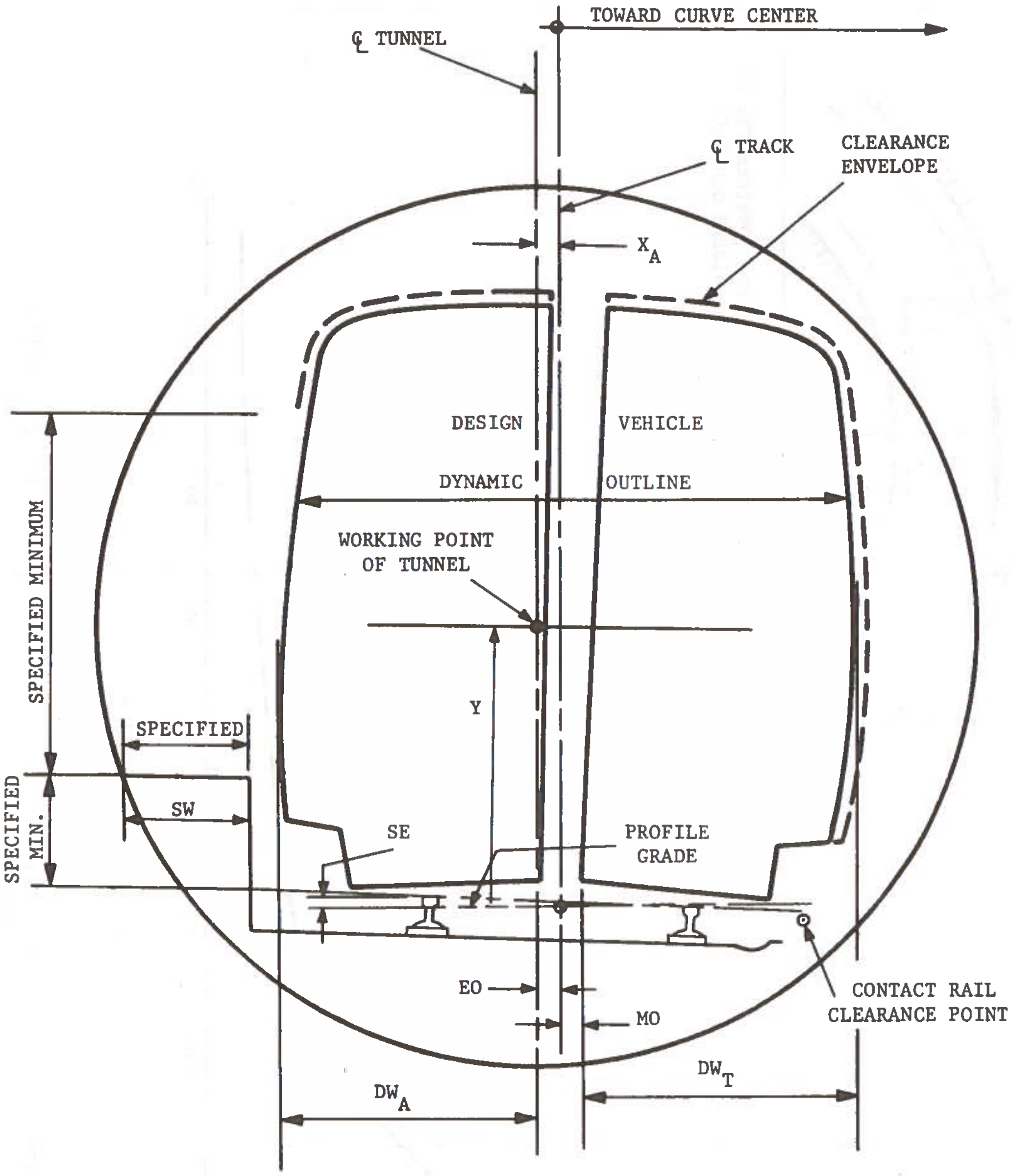
Figure 2. Design Vehicle Dynamic Outline Diagram —Tangent Track (Ref. 3)·



NOTES: 1. FOR DESIGN VEHICLE CLEARANCES, CONSIDER THE END OVERHANG, E.O. EQUAL TO THE MIDDLE ORDINATE.

2. SEE FIG. 4 FOR MO & EO.

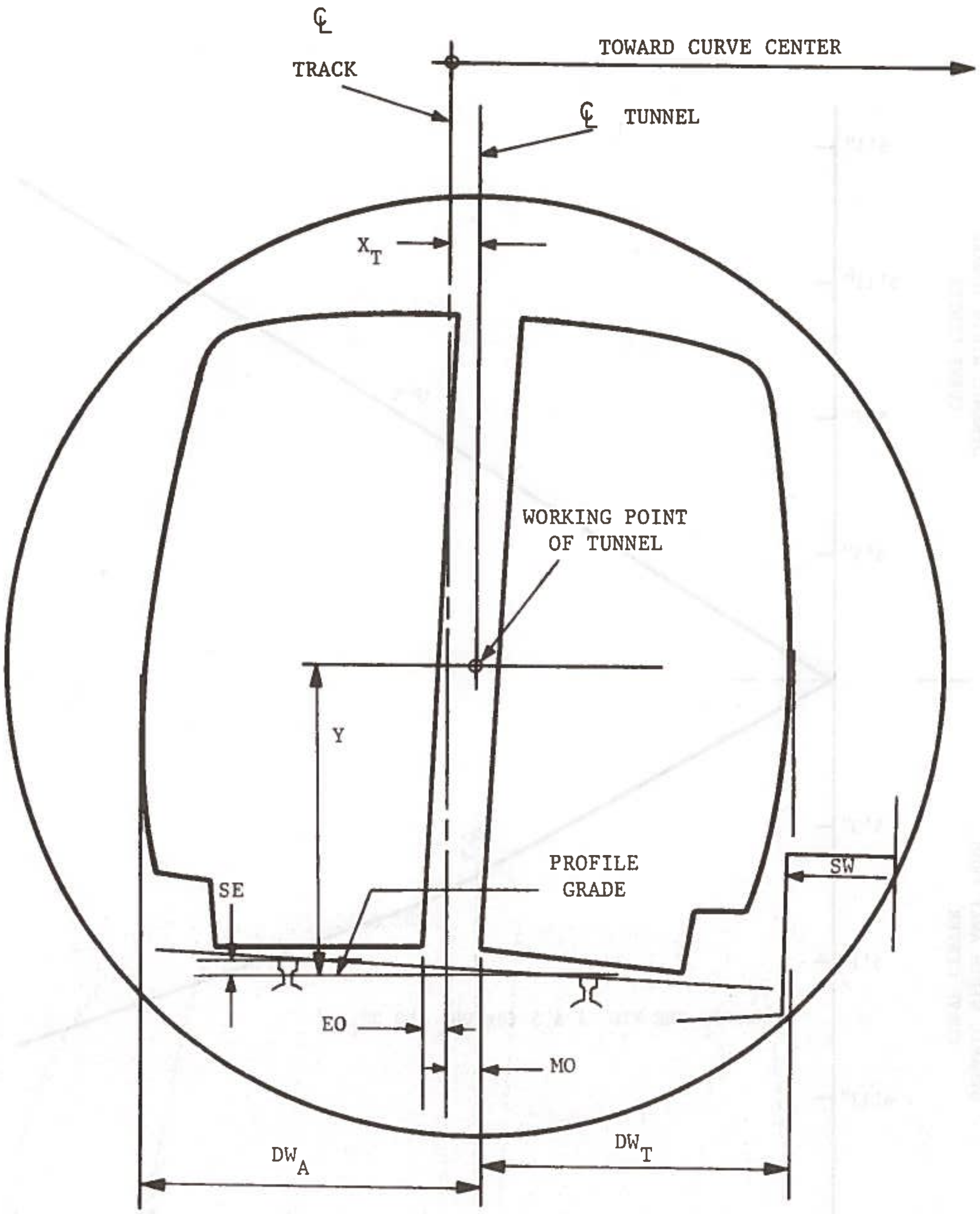
Figure 3. Middle Ordinate Displacement vs. Track Radius of Curvature (Ref. 3)



NOTES:

FOR X_A, Y, & SW VALUES SEE TABLE 4
FOR EO & MO VALUES SEE FIG. 3
FOR DW_A & DW_T SEE FIG. 6

Figure 4. Circular Tunnel Clearance Diagram (Ref. 3)—Safety Walk Away from Curve Center



NOTES:

FOR X_T, Y, & SW VALUES SEE TABLE 4
FOR EO & MO VALUES SEE FIG. 3
FOR DW_A & DW_T SEE FIG. 6

Figure 5. Circular Tunnel Clearance Diagram (Ref. 3)—Safety Walk Toward Curve Center

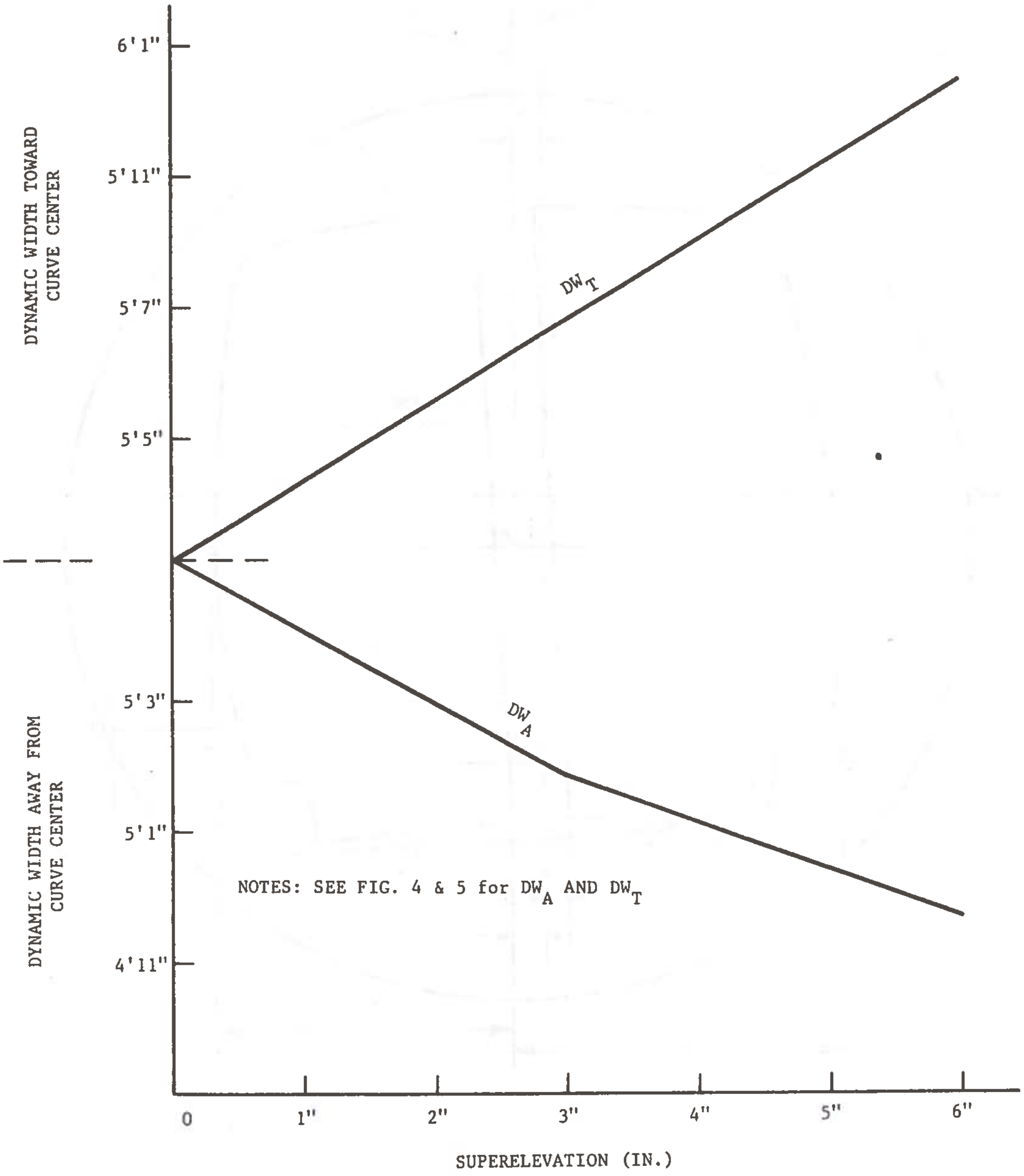


Figure 6. Dynamic Width Toward (DW_T) and Away (DW_A) from Curve Center vs. Superelevation (Ref. 3)

3.2 TUNNEL CLEARANCE ENVELOPE

The tunnel clearance envelope comprises the following factors:

3.2.1 Chorded Construction

Allowances are made when tunnel walls are constructed in chords whose lengths are measured along the inside face of the wall nearest the curve. Graphs are formulated giving additional widths for chorded construction vs. radius of curvature (see Figure 7).

3.2.2 Construction Tolerance

The construction tolerance is usually specified according to type of construction material used (e.g. WMATA Design Criteria (Ref.3): Circular Segmental Tunnel: ± 2"; Circular Cast-In-Place Tunnel: ± 1").

3.2.3 Clearances

The design vehicle dynamic outline is located to satisfy the following criteria for the case of circular tunnels (see Figures 4 and 5):

- A specified minimum between any fixed installation or edge of safety walk and the design vehicle dynamic outline.
- A specified minimum between the inside face of the tunnel lining and the clearance envelope. Allowance shall be made for the construction tolerance.
- The design vehicle dynamic envelope shall not encroach into the safety walk space defined by a vertical line through the edge of the safety walk.
- A specified minimum from the inside face of the tunnel lining to the contact rail clearance point. Allowance shall be made for the construction tolerance. The contact rail clearance point is defined as that electrically energized point on the contact rail system which is closest to the tunnel liner.

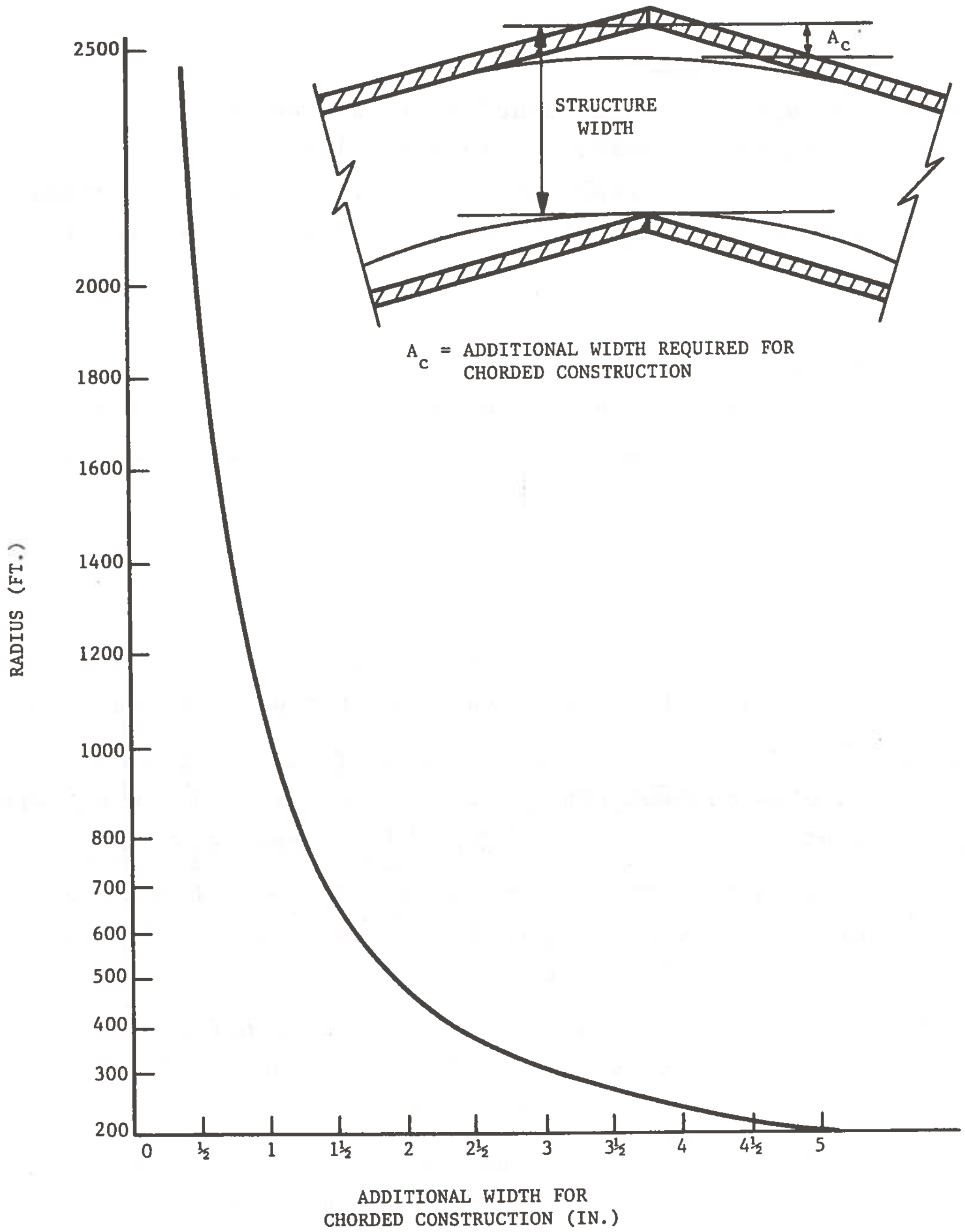


Figure 7. Additional Width for Chorded Construction (Ref. 3)

3.2.4 Location of Tunnel Working Point

The location of the tunnel working point is defined by the X_A, X_T, and Y values as shown in Figures 4 and 5. In the plane normal to the top of the low rail, the X_A and X_T values are measured horizontally from the centerline of track; the Y value is measured normal to the top of the low rail. Tables are formulated giving the dimensions X_A, X_T, Y, and SW (see Table 4) as a function of superelevation and radius of curvature.

3.2.5 Location of Safety Walk

The location of the safety walk is as shown in Figures 4 and 5.

All these factors must be accounted for in assuring that the tunnel size is adequate under all conditions.

3.3 POINTS AFFECTING CIRCULAR TUNNEL DIAMETER

For the case of circular tunnels for BART (Ref. 4) six distinct points can potentially affect the tunnel diameter (see Figures 8 and 9). The first is a function of the size and location of the contact rail; the second and third are a function of the walkway; and the car accounts for the remaining 3 points. They are as follows (Reference 4):

"A. Clearance Point for Contact Rail

This is the point of contact rail which is normally opposite the walkway. This point constraints in the "bottom" of the circle.

"B. Walkway Tread Clearance

The service walkway tread in tunnels must be a certain distance above the rail which is adjacent to the walkway. Clearance must be provided between the transit car and the walkway tread. Further, this walkway tread has a certain minimum width. The intersection point of tread and tunnel may become an extreme point constraining the tunnel diameter.

TABLE 4. CIRCULAR TUNNEL DESIGN TABLES (REF. 3)

SAFETY WALK TOWARD CURVE CENTER

Radius	Superelevation = 0"			Superelevation = 2"			Superelevation = 4"		
	X_T	Y	SW	X_T	Y	SW	X_T	Y	SW
700'	4-1/4"	5'4"	1'11"	7-1/4"	5'4"	1'11"	10-1/8"	5'4"	1'9-1/2"
900'	4-1/4"	5'4"	2'0"	7-1/8"	5'4"	2'0"	9-7/8"	5'4"	1'11-1/2"
1200'	3-1/2"	5'4"	2'0"	6-3/8"	5'4"	2'0"	9-5/8"	5'4"	2'0"
1600'	2-1/2"	5'4"	2'0"	5-1/2"	5'4"	2'0"	8-5/8"	5'4"	2'0"
2000'	2-1/8"	5'4"	2'0"	5"	5'4"	2'0"	8-3/8"	5'4"	2'0"
3000'	1-1/2"	5'4"	2'0"	4-3/8"	5'4"	2'0"	7-5/8"	5'4"	2'0"
5000'	1"	5'4"	2'0"	3-7/8"	5'4"	2'0"	7-1/8"	5'4"	2'0"
20000'	1/4"	5'4"	2'0"	3-1/4"	5'4"	2'0"	6-1/2"	5'4"	2'0"
TANGENT	0"	5'4"	2'0"						

SAFETY WALK AWAY FROM CURVE CENTER

Radius	Superelevation = 0"			Superelevation = 2"			Superelevation = 4"		
	X_A	Y	SW	X_A	Y	SW	X_A	Y	SW
700'	4"	5'4"	1'9-1/2"	2-1/2"	5'4"	1'11-1/2"	0"	5'4"	1'10-1/2"
900'	4-1/4"	5'4"	2'0"	2-1/2"	5'4"	2'0"	0"	5'4"	2'0"
1200'	3-1/2"	5'4"	2'0"	1-1/8"	5'4"	2'0"	0"	5'4"	2'0"
1600'	2-5/8"	5'4"	2'0"	1/4"	5'4"	2'0"	0"	5'4"	2'0"
2000'	2"	5'4"	2'0"	1/8"	5'4"	2'0"	0"	5'4"	2'0"
3000'	1-1/2"	5'4"	2'0"	0"	5'4"	2'0"	0"	5'4"	2'0"
5000'	1"	5'4"	2'0"	0"	5'4"	2'0"	0"	5'4"	2'0"
20000'	3/8"	5'4"	2'0"	0"	5'4"	2'0"	0"	5'4"	2'0"
TANGENT	0"	5'4"	2'0"						

Note: See Figures 4 and 5 for X_A, X_T Y and SW

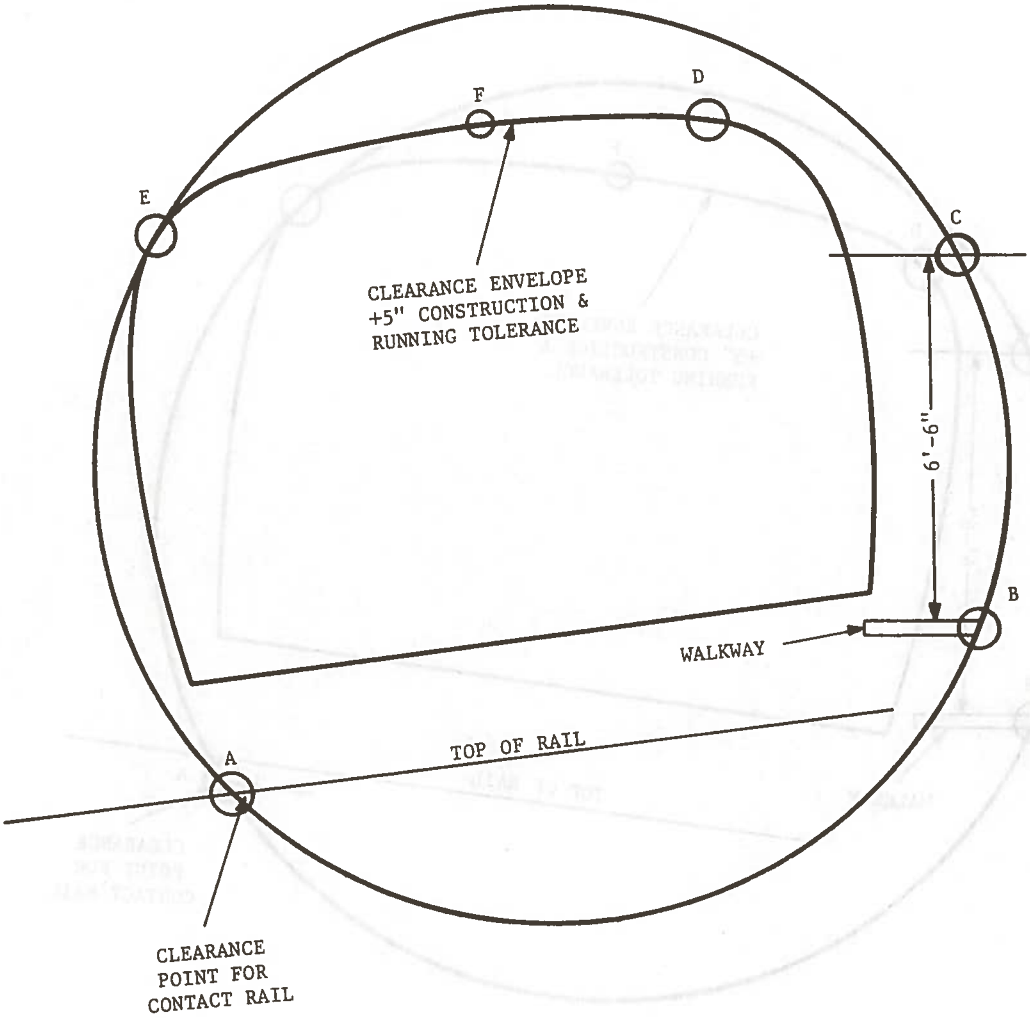


Figure 8. Six Points Affecting Tunnel Diameter (Ref. 4)—Walkway on Opposite Side of Curve Center

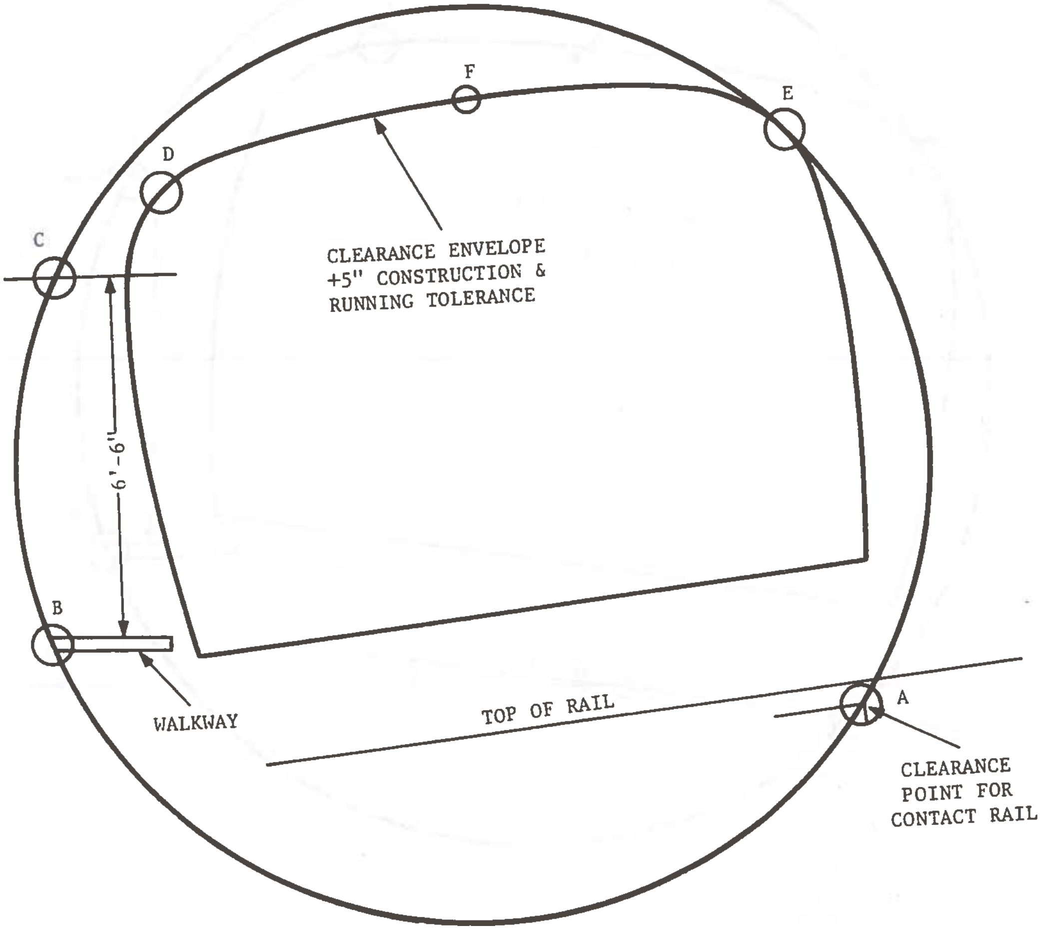


Figure 9. Six Points Affecting Tunnel Diameter (Ref. 4)—
Walkway on Same Side of Curve Center

"C. <u>Walkway Head-Room Clearance</u>

Clearance must be provided between the transit car and the top of the walkway envelope. The walkway envelope has a specific minimum width at its top. With superelevation the combination of these factors produces a point that may constrain the width of the tunnel.

"D.\
E.} <u>Corner of Envelope Interference Points</u>

Contact of one (or even both) of the upper vehicle corners with the tunnel may be critical points, constraining the tunnel diameter.

"F. <u>Top Point of Car</u>

The intersection of the centerline of the car and the roof of the car may be a critical point, if, for instance, the car has a pyramidal shape or carries air-conditioning equipment on the vehicle-roof."

3.4 CONCLUSION

The potential for standardization exists. If transit vehicles can be standardized, a standard vehicle dynamic envelope can be developed. The non-standard parameters would be vehicle speed and radius of track curvature, which are site-dependent. Yet standard clearance envelopes may be developed for similar track curvatures, superelevations, and speeds. Thus, standardization of tunnel sizes may initially be approached by standardizing the individual parameters which must be accounted for in deriving the interior dimensions of tunnels.

4. METHOD OF CALCULATION OF CIRCULAR TUNNEL DIAMETER (REF. 4)

The normal approach used to determine both circular and non-circular tunnel dimensions involves numerous hand calculations over a range of track-curve radii under four distinct conditions:

- Walkway on inside of curve: zero superelevation
- Walkway on inside of curve: maximum superelevation
- Walkway on outside of curve: zero superelevation
- Walkway on outside of curve: maximum superelevation.

For the particular case of circular tunnels, the six distinct points which can potentially affect the tunnel diameter are again identified (see Figures 8 and 9):

A - Clearance point for contact rail
B - Walkway tread clearance
C - Walkway head-room clearance
D & E - Corner of vehicle envelope interference points
F - Top point of car

These six points, defined earlier, reflect combinations of three parameters:

- Location of walkway
- Zero or maximum superelevation
- Track radius of curvature.

For each combination of these parameters a tunnel diameter is calculated using the following procedures:

1. Compute the coordinates of the six critical points. Each point has a specific geometric relationship to the control point. Each point offers a feasible method for computing these coordinates.

2. Generally, only three of the six points will be on the actual perimeter of the circle, but it is not obvious which three are critical. Thus, each possible triplet of points (20 in all) is considered.

3. For each triplet we calculate a circle passing simultaneously through the three points. Circles not including all six points are discarded. The remaining circles pose feasible tunnel diameters, and the minimum of these is selected.

The preceding graphical solution to calculating the tunnel diameter obviously is time consuming and tedious. Oftentimes this effort must be undertaken when the transit car and other required criteria are in preliminary stages of consideration, and when key dimensions change, the graphics often have to be completely reworked. To alleviate this tedious and time-consuming manual procedure, a computer code can be used to carry out the necessary calculations (Ref. 4). Codes such as these have the potential of substantially reducing the time required for design in future transit projects and can provide more accurate information toward the standardization of tunnel sizes.

5. SUMMARY OF RESULTS

Tables 1 and 2 are a presentation of the collected data. Table 1 identifies existing rapid transit tunnels in the U.S., giving the shape and inside dimensions of each. Table 2 identifies the proposed rapid transit tunnel shapes and sizes to be built in the U.S. Some cities which are identified as potential sites have not yet determined their final engineering criteria, and thus tunnel sizes may undergo future revision.

Table 3, derived from Tables 1 and 2, gives the range of tunnel inside dimensions for circular and non-circular tunnels.

Figures 10 and 11 compile the data found in Tables 1 and 2 to illustrate visually the variations of inside dimensions found in each of the tunnel shapes identified in Figure 1. Figure 10 illustrates the variation of the dimensions "H" and "ID" (Figure 1), Figure 11, the dimension "W."

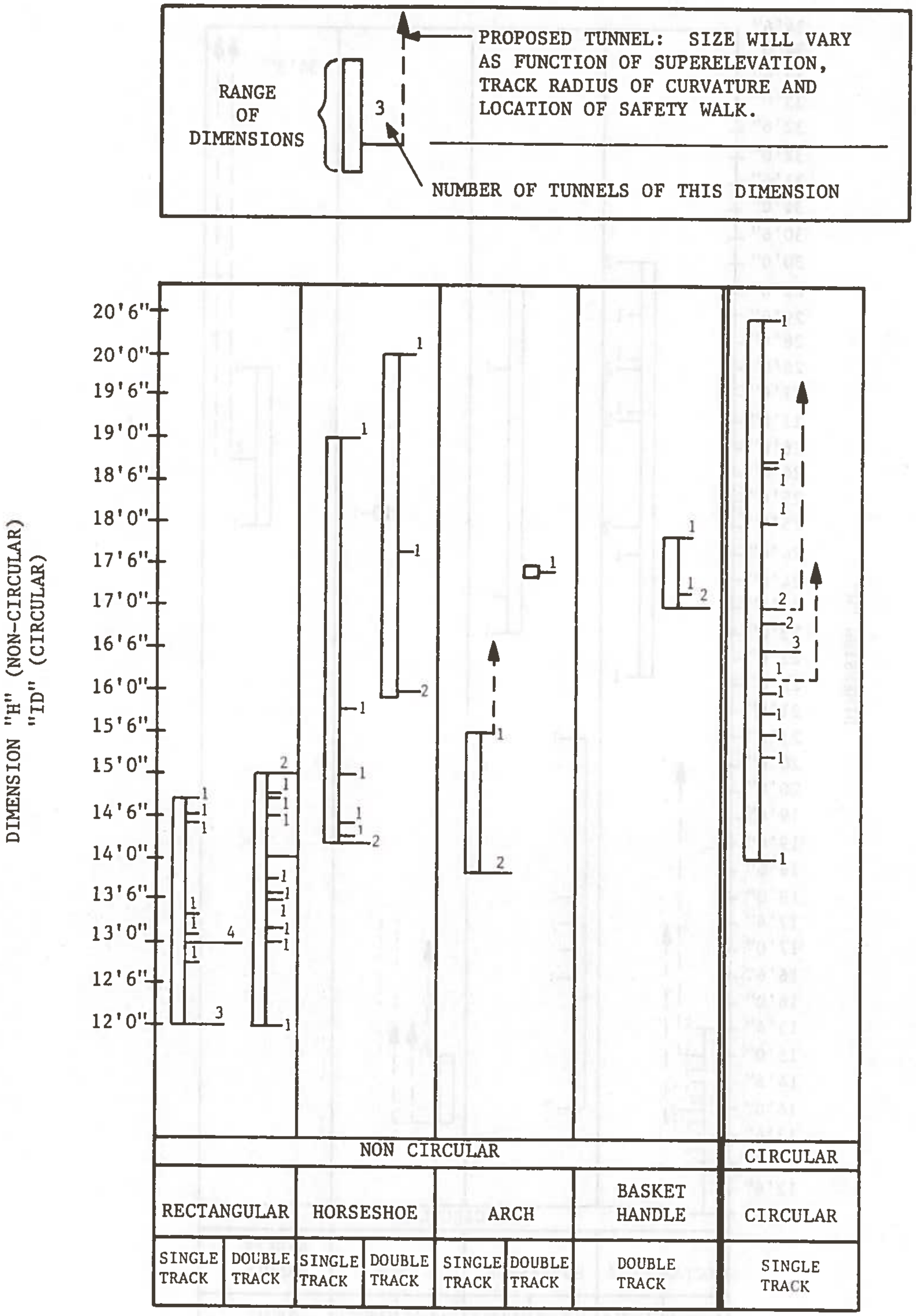


Figure 10. Variations of Dimension "H" (see Fig. 1) (Non-Circular) and "ID" (Circular)

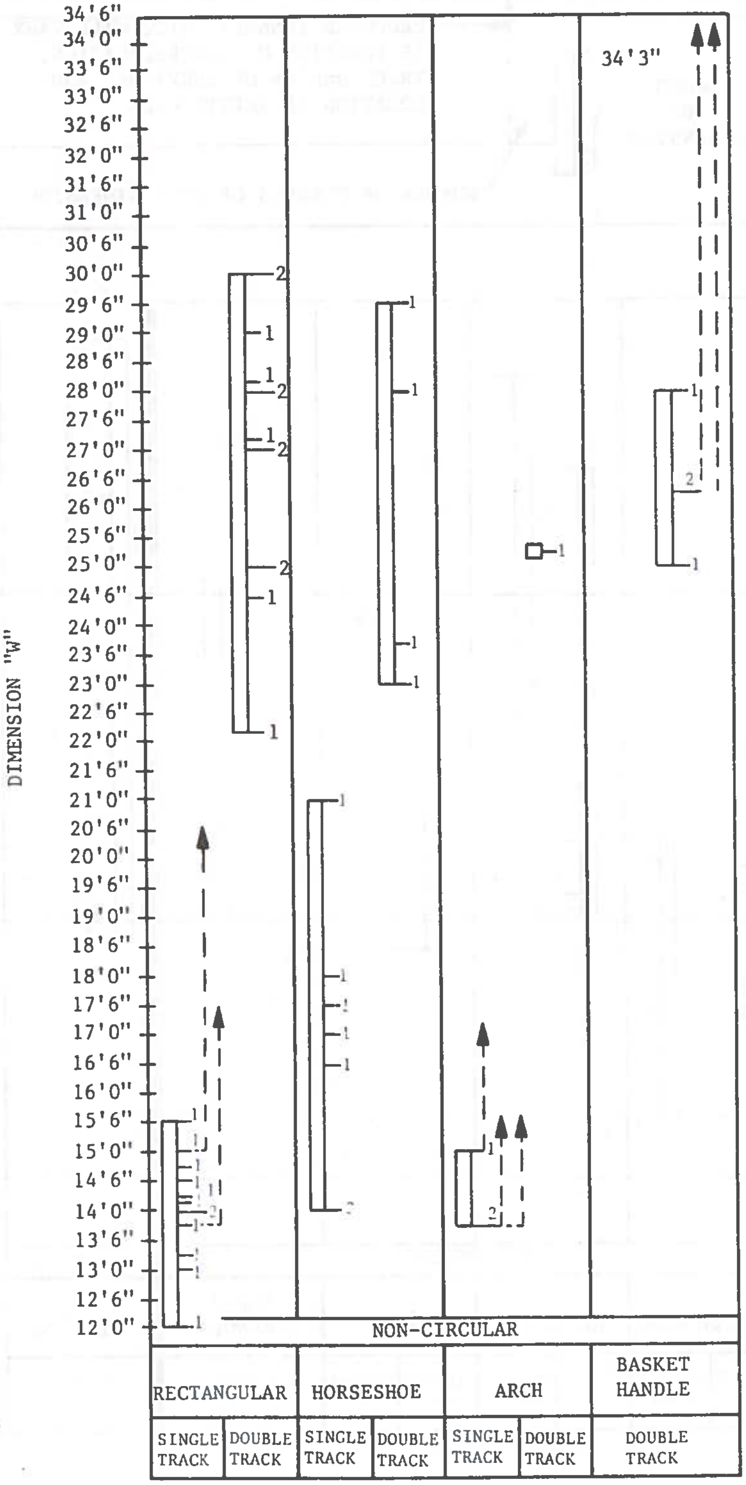


Figure 11. Variations of Dimension "W" (see Fig. 1)

REFERENCES

1. W. VanDyke, Report on Subway Tunneling Needs of 13 Selected U.S. Cities, 1971-1975, Report No. DOT-TSC-UMTA-72-5, June 1972.
2. Report on Tunneling Demand 1960-1980, Advisory Conference on Tunneling, Organization for Economic Co-operation and Development, June 1970.
3. National Capital Transportation Authority (NCTA) Engineering Standards, DeLeuw Cather and Company.
4. F.P. Wyman and H.J. Hefland, A Computer Model for Sizing Rapid Transit Tunnel Diameters, DOT Report (In preparation).
5. Robert S. Mayo et al., Tunneling - The State-of-the-Art, PB 178-036, January 1968.
6. K. Szechy, The Art of Tunneling, 1970.
7. J. Birkmyer, Betchel, Inc. (1974) Personal Communication.
8. L. Harrison, Bechtel, Inc. (1974) Personal Communication.
9. Jane's World Railways, 1972-73.
10. Physical and Geometric Data for Subway System Components, Kaiser Engineering, PB 205-879, September 1971.
11. San Francisco Bay Area Rapid Transit District, Civil and Structural Design Criteria, Vol. I, Parsons, Brinckerhoff, Tudor, Bechtel, 1968.
12. Single-Track Subway System Components, Subway Environmental Research Project, Institute for Rapid Transit, PB 201-877, January 1971.
13. Standards, Chicago Transit Authority, Engineering Department.
14. Subway Environmental Survey, Chicago Transit Authority System, Institute for Rapid Transit, PB 201-875, May 1971.
15. Subway Environmental Survey, Cleveland Transit System, PB 206-898, October 1971.
16. Subway Environmental Survey, Massachusetts Bay Transportation

Authority, PB 206-781, September 1971.

17. Subway Environmental Survey, PATCO, PB 206-897, October 1971.

18. Subway Environmental Survey, Southeastern Pennsylvania Transportation Authority (SEPTA), DeLeuw Cather & Company, PB 206-780, August 1971.

19. Subway Environmental Design Handbook, Volume I, Report No. UMTA-DC-06-0010-74-1, 1975.

20. Chicago Central Area Transportation Planning Study, Vol. III, Preliminary Plans.

21. R. Gallagher, Southern California Rapid Transit District (1973), Personal Communication.

22. E.H. King, Parsons, Brinckerhoff, Quade & Douglas (1973) Personal Communication.

23. Charles Nelson et al., Interim Report on Low Cost Tunneling for the Metropolitan Transit Commission, May 23, 1973.

24. Niagra Frontier Mass Transit Study: Technical Report, PB 210-686, September 1971.

25. Henry L. Stuart, The Atlanta Plan: Rapid Transit for the People, PB 197-259, July 1970.