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Accessibility For Level-Entry Urban Rail Systems

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Final Report

U.S. Department of Transportation
Urban Mass Transportation Administration

Office of Technical Assistance
Office of Systems Engineering
Washington DC 20590

U.S. Department
of Transportation
**Urban Mass
Transportation
Administration**

Headquarters

400 7th Street S.W.
Washington, D.C. 20590

July 19, 1982

Dear Colleague:

Enclosed is a copy of a report entitled "Accessibility for Level Entry Urban Rail Systems." This report represents the findings of a study of the potential methodologies available for improving access by wheelchair-bound, and other mobility limited individuals onto "level entry" transit vehicles across vehicle/station platform "gaps" or discontinuities. This study was sponsored by the Urban Mass Transportation Administration's Office of Systems Engineering, and is part of an ongoing project conducted by the Transportation Systems Center (TSC), aimed at identifying and evaluating techniques for improving accessibility to urban mass transit. In this report, the various techniques and considerations involved in crossing vertical and horizontal discontinuities are discussed, and the impact of these techniques on rail transit operations and maintenance are described. The report is based on contributions from a number of organizations including:

- results and implications of research conducted by the Veterans Administration Rehabilitation Engineering Center (VAREC) under interagency agreement with TSC to determine the gap crossing abilities of wheelchair users with various types of handicaps, and various levels of proficiency in the use of their wheelchair.

- investigations by the TRAAC Corporation (under contract to TSC) into the engineering and design considerations involved in reducing and/or bridging the vehicle-station gap mechanically or with the aid of transit system crew; and,

- the enthusiastic participation of members of the handicapped community representing organizations such as the Eastern Paralyzed Veterans Association (EPVA) in the experimental aspects of the study.

We feel that this report provides insights into the gap problem, and suggests practical and cost effective methodologies for enhancing accessibility. We hope that you find it useful in your work.

Sincerely,

Jeffrey Mora
Urban Mass Transportation
Administration

E. D. Sussman
Transportation Systems Center

Enclosure

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16. Abstract

Accessibility of public transit for the elderly or handicapped is sometimes impeded by the gap which occurs at the interface between railcars and level-entry station platforms in urban rail transit systems. The gap is analyzed and evaluated to determine its actual range of effect in impeding wheelchair travel. The problem of determining adequate and feasible gap standards is addressed. Several forms of active and passive mechanical filler devices are considered. It is found that such devices may be impractical in terms of cost and safety. It is proposed that the participation of train crew coupled with effective training for the elderly or handicapped in wheelchair operation could form the basis for an adequate solution to the gap problem.

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Preface

This report was prepared by Technology Research and Analysis Corporation (TRAAC), Arlington, VA under contract DOT-TSC-1711 to the Transportation Systems Center, U.S. Department of Transportation. Donald Sussman was the contract technical manager, and Jeffrey Mora was the program manager from the Urban Mass Transportation Administration. Joel Edelman and Arne Hungerbuhler were the principal TRAAC personnel. Wheelchair maneuverability test results were provided by Anton J. Reichenberger of the Veteran's Administration Research and Engineering Center, New York, N.Y. The first phase of the study was contributed by F. T. McInerney.

METRIC CONVERSION FACTORS

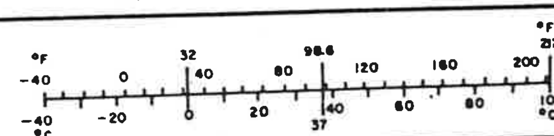
Approximate Conversions to Metric Measures

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

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.

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



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Executive Summary

The objective of this study was to develop a comprehensive analysis of the clearance gaps which occur between railcar doorways and station platforms, to investigate the relationship of these gaps to elderly or handicapped (E&H) passenger accessibility, and to evaluate alternative solutions to the impediment presented by these gaps.

In general the gap will consist of both horizontal and vertical components. The gap originates in part from design considerations, including both static and dynamic tolerances. Thus it is not possible, even with ideal maintenance and operations, to eliminate the gap completely.

At present there is no universally accepted standard for gap dimensions in level-entry rail transit. There are standards for similar operations, such as elevators, but there are sufficient differences between these operations such that the gap standards for one cannot simply be transferred to the other.

A review of existing rail transit systems reveals that the newer rapid rail systems (BART, MARTA and WMATA), generally have the lowest gap magnitudes and, as evidenced by their E&H patronage, are considered accessible. The older systems are generally not accessible and in some cases contain inherent design shortcomings, and thus many of the alternative solutions to the gap problem are not practical.

There are several gap filler installations, including active and passive gap fillers, which suggest directions for the development of technological solutions to the gap problem. There are no present installations whose designs can be directly applied to the older transit systems without further developmental effort.

A Veteran's Administration study reveals that experienced wheelchair users can successfully cope with the moderate gaps common to many level-entry stations; users with poor technique were able to cross only the smaller gaps. Thus, the proper training of E&H patrons is viewed as a significant factor in the solution of the accessibility problem. Innovation in wheelchair design is also seen to show promise as a contributor to increased urban rail system accessibility.

Purely technological solutions in the form of active (mechanically mobile) or passive (stationary) gap fillers are considered to be unfeasible because of the developmental cost, installation cost, maintenance cost, high safety risks, and limitations of applicability. A possible solution to occurances of extremely large gaps is the use of a manually operated detached ramp or bridgeplate, carried on the railcar and placed in service by a traincrew member upon demand.

1.0 INTRODUCTION

Public transportation has traditionally evolved without explicit concern for the problems of accessibility by elderly and handicapped (E&H) travelers. Recent research and development has sought to correct deficiencies in many areas of public transit. Railcars which have steps for entry from low-level platforms are being considered for various designs of lifts to elevate the patron to the level of the vehicle floor. Lift applications to buses are proceeding, with over 2000 lifts installed or on order. Rail applications are just beginning, with 14 lift-equipped light rail vehicles in San Diego.

Accessibility at level-entry stations, as encountered on all rapid rail systems, and some light rail and commuter rail systems, has generally focused on providing accessibility to the station platform. However, most high platform stations are only nominally level-entry because of the vertical gap that usually exists with either the car or platform high. These horizontal and vertical discrepancies can present serious or insurmountable impediments for some patrons, effectively making the system unusable, even after platform access has been provided.

There are other impediments to accessibility that may need to be resolved. The most visible one is inadequate door width for wheelchairs on some systems or cars. On the Chicago Transit Authority system the 6000, 2000 and 2200 series cars have an arrangement known as "blinker doors," with a center post in the doorway that renders the opening inaccessible. Once inside the car, the wheelchair user must have proper travel accomodations, which is at a minimum sufficient space to maneuver. The placement of stanchions is frequently an obstruction. Securement areas are not now provided on any of the three new rapid rail systems in Washington, Atlanta or the San Francisco Bay Area.

This report examines the technical issues associated with improving platform to vehicle accessibility. Section 2.0 examines the factors that constitute horizontal and vertical gaps at the car-to-platform interface, and also suggested guidelines which might be used to establish gap standards. Section 3.0 reviews gaps on existing systems, and reviews the state of the art for gap filling devices. Section 4.0 presents the results of the Veteran's Administration Rehabilitation and Engineering Center (VAREC) studies, and develops the functional requirements for implementation of solutions to the gap problem. Section 5.0 evaluates generic and specific designs for passive (fixed) and active (controlled motion) gap fillers and discusses the manually operated bridgeplate as an alternative.

2.0 PROBLEM DEFINITION

The gap that exists between a transit car and a platform has two components: The horizontal gap necessitated by the requirement to avoid striking the platform with the transit car, and the vertical step occassioned by the impracticality of maintaining the car floor exactly level with the platform. The vertical and horizontal discrepancies can best be examined by considering the tolerances in vehicles, on the track and station structures, and the interaction between track and vehicles.

The gap that exists at the car to platform interface has properties that are statistical in nature, not deterministic, because a set of cars (and doors, sides, etc.) can interface in many ways with a set of platform positions at which cars can stop. Wear on cars, and track or platform shift in stations produces a situation in which the true individual car threshold locations and true individual platform locations have a distribution of values about some average. It is not necessary that the true averages equal the design values.

The statistical nature of gaps and steps is important because it impacts both the manner in which gap standards are set, and the actual gaps the system user is likely to experience. Although gaps and steps at the extreme limits can occur, users observe the greatest number of gaps and steps near the average value.

For level-entry service the minumum possible gap and zero step are desired. For operational and maintenance considerations, the maximum tolerable gap and step are desired. The algebraic difference between the maximum limit and minimum limit is the total range available for the component tolerance addition. Existing transit practice represents a historically established balance between user requirements and O&M requirements.

Although a platform and its associated track segment are usually referred to as one unit, in reality a platform has many possible alignments relative to the track. A single platform must be considered as a series of stopping locations each with a quantifiable relation to the adjacent track.

The car threshold positions similarly require individual quantification of their true dimensional locations. Threshold position is always referenced to the track centerline and track surface.

If the set of car threshold positions could be compared with the set of positions for platform stopping locations, the true picture of car-to-platform alignment could be determined. The result would be an approximately normal statistical description expressing the probability of observing a gap and step of x and y dimensions at a randomly chosen platform location, when a random car stops.

The above description is valuable as a first-order analysis of the situation. Several possible refinements are applicable if a more detailed car-to-platform alignment description is desired:

- The car-to-track alignment is established at the trucks; hence the track-to-platform alignment at the mid-car position is unimportant. The mid-car platform position should theoretically be referenced to the average of the track positions at the trucks.
- All cars deform measurably from the empty to crush loaded condition. The maximum deflection occurs at the center of the car.
- Without height control, the primary suspension can vary up to 3 inches from the empty to crush loaded condition.
- A stopped car is not static; people entering and exiting can cause significant roll about a longitudinal axis, which appears as oscillations in the gap and step dimensions.

With a detailed understanding of how the gap and step dimensions originate, it is possible to determine which components of each are the easiest to reduce, or which components, if improved, would yield the greatest net improvement in the gap or step.

2.1 Components of Gaps and Steps

The components of gaps and steps have many characteristics, which in turn suggest or determine what actions would be appropriate to tighten control of a given component. Table 2-1 defines seven characteristics of gap and step components.

TABLE 2-1. CHARACTERISTICS OF GAP AND STEP COMPONENTS

1. Allowance - The value added to the build-up of tolerances to ensure the desired operating conditions, such as the designed positive residual gap when all car and wayside tolerances add algebraically to reduce the nominal gap.

2. Drift - Change of a value that is theoretically constant with time without measurable wear, such as springs relaxing to a shorter length, track shift, car sag; all plastic deformation is drift.

3. Geometric Variations - Unavoidable theoretical misalignments, such as the gap between a car and a curved platform, or the height mismatch between a straight platform and cambered car.

4. Hysteresis - Failure of a dynamic component to repetitively assume the same dimension at the same force or other constraints. Examples are deadbands in height adjustment valves, friction in swing hangers, wheelset position within track gauge.

5. Manufacturing Variation - The deviation from nominal dimension of all manufactured components, such as wheel diameters, car width, car straightness. The acceptable limits of manufacturing variations are called tolerances.

6. Static Deflection - The change of a dimension in direct proportion to the change in applied load. Vehicle springs and the vehicle structure exhibit significant static deflection as the passenger load varies.

7. Wear - Change of a dimension by loss of critical material, such as decreasing wheel diameters or increasing track gauge. The acceptable range of wear is called the wear limit.

Some components may have more than one characteristic. For example, track gauge (new) has a positive allowance relative to wheel gauge (new), and the wheel to rail lateral clearance is further increased by wear of both components. At any given stop, the lateral position of the wheelset within the gauge is uncertain within the limits set by flange contact, a condition best described as a hysteresis type of phenomenon.

The basic theoretical dimensions of transit systems, such as track-to-platform horizontal distance and car width, are established to ensure that a vehicle cannot impact a platform under the maximum conditions of dynamic movement and tolerance accumulation. The vertical dimension, including platform height and car floor height, are set to provide nominally level entry, although some operators bias their vertical dimensions to maintain car floor height above platform height at all times.

Table 2-2 lists the components and their characteristics that contribute to the build-up of gap and step dimensions and tolerances. These components are illustrated in Figure 2-1. It is important to realize that all of the tolerances on nominal dimensions have a statistical nature, and thus gaps and steps are best characterized by a statistical description. On a given system, gaps and steps will each have a nominal value, with a range of variations that can be expressed in terms of standard deviations (assuming the variable have normal distributions) or other parameters of distribution.

The platform-to-vehicle alignment of rail vehicles is the result of two separate events: the establishment of alignment, and the occurances of alignment. The establishment of the nominal relative positions of each component occurs at the design stage, and is governed by a linear addition of tolerances. The occurrences of alignment are the gap and steps that passengers experience at every stop, which are governed primarily by a statistical distribution of tolerances which may be assumed to be approximately normal.

Figure 2-2 shows a platform and car cross section, and the nature of the two types of horizontal positioned variations: linear and statistically normal. Vertical variations are developed in a similar manner, except that platform height and car height may be set equal because there is no possibility of mechanical interference.

TABLE 2-2. DETAILED ELEMENTS OF GAPS AND STEPS, AND THE MAJOR COMPONENTS THAT CONTRIBUTE TO EACH

Horizontal Gap	Mech.	Vertical Step	Mech.
VEHICLE ELEMENTS			
Wheel gauge	MV	Wheel radius	MV,W
Wheel profile	W	Truck height-castings	MV
Truck ℄ to veh. ℄	MV,H	Spring height	D,SD
Lateral motion	A	Airbag height	H,SD
Chassis width & curvature	MV	Chassis camber,twist	MV,SD
Vehicle oscillations	SD	Vehicle oscillations	SD
Clearance	A		
WAYSIDE ELEMENTS			
Track gauge	MV,W	Rail height	W
Track ℄ to platform	MV,D	Track alignment (vertical and crosslevel)	MV,D
Track alignment (horizontal and crosslevel)	MV,D		
VEHICLE TO WAYSIDE INTERACTION			
Position in gauge	H,A	(There are no vehicle to wayside interactions that have any significant effect on the vertical step)	
Car to platform	G		
Clearance	A		

COMPONENTS:

A - Allowance
D - Drift
G - Geometric Variations
H - Hysteresis
MV - Manufacturing Variations
SD - Static Deflection
W - Wear

(Refer to Table 2-1 for definitions)

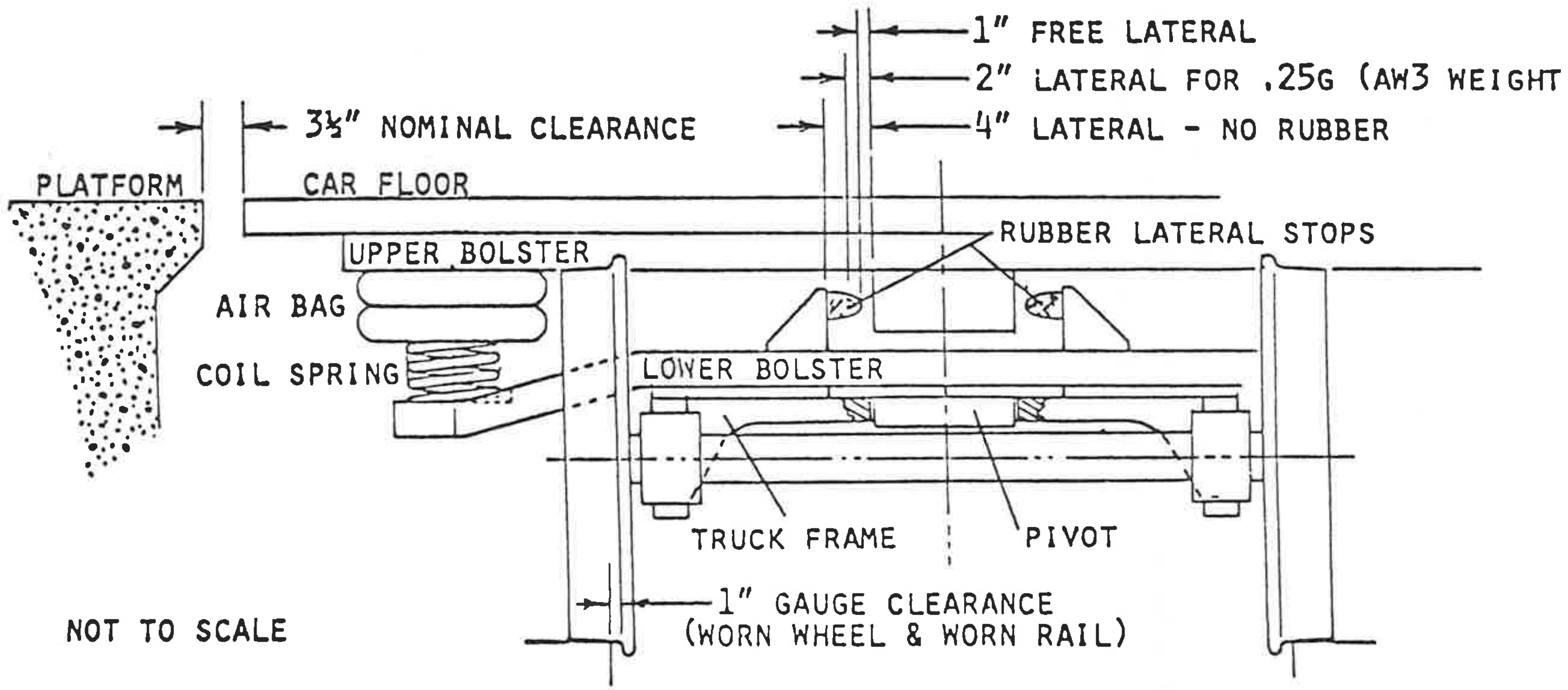
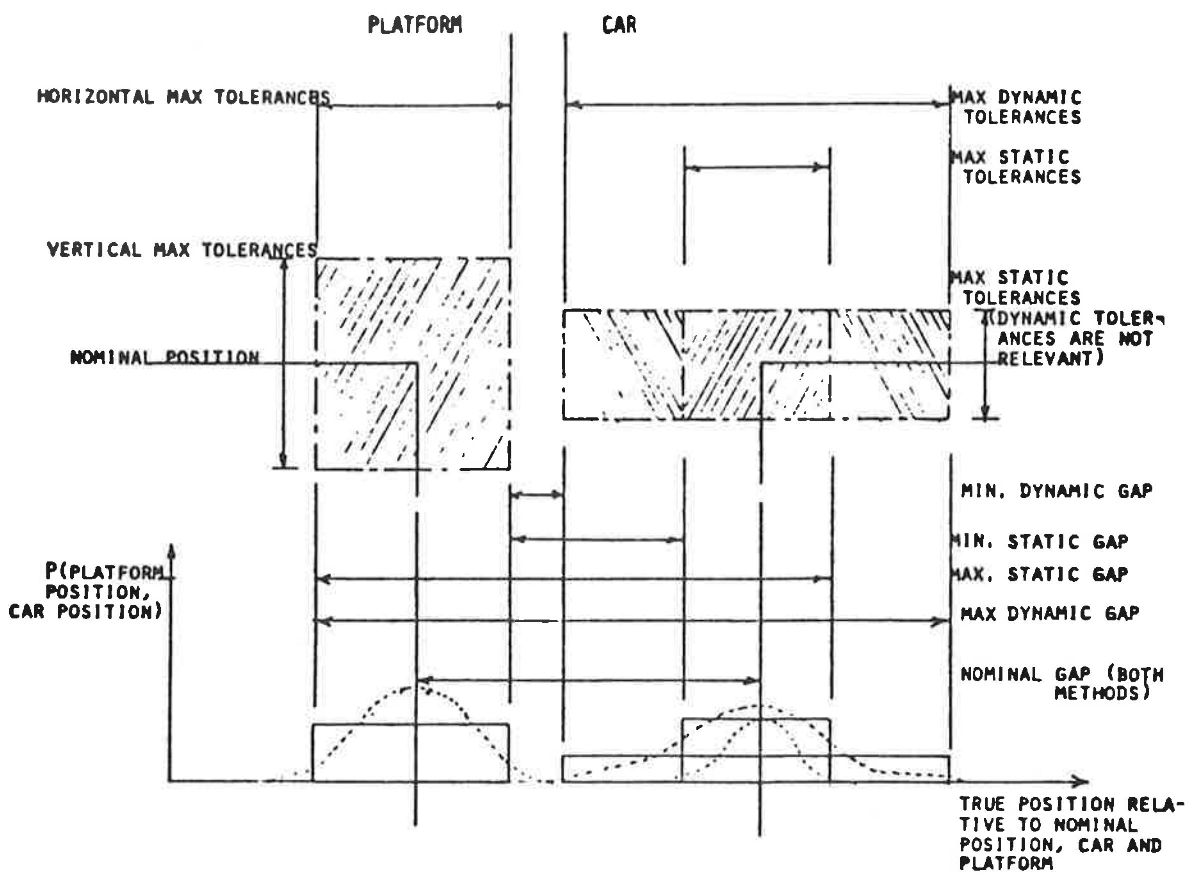


FIGURE 2-1. TYPICAL RAPID RAIL TRUCK AND CAR SECTION AT PLATFORM



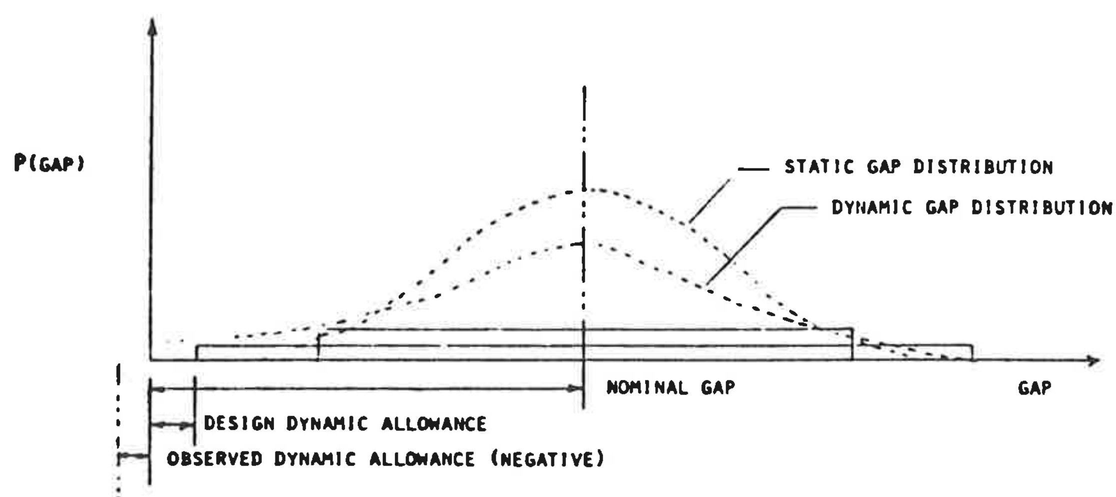


FIGURE 2-2. ALIGNMENT OF CAR AND PLATFORM WITH CONSIDERATION OF STATIC AND DYNAMIC TOLERANCES

In practice, the actual positions that occur are best represented by the normal curves of Figure 2-2, and as a result, the net horizontal gaps are also approximately normally distributed. There is no minimum or maximum gap for normal distributions; instead the range of gaps observed must be represented as the percent gaps that are within certain limits. Therefore there is a small probability of observing very large gaps and very small gaps, which include zero gaps or impact. Proof exists in the physical evidence on both cars and platforms that impact has occured at some time.

A linear addition of the tolerances for each dimension of the components that affects the gap can be assumed to be approximately equal to the 3σ limits of a normal distribution. The 3σ limits include 99.74% of the possible car dynamic positions, leaving a very small but finite probability that a car can strike a platform if the 3σ limit toward the platform leaves zero clearance. In Figure 2-1, the development of the nominal horizontal position proceeds from the establishment of the minimum gap and the algebraic limits of car and platform position.

As Figure 2-2 shows, there are two elements in the car's contribution to the gap. Part of the measured gap is due to tolerance accumulations of a vehicle at rest, the static tolerances. It is also necessary to consider car-to-platform clearances for dynamic conditions. On all systems, the platform areas are entered at a speed high enough to cause substantial dynamic perturbations of the car, in response to track variations.

The approximately normal distribution of gap and step suggests that more workable limits for car-to-platform alignment could be set based on achieving a portion of gaps and steps within established values rather than setting an absolute limit based on median or extreme values.

2.1.1 Wayside Conditions

The wayside components that determine gap and step are fewer in number and easier to describe than those of the vehicle, although not necessarily easier to control or adjust.

The station platform edge may be taken as the fixed reference for examining wayside conditions; platform slope, if any, has little impact on the gap and step problem.

Relative to the platform edge, track location at any longitudinal position can be fully described by:

- gauge
- horizontal distance to gauge line of near rail
- vertical distance to top of near rail
- cross-level variation

These dimensions can, and usually do, exhibit variation over the length of the platform.

In addition, it is necessary to describe the longitudinal characteristics of a station:

- Lateral curvature - convex, straight, or concave
- Vertical curvature (rare) - convex, straight, or concave

Curvature of a station causes gap problems because a straight vehicle cannot mate correctly at all door locations along the car with a curved platform. On a convex edge, the ends of a car must necessarily be farther from the platform than the center of the car, and only a centerpoint door can be at the design distance from the platform. On a concave edge, the extreme ends of the car must maintain at least the minimum car to platform distance, and all doors are farther from the platform than the design straight-edge distance. Platforms can have any combination of shapes, such as primarily straight plus a curved end, S-shaped, etc., but most rapid transit systems have predominantly straight platforms.

In the horizontal direction, the platform-to-gauge-line dimension exerts the most direct control on the platform-to-car horizontal gap. However, cross-level variation also affects the horizontal dimension by tipping the car toward (as shown in Figure 2-3) or away from the platform. Gauge is a moderate influence on the gap dimension. Wear on the near rail allows a car to approach the platform and wear on the outer rail, of course, allows a wider gap.

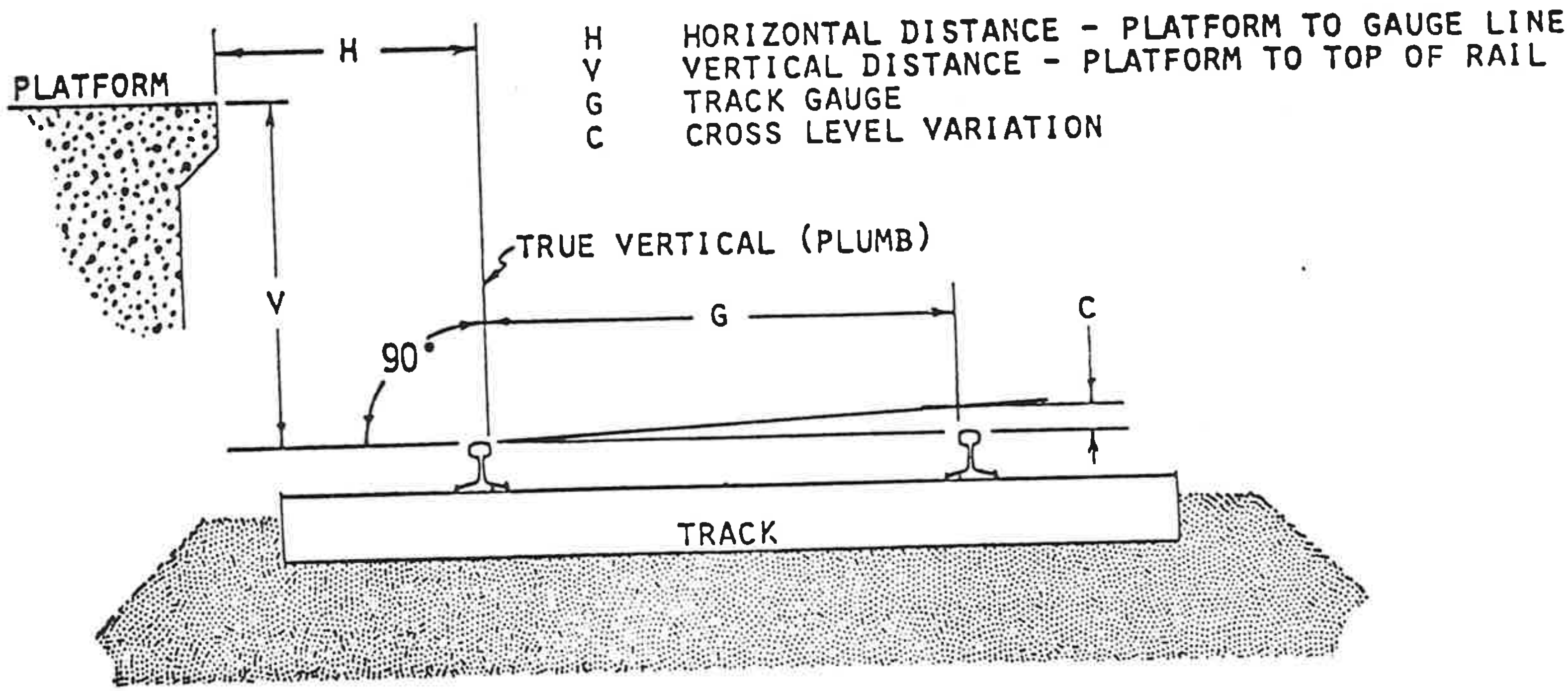


FIGURE 2-3. PLATFORM TO TRACK RELATIONSHIP

2.2 Existing Guidelines for Gap Standards

There are few guidelines available for use in determining the gap standards that should apply to level entry rail systems, which at present encompass rapid rail systems, some commuter rail systems, and three light rail systems. Fewer still are standards which may be useful for determining desirable conditions for elderly and handicapped accessibility. Most guidelines in existence for rail systems are set by the operating authorities themselves, although state public utility commissions impose some requirements on commuter rail systems. Historically, existing standards were established presuming that all patrons were ambulatory. Some feel that existing standards allow much too great a gap when handicapped patrons also expect to use a transit system with ease and safety.

The standards set by rapid rail operating authorities usually specify the average gap for design purposes, which allows for car and platform positional tolerances, plus car dynamic movement. The existing rapid rail values range from 3" to 3 5/8" nominal gap for new systems. Older systems may specify larger nominal gaps to the hard platform edge, but the actual gap is sometimes reduced with wood nosing strips.

Commuter rail operations on lines which also accomodate freight traffic expect a gap of about 6" to 8" nominal. On a few commuter-only lines, gaps are on the order of those of rapid rail, about 3½". Commuter rail lines are sometimes subject to regulatory agency clearance requirements which effectively mandate gaps of 6" or more. These operators would require a waiver before gap reduction alteration could be instigated.

Elevator standards are frequently cited as suitable objectives for gaps and steps that occur in the platform-to-vehicle interfaces of transit systems. Although they are entirely acceptable to some of the handicapped, they do not appear workable for transit systems.

Table 2-3 lists some criteria and an assessment for the two modes of travel. The major differences that significantly affect the achievable minimum gap are:

- Maximum speed, and therefore, greater range of lateral motion.
- Guideway construction and stability is lower for rail systems.

TABLE 2-3. COMPARISON OF ELEVATOR AND RAIL TRANSIT CHARACTERISTICS

CHARACTERISTIC	RAIL TRANSIT SYSTEMS	ELEVATORS
Maximum Speeds	40 to 80 mph (3500 to 7000 ft/min.)	200 to 1800 ft/min.
Environment	Extremes of outdoor ambients	Usually indoors or moderate outdoors
Stability of Guideway	Good in tunnels; fair to poor outside	Good
Lateral Guidance	Lateral clearances plus lateral springing	No springs and very small clearance
Design Codes	Weak	Very strong
System Maintenance and Inspection	Poor to gcod	Good to excellent
Doors per Vehicle	Four to eight	One or two
Guideway Length	Very long; up to 103 miles (commuter rail)	0.25 mi. max. per segment
Curved Guideway	Yes	No
Curved Platforms	Many on older systems	No
Vertical Alignment	Self-leveling cars on some systems	Self-leveling is common
Veh. & Guideway Wear Rates	High	Moderate

- Environment is harsher for rail systems.
- Multiple doors and vehicle interfaces with each platform for rail.
- Lateral freedom in rail vehicles at rail and on car.
- Higher rates of wear for rail.

The conclusion to be drawn from Table 2-3 is that elevators and rail systems are of significantly different scale, and therefore, it should be expected that the practically achievable tolerances are inherently different.

The gap standards now in effect for and met by elevators are much more restrictive than those currently observed in rail systems, and there appears to be little hope that rail systems could meet these standards with current practice.

Some opinions have been expressed that elevator standards are too generous in some respects for the handicapped. The maximum allowable gap is in excess of the minimum dimensions of handicapped aids such as crutch tips, walker tips, and the width of caster wheels on many wheelchairs. The significant problem with wheelchair wheels at all gaps greater than caster wheel width is that the caster wheels can turn parallel and drop into the gap. Most wheelchair-users could not free themselves from this situation without assistance.

The minimum gap required, and the maximum gap tolerable by the handicapped population needs discussion and clarification. There is presently no concensus, since the gap acceptable to a handicapped person varies with degree of handicap and with the level of experience of each individual.

Elevator standards are discussed in greater detail in Appendix A. Other gap standards are suggested in addition to elevator standards. The Section 321(a) rapid rail study[1] discusses a horizontal maximum limit of 2½", and a vertical limit of 1". Design specifications for new rapid rail systems have been set initially as low as 1" maximum horizontal gap, later to be revised upward.

2.2.1 Impact of "Gap" Standards on Equipment and Facilities

It is necessary to consider the effect of gap standards on transit equipment [vehicle, station and track] design and operation. In the vertical direction, a maximum step limit could allow twice the limit as a working range. That is, with a level entry, a 1" step limit would permit the car to be 1" low to 1" high, for a range of 2". This range must be allocated between structural tolerances (car and platform) and static deflection.

The static vertical deflection of a car without height control is preordained by suspension stiffness (which, in turn, is determined by the choice of natural frequency in the vertical bounce mode) and the gross-to-tare ratio of the chassis. Natural frequency is restricted to about 1¼ to 1½ hz., for ride comfort and dynamic load considerations. The gross-to-tare ratio, which is a measure of the dead weight to useful payload relationship is, of course, always under economic pressure to increase. As a result, modern transit cars experience about a 2¼" to 3" deflection from the empty (tare) to the crush loaded (gross) condition. This is already outside the 2" range of the Section 321(a) study criteria, excluding additional structural tolerances.

In the horizontal direction, the working range is obtained by subtracting the minimum gap from the maximum limit. For a 2½" maximum gap, and a minimum clearance of ½", the working range is 2" which is symmetrical about a central position, or ±1". Thus the nominal position of a car is 1½" from the platform. As with the vertical range, the horizontal range must be allocated between structural tolerances and operating variations.

The normal lateral freedom of the chassis with respect to the truck is from ± 1¼" to ±2", and gauge clearance can be up to ± 3/4". Table 2-4 shows the tolerance addition for the Washington Metropolitan Area Transit Authority rapid rail system (WMATA), and a determination of the expected static position range. The figures indicate that a range of gaps of about 2" to 5" is expected, centered on about 3½". This corresponds satisfactorily with qualitative observations.

There are only two basic ways to reduce the gap and step, respectively. In the vertical direction, the two fundamental choices are:

- the provision of stiffer suspensions to limit the tare to gross weight height change, or

TABLE 2-4. LATERAL TOLERANCE ADDITION FOR WMATA STATIONS

LATERAL COMPONENT	[1]DESIGN CALCULATION FOR REQUIRED CLEARANCE		[2]EXPECTED STATIC GAP RANGE
Gauge Clearance	± .406		.406
Lateral at Bolster[3]	± 1.313		.125
Wheel Wear	± .25		.25
Rail Wear	± .5		.5
Total Dynamic Tolerances		± 2.469	
Car Structural Tolerance	± .125		.125
Truck Assembly Tolerance	± .125		.125
Track Positional Tolerance	± .25		
Total Structural		± .5	
Allowance for positive clearance or 3½° roll[4]		± .656	
Total and nominal gap		± 3.625	±1.531

Notes

1. WMATA figures
2. Author's figures
3. Full dynamic range must be used to set the gap because train enters station at significant speed. Standing, the car is close to centered except for hysteresis effects in suspension.
4. Lower roll center with respect to floor height not known. 0.656" and 3½° corresponds to 10.75", which is reasonable.

- the provision of pneumatic height control, which is a form of vertical step reducer.

In the horizontal direction, the same choices appear:

- provide lower limits to lateral freedom.
- provide horizontal gap fillers.

Limiting movement in either direction is not a practical option. Reducing the empty-to-loaded deflection constitutes reducing the springing, which implies that the vertical ride becomes harsher. As the forces the passenger feels increase, similar increases are imposed on the track and trucks. These increased forces contribute to accelerated wear and fatigue.

In a similar manner, reducing lateral freedom causes lateral ride deterioration, and increased forces on the track and trucks. Thus it can be seen that, as gap and step limits are progressively reduced, improved tolerances will quickly fail to yield improvements beyond fractions of an inch. The resultant improvements will then have to come from reducec equipment design parameters, which carry a price in terms of increased maintenance, or active gap fillers will have to be provided. Hence, the development of limits on gaps must be done with full cognizance of the impacts and trade-offs that must occur.

3.0 EXISTING SYSTEMS AND GAP FILLER INSTALLATIONS

This section examines the state-of-the-art for car-to-platform alignment and for existing approaches to gap filling or reduction. The horizontal and vertical car-to-platform alignment is often cited as a major E&H accessibility impediment at nominally level entry stations, but not all of the older systems are inferior in this aspect.

Gap filling devices to reduce or eliminate the car-to-platform gap are not new. There are some now in daily use on the NYCTA system. Others, which have served and since disappeared, were installed to reduce major gaps occasioned by track crossovers that cropped the corners of a platform in Boston. Not all are or were suitable for E&H requirements, but they serve to illustrate what has been attempted to date.

3.1 Existing Gap Conditions on Rail Transit Systems

There are three urban rail modes that operate from high platforms all or part of the time: rapid, light, and commuter rail. The car-to-platform alignment characteristics are not the same for the three modes. Commuter rail necessarily operates with larger clearances when freight is handled on the same line, and is generally not E&H accessible. By contrast there are three recently constructed rapid rail systems which were designed to be E&H accessible. These three systems constitute a baseline for accessibility against which to compare the other rapid rail systems, and to some extent the commuter and light rail systems Finally, there are only three light rail systems which operate wholly or in part from high platforms; of the two newer systems, one is apparently very accessible, judging by its handicapped patronage.

3.1.1 New Rapid Rail Systems

There are three recently constructed rapid rail systems which were designed to be accessible at the car-to-platform interface: BART, WMATA, and MARTA. Because they are the most recent examples of construction and technology, these systems were contacted to determine their car-to-platform design standards and actually achieved results. In addition, the level of accessibility they actually provide was guaged based on complaints received by the systems and other documentation if available.

MARTA The Metropolitan Atlanta Rapid Transit Authority (MARTA) system was originally designed for nominal 5" horizontal gap and a nominally level vertical alignment. It was found that the 5" gap could safely be reduced to a nominal 3½" gap, and aluminum extensions were added to the car thresholds. There is no indication that the cars have struck the platform, even with the extension. The extension plates are considered expendible, and therefore constitute a form of frangible gap reducer. The range of gaps experienced has not been determined.

The vertical step is nominally zero (car floor tangent to platform surface), and very good vertical alignment is achieved with the cars, because the cars have pneumatic suspension with height control. The deadband is approximately ½".

In the design stages of the system, MARTA worked closely with representatives of the local handicapped community to achieve system accessibility. Although the handicapped group initially desired a horizontal gap approaching zero, they were able to accept the much larger gap necessitated by car dynamic considerations. MARTA reports that handicapped persons regularly use the system. Wheelchair confined patrons cross the gap by backing into the car. The system has not received complaints of inaccessibility with regard to car-to-platform alignment.

WMATA The Washington Metropolitan Area Tansit Authority is designed to have a 3 5/8" horizontal gap, and a 1 in step into the car, although the step is largely masked by the sloping thresholds. At the car-to-platform interface, WMATA reports that the horizontal gap ranges typically from about 2" to 4½". There have been problems with the height control feature of the cars, causing the vertical step to range more than the ± ½" normally expected.

Although the system is considered accessible at the car-to-platform interface by WMATA, one recent report[2] found some possible deficiencies in this area. The report states that random observations of horizontal gaps of up to 7 " and vertical steps of up to 4" were made. Thus the WMATA system may not be universally considered accessible at the car-to-platform interface with the presently achieved alignment dimensions, although handicapped persons use the system daily.

BART The San Francisco Bay Area Rapid Transit system has been operating since 1972. The design car-to-platform alignment was initially 4" nominal horizontal gap, and level vertically. The range of gaps now reported is about 3 " to 5" horizontally and ±1 vertically. These values are substantially constant over time, indicating that the permanent way is acceptably rigid, and that cars are maintained within original tolerances. The cars have pneumatic suspension with height control, which contributes substantially to achieving good vertical alignment. (BART is 5'6" gauge, unlike other systems which are almost all standard gauge, 4'8½" . The increased gauge does not impact the car-to-platform alignment).

The system is considered to be accessible at the car-to-platform interface, based on an absence of reports to the contrary.

The California Public Utility Commission requires a 4 " minimum car-to-platform horizontal gap.

3.1.2 Older Rapid Rail Systems

The range of horizontal gaps and vertical steps that exist on the older Rapid Rail systems is greater than the range on the three newer systems, as expected. However, data gathered by Deleuw Cather and Ralph Parsons Company[1] shows that some of the older systems achieve lower average gaps than do the newer systems.

Table 3-1 shows that over half of the older systems operate with less than 3½" average gap, based on the 321(a) study data. Curved platforms were disregarded, because the increased gap is geometrically unavoidable and including that data would not contribute to an understanding of the nature of a system's achieved performance at straight platforms.

In Table, 3-1 the transit systems (and some system individual lines) are ordered by value of four characteristics of the car-to-platform alignment. This table illustrates two basic properties of the car-to-platform alignment. The range of values (horizontal gap or vertical step) is indicative of maintenance standards and track-to-platform relative stability.

The vertical step existing on most of the older systems is greater than experienced on the new systems, which are designed to be nominally level or car high up to 1".

For three of the older systems, MBTA, NYCTA and SEPTA, the average gaps and steps are shown for individual lines. As Table 3-1 shows, there is considerable variation between or among lines of a given system. Historically, the lines of a system that is nominally homogeneous were often built at different periods, using different construction techniques, and possibly different target values for platform height and set-back.

Not all systems now operated by one authority are even nominally homogeneous, though. Non-homogeneity makes it advisable to evaluate systems on a line-by-line basis when assessing the car-to-platform alignmer It will then be found that there are some portions of systems on which the car-to-platform alignment compares favorably with that of the three newer systems. Conversely, other portions of certain systems will be correctly identified as having much poorer car-to-platform alignment than an overall average would indicate.

TABLE 3-1. RAPID RAIL SYSTEMS ORDERED FOR FOUR CHARACTERISTICS OF CAR TO PLATFORM ALIGNMENT (SECTION 321(a) STUDY DATA)

HORIZONTAL GAP		VERTICAL STEP		HORIZONTAL GAP		VERTICAL STEP	
System	Avg Gap (in.)	System	Avg Step (in.)	System	Gap Range	System	Step Range
IND[1] (NYCTA)	1.82	MARTA	0 Nom.	Broad St.	1.38	PATCO	2.5
BMT[1] (NYCTA)	2.08	PATCO	.49	PATCO	2.	IND	2.88
PATH	2.5	T-Blue	.92	PATH, Mkt-Ffd	2.5	Broad St.	3
IRT[1] (NYCTA)	2.82	WMATA	1 Nom.	T-Blue	3.25	GCRTA	4.13
Broad[2] (SEPTA)	2.98	T-Red	1.01	BMT	3.38	BMT	4.38
GCRTA	3.11	GCRTA	1.17	GCRTA	3.63	T-Blue, Mkt-Ffd.	4.75
PATCO	3.15	PATH	1.56	T-Red	3.81	T-Red	5.63
T-Blue[3]	3.31	IRT	1.74	IND	3.88	T-Orange	5.88
T-Orange[3]	3.4	Broad St.	1.89	IRT, CTA	5.75	PATH	6.13
MARTA, WMATA	3½ Nom.	BMT, T-Orange	2.48	T-Orange	6	CTA	6.5
T-Red[3]	3.66	CTA	2.86			IRT	7.38
CTA	3.77	IND	2.94				
Mkt-Ffd.[2] (SEPTA),	4.05	Mkt-Ffd.	4.60				

Notes:

1. NYCTA predecessor lines IND, BMT, IRT.
2. Philadelphia, Broad Street line and Market-Frankford line, SEPTA.
3. Boston MBTA (the "T") Red, Orange, and Blue lines.

The New York City transit system consists of two major divisions, the IRT and GMT/IND. Two dimensionally different sets of equipment are required for use on the IRT and on BMT/IND segments because the lines were built to use cars nominally 9' and 10' in width respectively. Platforms are set back nominally 4'11 3/4", and 4'5½", to give nominal horizontal gaps of 5 3/4" and 5½" respectively. Wood nosing strips on the platforms reduce the gaps by about 3½" to 2". This value agrees moderately well with the measured values, allowing for attrition of the wood because of occasional impacts.

The SEPTA rapid rail system in Philadelphia is two distinctly different lines. The Broad Street Line, built in 1928, is standard gauge, 4'8½". The Market St./Frankford St. Line, built in 1905 and extended in 1920 is 5'2½" gauge. The significantly higher vertical step on the latter system, Table 3-1, is reportedly due to the replacement of the original rail with heavier, and theretore higher rail. No adjustment was make to increase platform height or to lower the roadbed to achieve a more level entry.

In Chicago, the elevated system was completed between 1892 and 1900. Subway construction did not commence until the State Street Line was opened in 1943, followed by the opening of the Milwaukee-Dearborn-Congress route in 1951, the Eisenhower Expressway surface route in 1958, and the Dan Ryan and Kennedy Expressway routes in 1969 and 1970 respectively. Although constructed in several periods the Chicago system is built to one set of standards, and all cars can operate over the entire system. Because of the different construction periods, it would be appropriate to access the Chicago system in separate segments when evaluating the quality of the car-to-platform alignment. It was not possible to reduce the available 321(a) data on a segment by segment basis.

The most difficult problems to address in Chicago are the curved and the narrow platform stations on the elevated lines. As longer trains became necessary to handle increased traffic, platforms were extended on either or both ends, wherever space was available. The extensions are often on curves, and are often severely confined between the track and a building that existed before the extension was made. Because extensions were made on either end of the platforms and because some platforms have centrally located curves (i.e., s-shaped platforms) the full length of a train may interface with a curved platform portion at successive stops. At the more severely curved platform locations, superelevation of the track contributes vertical misalignment as well as accentuating the horizontal gap. One of the most extreme situations occurs at the Merchandise Mart Station, where a gap of about 18" is reported in the 321(a) data.

In Chicago, the CTA reports that track structures and platform structures vary in their stability and ease of re-alignment, which affects the degree of difficulty in achieving initial car-to-platform alignment and in holding the alignment initially achieved. There are four track structures in use in Chicago, each with its own characteristics of stability and adjustability:

Track Type	Stability	Adjustability
Elevated	poor	poor
Surface, Ballasted	poor	good
Subway, Ballasted	good	good
Subway, Concrete	excellent	poor

The stations in Chicago have similar characteristics:

Station Type	Stability	Adjustability
Steel/wood (elevated)	poor	fair
Steel/wood (surface)	good	fair
Concrete (surface)	good	poor
Concrete (subway)	excellent	poor

Not unexpectedly, the structures located in subways have good stability because they are well protected from the environment, primarily frost and temperature extremes. Surface structures are most affected by frost heaving, and elevated structures are very flexible in comparison with surface and subway construction. It can be seen that a trade-off between improved stability and improved adjustability is necessary.

The Boston rapid rail system was similarly built in several stages. The Orange Line is the oldest portion and has a consistently larger vertical step than the Blue Line in Table 3-1.

The Southern portion of the Orange Line is scheduled to be removed in the near future. The Blue Line achieves the best car-to-platform alignment on the MBTA system.

3.1.3 Light Rail Systems

Although light rail systems are usually step entry, there are three systems in the U.S. that use high platforms, and several others that have included high platform operation in expansions plans. San Francisco uses high platforms for level entry to the Boeing LRVs in the Market Street tunnel. The Norristown high speed line of SEPTA uses all high platforms, and the line operated by the Tandy Corporation of Dillard's Department Store in Fort Worth uses PCC cars converted to operate at high platforms.

The design gap for the San Francisco Muni system is four inches, necessitated by the high/low boarding arrangement. Because the doors must extend down to the bottom step, they necessarily pass in front of the vehicle level entry threshold, as shown in Figure 3-1A. At doorways intended for level entry only, the vehicle threshold is under the doors, Figure 3-1B, allowing it to extend to the maximum allowable lateral limit.

The Norristown Line cars of SEPTA are about 50 years old. The existing car-to-platform alignment would have to be considered excessive because large gaps occur.

The Dillard's Department Store light rail line in Fort Worth currently achieves a nominal 2" horizontal gap. The originally angled front entry has been modified to interface with high platforms with a parallel gap. The floor height is maintained very level with the platforms for empty cars, and is about 1" low with fully loaded cars, approximately 100 people.

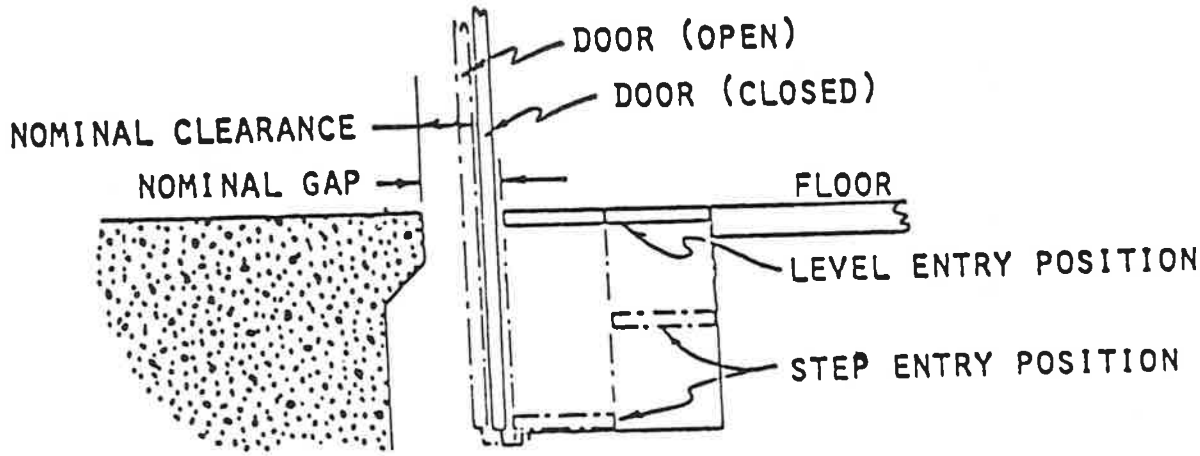


FIGURE 3-1A. HIGH/LOW ENTRY AT HIGH PLATFORM

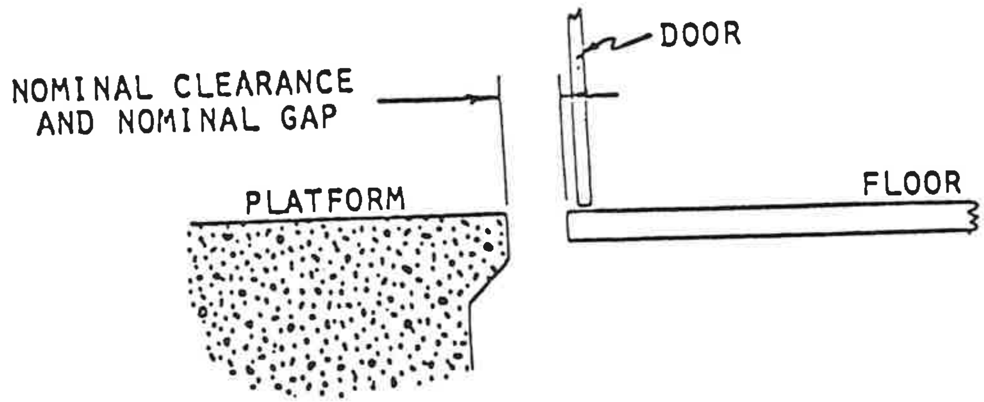


FIGURE 3-1B. CONVENTIONAL RAPID RAIL ENTRY AT HIGH PLATFORM

The line is now handicapped-accessible, as evidenced by having numerous patrons in wheelchairs, some of whom are regular users of the system. Platforms are either ramp-accessible, or elevator accessible, and because the system is free for all riders, there are no fare barriers. No securement devices or special areas are provided in the cars for wheelchairs. The wheelchair is secured for travel only by its own brakes. Because the system operates at low speed, no additional securement provisions are necessary. Bench seating along the sides of the cars is used, which makes the entire center aisle of the car available to wheelchair users. Wheelchair users board and exit through either door. There have been no known instances of wheelchairs having the front caster wheels turn 90° to drop into the 2" car-to-platform gap, one of the hypothesized hazards for other level entry systems as they become accessible to wheelchair users.

3.1.4 Commuter Rail Systems

Commuter rail systems operate with larger horizontal gaps at some stations than do rapid rail systems because station platforms must be kept outside of the clearances required for freight cars. The maximum width dimension allowed for freight cars that are not restricted in their movement is 10'8", and platforms must necessarily be placed further from the track centerline than 5'4" to maintain a positive clearance. The usual minimum dimension for passenger platforms is 5'6" from the centerline of the track.

Commuter cars are typically 10' maximum width over thresholds, and thus the nominal gap is 6". The variations about the mean at straight platforms are similar to those observed on rapid rail systems, about ± 2", because car and track tolerances are similar for both systems.

There are three door arrangements in use on the commuter cars now in service: end doors, center doors and quarter point doors. All door locations give rise to geometrically unavoidable gaps at either convex or concave platforms. End doors experience the maximum gap at convex platforms, and conversely, center doors experience the maximum gap at concave platforms. Quarterpoint doors have an unavoidably larger gap at both convex and concave platforms.

In addition to the horizontal gap increases experienced at curved platforms, superelevation of the outer rail of the curve can have an appreciable impact on the vertical alignment. At convex platforms, the car floor is usually low, and at concave platforms the car floor is usually high with respect to the platform. Figures 3-2 to 3-4 show cars that have the above-mentioned door locations.

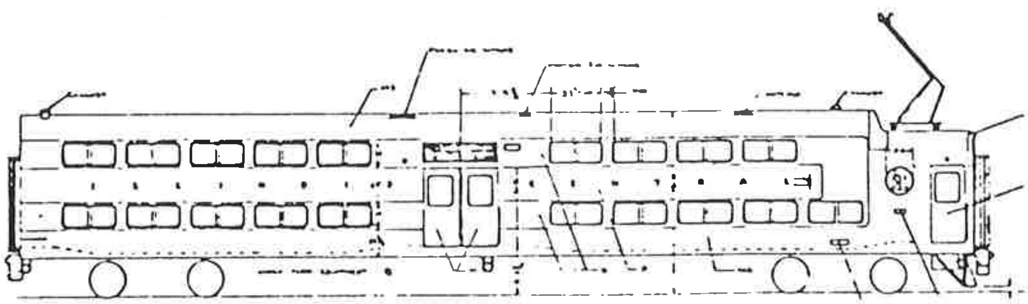


FIGURE 3-2. BILEVEL EMU COMMUTER CAR

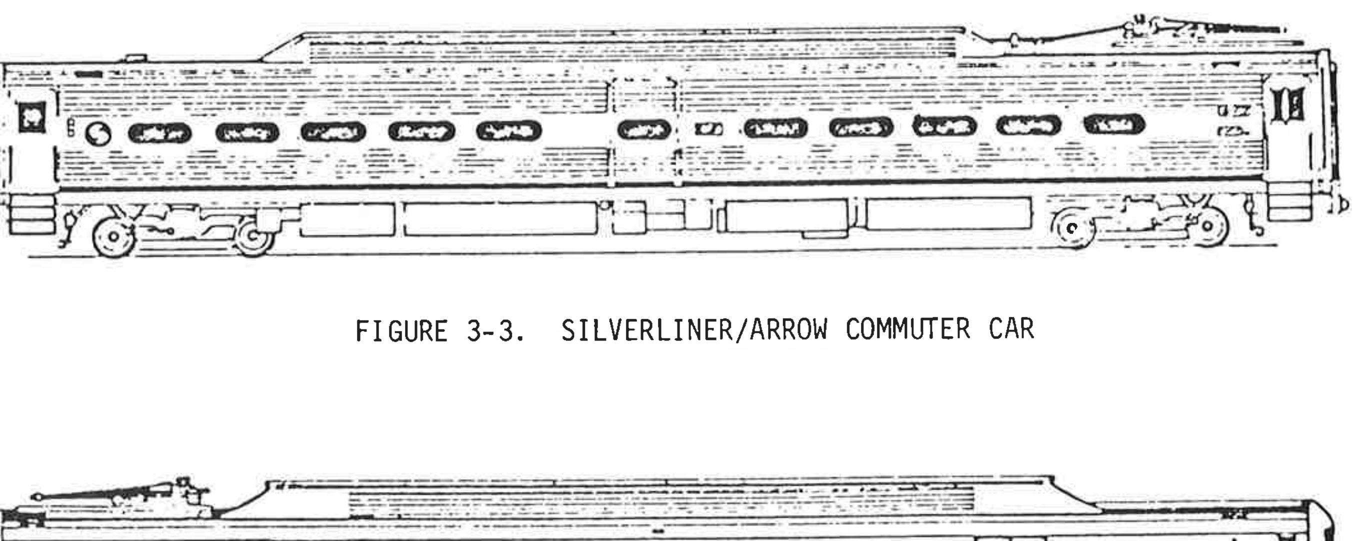


FIGURE 3-3. SILVERLINER/ARROW COMMUTER CAR

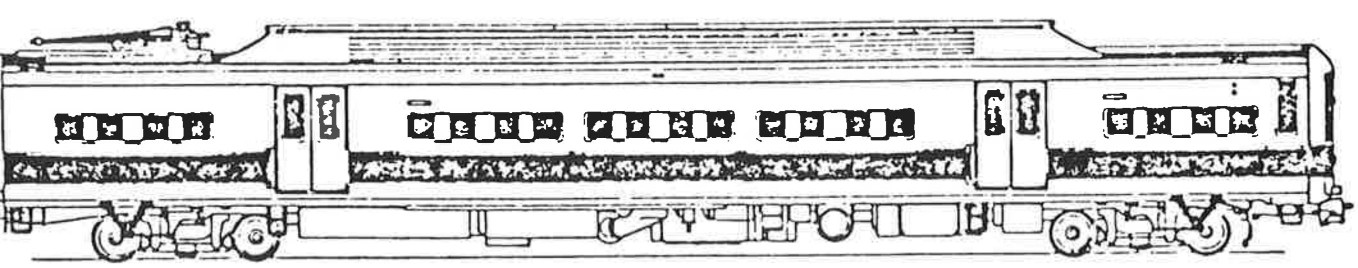


FIGURE 3-4. METROPOLITAN/COSMOPOLITAN COMMUTER CAR

In comparison with rapid rail systems, commuter rail systems typically operate with more train crew members, longer dwell times, and lower train frequencies. Each of these three factors favors the use of manually operated devices to reduce or eliminate gaps at platforms.

3.2 Gap Filler Installations

The reduction of the horizontal gap between rail cars and platforms has been addressed in several ways. Generically, the only options are to (1) extend the platform toward the car, (2) extend the car toward the platform, or (3) use arrangements that will tolerate the occasional impacts between car and platform which occur with small nominal gaps. Each of the three techniques has been used.

In the vertical plane little has been tried to reduce the gap between car and platform, although the necessary technology is available. There are only two approaches possible; (1) adjust the car height to the platform, or (2) adjust the platform to the car height. There is no corollary technique (3) above because a car cannot reasonably strike a platform in the vertical direction.

Vertical Gap Filling Devices

The most common method of vertical gap control, if not the only method, is height control of air bag suspension. Height control of the air bags is necessary to prevent over-or under-extension of the bags as the car experiences its maximum range of weight change. Because the other elements of the vehicle in series vertically with the air bags (wheels, axles, truck frame, bolster, chassis) are very stiff compared to the air bag, control of the air bag height effectively controls floor height above the rail. Long term height change, due primarily to wheel wear, is controlled by shimming at some point in the suspension system.

No other method of active vertical height control is known to be in use on cars or on platforms. Some operators prefer cars that have no air system on them at all, because of the favorable effect on maintenance time and cost. Purely mechanical equivalents of pneumatic height control could be proposed for cars with only mechanical springs. However, it is reasonable to assume that the application of such a system to existing cars would not be economically feasible.

The pneumatic self leveling now used does not seek to eliminate the vertical step between the car and platform, but rather seeks only to keep the car floor at a constant height above the rails. Thus the alignment achieved is only as good as the track-to-platform alignment.

Existing height control systems are closed loop control systems on the car, but open loop control systems with respect to platforms. To achieve still better vertical alignment, assuming mechanical tolerances are at the practical limits of maintenance, it would be necessary for a car-borne height control system to identify the actual platform vertical position, and adjust the car height to suit.

Horizontal Gap Filling Devices - Platform-to-Car

More varied solutions have been implemented for horizontal gap reduction or elimination. These, as outlined above, consist of three basic approaches. The first approach is to move the platform to the car after the train has come to a stop.

To reduce the car to platform gap to less than that possible with a passive interface, i.e., passive stations and passive door thresholds, devices are in use on transit system platforms which move to reduce the horizontal gap after the vehicle or train stops. In a few stations gap fillers are currently used to reduce the large gaps that occur unavoidably at curved platforms. However, there are no known use of gap closers on straight platforms.

The only platform-mounted gap filling devices on a rail transit system currently in use are on the New York City Transit Authority system at three stations with curved platforms: South Ferry Station, the 14th Street Station on the Lexington Avenue line, and the Times Square Station on the Times Square - Grand Central Shuttle. The three devices used are different. None of the gap fillers effect any change in the vertical discrepancies that may exist between car and platform. At all locations, the fillers are operated only with the vehicle doors closed.

The gap fillers at the Times Square Station are manually operated by a platform attendent. They have very little, if any, applicability to E&H accessibility because they are mounted several inches below the platform surface. They are primarily intended to prevent people from falling between a car and the platform at the center doorway. Passengers ordinarily do not step on the gap fillers as they enter or leave the car. The end doors of a car are closer to the platform, and no gap fillers are provided at those locations.

The gap fillers at the other two sites are only marginal to improve accessibility. At these sites, grate-type gap fillers are constructed of a set of intermeshed bars about ½" in width. Alternate bars are fixed to the platform, or attached to the movable portion of the gap closer, to provide an extendable surface. When the gap filler is extended both the fixed and movable portions have a series of ½" gaps between the bars, and a solid surface only where the two sets of bars intermesh. This concept is illustrated in Figure 3-5.

The most extreme situation is at the South Ferry Station, located on a 191 ft. radius curve, where gap fillers are installed to interface with all three doors of each car of five cars the platform can accept. (Longer trains extend past the last platform position and cannot discharge passengers. Prior to entering the station, South Ferry passengers are advised to move to the front five cars). As the South Ferry station is a loop terminus, only one platform is used, located on the outside of the loop. The short radius causes significant gaps even at the end doors. Figure 3-6 illustrates this problem.

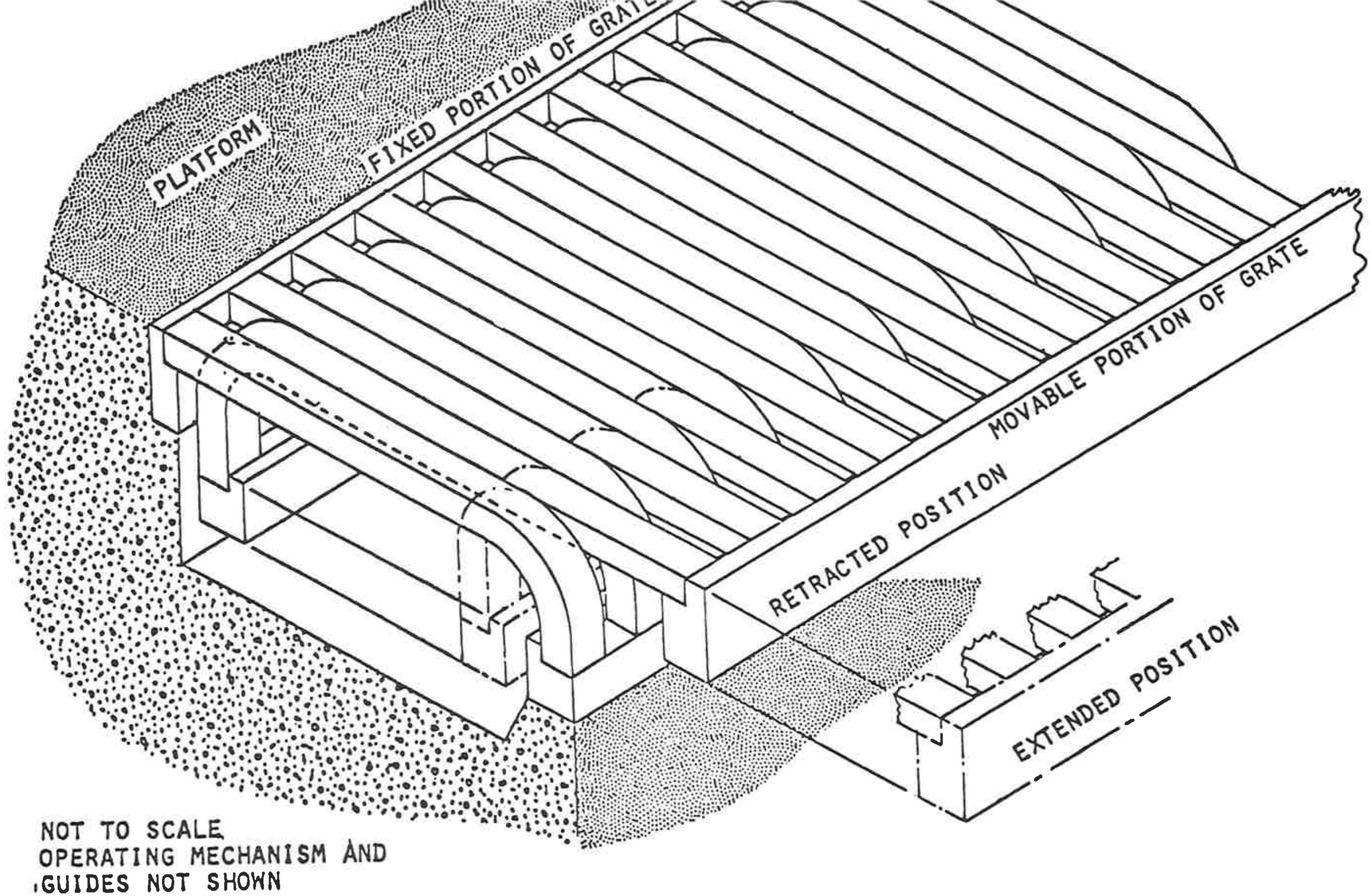


FIGURE 3-5. NEW YORK CITY TRANSIT AUTHORITY GRATE TYPE GAP FILLER

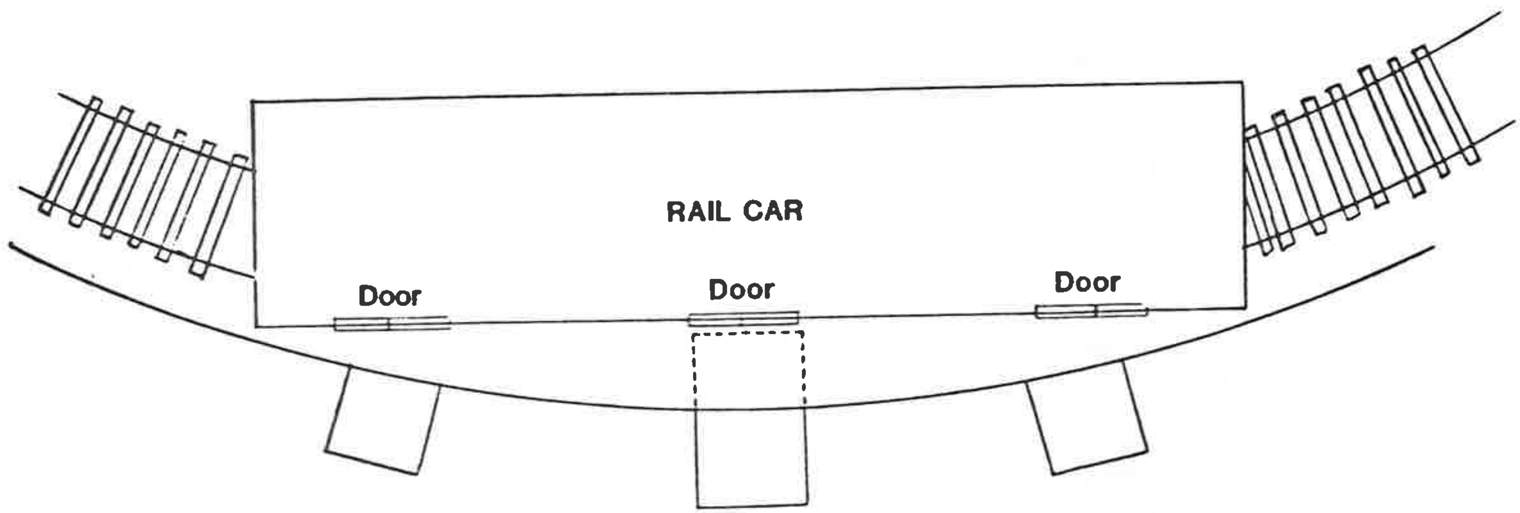


FIGURE 3-6. ARRANGEMENT OF GAP FILLERS AT SOUTH FERRY STATION

The 14th St. Station is located on a less severe curve than the South Ferry Station, but trains use both the concave and convex sides of the platforms. Gap fillers are used only for the end doors of cars on the convex side of the platform, and for the center door of each car on the concave platform locations respectively are judged to be close enough to the platforms for ambulatory patrons.

The gap fillers at South Ferry and 14th St. are automatically deployed when the train is positioned correctly, as determined by the lead 3rd rail shoe contacting a special portion of 3rd rail. Gap fillers are extended only if cars are present at gap filler locations. The conductor opens the doors when a signal on the wayside indicates that the gap fillers have deployed. On departure, the doors are closed, and the train moves slowly forward until the lead 3rd rail shoe contacts a portion of the 3rd rail which causes the gap fillers to retract. When a signal indicates that the gap fillers are retracted, the train may accelerate to normal speed for departure. While the train is moving slowly forward, it may contact a gap filler and begin to physically push it toward the retracted position. The presence of gap fillers adds approximately 15 to 20 seconds to a station stop on the MTA for three reasons:

- Slower approach to the stopping position is necessary,
- The doors are not opened until gap fillers extend, and
- Slower departure is necessary until gap fillers retract.

The automatic gap filler operation can be overridden by platform attendants if manual actuation is necessary.

Horizontal Gap Filling Methods - Car-to-Platform

At present, there are no car-mounted gap fillers analagous to the platform-mounted devices. However, it is convenient here to interpret the car-to-platform direction of motion rather broadly, thereby allowing the inclusion of a description of gauntlet tracks.

A somewhat different approach to horizontal gap reduction has been used on commuter rail lines, with level-entry, on which freight traffic must also be accomodated. To maintain the greatest possible clearance for freight, the main track is positioned farther from platforms than is suitable for passenger operations.

To bring the passenger cars sufficiently close to the platform, an arrangement known as a gauntlet track is used. As Figure 3-7 shows, one form of gauntlet track is comprised of two pairs of switch points, without the frogs normally associated with switches. The first pair of points divert a train to a parallel set of rails, one of which remains between the main rails, and the second set merges the two routes again. Alternatively, the gauntlet track may be used to move wide traffic away from a platform instead of moving the passenger equipment toward the platform. (The gauntlet track is usually considered to be the one displaced from the tangent route.)

Since normal car-to-platform horizontal clearances must be maintained, this approach may not be useful for gap reduction goals on light rail and rapid rail systems, but it could contribute to improvement on commuter rail systems. However, at best this device can only bring commuter rail systems in line with the present state-of-the-art as exemplified by present rapid rail gap magnitudes. Further, this type of device introduces additional complexities associated with control of the switches. At a minimum, it would require a method for the railcar operator to signal his needs regarding switch position, either to a tower operator or an automated system to actuate and monitor the switch operations, and fail safe protection in the event of any mode of failure.

Horizontal Gap Filling Methods - Passive

Extending the platform toward the car, or the car toward the platform requires operating equipment, which in turn implies that capital, operating, and maintenance costs will be incurred for the equipment. Reduction in the three cost areas can be achieved if passive gap filling devices are used. Devices in this category include expendable or deformable devices, and deflectable devices. Ordinarily, car-to-platform contact would not be expected, but car threshold or platform edges can be extended with material which will yield if contact occurs, before more severe damage is caused to the car or platform.

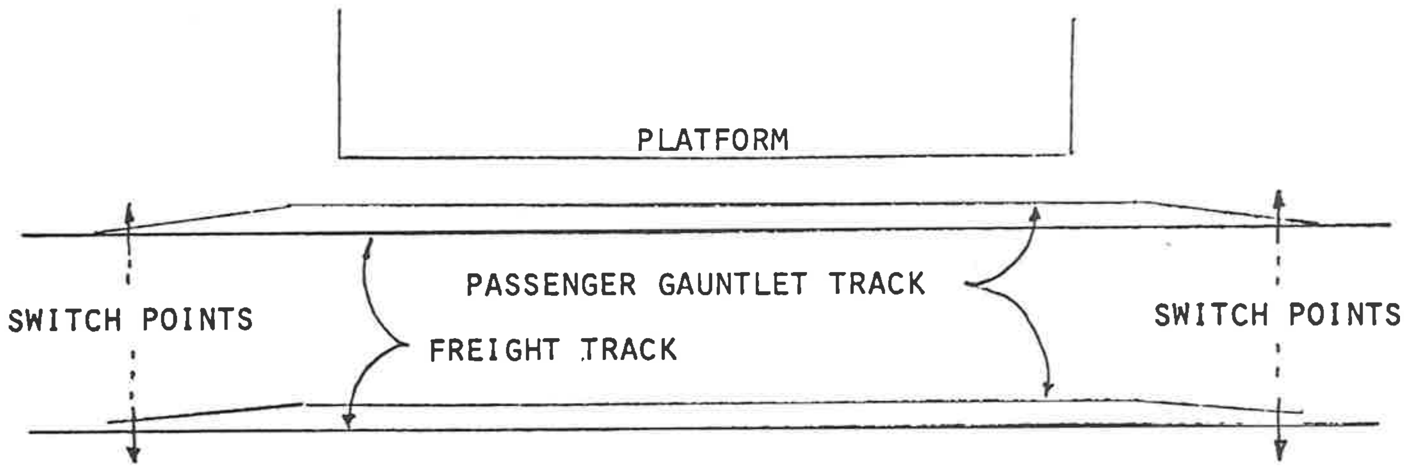


FIGURE 3-7. GAUNTLET TRACK ARRANGEMENT

An aluminum extension is used on the thresholds of the MARTA cars to reduce the gap from a nominal 5" to a nominal 3½". Although no contact has occurred, the aluminum extension would crush before the platform or other parts of the car were damaged. Wood has been used in other systems to extend either platform edges, or car thresholds.

It is important that an expendable material not create flying fragments if a car impacts a platform, because of the obvious hazard to passengers on the platform. Thus, the required material property of an expendable gap reducer includes a propensity toward failure by deformatio rather than by fracture.

The capital costs of expendable gap fillers are clearly very much less than any currently known movable types. There is no operating cost, and maintenance cost is potentially zero or very little, depending on the tolerances achieved on station and car alignment. The most significant improvement that can be made in expendable devices is the substitution of elastically deformable devices for plastically deformable ones.

Ford ACT Gap Fillers

Outside of the rail transit field, the Ford ACT system located outside Detroit uses an elastically deformable form of gap filling device. Rubber finger-like extensions on the platform are sufficiently flexible to be deflected if the vehicle strikes them, but they are sufficiently stiff vertically to support the weight of a person. Figure 3-8 illustrates these devices.

The maximum speed of the system is 22 mph, and the vehicle approach to the docking position is much slower than that. Hence, the gap fillers are not frequently struck. Greater wear and damage could be expected if this type of gap filler were used on a rail system, but the wear might be within acceptable limits with the right choice of materials. This concept is potentially usable on light rail and rapid rail systems, subject to adequate development and testing.

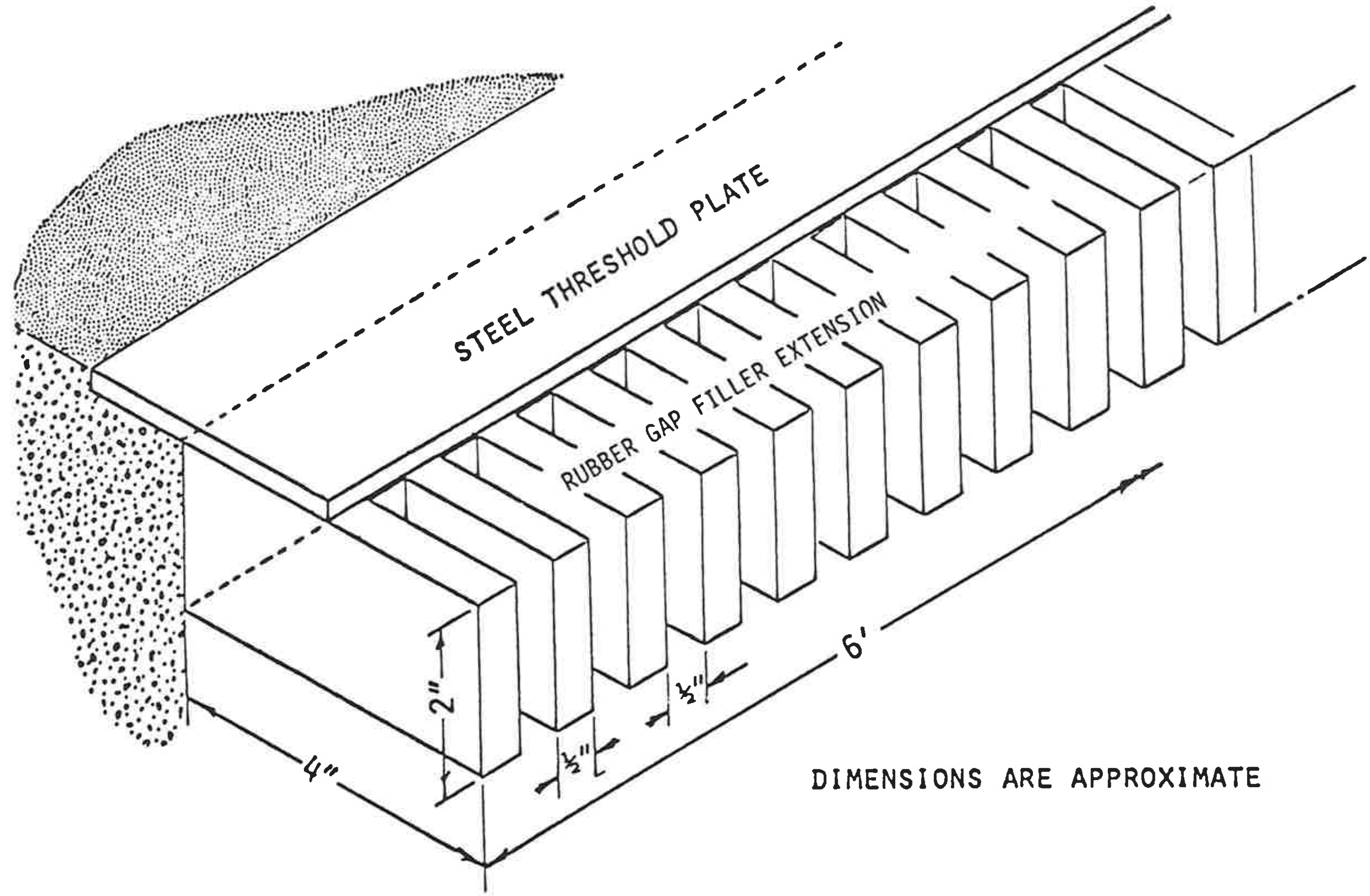


FIGURE 3-8. PASSIVE GAP FILLING DEVICE: FORD ACT SYSTEM AT FAIRLANE SHOPPING CENTER

4.0 GAP FILLER REQUIREMENTS

A project was conducted by the Veterans' Administration in an attempt to obtain accurate data regarding the abilities of persons in wheelchairs to cross gaps safely and independently. This study was sponsored by the Urban Mass Transportation Administration and was directed by the Transportation Systems Center in cooperation with the VA Rehabilitation Engineering Center (VAREC) in New York City. The study delineates the parameters by which acceptable horizontal and vertical gap standards might be established.

The functional requirements for gap fillers depend to a large extent on the allowable maximum limits for horizontal and vertical gaps at transit car doors. A standard of very close limits requires movable devices on the car or platform. Broader limits, on the other hand, allow for passive solutions, such as one-time adjustment of out-of-limit systems followed by improved maintenance.

The following sections describe the VAREC study in detail and discuss the effect gap standards might have on the implementation of corrective action.

4.1 Functional Requirements

Purpose

The purpose of the VAREC investigation was to gather data on:

(a) The acceptable range of maximum gaps (various horizontal and vertical spacings in combination) which can be safely crossed by individuals in manually propelled or powered wheelchairs.

(b) Suitable techniques for safely and independently crossing such gaps in a wheelchair.

(c) The abilities of persons in wheelchairs with different disabilities safely and independently to cross the gaps.

(d) The effects crossing these gaps repeatedly may have on the structural integrity (durability and life expectancy) of wheelchairs.

Procedure

Equipment. Achieving the objectives outlined above required test equipment for laboratory simulation of horizontal and vertical gap dimensions between station platforms and a vehicle door threshold. A Portable Gap Simulator was developed for possible data collection at several local VA Medical Centers. It permitted a reasonable range of gap and vertical height adjustment.

Since nearly all test subjects preferred to use their personal wheelchairs during the experiments with the Gap Simulator, there were no specific requirements on type, size or style of wheelchair. It was felt that the use of personal wheelchairs on the Gap Simulator increases the validity of the test results by controlling possible training or learning variables.

Testing wheelchairs for durability and life expectancy was done by use of a Test Carousel. The wheelchairs were to be driven 3600 times over a test course including a gap having maximum horizontal and vertical dimensions as previously established by experimentation on the Gap Simulator. Frequent measurements of changes in the drive wheels (wheel rim lateral distortion or runout, wheel concentricity, bearing wear, spoke changes) were to be taken to assess the degradation of the wheels as the test program progresses. Damage observed in other parts of the wheelchair were also recorded. Measurements of changes in drive wheels were made after 50, 100, 200, 400, 800, 1600, and 3600 test cycles. The test was halted if substantial damage to the wheelchair became evident.

Safety. Appropriate measures to insure the safety of test subjects and laboratory personnel were in use throughout the project. The safety system consisted of an optional restraining belt at abdominal height to keep an individual in the wheelchair. In addition, two trained experimenters were always close by whenever subjects passed over the gaps.

Subjects. Test subjects were wheelchair-bound volunteers, who agreed to participate in these laboratory experiments. Veterans from within the VA system (hospitals, clinics, etc.) as well as other organizations

(Paralyzed Veterans of America, etc.) were asked to participate.

Wheelchair mobility and user technique to cross a variety of simulated rapid rail platform-vehicle floor misalignments, or so-called "gaps" was demonstrated by the performance of twenty-six (26) arbitrarily selecte wheelchair-bound test subjects. The population tested was subdivided into two test groups: 1) eleven test subjects were examined at the VA Rehabilitation Engineering Center, New York, and 2) fifteen test subjects examined at the VA Medical Center, New York. The first group tested at VAREC were all members of the Eastern Paralyzed Veterans Association (EPVA), who graciously consented to participate in the joint DOT/VAREC study. These were all totally self-sufficient active individuals, who generally had little difficulty in completing the exercises on the gap-simulator. The second group tested were in-patients at the VA Medical Center, New York, who obviously were less experienced in the use and control of their wheelchairs.

<u>Laboratory Test</u>. A portable gap-simulator apparatus built at the VA Rehabilitation Engineering Center, New York, was used in trials with twenty-six test subjects. The gap-simulator (shown in Figure 4-1) has two platforms, one representing the station platform, the other the rail vehicle floor. These two platforms can be separated horizontally from 2" to 5", and offset vertically from 1" to 4" to simulate a variety of gap combinations. The test conditions established for the study are shown in Table 4-1.

Nearly all wheelchair users seemed to prefer travelling forward when moving from a lower to a higher platform, simulating entering through the doorway of a rail vehicle. The method of testing for each combination of horizontal and vertical adjustment of the gap-simulator was as follows:

(1) Position the wheelchair on the lower platform so it is close to the gap edge of the higher platform, considering the possibility of the interference of both footrest extensions.

(2) Perform a "wheelie" (accelerating the chain so that the front casters are momentarily off the ground) just big enough to lift both caster

wheels over the higher platform edge. This is a maneuver in which an impulse to the drive wheels is transferred through the wheelchair frame and results in a slight raising of the caster wheels. Some skill in wheelchair use is required, since both the wheelchair and its occupant are momentarily unstable.

(3) Advance drive wheels to edge of higher platform, and raise wheelchair fully onto platform.

(4) Descending from higher platform by travelling backward, i.e., drive wheels first. Caution must be exercised not to entrap caster wheels in gap during descending maneuver.

Figure 4-2 shows a diagram of the wheelchair maneuver required to cross gap in the forward direction.

Test Results. All 26 test subjects preferred to use their personal wheelchairs during experiments with the gap-simulator. The study was limited to users of manual wheelchairs, since powered wheelchairs cannot operate safely under the test conditions shown in Table 4-1. Powered wheelchairs intended for gap crossing would need a specially designed curb-climbing device, suitable for independent control by the wheelchair occupant. In Table 4-2, a summary of test results is presented. Specifically, the following should be noted:

(1) The first group of eleven test subjects are active and highly experienced wheelchair users. Their observed skill level ranges from medium to high. On the basis of their performance, most of these individuals would have little or no difficulty in crossing reasonable gaps in rapid rail transit. A curious event was the failure of 2 of these subjects to negotiate horizontal and vertical gaps of 2" and 4" and 4" and 4" respectively, although they were able to handle both smaller and larger gaps. We attribute this phenomenon to fatigue or maneuvering aberrations.

(2) All eleven test subjects prefer pneumatic wheels for greater personal comfort and ease of operation of the wheelchair.

TABLE 4-1. TEST CONDITIONS

GAP DESIGNATION	HORIZONTAL (X INCHES)	VERTICAL (Y INCHE
A	2.0	1.0
B	3.0	1.0
C	4.0	1.0
D	5.0	1.0
E	2.0	2.0
F	3.0	2.0
G	4.0	2.0
H	5.0	2.0
I	2.0	3.0
J	3.0	3.0
K	4.0	3.0
L	5.0	3.0
M	2.0	4.0
N	3.0	4.0
O	4.0	4.0
P	5.0	4.0

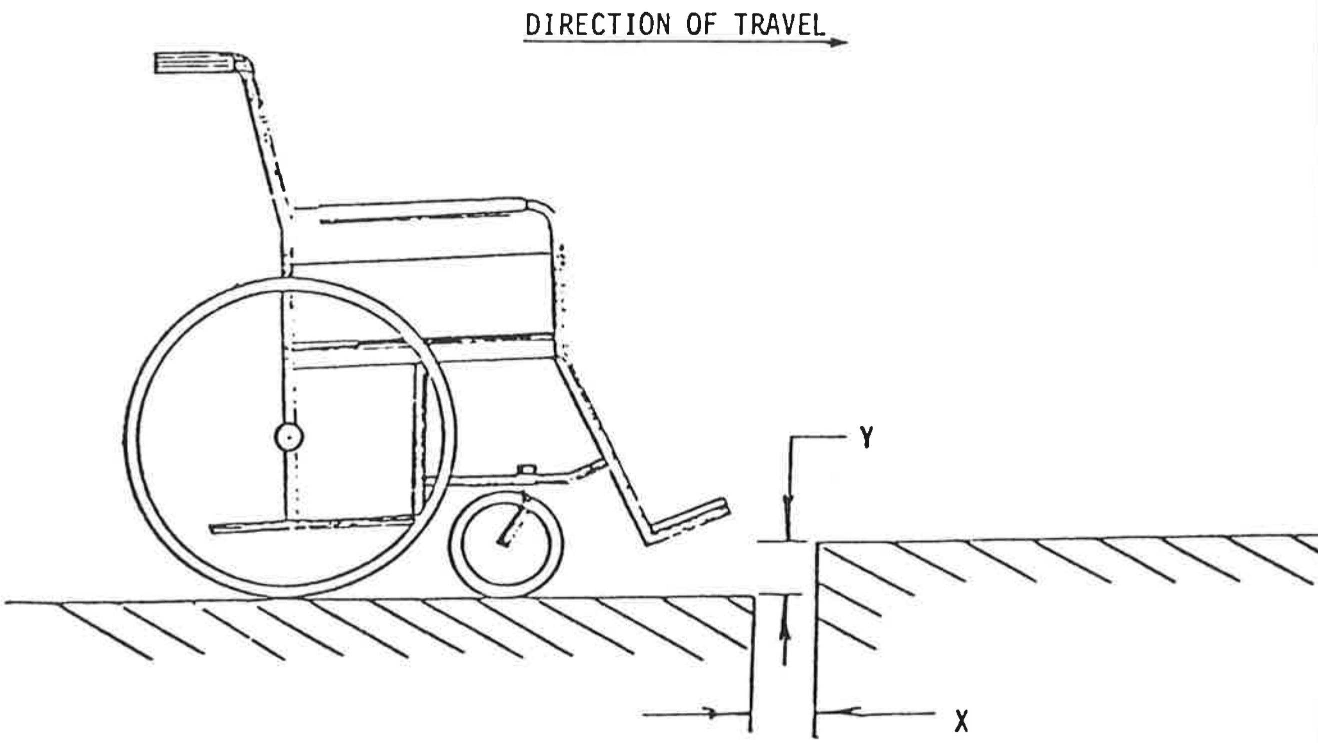


FIGURE 4-1. VAREC GAP SIMULATOR

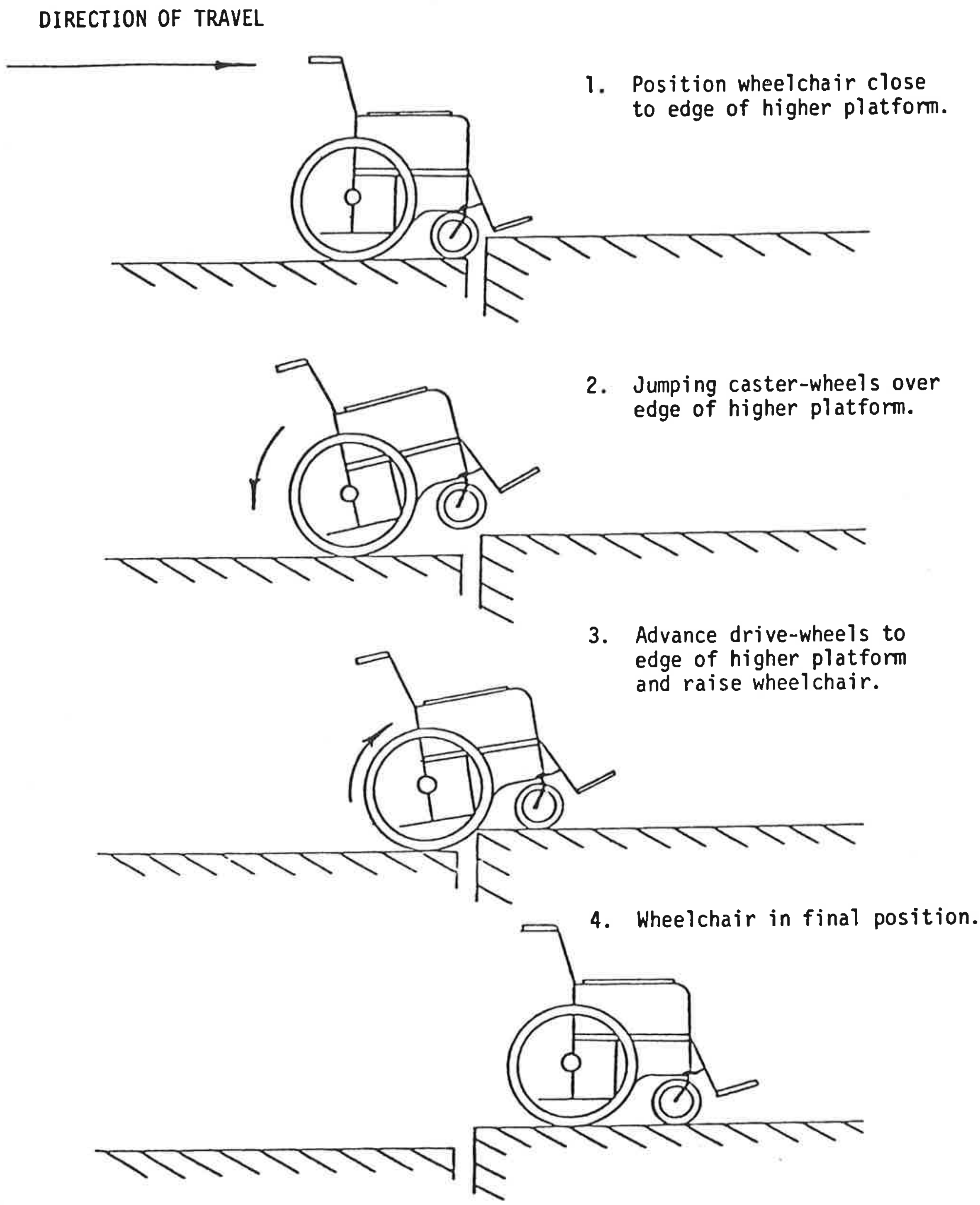


FIGURE 4-2. WHEELCHAIR MANEUVER TO CROSS GAP

TABLE 4-2. SUMMARY OF TEST RESULTS

SUBJ NO	AGE	SEX	DISABILITY	WHEELCHAIR DESCRIPTION	WT. (LBS)	OCCUPANT & W/C WT.	GAPS WHICH COULD NOT BE CROSSED FORWARDS	GAPS WHICH COULD NOT BE CROSSED BACKWARDS	OBSERVED SKILL LEVEL
1	48	M	Para. T-12	E&J, Pneu. Tires	42	252			High
2	28	M	Dbl. A/K Amp.	SS, Pneu. Tires	42	269			High
3	31	M	Quad. C-7	SS, Pneu. Tires	42	213			Medium
4	32	M	Para. T-10	SS, Pneu. Tires	42	223			High
5	62	M	Polio	E&J, Pneu. Tires	48	243			Medium
6	35	M	Quad. C-6	E&J, Pneu. Tires	34	215	I-P	I-P	Medium
7	32	M	Para. T-1	E&J, Pneu. Tires	50	209			High
8	34	M	Para. T-10	SS, Pneu. Tires	45	209			High
9	47	M	MS, T-10	SS, Pneu. Tires	38	178			High
10	35	M	Para. T-10	SS, Pneu. Tires	42	175			High
11	40	M	Para. T-6	E&J, Pneu. Tires	35	225			High
12	61	M	Rt. leg B/K Amp.	E&J, Solid Tires	52	242	C-P	C-P	Low
13	30	M	Recent SCI	E&J, Solid Tires	52	186	D-P	D-P	Low
14	23	M	Recent SCI	E&J, Solid Tires	52	291	B-P	B-P	Low
15	80	M	Hemiplegic	E&J, Solid Tires	52	197	A-P	A-P	Low
16	43	M	Hemiplegic	Mobilaid, Solid Tires	51	312	A-P	A-P	Low
17	89	M	Dbl. B/K Amp.	Rolls, Solid Tires	54	234	A-P	A-P	Low
18	64	M	Dbl. B/K Amp.	E&J, Solid Tires	52	200	C-P	C-P	Low
19	59	M	Recent SCI	E&J, Solid Tires	52	253	A-P	A-P	Low
20	63	M	Hemiplegic	Mobilaid, Solid Tires	51	190	A-P	A-P	Low
21	52	M	Recent SCI	E&J, Solid Tires	52	182	D-P	D-P	Low
22	55	M	Hemiplegic	Mobilaid, Solid Tires	51	218	A-P	A-P	Low
23	50	M	Hemiplegic	E&J, Solid Tires	52	188	B-P	B-P	Low
24	72	M	Hemiplegic	Mobilaid, Solid Tires	51	170	B-P	B-P	Low
25	39	M	Recent SCI	E&J, Solid Tires	52	197	C-P	C-P	Low
26	77	M	Hemiplegic	Mobilaid, Solid Tires	51	215	A-P	A-P	Low

DISABILITY ABBREVIATIONS USED

T = Thoracic Spinal Cord Injury

C = Cervical Spinal Cord Injury

number following indicates vertabrae, e.g., T-12 indicates injury at the 12th thoracic vertabrae

SCI = having sustained some degree of spinal cord injury

MS = Multiple Sclerosis

A/K = Amputation above knee

B/K = Amputation below knee

WHEELCHAIR MANUFACTURERS

E&J = Everest and Jennings

SS = Stainless Specialties

Mobilaid

Rolls

GAP DESIGNATIONS

see Table 1

(3) The second group of fifteen test subjects uniformly lacked skill and technique in the use of a wheelchair. These individuals had all been confined to wheelchairs within the past 6 - 12 months, and had no real experience in the operation of a wheelchair outside the hospital environment, Accordingly, their observed skill level was uniformly low. It would not appear likely that any test subject from this group could use a rapid rail transit system independently.

The impact on the service life of conventional wheelchairs used in gap crossing is difficult to predict. However, a general degradation of mechanical components and hardware, e.g., bearings, spokes, wheel rims, axles, etc. usually occurs with atypical use of a wheelchair. The repeated impact between wheelchair and platform or vehicle floor level during gap crossing could easily result in some damage over a period of time. For example, as shown in Fig. 4-3, severe distortion of wheel rims to the point where the wheelchair is no longer operational. The damage occured gradually over a period of 3600 test cycles. The wheelchair including a 150 lb. anthropometric dummy descended from a curb height of approximately 6", drive wheels going first. This descent maneuver is nearly identical to the work done on the gap-simulator.

Conclusions and Recommendations. The conclusions drawn from this study are based on data collected, and our general observations of twenty-six wheelchair-bound test subjects using the gap-simulator. It appears that poor technique in wheelchair use directly relates to the low level of achievement of the fifteen individuals tested at VAMC, New York. The type or severity of disability of these wheelchair users alone does not seem significant. They all performed poorly, regardless of their level of disability.

On the other hand, the highly experienced group of eleven wheelchair users tested at the VA Rehabilitation Engineering Center, New York had nearly full control of the wheelchairs throughout the test. The following recommendations are offered:

(1) The need of a training program to teach wheelchair-bound individuals special techniques in gap crossing, etc.,

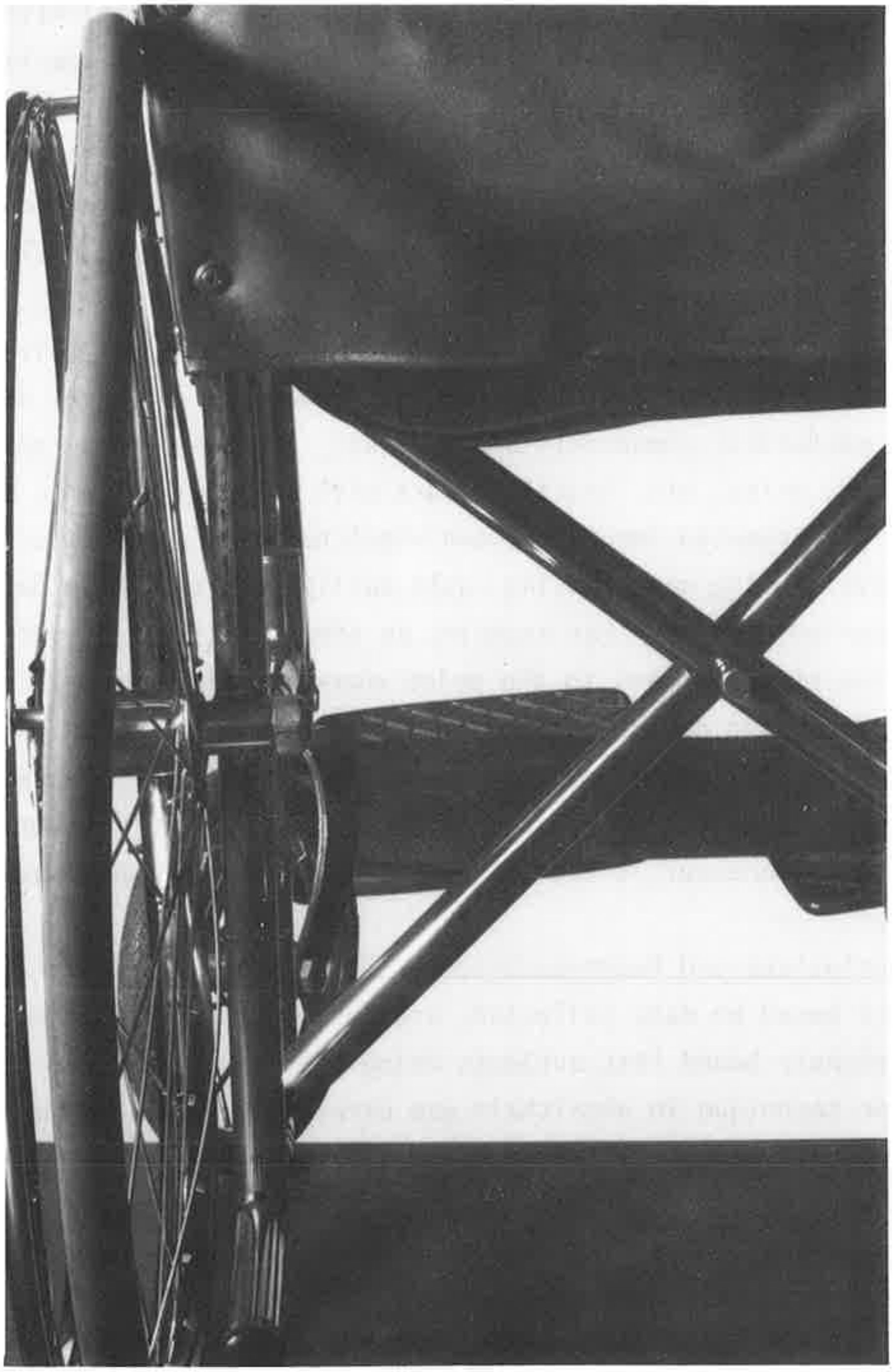


FIGURE 4-3. DAMAGE TO W/C AFTER 3600 TEST CYCLES

would be essential in making rapid rail transit accessible to the handicapped. Rehabilitation centers would provide the special training needed by some otherwise self-sufficient wheelchair users.

(2) There is a need for more research and development of special wheelchairs for greater mobility by the handicapped. Designers engaged in wheel chair development should be aware of "gap" crossing requirements. As new designs are developed "gap-crossing" features can be made in intergral to the design. An example of on-going R&D is the University of Virginia "Grasshopper" experimental wheelchair shown in Figure 4-4.

(3) Special attention should be given to currently available "add-on" curb-climbing devices for both manual and powered wheelchairs. Gap crossing with powered wheelchairs will require dependable and easily operated special devices such as shown in Figures 4-5 through 4-8. These devices present the current "state-of-the-art" of curb-climbing devices, some of which might be useful to overcome obstacles found in rapid transit.

4.2 Parameters for Implementation

The functional requirements for achieving gap and step reductions, differ between rail system types even though they, depend on the maximum acceptable limits eventually established for horizontal and vertical gaps. Commuter rail and rapid rail have somewhat different requirements because of the nature of operation and the size of discrepancies encountered. The requirements are listed for each system type in increasing order of development required, or equivalently, in increasing order of complexity or difficulty of implementation.

Rapid Rail

The first requirement is to address the vertical step problem, be-

FIGURE 4-4. UV "GRASSHOPPER" EXPERIMENTAL WHEELCHAIR

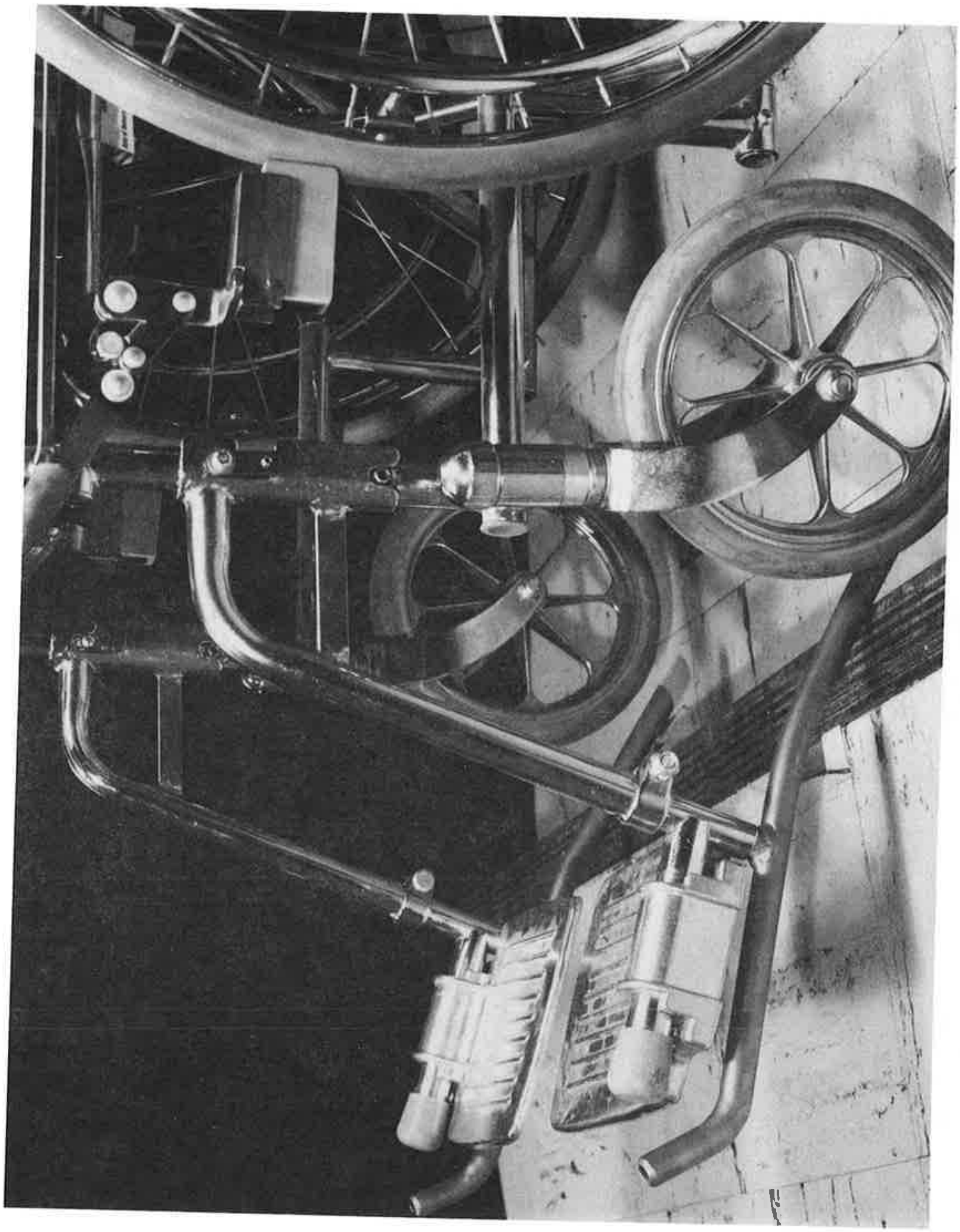


FIGURE 4-5. F. DEUTSCH CURB-CLIMBING DEVICE

FIGURE 4-6. LOCKE CURB-CLIMBING DEVICE

FIGURE 4-7. AZTEC, DROPBACK DOLLY CURB-CLIMBING DEVICE

FIGURE 4-8. VESSA POWER CHAIR AND CURB-CLIMBING DEVICE

cause success of an accessibility improvement program depends on reducing vertical steps to manageable limits.

Vertical Step Reduction

1. Reduce the vertical step on rapid rail systems to a nominally zero difference condition.
2. Provide a method of keeping the car height vertical variations with load within the limits mandated by acceptable gap dimensions.

The static deflection of a mechanically sprung car is on the order of 3" from tare (AW0) to crush (AW2); hence the minimum step is ± 1½" without allowance for other variations. The only demonstrated method of vertical height control on cars is pneumatic suspension, which can reduce the step to ± ½", plus other allowances.

Although provision of air for height control is an attractive solution:

- It is of questionable practicality to retrofit the trucks of cars that do not have pneumatic suspensions.
- Many cars do not have compressed air.
- It was considered a product - improvement (because of the maintenance reduction) when the PCC all-electric car superseded the version with an air compressor.

Various existing recommendations for gap and step limits, analysis, observations, and discussions with people knowledgeable in the handicapped area support the conclusion that the vertical step is the more difficult impediment for a handicapped person in a wheelchair to negotiate. This is unfortunate, because the vertical step is the more difficult of the two components to adjust at the track, platform, or on the car. There are no known vertical step reducers, and there are many cars without pneumatic height control.

Passive Gap Reduction

1. Investigate the possible trip impediments and procedural controls required for each system if only the tangent portions of platforms permit access to the cars.

2. Develop flexible gap fillers which will tolerate some amount of impact. Either station mounting or car mounting would be acceptable. The device used on the Ford system is relatively suitable.
3. Utilize semi-permanent gap fillers, such as the aluminum threshold extensions applied by MARTA.

Active Gap Reduction

1. Investigate new approaches that circumvent door-by-door gap fillers, such as lateral car displacement on the trucks.
2. Develop station-mounted or car-mounted gap closers if other solutions appear unworkable.

Active gap fillers could be developed for either cars or platforms. Car mounted devices would minimize the time penalty associated with precision stopping for platform mounted devices such as those now used in New York. However, the number of units required would be significantly greater than with platform mounted gap fillers, because there are many more car doors than platform door positions on all systems.

It appears desirable to locate active gap filling devices entirely outside of the doorway, so that they can be operated before people can begin to cross them. If they are inside the car, and project through the doorway, they must be able to hold and transport all the people who can fit onto the device. However, the major operational problem is that a potential crushing situation could be established between the gap filler and the platform, or worse, a shearing situation of the gap filler projects over the platform to form a ramp. Gap fillers of this type are probably suitable only if gap filler operation is on demand and supervised by a transit employee.

It is possible that some active gap fillers could fail in a manner that prevents a train from departing a station, or alternatively prevents a train from entering a station. New York reports that an incoming train will on occasion strike an incompletely retracted gap filler, usually damaging the gap filler and possibly the train. These occurrences have been implicated in derailments. It follows that in a large-scale deployment of gap fillers, reliable and complete retraction is of utmost importance to insure safe train operation.

The horizontal gap may be controllable by more frequent maintenance, to bring older systems within the limits gap tolerance of the newer systems. If gap fillers are deemed necessary, there is some body of information with which to begin development.

The curved platform gap should be considered separately, and should not be the driving consideration to develop active gap closers for use at all doorways. A limited number of gap closers at curved platforms will present a project of an entirely different order of magnitude for maintenance than will extensive installation of gap closers at all locations. If the tangent car-to-platform alignment is acceptable, it may be possible to achieve system E&H accessibility without providing full platform accessibility.

Commuter Rail

Commuter rail and rapid rail have similar problems in the vertical direction:

- nominally non-level alignment
- many cars without pneumatic suspension.

However, the nature of commuter rail operations may make solutions acceptable that would not be suitable for rapid rail. In the horizontal direction, some commuter rail systems experience larger gaps than rapid rail, primarily because of the necessity to provide for freight car clearances.

However, the use of a mini-platform and manually placed bridgeplate will circumvent the need for other mechanical gap and step reduction measures. In using a mini-platform/bridgeplate solution, it is likely that a train crew member may have to assist wheel-chaired passengers if the vertical grade is in the 5 - 10% range.

5.0 ELEMENTS OF GAP FILLER DESIGN

There are two generic solutions to the problem of gap reduction: passive gap fillers, and active horizontal or active horizontal-plus-vertical gap fillers. Each of these types possesses unique characteristics in operational terms, and these characteristics are necessarily reflected in the determination of design requirements. In the following sections, each solution will be considered as a design problem, and the constraints and limitations for each will be discussed. Finally, the concept of a manually operated bridgeplate will be evaluated as an alternative to the purely technological solutions.

5.1 Passive Gap Fillers

At present, no devices are known which would serve as useful prototypes for rapid rail passive gap fillers. Previous mention has been made of two deployed devices - the aluminum extension on MARTA cars and the rubber platform extension on the Ford ACT system. However, the MARTA device does not eliminate the gap, and the Ford ACT device is satisfactory only in a low speed application with a minimal range of lateral motion.

Although there are no useful prototypes in service, there is apparently no lack of useful materials. Such materials can be found in use as truck dock bumpers and marine bumpers. In all cases the inadequacy of the system is only a matter of design, and there should be no difficulty arranging for the manufacture of a properly designed system.

Functional Requirements

Stiffness. A passive gap filler must be laterally compressible with a sufficient range and a low enough spring rate to minimize interference with railcar operation. At the same time it must be stiff enough vertically to support pedestrian traffic without excessive deformation. A detailed discussion of gap filler stiffness is included in Appendix B.

Surfaces. The top horizontal surface must be of suitable quality for ambulatory and handicapped traffic. Considerations for the top surface include texture, frequency of discontinuities, and the surface hardness. Although it is not necessary to maintain an ideal surface in the deflected position, distortions and buckling should be minimized and restricted to the region nearest the edge.

The vertical surface which contacts the railcar must be suitable for sliding against the car surface. The requirement is for minimal effect on the railcar, adequate wear properties, and environmentally acceptable wear products. If a hard vertical surface is used over an elastic material, such as a steel plate on rubber, the composite should be designed so the hard surface cannot yield and form a permanent kink.

The coefficient of friction of the sliding edge is important because of the resulting longitudinal frictional forces transmitted to the platform.

Attachment. A satisfactory lead-in must be used to prevent a rail car from dislocating the end of a gap filler. Because of the elastic nature of a passive gap filler, separation at the leading edge could result in a peeling of the gap filler and a possible wedging of the material between the platform and the railcar.

The consequences of a peel-off are almost certain fatalities on the platform from flying fragments of the gap-filler, concrete or other materials, and possibly (and probably) train derailment if the gap-filler wedges between the train and the platform.

Where train movements at a platform may be reversed, a satisfactory lead-in is necessary at both ends of an installation.

In addition to the method of attachment, the strength of the entire platform is important because of the force input when the edge is struck by a car. Additionally, the longitudinal force developed must be adequately reacted by both the attachment methodology and the platform structure.

Operational Impacts. Ideally, there would be no impact on normal operations with passive gap fillers. Actual operational impacts might be:

- The necessity of limiting train entrance speed to a station
- The necessity of limiting train run-through speed in express operations

Maintenance impacts are:

- More frequent inspection of passive gap fillers than of existing platform edges
- Better track/platform alignment tolerances must be maintained preceeding and adjacent to the gap fillers
- Vertical face wear
- Vandalism of elastomeric materials

The maintenance requirements of a passive gap filler can be minimized by using elastic connections where possible, in preference to sliding or pivoting connections. In addition, adequate wear material should be provided where wear is unavoidable, primarily on the top surface and vertical surface. Replaceable surfaces could be used for the top surface, and for the vertical surface if attachment safety was assured.

Hazards. Failure modes of passive gap fillers are expected to be minimal:

- Wear-out of vertical surface or top surface
- Mechanical failure of internal components, such as spring breakage, elastomer fatigue, and other material failures
- Catastrophic failure on impact by train, i.e., attachment failure and peel-off

Of the possible failure modes, only the last is serious; however, it is so serious in its consequences that its probability of occurrence must be driven to an extremely small value.

The number of deployments between failures is then:

$$\frac{5 \text{ trains}}{\text{edge-hr}} \times 1000 \text{ edges} \times \frac{24 \text{ hrs}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{100 \text{ years}}{\text{failure}} =$$

$$4.38 \times 10^{9} \frac{\text{trains}}{\text{failure}} \text{, or } 4.4 \text{ billion } \frac{\text{trains}}{\text{failure}}$$

The failure rate calculated is probably achievable, because 4.4 billion train interfacings would represent a similarly large number of pedestrian crossings and train impacts. The gap filler would probably have to be replaced much more frequently due to wear on the top surface or vertical surface.

It appears that one mode of car impact on the passive gap filler could result in sustained oscillations. Impacts on a front or near corner of a car caused by car yaw about a vertical axis could be sustained or intensified by the action of the gap filler. However, practically speaking, it does not appear that sustained forced oscillations will be a real danger for short lengths of passive elastic gap fillers.

Modifications to Railcars

The only necessary modification to the cars would be to provide each car with a standard width over the thresholds, a standard threshold vertical face, and a standard leading edge configuration. In practice, a lead-in (i.e., ramp, etc.) at each end of a vertical surface would be necessary because all subway cars are bidirectional. Gap filler contact plates could be local, at each doorway, or one long plate for each side of a car spanning all doorways. One plate requires fewer lead-ins, but the net lateral loading from the gap filler would be much higher for a full-length plate because more length of the gap filler must be compressed.

A corollary modification or adjustment will have to be made on car height, to bring all cars to the same nominal height. Additionally, most stations will require a one-time modification to platforms or tracks to provide nominally level entry to cars, at least over the length of a gap filler, because passive gap fillers will not provide any contribution toward reducing vertical mis-match between the car and the platform.

Figure 5-1 shows the sled-end design necessary for the car threshold. Also shown is an alternate method with roller ends. Although the alternate method would reduce wear, the rollers introduce additional moving parts which are more expensive to install and maintain.

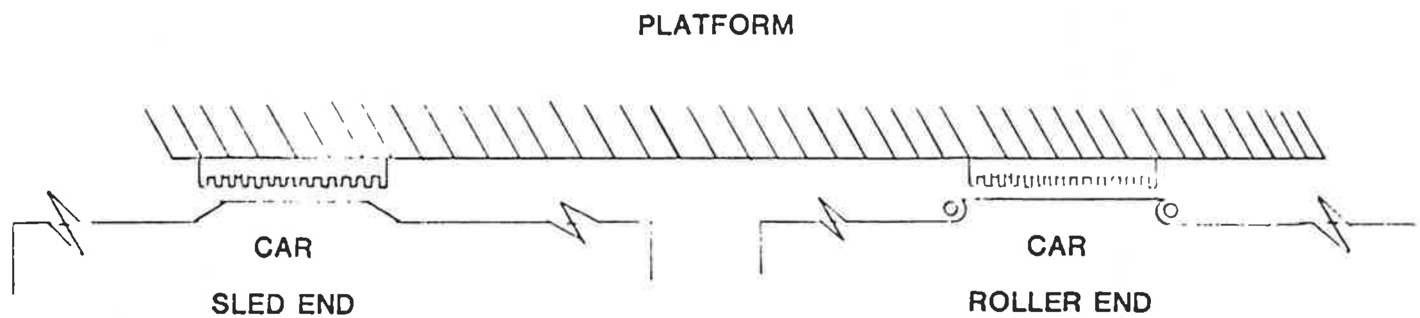


FIGURE 5-1. MODIFICATIONS TO RAILCARS

Design Concepts

There are several ways in which a passive gap filler can be mechanically deflected. These mechanisms are:

- Compression - the device moves only perpendicular to the rail car.
- Longitudinal Rotation - pivot about the vertical axis.
- Vertical Rotation - pivot about the horizontal axis parallel to the rail car.

Longitudinal rotation is difficult to implement for long sections, because the entire device will not be impacted at the same moment. Thus one section trying to rotate will have to pull on all following sections and push on all leading sections, unless an effective longitudinal break can be designed. The break must not offer a car the opportunity to pick an edge and begin peeling the device off the platform.

To some extent all devices share the same problem of tension induced in the device by local compression. This effect adds to stresses in the unit, and increases the apparent compression stiffness.

Gap fillers may be fabricated from any of several materials or composites, including:

- Rubber
- Rubber/steel (Metalastik)
- Urethane elastomers
- Mechanical springs,
  - coil
  - leaf
  - wire rope

Compression will have to be limited to about 50% for most materials. Therefore, a 3" maximum deflection will require about 6" of working material. The following figures illustrate designs for elastomeric devices, both solid elastomer and composite. Adequate longitudinal and vertical stiffness is shown by some designs. The lead-in problem should be addressed for all designs.

Figures 5-2 illustrates several conceptual designs for gap fillers. Figure 5.2.1 is the Ford Fairline type of device, which is characterized by inadequate crush depth capacity for rapid rail applications. Figure 5.2.2 is an improvement of the basic design but with a marginal crush depth of approximately one-third of the finger length. Further it is limited to unidirectional applications. Figure 5.2.3 illustrates the use of an elastomer behind the edge. This design provides a greater range of motion and better vertical support. Figure 5.2.4 is similar to Figure 5.2.3 but provides better control of the contact edge. Figures 5.2.5 through 5.2.8 illustrate variations of these concepts.

Although passive gap fillers provide an intermediate-cost solution to the problem of gap reduction, their installation presumes a rigorous program of detailed design efforts and prototype testing, particularly because of the risks associated with peel-off. Development of passive gap fillers will also necessarily be associated with concern for the resulting acceleration of structural deterioration of the rail cars. An additional area which should be addressed is vehicle damage as a result of impact with the gap fillers at speed.

5.2 Active Gap Fillers

There are two types of active gap fillers that could be developed to suit the range of level entry situations for railcars. The first type, for use in situations in which the platform and car floor are substantially in one plane, would extend only horizontally. The second type, which would move vertically as well as horizontally (horizontal/vertical) would be required for systems in which there was significant vertical mismatch between the car and platform. Such mismatch might be caused by basic car-to-platform alignment dimensions or more likely by the gross-to-tare height variation on cars without self-leveling. There is no apparent need for a vertical-only gap filler.

The most difficult problem to solve for the vertical component of motion is the accurate identification of car floor height in a simple, effective, and reliable manner. Unlike the horizontal direction, for which all car locations will be substantially the same, there is expected

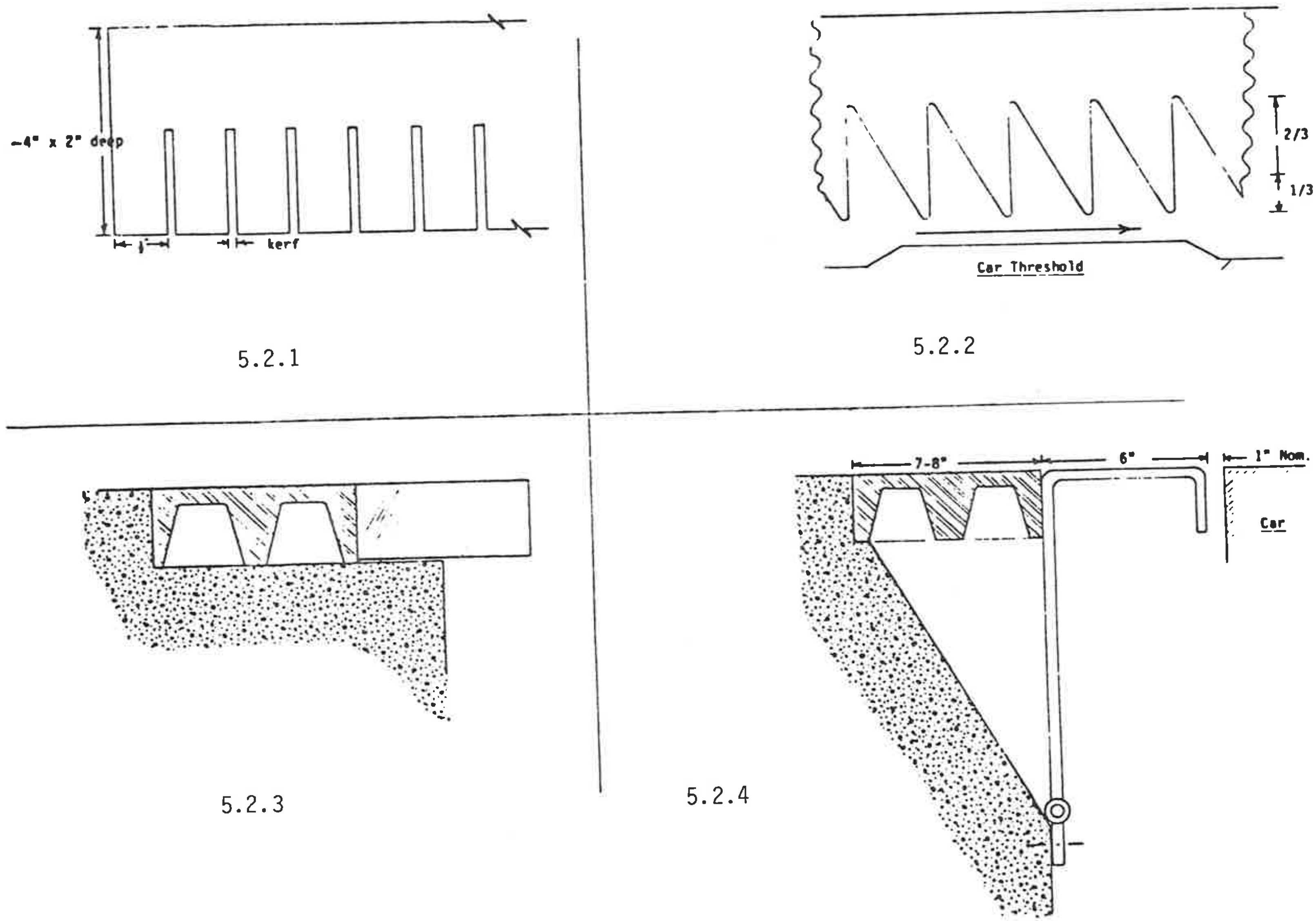


FIGURE 5-2. PASSIVE GAP FILLER DESIGNS

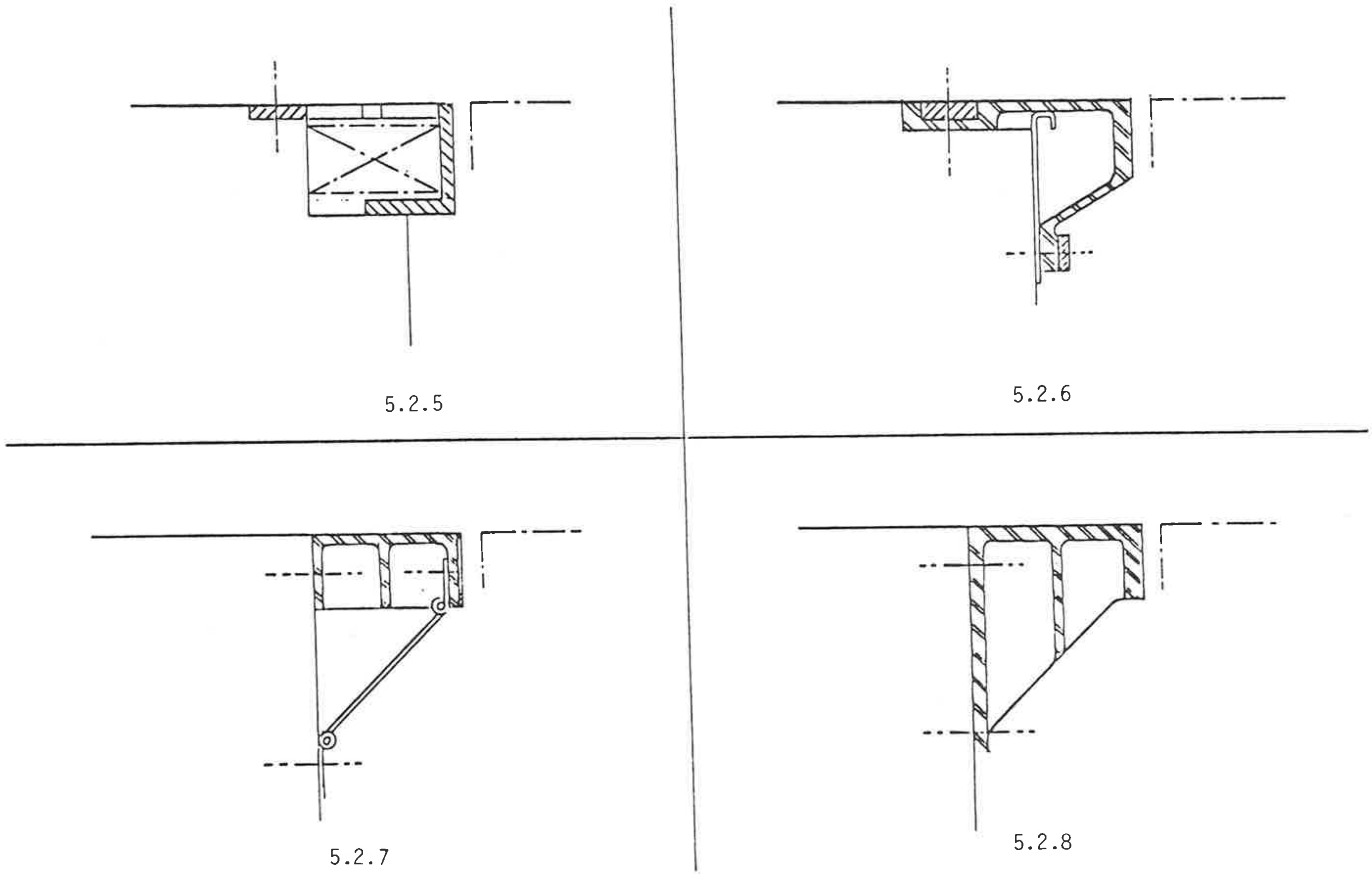


FIGURE 5-2. PASSIVE GAP FILLER DESIGNS (CONTINUED)

to be significant variation in car floor height. In fact, without the variation in car floor height, there would be no need for a vertical gap filler because a one-time platform height adjustment would suffice.

Functional Requirements

There are two control options for gap fillers. The first would duplicate current practice on the NYCTA which is to extend the gap fillers for each train. However, there is a time penalty of about 15 to 20 seconds associated with the deployment of the gap fillers because of the slow approach to an accurate stop, waiting with the doors closed until the gap fillers are deployed, and then the slow departure until the gap fillers retract.

The second option, which is appropriate for locations where ambulatory patrons do not need a gap filler, is to deploy the unit only for handicapped patrons. With this method, the time penalty would be incurred only occasionally on a random basis, and on the average would probably not have a discernable effect on system performance.

A gap filler request system would send an appropriate signal to the motorman indicating that an accurate stop was required to allow a person to board (or deboard) the train. From this point onward, the cycle would be the same as the currently-used every-stop cycle. The only foreseeable disadvantage is that such a system might be subject to numerous false indications as the disruptive element of society learned the effect of the gap filler request button. At some stations supervision by attendants now present might be possible.

On the train, the problem of indicating to the motorman the stop at which the gap filler user wanted to disembark is more difficult. Conceptually a stop request system as used on buses is sufficient, but on rapid rail systems the stop request wiring would have to be added to all cars and trainlined. On some systems there are no spare wires available for extra functions. This approach would also be subject to the same abuse as the platform gap filler request system, and perhaps more so, because it would be possible to give a stop request from any car in a train, not just the one car that aligned with all of the accessible zones.

A corollary problem is to define the method of selectively actuating the gap filler from the train for disembarking passengers. Several methods are possible:

- An electrical shunt similar to the track switch control used on light rail systems.
- A stopping position sensitive system.
- Manual actuation of the wayside system by the motorman or conductor.

The last method is the simplest, and if the conductor's location is (or could be) adjacent to the accessible platform location, the stop signal would not have to be trainlined. There are several advantages to having the conductor at the accessible platform position:

- Minimization of on-board equipment or changes to the car.
- Enhanced safety of gap filler operation and use because of direct supervision.
- Reduced dwell time, because direct supervision of gap filler use would enable quicker rectification of difficulties, such as interference with doors.
- Avoidance of nuisance actuation requests both on car and on wayside.

The present approach to accessible rapid rail service conceives that only a limited length of platform would be modified to ensure access to the train. However, it is envisioned that all cars would be accessible to avoid switching problems for special cars. To ensure that a trip could be made by a handicapped individual, the same car (or even a specific doorway) would have to align with each accessible zone on a line once a run was initiated. All other cars, although technically accessible, would not be used by handicapped patrons during that run.

The necessity of maintaining a constant stopping position occurs when considering a handicapped passenger on the train wishing to exit. Although a person could always go from an accessible platform location to any random position on the train (because all doorways are postulated to be accessible), the reverse is not true. Once on the train, the person's location is fixed, and the person's location within the train must align with the accessible zone on the platform when the train stops. Thus an error-free handicapped trip can only be made if the train alignment with the accessible zone is constant on a given run.

Although the stopping requirements for a train are fixed for a given run, there is some remaining flexibility to the foregoing principle:

- Trains of different length do not necessarily have to align the same numerical doorway with the accessible zones on a given line.
- It is not necessary for the same doorway of given length trains to align with the designated accessible zone on different lines.
- For the common portion of branching routes, it is possible have two mutually exclusive accessible zones on the common platforms.
- In-bound and out-bound accessible zones do not have to have any specific inter-relationship if they do not serve the same train.

An operating mode for an active gap filler is shown in Table 5-1. The modes included are for request-response systems, for boarding, or disembarking. The maximum additional dwell time required is estimated.

TABLE 5-1. ACTIVE GAP FILLER OPERATING MODES

STEP	OPERATION	ADDITIONAL TIME REQUIRED
1	Patron signals need for gap filler	-
2	Motorman stops train in position	5 sec.
3	Doors open, conductor exits	5 "
4	Conductor deploys gap filler	5 "
5	Patron boards	10 "
6	Conductor retracts gap filler	5 "
7	Conductor boards train; signals motorman	5 "
8	Doors close, train departs	-

Modifications to Cars

The modifications required on the cars vary with the operational characteristics of the system which is used. The simplest case is a system which is manually operated, as needed. For such a system there are no necessary modifications to the car. For systems which are active in the horizontal direction only, modifications would be limited to installation of signal transmission equipment, including trainline stop request devices and a train-to-wayside signal system. In any system incorporating automated vertical alignment capability, there is a requirement for some type of target on the car which will allow the gap filler to determine the correct elevation within reasonable tolerances.

Design Concepts

The design parameters for horizontal and horizontal/vertical gap fillers are essentially similar. The basic parameters are:

- platform size
  - length (parallel to train)
  - width (perpendicular to train)
- operating range
- weight capacity
- operating time

The horizontal/vertical gap filler would probably employ the basic mechanism of the horizontal gap filler, with a vertical mechanism super- or superimposed.

There are several options for platform configuration on the two types of gap fillers. For the horizontal unit, an arrangement similar to the existing NYCTA gap fillers would be suitable. The effective gap filler width would be relatively narrow bacause of the interleaved bars of the gap filler. (The units are now used in several different lengths at the different stations.)

All NYCTA gap fillers are presently used only on curved platforms, where the car-to-platform gap is unavoidably enlarged above nominal tangent gap dimensions. For horizontal gap fillers used on tangent platforms, the width dimension of NYCTA - type units could be even less, because the required travel is less at tangent platforms.

The horizontal/vertical gap filler presents a much different situation. To interface with cars of different floor height, there are two basic ways the unit can be configured. The simplest approach would be an adjustable angle ramp surface, with the slope perpendicular to the car, from platform level to car floor height. The unit could be of any reasonable length parallel to the train. With this arrangement, a wheelchair user would be required to traverse the ramp immediately prior to traversing the residual gap and step at the car.

The alternative approach is to provide an adjustable-height level entry to the car. This would considerably reduce the effort required of a person in a wheelchair to get across the residual gap and step. The platform should have a ramp approach to it; otherwise the person would have to be on the gap filler platform before it raised into position. More significantly, a deboarding passenger would have to wait on the gap filler platform until it lowered to station platform height. (The maximum height would be on the order of 3" to 4", depending on car gross/tare variation and nominal car to platform alignment). The level-entry design is illustrated in Figure 5-3.

A level-entry gap filler platform could have an access ramp located on any of three free edges. The preferred location would depend on general traffic flow on the station platform at the gap filler location. Where the traffic flow is substantially perpendicular to the train, the ramp should be on the back edge of the gap filler. At other locations, where pedestrian traffic is substantially parallel to the train, two ramps should be provided, one at each side of the gap filler platform. Plans for perpendicular and parallel orientation are shown in Figures 5-4 and 5-5, respectively.

A small, variable, uncommon vertical discontinuity, such as the raised gap filler platform, presents a greater hazard than a full step or set of steps because of its unexpected nature. For this reason, unramped edges in either case will probably require railings. Railings will prevent the handicapped as well as the ambulatory from attempting to use an unramped edge. Proper orientation of ramps and railings should minim ze the disruption to pedestrian flow.

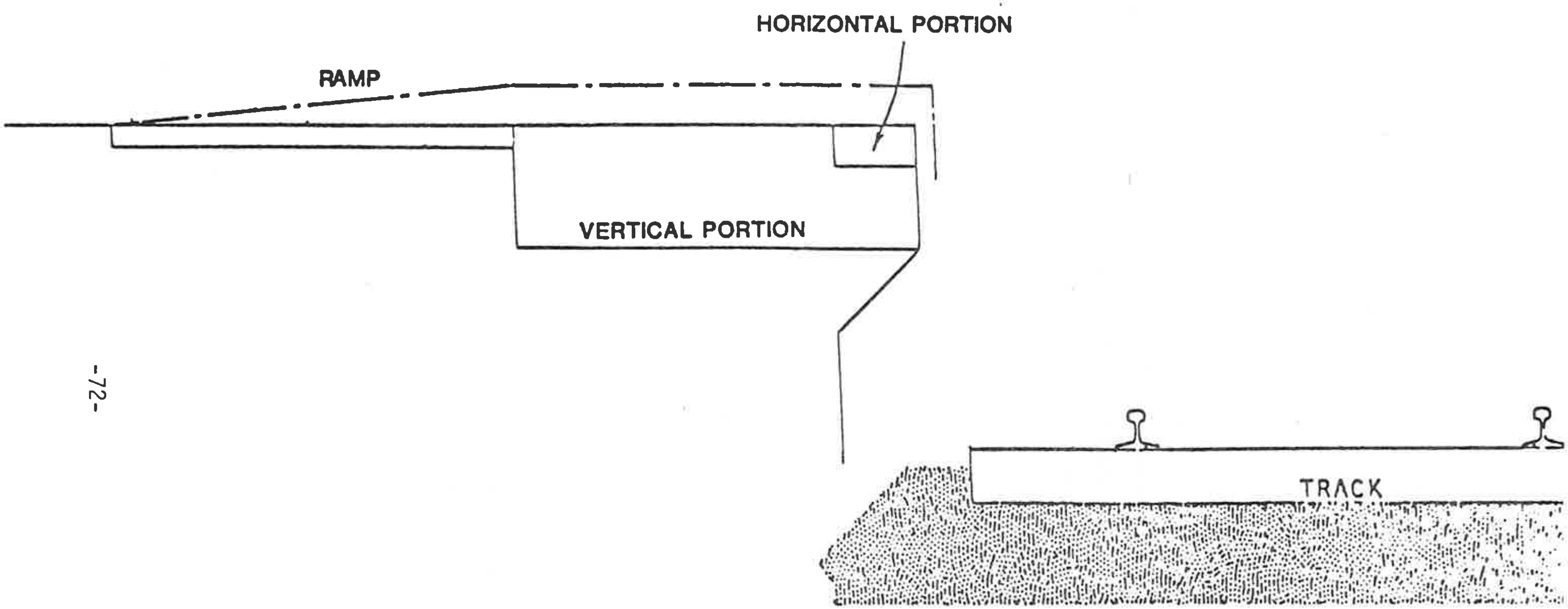


FIGURE 5-3. VIEW OF LEVEL-ENTRY ACTIVE GAP FILLER

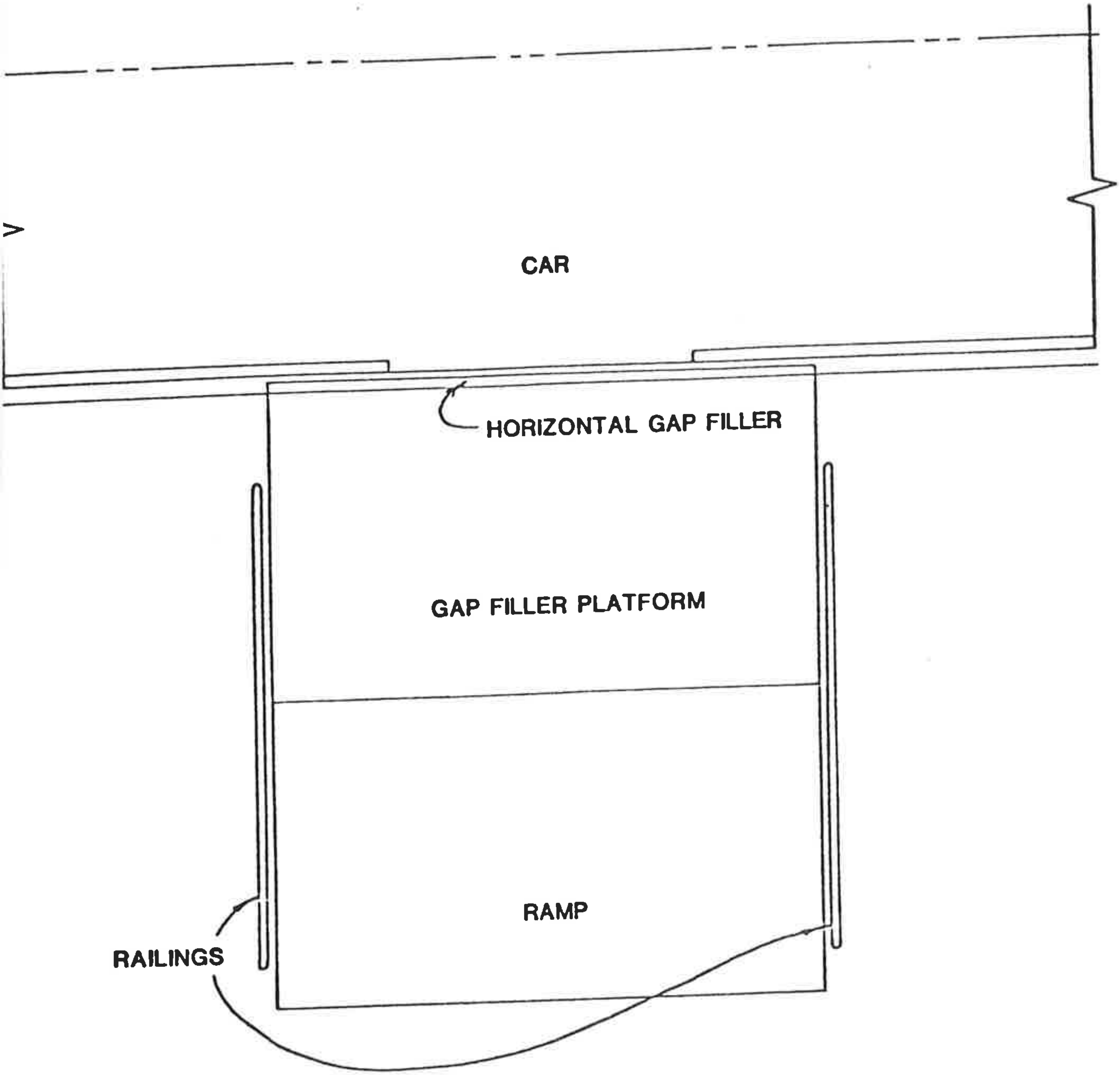


FIGURE 5-4. ACTIVE GAP FILLER-PERPENDICULAR ORIENTATION

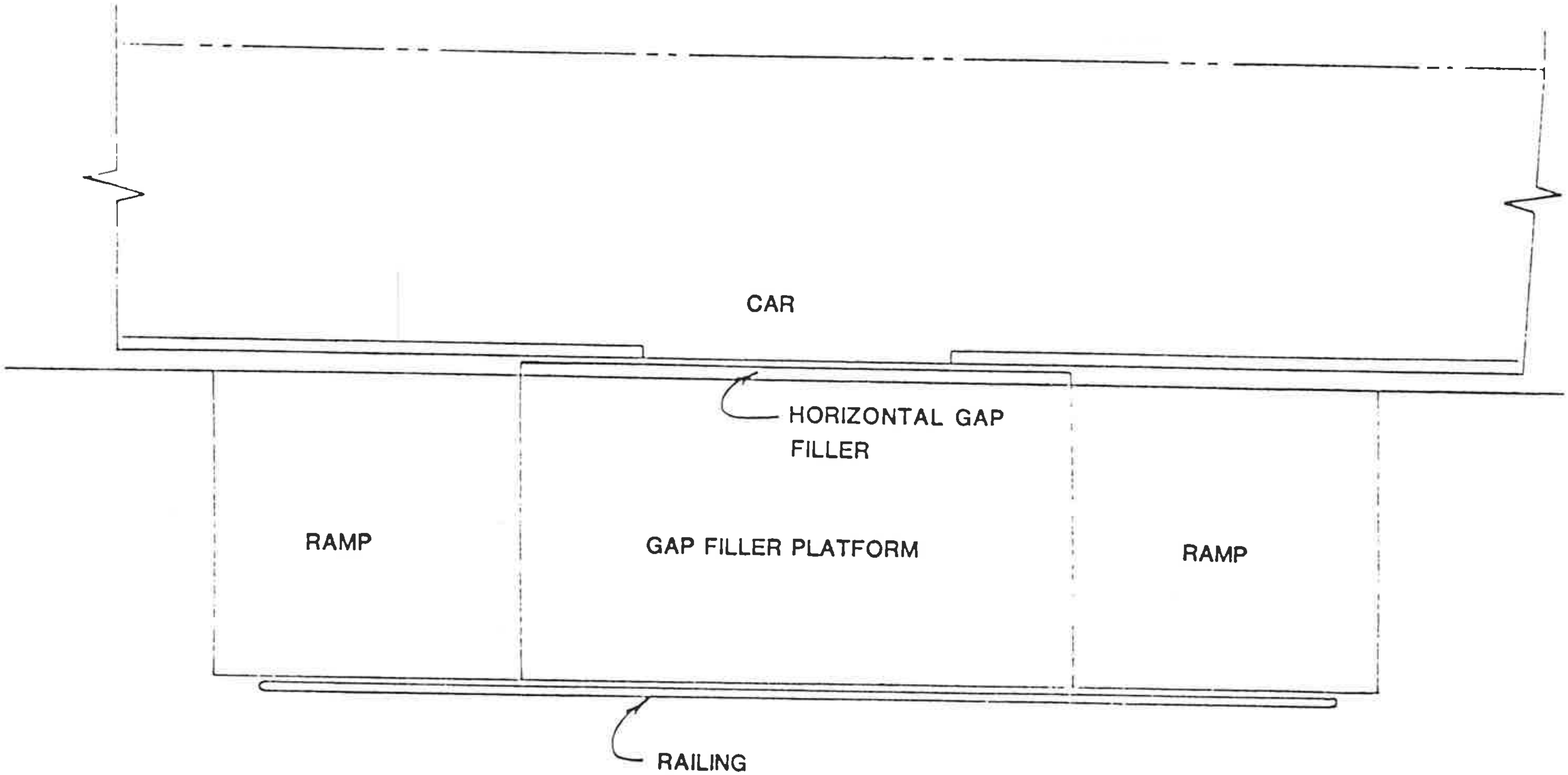


FIGURE 5-5. ACTIVE GAP FILLER - PARALLEL ORIENTATION

The effectiveness of these design features will depend on the final specifications by which they are incorporated. Exact dimensions may vary with the location at which gap fillers are to be installed, but there are some general guidelines which will assure usability and safety. These guidelines can be summarized as follows:

1. Vertical adjustment capability, up to 6" from rest position.
2. Horizontal adjustment capability, up to 6" from rest position.
3. Horizontal platform portion, approximately 4' longer than doorway, and extending at least 5' from platform edge.
4. Ramps, not exceeding 1:10 slope, to vertical surface; one ramp if perpendicular to train, two ramps if parallel to train.
5. Railings to protect all non-ramped edges (i.e., steps in the floor surface occasioned by the gap filler).

It may be desirable to increase the illumination level at the device, sufficiently greater than the general station platform illumination level to make it unlikely that ambulatory patrons would not notice the horizontal/vertical gap filler. Focusing the attention of ambulatory patrons on the horizontal/vertical gap filler area should be sufficient to prevent railings and ramps from being a hazard to this group. Increased illumination would not be detrimental to handicapped users of the gap filler, and it might be beneficial to them.

Sonic warnings of the gap filler operation would be an alternative way of calling attention to the special circumstances, similar to presently-mandated back-up warnings on commercial and construction vehicles. However, audible warnings might also be overlooked in the present noisy transit environment. Furthermore, such devices may create a discomforting conspicuousness for the handicapped patron. The mere presence of a handicapped patron may be sufficient warning.

The use of horizontal or horizontal/vertical gap fillers may present a marginal hazard increase to ambulatory system patrons, and in the final analysis, possibly no hazard increase to ambulatory patrons with proper ramps, railings and other safety precautions. Existing horizontal gap fillers on the NYCTA system are well signed as to what they are, with warnings to stay off the gap fillers when they are moving. They are provided with railings (actually chains, to accomodate the movement) to keep patrons from falling off the units between the cars and platforms. The safety experience with these units is satisfactory.

Gap fillers should present handicapped users with enhanced safety when boarding or alighting from a train. Indeed, it would be counterproductive if gap fillers caused any safety degredation for handicapped users. Similarly, the use of gap fillers should not present any identifiable hazards for employees, other than normal industrial hazards associated with maintenance operations for devices of similar complexity.

The greatest hazard associated with gap fillers exists for the train, and in a reciprocal manner, for the gap filler itself. For any equipment that projects into the car dynamic envelope at any time, there is a risk that a train will strike the equipment if it is not fully retracted. This type of incident has occurred with the NYCTA gap fillers in spite of safety features designed to prevent such incidents.

A horizontal/vertical gap filler could potentially strike a train slightly above the floor level. However, as the gap fillers presently under consideration are intended primarily for tangent platforms, the risk of being struck is somewhat less than the risk for gap fillers on curved platforms. If a train strikes a gap filler serious damage to the device may result, as well as damage to the railcar, up to and including, derailment.

Perhaps the most difficult aspect of a vertical gap filler is reliably determining the floor level of a car. Horizontal gap fillers are now set to extend a predetermined distance toward the rest position of a car, which can be theoretically determined. The vertical position is, however, largely random, and it depends primarily on individual car passenger load. Tare heights would in practice be maintained close to the desired nominal position by regular maintenance procedure, but there is no way to predict passenger load with sufficient accuracy.

An associated problem is interfacing with a rocking car. The movement caused by people entering and exiting a car can be as much as ± 3/4" and motion often continues for the entire duration of the stop. It seems undesirable for a vertical gap filler to continuously adjust to the oscillating floor height of a car. Instead, a gap filler should adjust to a median position and hold for the duration of the train dwell.

Although active gap fillers potentially offer a superior solution to the problem of gap reduction, they are inherently the most complex solution from an engineering standpoint, and consequently they are associated with more problems than passive gap fillers in the areas of initial costs, maintenance, efficiency and safety. Although there is sufficient off-the-shelf technology available to minimize development risks on the component level, the systemic application, including operational design and railcar modifications, can easily become prohibitive in scope.

5.3 Accessibility with Crew Assistance

In a significant number of cases the gap impediment to accessibility by handicapped patrons may be reduced by the intervention of crew in assisting passengers in the boarding and disembarking process. This procedure in most instances would eliminate the need for hardware installation, operation and maintenance and, through the flexibility of human involvement, provide a high level of reliability, security and safety.

Successful implementation of this approach requires development of procedures and provisions in three key operational areas: location of the E&H patron on the station platform, positioning of the train upon arrival at the station, and a signal system between patron, trainman, and motorman or engineer.

The demarkation of a specific location in each station for the handicapped patron to wait for a train is beneficial to both the patron and the train crew. The fixed location adds an element of familiarity for the patron and thus counters the relative hostility of the public transit environment. If the location is clearly marked it increases the patron's visibility. The markings can provide safety and convenience features relevant to all forms of handicap, including deafness and blindness.

Delineation of a fixed location for E&H patrons also benefits train operations by reducing the physical size of the station area in which assistance may be needed. Further, the fixed location may in some cases provide a passive signal system to indicate a potential need of crew assistance.

A corresponding concern is the correct positioning of a train upon arrival at a station. If a fixed platform location is established for patrons to wait for a train, then it is desireable for the train to stop in a position which places an available crew member as near as possible to the patron. In the case of a disembarking handicapped patron it may be necessary to avoid stopping the train in a position in which pillars or posts on the platform can interfere with the departure of the rider.

The operation of a system incorporating these elements is dependent upon a proper system of signals. The ideal plan would incorporate presently available hardware, particularly in providing trainline communications. There are two messages to be incorporated: either a patron needs special assistance to board, or a patron needs special assistance to disembark. There may be as many as three members involved: the patron, a conductor or trainman, and an engineer or motorman.

The boarding patron might effectively signal the train crew of his/her needs by his/her mere presence in a designated area. This can be supplemented by a light, for example, activated by the patron upon entering the designated area, verified by the motorman or approaching the platform by visually observing the presence of the patron, and finally deactivated either manually by the assisting crewman or automatically by the departure of the train. The disembarking patron could verbally indicate his intent to a crew member who would then transmit the message to the motorman or engineer via a presently available mode, such as an intercom or a horn or whistle.

In instances in which it is not feasible to reliably stop the train in such a manner as to have a crewman immediately present to assist a patron, other actions can be planned. Representatives of some systems have indicated that they would, as an alternative, move the train up as much as necessary following the initial stop at the station.

This demand-responsive system would probably have at worst a negligeable effect on system operating time and cost. The number of E&H patrons in the most accessible systems is not high, and it can be reasonably assumed that most of the E&H patrons who would venture further in the public transit network would be largely self-sufficient or travelling with a companion or aid, and thus the number of requests for train crew assistance would be very low. This number could be lowered further and kept low through effective support of training, as illustrated by the results of the VAREC study.

In a few instances there may be gaps of such magnitude that, even with crew assistance, the boarding process would be difficult and unsafe. Such circumstances were addressed in the 321(b) studies[6] of commuter and light rail accessibility. The recommendations evolving from these studies included the incorporation of a portable bridgeplate for use on demand by E&H patrons.

The bridgeplate is conceptualized as a lightweight platform approximately three feet wide and eighteen inches deep as a minimum. The leading and trailing edges are to be ramped to facilitate wheelchair passage, and a low edge rail is to be attached for safety and handling convenience. A pin or securement device will be necessary to prevent motion of the bridgeplate during its use.

The bridgeplate would be placed across the gap by a trainman whenever requested by a handicapped patron. In the event that the bridgeplate were to rest at a steep angle, as may occur at some curved platform interfaces, the trainman would assist the patron in crossing the bridgeplate. At all other times, the bridgeplate would be stowed on the railcar.

Deployment time for a bridgeplate may be a problem for rapid rail systems with very short headways. However, this problem would be severe only during peak operating periods, and E&H representatives have consistently indicated a widespread disinclination toward use of public transit during these periods. Thus the net disruption to service would be minimal.

Theft is an additional problem associated with use of a bridgeplate. Because the bridgeplate is not "hinged" or rigidly mounted, it presents unique security demands which require a flexible attachment with enough length to allow the ramp to be moved from its stowed position to its operational position in the car doorway.

6.0 Conclusions

The gap phenomenon can be characterized by its wide variety of magnitudes and associated problems. Each transit system is unique in its structure, and even within a single system there may be a diversity of characteristic problems at different stations. Rapid rail systems are predominant in presenting gap problems. Light rail, on the other hand, involves only two UMTA funded systems with high platforms and consequent potential gap problems. The commuter rail problem is unique because of obligatory minimum clearance for freight traffic. Thus, from the outset, there is evidently no simple solution which can be applied universally with consistent and satisfactory results.

The gap impediment is only one component in the overall concept of accessibility and should be viewed in relation to other impediments, such as the absence of ramps or elevators to provide platform access. As a contributing component, however, it is evident that a gap problem does exist. In the worst cases there are gaps of up to 19 inches at some rapid rail curved platforms. In the best circumstances minimal gaps must still be tolerated, and these gaps are an impediment to the less experienced or less capable handicapped patrons.

Generally the gap problem at any level of severity is less amenable to hardware solutions than to solutions involving people - the E&H partons and the trainmen. Hardware solutions present risks and difficulties to both operators and users, and for most systems these obstacles are of such magnitude that for all practical purposes hardware must be considered as operationably infeasible. These obstacles are particularly severe in a retrofit environment. The principal obstacles are as follows:

- There is no precedent for the use of unmonitored gap filler hardware, and thus there are additional costs and risk in the development and first use of such equipment.
- The installation of gap filler hardware on either the railcar or the platform entails additional capital expenditures which effectively are non-revenue producing.
- In some instances gap filler hardware introduces operational complications and increased dwell times.

- It may not be realistic to develop fully automated active gap fillers, and thus the hardware solution would be partially labor intensive.
- Gap filler hardware introduces additional maintenance.
- Large numbers of cars have been ordered recently without self-leveling capability. Thus fewer systems can consider leveling as a near-term hardware solution to the gap problem.

A reasonable alternative to the hardware solution is to involve both the E&H patrons and the train crew as participants in overcoming the gap impediment. This approach requires appropriate training for both the train crew and for patrons. Train crew would need briefing on the needs of the E&H and appropriate methods of providing assistance. Wheelchair-bound patrons would require adequate training and practice in manuevering and controlling their wheelchairs. Given that platform access already exists (elevators or ramps), this approach can go a long way toward solving the accessibility problem. Only in a few isolated instances would there be a necessity for any form of hardware.

There has been continuing work in the development of wheelchairs with expanded capabilities. Some of these wheelchairs may be more suited to the gap impediments encountered in public transit. The selection of wheelchairs appropriate to public transit use is a reasonable prerequisite to travel in this mode.

Further dissemination of wheelchair technology is an alternative that should be pursued. Although the size of the market is indeterminate, a market does exist to support devices to make wheelchairs more suitable for transit. As transit and other public services become more accessible, this market will increase further. Devices which are designed specifically to cope with vertical and horizontal gaps in transit systems may find application in providing handicapped access to other urban areas.

REFERENCES

1. Deleuw Cather and Ralph Parsons Company, Section 321(a) Rail Retrofit Evaluation, Handicapped Accessibility: Estimated Costs and Comments. December 1979.

2. "The Additional Cost of Providing Mobility for the Elderly and Handicapped on the Washington Metropolitan Rail Rapid System," Urban Mass Transportation Administration, May 1973.

3. Middleton, W. D., The Time of the Trolley. Milwaukee: Kalmbach, 1974.

4. Middleton, W. D., When the Steam Railroads Electrified. Milwaukee: Kalmbach, 1974.

5. (New York) Metropolitan Transportation Authority et. al., "Operator's Comments on Section 321 Rail Retrofit Evaluation Studies," New York: March 1980.

6. Crain & Associates, Summary Report: 321(b) Rail Retrofit Evaluation - Light and Commuter Rail Systems, Volume I. December 1980. PB81-187148.

7. American National Standard Specifications for Making Buildings and Facilities Accessible to and useable by Physically Handicapped People. March, 1980. American National Standards Institute, New York.

8. Coleman, D. M. Graye, E. S., Negotiating the Subway by the Elderly and Handicapped; METRO: A Case Study. September, 1979. PB80-156995.

APPENDIX A

ELEVATOR GAP STANDARDS

APPENDIX A

A-1 Elevator Standards

In discussions of the appropriate gap standards for rapid transit systems, ranging from commuter and rapid rail to DPM systems, mention is frequently made of the possibility of applying elevator gap standards. These are usually cited variously as "5/8 in. gap, 1/2 in. step", or "1 in. gap, 1/2 in. step". The implication is that these dimensions are maximum limits. They are understandably attractive to the various concerned groups. However, in the course of researching rail gaps, in considering the applicability of the elevator "standards", in observing gaps at elevators, and in studying elevator literature, disconcerting discrepancies appear.

Actual gaps observed at elevators are usually on the order of 1" to 1½"; one manufacturer's literature consistently shows a 1½" gap; and consideration of applying "elevator standards" to rail discloses many significant differences between the two modes that mitigates against rail transit ever achieving elevator quality gaps with passive components and tolerances.

Further research discloses possible, and perhaps probable, sources of the 5/8 gap, 1/2 step. The applicable ANSI standards for elevators, A17.1, "Safety Code for Elevators, Dumbwaiters, and Moving Walkways", specifies:

- ½" minimum gap for side guided elevators, (common configuration for one or two doors)
- 3/4" minimum gap for diagonally opposite corner guides (rare configuration used for doors on two adjacent walls)

The applicable section is 108.1d. The ANSI standards do not specify the maximum allowable step. The elevator target for vertical mismatch is generally ± ¼ inch, but the actual achievement depends very much on the hoist mechanism and controls. Editorially, it appears possible that ½ in. and 3/4 in. minimum were averaged at some point to the 5/8" dimension. No explanation is advanced here for the 1" gap.

Figure A-1 is a plot of horizontal gap vs. speed, showing the maximum operating speeds for elevators and selected transit systems. The elevator gap standards are shown and projected from the 1800 fpm (20 MPH) elevator line. There are many ways to project from one situation to another; the validity depends on the correct selection of a rationale for projection.

One form of projections from the elevator standards based on maximum speed can be expressed succinctly as:

$$G_R = \left[\frac{V_R}{V_E}\right]^x \cdot G_E \ , \ o \leq x < a,$$

where

G_R, G_E = Gaps for rail and elevators, respectively, of the same type, ie., both minimum gaps, both target gaps, etc.

V_R, V_E = Maximum velocity of rail and elevator systems, respectively

x = Power of V_R/V_E ratio.

a = Some upper limit of x.

It is clear that when x=o, $V_R/V_E = 1$, and the projections are lines of constant value for any speed. For x=1, the projections are straight lines through the origin and the elevator gap values; x=2 yields parabolas. Fractional powers are admissible.

It is not possible at this point to state the ideal value of x with certainty and authority. However, certain observations can be made in the interest of setting the stage for further analysis and discussion:

- Values of x:
  - x=o seems improbably optimistic.
  - x=1 seems plausible - many 1st order terms appear in velocity analyses in general; encouragingly representative of currently achieved gaps in some rail systems.
  - x=2 seems pessimistic - although 2nd order terms also appear frequently in velocity-related analyses, greatly exceeds currently achieved gaps in rail systems.

- V_R (maximum system velocity) may not be the exact value on which to focus, but:
  - On some systems trains do enter stations at maximum speed,
  - On skip-stop operations, trains do run through stations at maximum speed, and
  - Lateral (and vertical) suspension characteristics are set by maximum speed considerations.
- V_E (maximum elevator velocity) may still not be the upper limit for elevators for which the existing standards would be practical, thus all projections for $x > o$ would be reduced in value.

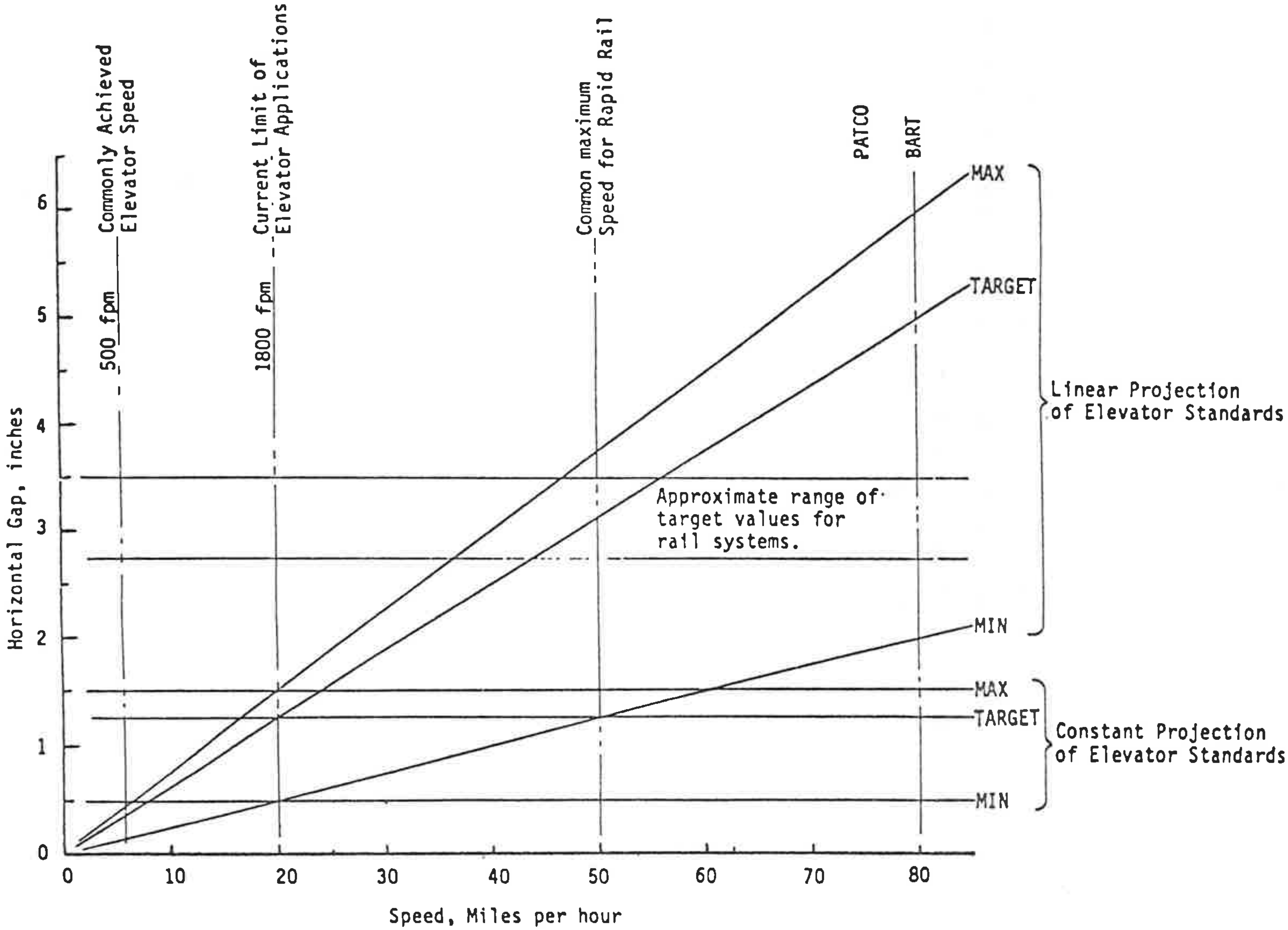


FIGURE A-1. HORIZONTAL GAP VS. SPEED FOR SOME GUIDED TRANSIT SYSTEMS

The ½ in. vertical step "standard" is more elusive. At this writing, no known ANSI standard numerically specifies the ½" step. There is however, a tentative link between two accessibility standards:

- ANSI A117.1,* states:
  - 5.9 Elevators.
    - 5.9.2 "Elevators shall allow for traffic by wheelchairs in accordance with 3.1, 3.2, 3.3 and 5.3".
  - 5.3 Doors and Doorways
    - 5.3.3 "Sharp inclines and abrupt changes in level shall be avoided at doorsills. As much as possible, thresholds shall be flush with the floor".

  (Sects. 3.1-3.3 are not relevant to this discussion. There are no other references to small vertical discontinuities, as distinguished from the steps of a set of stairs).
- Accessibility Modifications#, in contrast, does not address elevator thresholds, but specifically mentions a ½" vertical limit in connection with walkways and doorway thresholds, pp. 4,5,22,25, and 26.

These conclusions on the vertical step "standard" are of course circumstantial, but it is definite that the ANSI elevator standards do not specify the vertical limits, and further, the elevator standards are considerably more permissive than other authors state. In point of fact, the alleged standard appears to be an average minimum required gap, not, as implied, a maximum permitted gap.

The next step in the consideration of applying elevator standards to rail systems is to examine the ways in which the standards could reasonably be extended. The significant differences between elevators and rail that control achievable gaps are primarily guideway and suspension characteristics, which are determined by the maximum operating speeds.

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* Specifications for Making Buildings and Facilities Accessible to, and Usable by the Physically Handicapped; ANSI A117.1-1961 (R 1971). New York: American National Standards Institute, 1980.

\# Mace, R.I. Accessibility Modifications: Guidelines for Modifications to Existing Buildings for Accessibility to the Handicapped. North Carolina: Department of Insurance, 1976.

APPENDIX B

PASSIVE GAP FILLER STIFFNESS

APPENDIX B

Passive Gap Filler Stiffness

Lateral compression requirements for passive gap fillers can be estimated as follows: Assume that the force/car at maximum gap filler deflection is set as a limiting value:

$F = R_u$ x L x $_m$

F = Force at maximum deflection

R_u = Rate per unit length

L = Length compressed

$_m$ = Maximum deflection (design)

Assume further that F_{max} is chosen as a percent of chassis tare weight to limit rebound acceleration. A rapid rail vehicle weighs about 1000 lbs/ft. Trucks weigh about 15,000 lbs. Thus, to limit lateral acceleration to .1 g, F_{max} must be limited to 3000 lb.

It is preferable to limit the guidance forces to their intended components, i.e., the track and trucks, and away from the platform. Thus it can be seen that sufficient low-rate deflection must be provided in the gap filler so that it does not become solid before the track/truck path. Conventional gaps are set at about 3 1/2", and gaps of 3 1/2" nominal usually yield a gap range of 2 to 5 inches because of car and wayside tolerances. To guarantee a maximum gap of no more than 2 1/2" the new nominal gap must be set at 1" which will give a range of -1/2" to 2 1/2". The gap filler design deflection must be 2 1/2" minimum (3 1/2" conventional nominal - 1" new nominal). Allowing another 1/2" for contingencies, the gap filler design deflection becomes 3".

The compressed length of gap filler consists at most of four 5' doors having a total of 20' of contact length (including ramp ends). Thus,

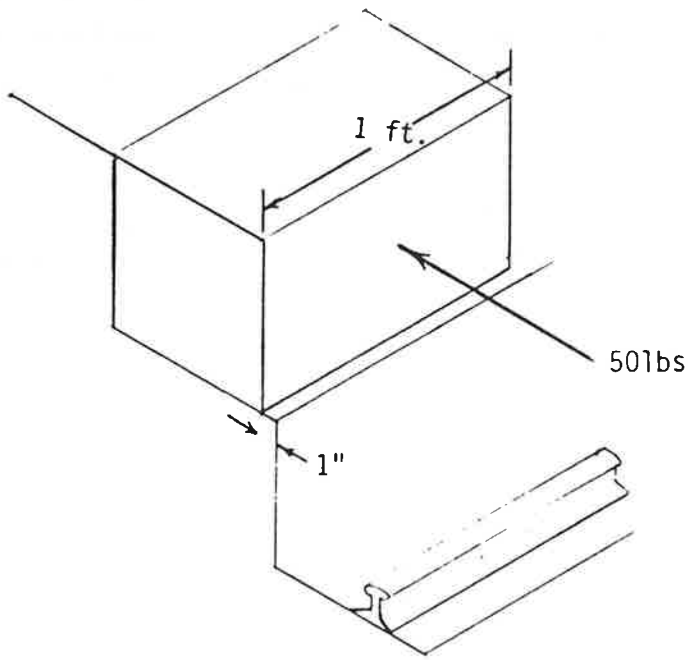

FIGURE B-1. PASSIVE GAP FILLER DEFLECTION FORCES

At the low rate of 600 lb/ft it is apparent that with single corner contact no appreciable restraint will be applied to a car, and deflection will continue until the car motion is arrested by conventional track/truck force paths, or until the gap filler deflects to the limit of its travel at which point its rate suddenly becomes very high.

The rather low required compression rate, which may be difficult to achieve, is fortuitous because it helps to ensure that large longitudinal friction forces will not be developed. For a coefficient of friction of .25 the maximum longitudinal force from a 3000 lb. lateral force is 750 lbs. A 750 lb. force produces a deceleration of .0125 g on a 60,000 lb. car. This would result in a speed drop of approximately 4.7 mph for a coasting car.

There are several spring rate schedules that could be used on passive gap fillers. Broadly speaking, spring rates can be linear, hardening, or softening and still produce the same force at the rated deflection. These spring rates are illustrated in Figure 5-2.

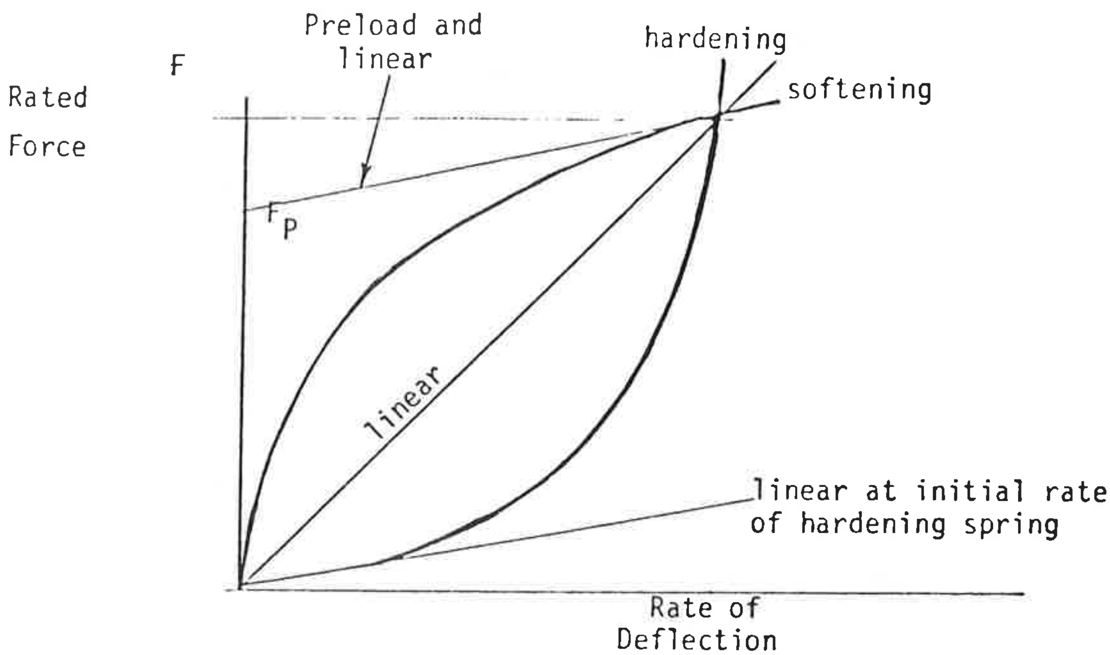

FIGURE B-2. SPRING RATES

A softening rate is the most harsh for the equipment and occupants. A preload followed by a linear rate is also a softening rate. A hardening rate is the easiest on equipment and passengers, but there is no reason for a rising rate if the low initial rate can be maintained to the necessary deflection. It is not intended that the gap filler should contribute any significant portion of the restoring force on the car.

APPENDIX C

NEW TECHNOLOGY

In conducting this study, the contractor has not created any new technology. However, in the course of the investigation, the analysis has resulted in two areas of major guidelines that will assist transit operators in selecting methods or equipment to sufficiently overcome the platform gap problem. These guidelines are:

- Methods - participation and training of E&H patrons and train crews for positive manuevering over platform gaps, Chapters 2, 5 and 6.

- Equipment - "gap" equipment is almost unique to each transit system but are categorized in Chapters 3 and 5. Wheelchair equipment is presented in Chapter 4.

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