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Wheelchair and Occupant Restraint on School Buses

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16. Abstract

This report presents the findings of a literature survey, wheelchair hardware survey, wheelchair usage on school buses survey and assessment of current worldwide standards to address securement of wheelchairs on school buses and other modes of public transportation. This research was performed to assess the current wheelchair securement and occupant protection systems on school buses to support possible future rulemakings. Several foreign and international organizations have recently issued standards for wheelchair and occupant securement. This report explores the potential application of these standards to FMVSS 222, "School Bus Seating and Crash Protection." Although data in this report are relevant to FMVSS 222, it was also prepared to disseminate information that may be useful to other standards organizations, wheelchair manufacturers, school bus manufacturers and school districts.

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PREFACE

This report presents the findings of a literature survey, wheelchair hardware survey, wheelchair usage on school buses survey and assessment of current worldwide standards to address securement of wheelchairs on school buses and other modes of public transportation. This research was performed to assess the current wheelchair securement and occupant protection systems on school buses to support possible future rulemakings. Several foreign and international organizations have recently issued standards for wheelchair and occupant securement. This report explores the potential application of these standards to FMVSS 222, "School Bus Seating and Crash Protection." Although data in this report is relevant to FMVSS 222, it is also prepared to disseminate information that may be useful to other standards organizations, wheelchair manufacturers, school bus manufacturers and school districts.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32) (5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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I. INTRODUCTION

BACKGROUND

Under the National Traffic and Motor Vehicle Safety Act of 1966, the National Highway Traffic Administration (NHTSA) was given authority to issue Federal Motor Vehicle Safety Standards (FMVSS's) which must be met by vehicle or vehicle equipment manufacturers. As part of this responsibility, the agency has developed, and continues to revise, safety standards that pertain to the construction of all vehicles, with several standards that are unique to school buses. The agency believes that it is important to have pupil transportation programs that allow for safe transport of occupants of school buses.

Currently, Federal Motor Vehicle Safety Standard (FMVSS) No. 222, "School Bus Seating and Crash Protection," specifies requirements for safe seating on school buses, but excludes "a seat installed to accommodate handicapped or convalescent passengers" (49 CFR 571.222.S4) from these requirements. Because FMVSS No. 222 does not include requirements for seating designed for disabled students, certain members of Congress and the pupil transportation community have requested that the National Highway Traffic Safety Administration (NHTSA) address this matter by issuing new safety regulations which account for the needs of medically fragile and disabled children for safe school bus seating. While there is some uncertainty as to whether section 504 of the Rehabilitation Act of 1973 is applicable to FMVSS, NHTSA is concerned about the safety of disabled children in school buses, and has decided to consider amending FMVSS 222 in this regard (55 FR 7346, March 1, 1990).

PROJECT GOALS

In response to this concern, an agency working group was formed with NHTSA staff from Rulemaking, Traffic Safety Programs, Research and Development, the Office of Chief Council and Plans and Policy. This group was charged with reviewing the crash protection and crashworthiness issues associated with the transportion of disabled school children. This group was also assigned the responsibility of developing research and program strategies and options from which task plans could be extracted. The first of these plans resulted in the project reported here.

The purpose of this project was to determine, from an engineering perspective, the state-of-the-art in safety performance standards for wheelchair tie-downs and occupant protection devices on school buses. As part of this effort, the authors of the study, in consultation with the NHTSA working group, have reviewed existing standards and practices from Australia, Canada, Sweden, and the United Kingdom, draft standards from the International Standards Organization (ISO) and the Society of Automotive Engineers (SAE), and the technical literature on this subject published over the last 15 years.

CONCLUSIONS

The authors conclude in this report that:

1. Persons transported in wheelchairs on school buses should preferably be in a forward-facing position.

2. Securement to the vehicle for both the occupant and the wheelchair should be independent.

3. Lap and shoulder belt systems are one means of effective occupant restraint.

4. The most universally adaptable, currently available securement system for wheelchairs relies upon a tie-down for the wheelchair to the floor of the vehicle with straps anchored at four points.

II. POPULATION OF SCHOOLCHILDREN USING WHEELCHAIRS ON SCHOOL BUSES

In the literature on transportation of the physically disabled, no population estimates specifically for children riding in wheelchairs on school buses were found. For this reason the approach to estimating the size of the population of children riding school buses while seated in their wheelchairs was to telephone several state and municipal boards or departments of education to ask for their statistics on the numbers of students transported in wheelchairs and the total school population. From these statistics a very rough range of estimates of the national population of students riding school buses while seated in wheelchairs was extrapolated for the Fall of 1990.

Table 1 shows the areas contacted and their responses. The number of students transported in wheelchairs and the total student enrollment appears under "Whch/Total," while the "Whch%" column shows the population of students using wheelchairs as a percentage of the total enrollment for that district. Table 2 contains the projected Fall 1990 public school population, kindergarten through twelfth grade [1]. Following that are a range of estimates for the national population of students using wheelchairs during school bus transport. Table 3 presents the same estimates based on the total projected public and private school enrollment for the Fall 1990. Two assumptions were used in making these estimates: private school enrollment 1987-1990 increased at the same rate as public school enrollment, and private schools transported the same percentage of their enrollment in wheelchairs as have the public schools. All the districts contacted for statistics were public districts.

The difference between the lowest estimate, 47,549 (Table 2), and the highest estimate, 78,170 (Table 3), of the national population is less than one-tenth of one percent of the projected total U. S. Fall 1990 enrollment. This is not a significant difference given that this population is so difficult to estimate because of the lack of data. At least in the states contacted, statistics on the number of children using their wheelchairs on school buses are not kept at the state level. Only the local school districts, in some cases only the transportation department in the district, keep records of these numbers.

It is to be noted that the last entry in Tables 2 and 3 is a national estimate based on the average of Michigan districts. This is presented as an upper bound number for two reasons. First, with 28 of 57 districts reported, a much more complete estimate can be made for Michigan, than for any other state. Secondly, in Michigan even the children living in institutions for the developmentally disabled are transported to public schools as much as possible, rather than educated on the grounds of the institution. This may not be the case in many other states [2].

TABLE 1

Students Transported in Wheelchairs
Populations for Several Areas
(1989-90 School Year)

Area	Whch/Total	Whch%
Kansas:		
Dodge City	1/9,600	0.010
Topeka	25/15,000	0.167
City of Los Angeles	798/600,000	0.133
Massachusetts:		
Brockton	28/15,000	0.187
Sharon	2/2631	0.076
Michigan:		
Barry	9/7,564	0.119
Berrien	41/31,076	0.132
Branch	10/6,563	0.152
Charlevoix-Emmet	7/8,368	0.084
Clare-Gladwin	11/8,728	0.126
Clinton	13/9,326	0.139
Delta-Schoolcraft	23/9,389	0.245
Dickinson-Iron	5/7,393	0.068
Eaton	38/16,300	0.233
Genesee	160/89,002	0.180
Gogebic-Ontonagon	5/4,880	0.102
Traverse Bay	27/22,082	0.122
Gratiot-Isabella	43/15,333	0.280
Huron	0/6,435	0.000
Ingham	110/51,517	0.214
Kalamazoo Valley	65/33,258	0.195
Kent	228/86,111	0.265
Lapeer	35/14,181	0.247
Livingston	37/19,288	0.192
Macomb	185/117,474	0.157
Marquette-Alger	14/14,806	0.095
Muskegon	73/32,791	0.223
Oakland	368/174,521	0.211
Sanilac	17/8,474	0.201
Shiawassee	16/15,383	0.104
Tuscola	31/12,774	0.243
VanBuren	28/16,688	0.168
Washtenaw	85/39,791	0.214

TABLE 1
(continued)

Students Transported in Wheelchairs
Populations for Several Areas

Area	Whch/Total	Whch%
New Jersey:		
Bricktown	11/9,450	0.116
Freehold Regional H.S.	6/7600 (9-12th grade)	0.079
Toms River	16/15,994	0.100
City of New York	1,223/936,153	0.131
Average of all districts gathered		0.154
Average of Michigan districts		0.168
Average of all districts, treating Michigan as one district reporting 1.68/1000 students in wheelchairs		0.117

TABLE 2

Students Transported in Wheelchairs
Estimated National Public School Population

- o Projected Fall 1990 K-12 public enrollment:
  40.752 million
- o Extrapolating the national population of students transported in wheelchairs from the average of all districts gathered (0.154%):
  62,873
- o Extrapolating the national population of students transported in wheelchairs from the average of all districts gathered, treating Michigan as one district (0.117%):
  47,549
- o Extrapolating the national population of students transported in wheelchairs from Michigan (0.168%):
  68,463

TABLE 3

Students Transported in Wheelchairs
Estimated National Population
Public and Private Schools

- o Projected Fall 1990 K-12 enrollment:
  46.530 million
- o Extrapolating the national population of students transported in wheelchairs from the average of all districts gathered (0.154%):
  71,656
- o Extrapolating the national population of students transported in wheelchairs from the average of all districts gathered, treating Michigan as one district (0.117%):
  54,440
- o Extrapolating the national population of students transported in wheelchairs from Michigan (0.168%):
  78,170

III. WHEELCHAIRS AND SECUREMENT DEVICE DESIGNS

There are many different designs for wheelchairs, wheelchair securement devices, and occupant restraint systems. This chapter provides a general description for several generic types of wheelchairs and devices used for the securement of the wheelchair and its occupant. The performance of some of the wheelchairs and the securement systems under various static and dynamic test conditions is provided in Section IV.

WHEELCHAIR DESIGNS

Wheelchairs come in a variety of sizes, configurations, and constructions. Even though many of the wheelchairs are similar in basic design, there is no precise definition for a standard wheelchair. Some are used strictly for indoor transportation of patients and some are designed for sport participation. In some cases, even three-wheeled scooters and travel carts for children are called wheelchairs. However, a recent study stated that it was the opinion of many International Standards Organization (ISO) committee members that the definition of a wheelchair be restricted to that of the "traditional" wheelchair, and would not include three-wheeled carts and many other types of mobile seating devices being used for technology dependent student transportation [3].

Though the term "wheelchair" may apply to mobile seating devices that are different from each other in many aspects, those currently used for the transportation of disabled students in school buses and vans can generally be classified into three functional groups: manual wheelchairs, battery powered wheelchairs, and special wheelchairs fitted with positioning systems for body support. Design features of these three groups of wheelchairs are provided in the following sections.

Manual Wheelchairs

Most manual wheelchairs have a metal tubular frame with two large rear wheels and two small front casters. A typical design is shown in Figure 1. The rear wheels are generally 24 inches in diameter with wire spokes and hand rims. The front casters are usually 8 inches in diameter but can be larger. Rear tires are either solid or pneumatic, made of rubber or polymer. The arms of the wheelchair can be full-length or desk-length, fixed or removable to provide ease of access. The footrests can also be fixed, adjustable, swing-away, or detachable. Seat depth is generally 16 inches with widths of 14, 16, and 18 inches for slim narrow, adult narrow, and adult models, respectively. For wider models, seats can be as wide as 22 inches. Some models have a reclining seat back that can be adjusted from 90 to 180 degrees (from a vertical to a horizontal position). The weight of the conventional manual wheelchairs ranges from 40 to 60 pounds. The dimensions of a 85th percentile manual wheelchair represented by a Everest & Jennings model are given in Figure 2 [4].

The manual wheelchairs have a hand brake to hold the wheelchair in position on level surfaces. Most can be folded for easy handling when not occupied. Some are equipped with a seat belt to hold the occupant in the wheelchair when in general use.

Some manual wheelchairs are of light-weight design. These wheelchairs generally adopt a modern style, as typified by the wheelchair shown in Figure 3. They usually have molded mag-style rear wheels and often use light-weight materials such as aluminum, magnesium, and composites. The reduction in weight helps to improve the rollability of the wheelchairs. The weight of this type of wheelchair ranges from 30 to 40 pounds.

Wheelchairs require adequate space to maneuver. For straight travel an aisle width of 36 to 38 inches is recommended for most wheelchairs [4]. The spaces required for 90 and 180 degree center pivot turning and 180 and 360 degree reduced wheel pivot turning of a 90th percentile manual wheelchair are shown in Figures 4 and 5 [4].

Motorized Wheelchairs

Motorized wheelchairs are basically manual wheelchairs equipped with electric motors and storage batteries for propulsion. A motor control system operated by a joystick is provided for the occupant to command the wheelchair. Because of the added weight, the motorized wheelchairs have stronger frames and components than those used in the manual wheelchairs. The rear wheels are smaller, typically 20 inches in diameter, than those of the manual wheelchairs. The tires are wider and have a deeper tread design for traction. A typical motorized wheelchair is shown in Figure 6.

The motorized wheelchair is capable of speeds up to 6 miles per hours on level surfaces and can be operated for several hours on a single battery charge. They can climb ramps and may have several forward and reverse speeds. Depending on how it is equipped, a motorized wheelchair can weigh close to 200 pounds with the batteries. Some motorized wheelchairs can be folded and placed in the rear trunk of a car.

Three-wheeled scooters have many different designs and are all battery-powered. The wheels are smaller and wider than those of the motorized wheelchairs. Some scooters are front-wheel drive and some are rear-wheel drive. Some can also be folded or disassembled without tools for storage in the car trunk or in the bus. The three-wheeled scooters are most commonly used by people with impaired mobility. Due to their design, they are inherently unstable and may not be suitable for the transportation of disabled students in school buses. A typical three-wheeled scooter is shown in Figure 7.

Special Wheelchairs

Wheelchairs designed especially for more severely disabled persons are equipped with positioning systems for body support and comfort. Figure 8 shows a typical special wheelchair. The positioning system can provide many adjustments to meet individual requirements. This type of wheelchair can be customized using optional hardware components to accommodate the user's unique needs. Some designs used for severly disabled children even allow the wheelchairs to "grow" as the children grow. Some special wheelchairs are equipped with various types of harness systems for the restraint of different segments of the body.

Depending on how it is equipped, a special wheelchair used for an adult can be much heavier than a manual wheelchair. These wheelchairs are most often manually propelled. The occupant of this type of wheelchair usually requires assistance to operate the wheelchair.

WHEELCHAIR SECUREMENT DEVICES

There are many designs for the securement of wheelchairs in a vehicle. Some are tailor made to meet special requirements. However, most of the wheelchair securement systems can generally be grouped into five generic types: T-bar, wall mounted rim pin, floor mounted rim pin, fender brackets, and cargo belts.

The T-bar system (Figure 9) consists of a screw rod and a straight bar. The straight bar is placed on the lower horizontal frame of the wheelchair and holds the wheelchair in place by tightening the screw rod to the floor of the vehicle. This system is simple and the wheelchair can be placed in any direction. As this system is out of the reach of the wheelchair occupant, assistance for operation is required.

The wall mounted rim pin system (Figure 10) uses a rod, or pin, placed between the wall mounted U-shaped brackets to hold the rims of the large rear wheels at axle height. An alternate form of this system has spring-loaded clamps which automatically lock the wheel rims when the wheelchair is backed into them. Since the brackets or clamps are mounted on the wall of the vehicle, the wheelchair must be placed facing sideways. The manual system requires assistance for operation.

The floor mounted rim pin system (Figure 11) is similar to the wall mounted rim pin system except that the clamps or U-shaped brackets are mounted to the floor of the vehicle. This system holds the wheelchair at the bottom of the wheel rims. With this system there is no restriction to the orientation of the wheelchair. Because this securement device can not be reached by the wheelchair occupant, assistance for operation is required.

The fender brackets system (Figure 12) has brackets mounted either to the wall of the vehicle or to posts installed on the floor of the vehicle. To secure the wheelchair these brackets are lowered onto the large rear wheels and hold the top of the wheels in position. Though operating parts of this system can be reached by the wheelchair occupant, the spring-loaded mechanisms may require considerable force for operation.

The cargo belt system (Figure 13) uses adjustable belts with buckles for quick connection to structural members of the wheelchair and track fittings mounted on the vehicle wall or floor. The wheelchair is generally secured at four structural points. With this system the wheelchair is placed either along or perpendicular to the vehicle axial direction. The securement belts can not be fastened and released by the wheelchair occupant. The cargo belt system can accommodate motorized wheelchairs.

OCCUPANT RESTRAINT SYSTEMS

The wheelchair occupant can be restrained to the wheelchair or secured to the vehicle. Restraining the occupant only to the wheelchair does not protect him in a crash if the frame of the wheelchair, or the securement system holding the wheelchair to the vehicle, fails. Securing both the occupant and the wheelchair independently to the vehicle normally provides the occupant with greater crash protection. This type of occupant securement system has three forms: lap belt, lap and shoulder belt, and harness belt.

The lap belt system is shown in Figure 14. It provides pelvic restraint to the occupant. The belt passes around the occupant and fastens to latches installed on the floor of the vehicle or attaches directly to the rear tie-down belts securing the wheelchair to the vehicle. The belt is adjustable and has a buckle for quick engagement and release.

The lap and shoulder belt system has a lap belt for pelvic restraint and a shoulder belt for torso restraint as shown in Figure 15. The upper anchor point of the shoulder belt is located on the wall of the vehicle, or on a special bracket attached to the floor of the vehicle, and can be placed on either side of the occupant, depending on the arrangement of wheelchairs in the vehicle. The lower end of the shoulder belt can be attached directly to the floor of the vehicle or to the rear tie-down belt securing the wheelchair.

The harness belt system generally consists of one lap belt and two shoulder belts as shown in Figure 16. The lower ends of the shoulder belts can be attached either directly to the floor of the vehicle or to buckles fastened to the rear tie-down belts for the wheelchair. The upper ends of the shoulder belts are anchored to the wall of the vehicle.

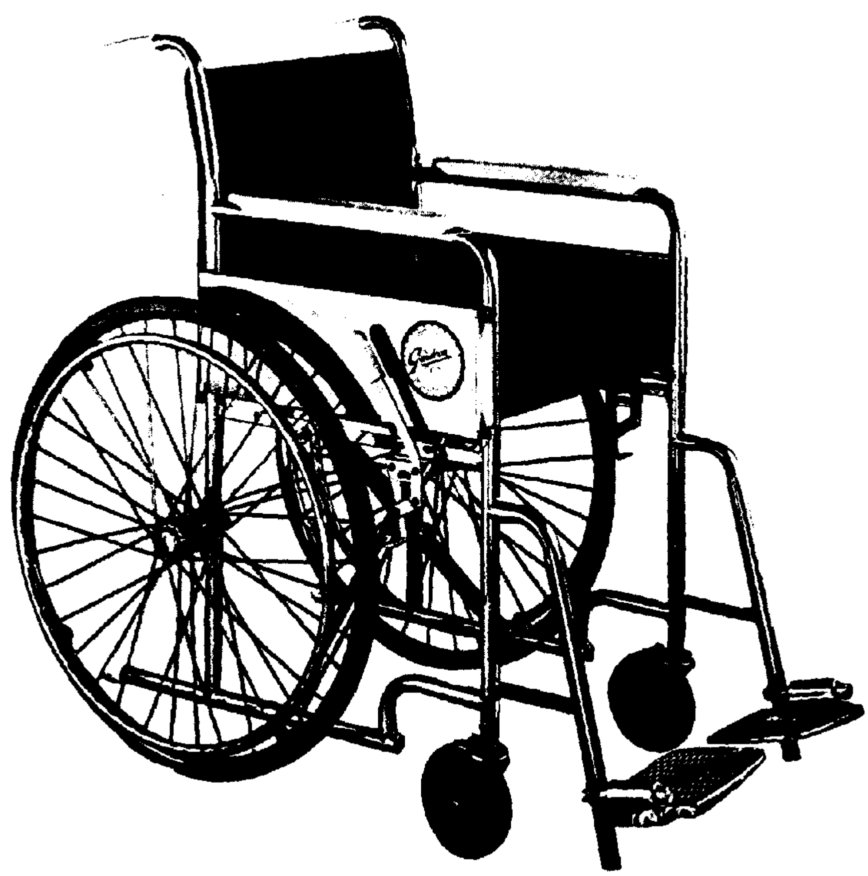


Figure 1. Manual wheelchair of traditional style.

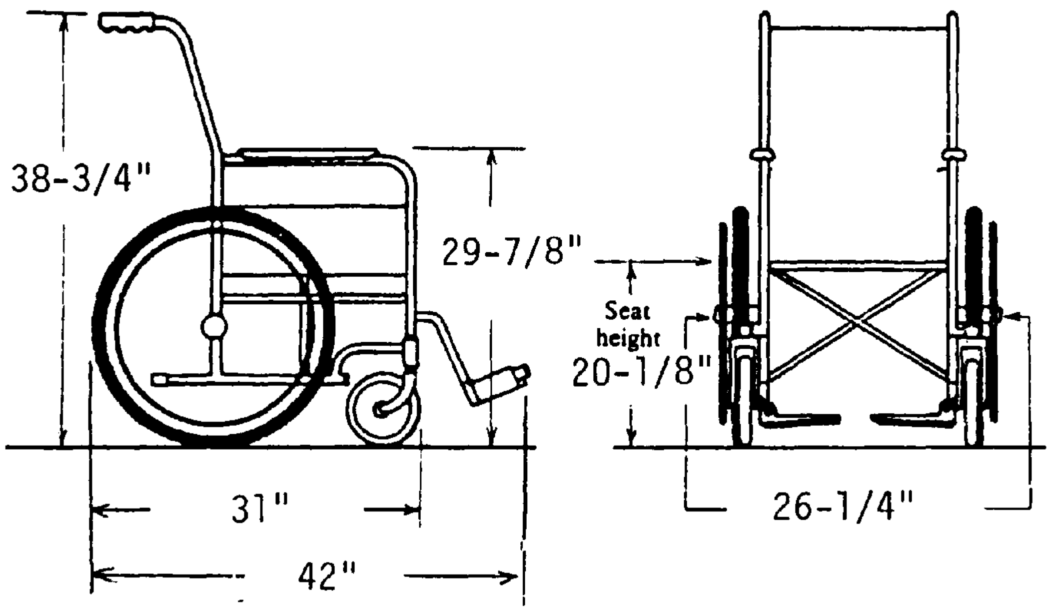


Figure 2. Dimensions of a typical manual wheelchair.

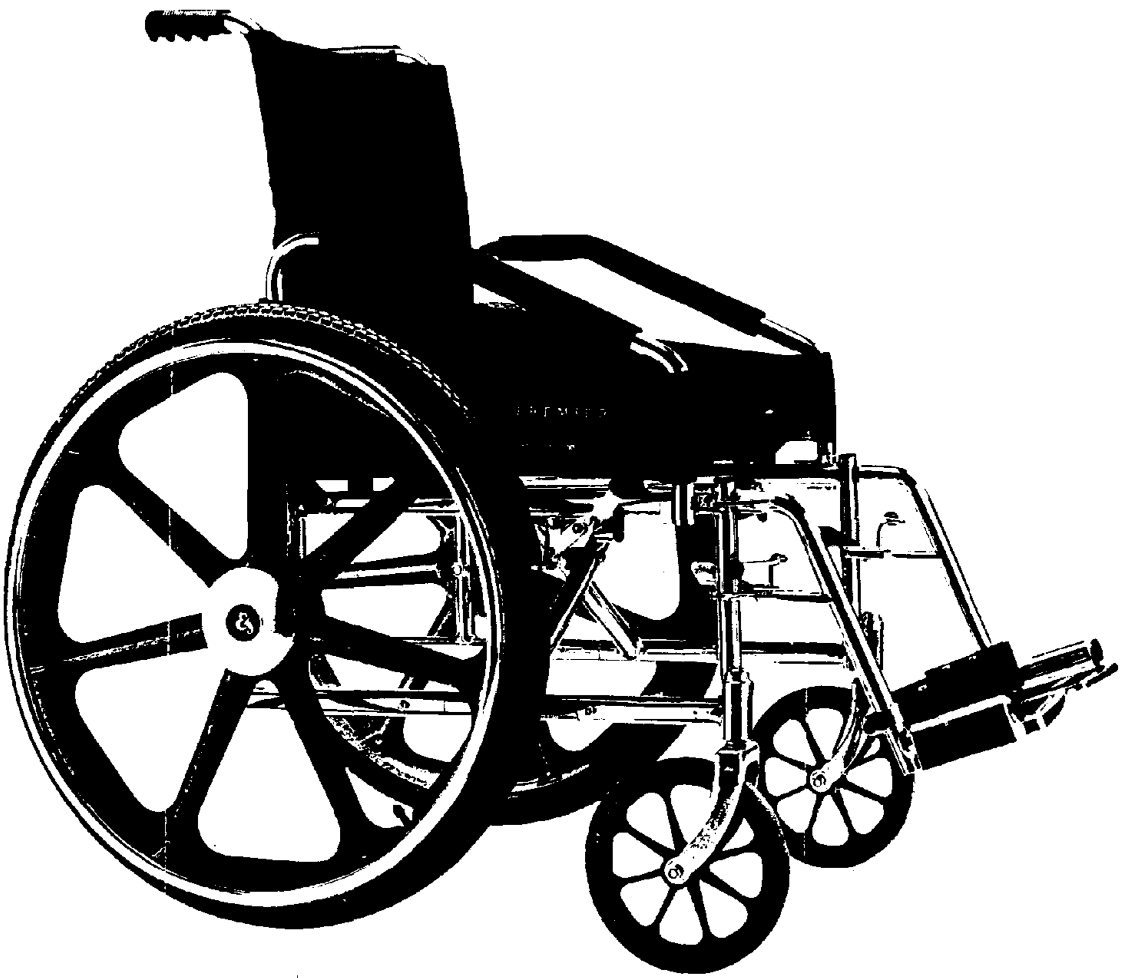
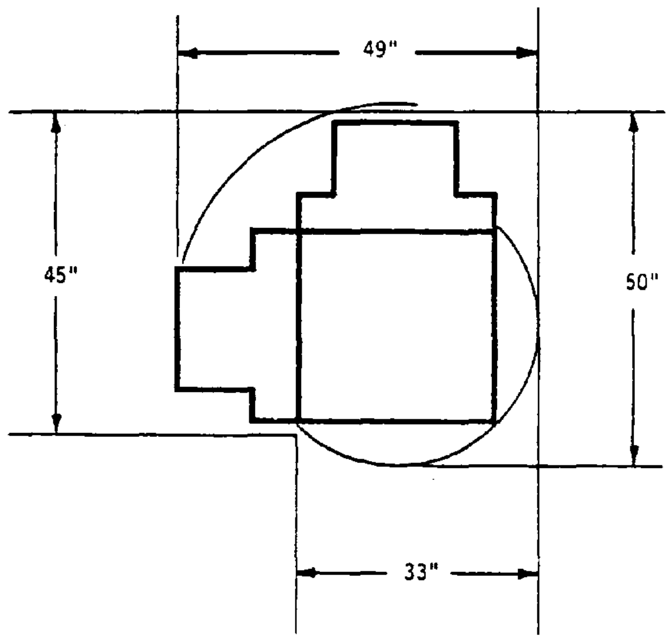


Figure 3. Manual wheelchair of modern style.



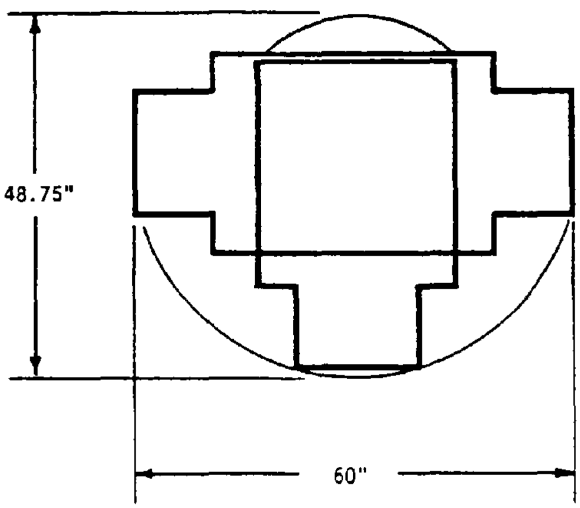


Figure 4. Space required for 90 and 180 degree center pivot turning.

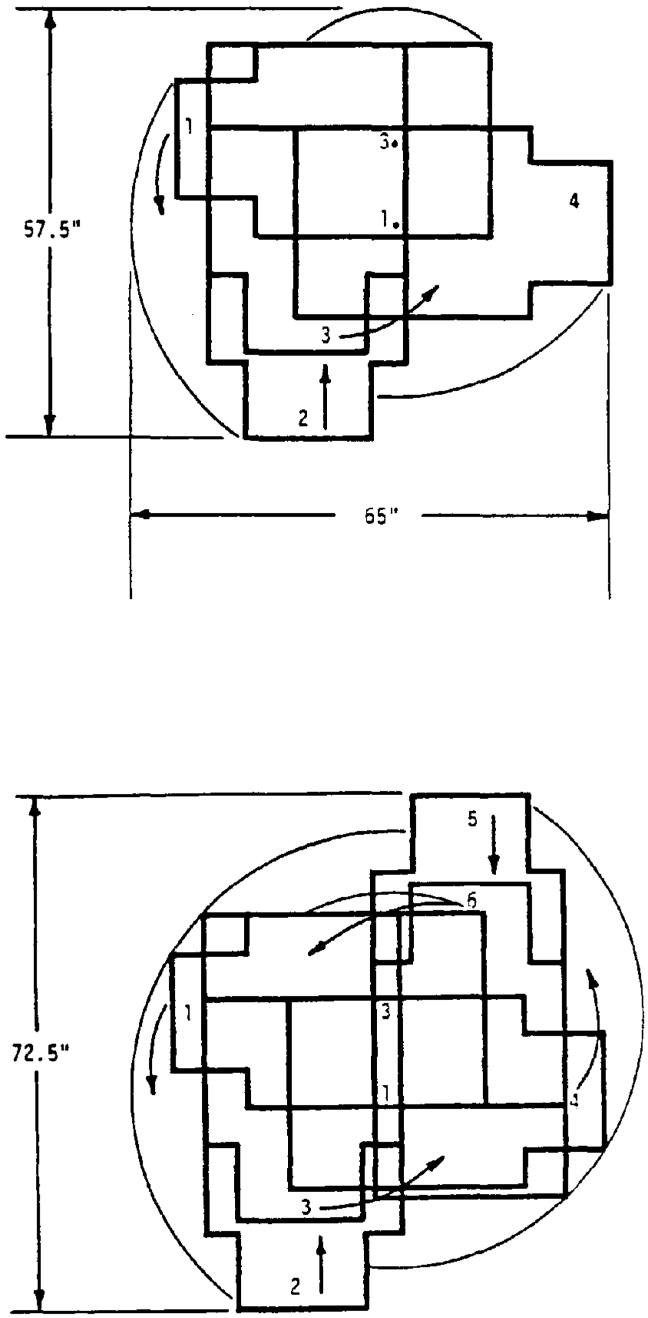


Figure 5. Space required for 180 and 360 degree reduced wheel pivot turning.

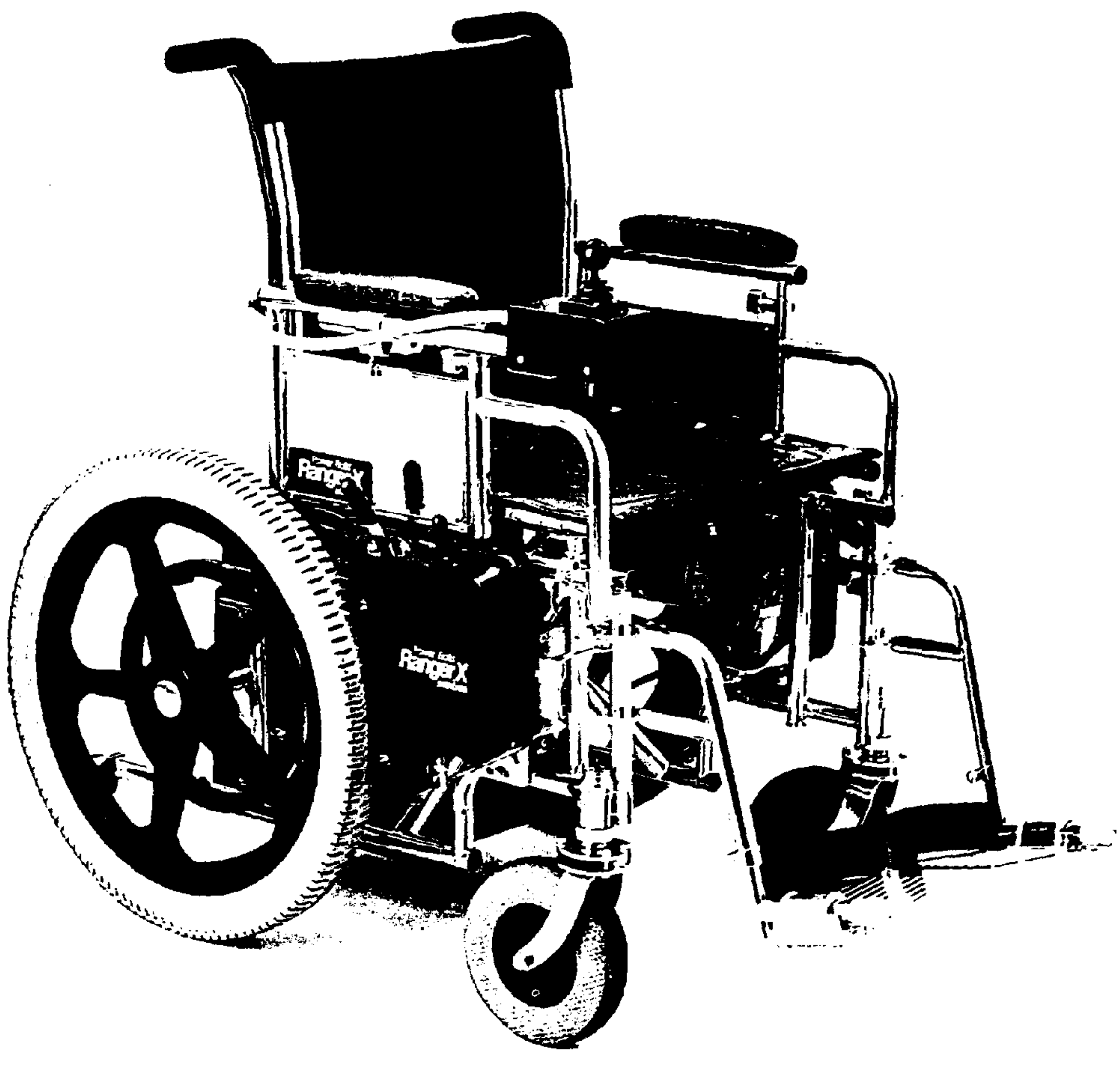


Figure 6. Motorized wheelchair.

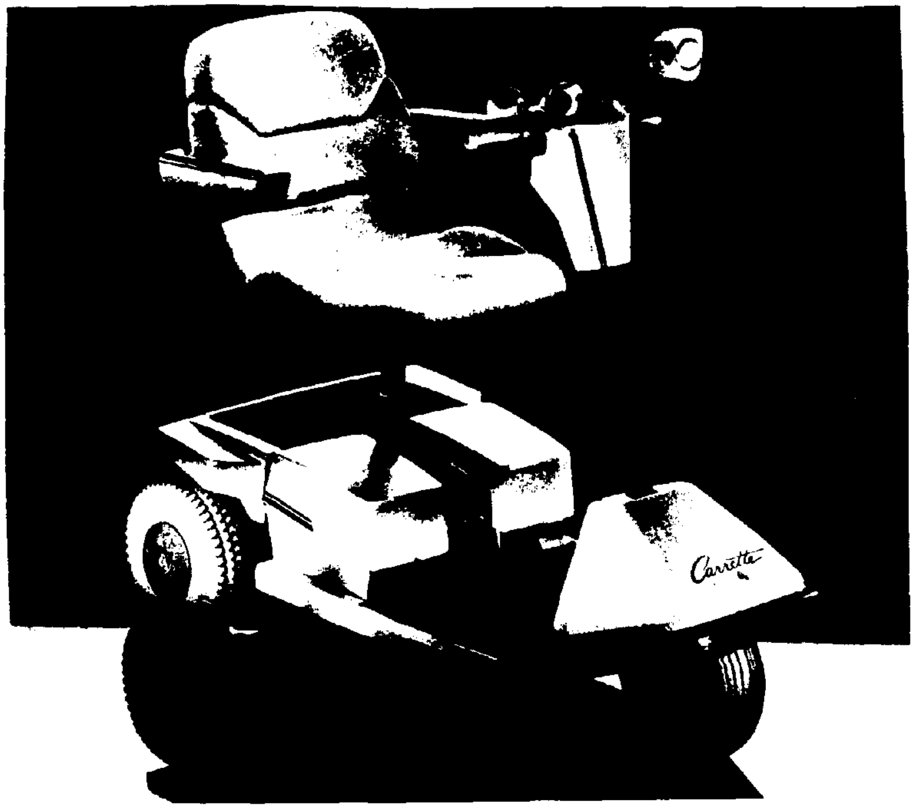


Figure 7. Three-wheeled scooter.

Figure 8. Wheelchair with positioning system.

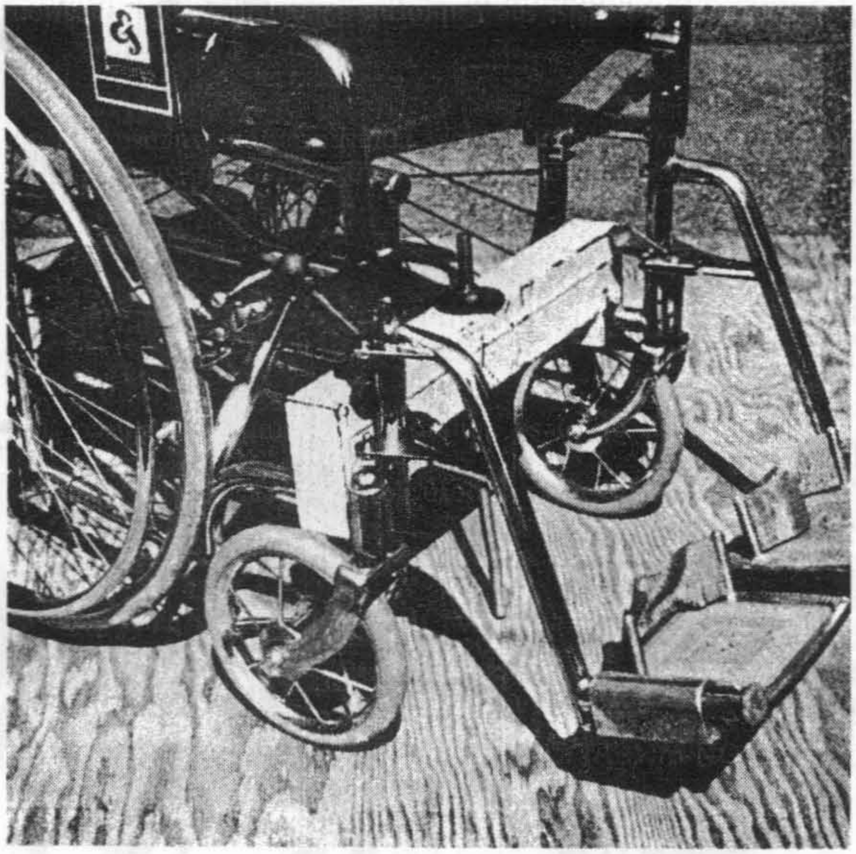


Figure 9. T-bar securement system.

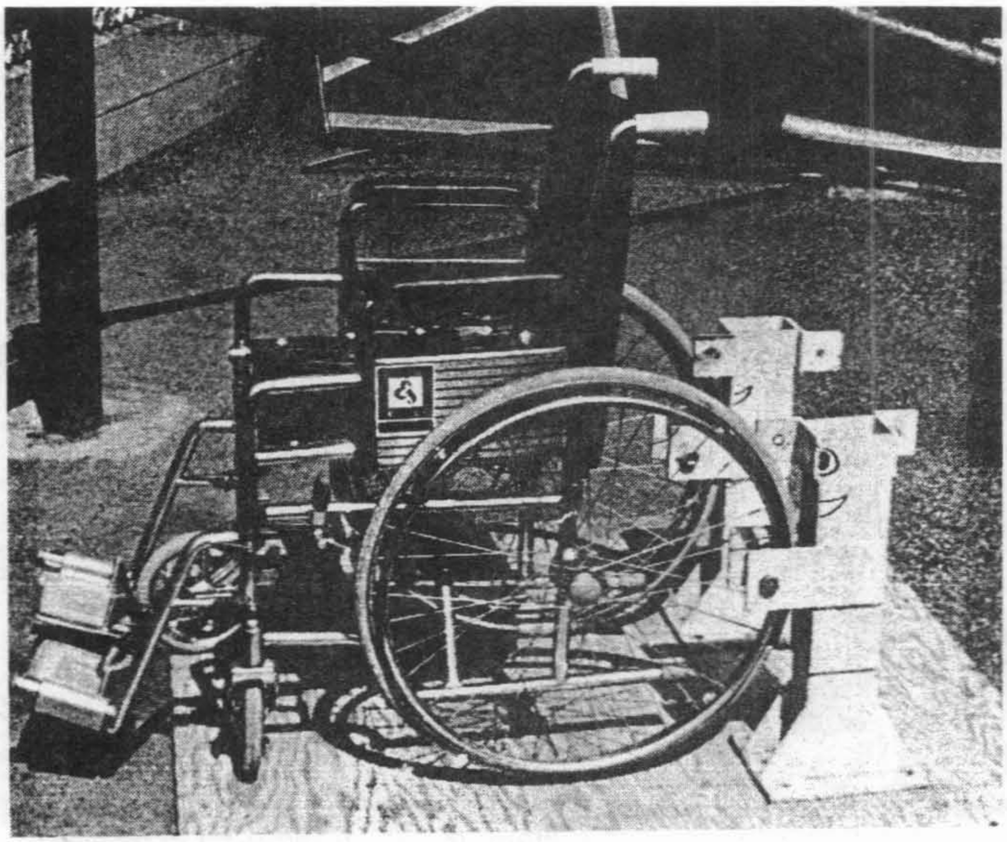


Figure 10. Wall mounted rim pin securement system.

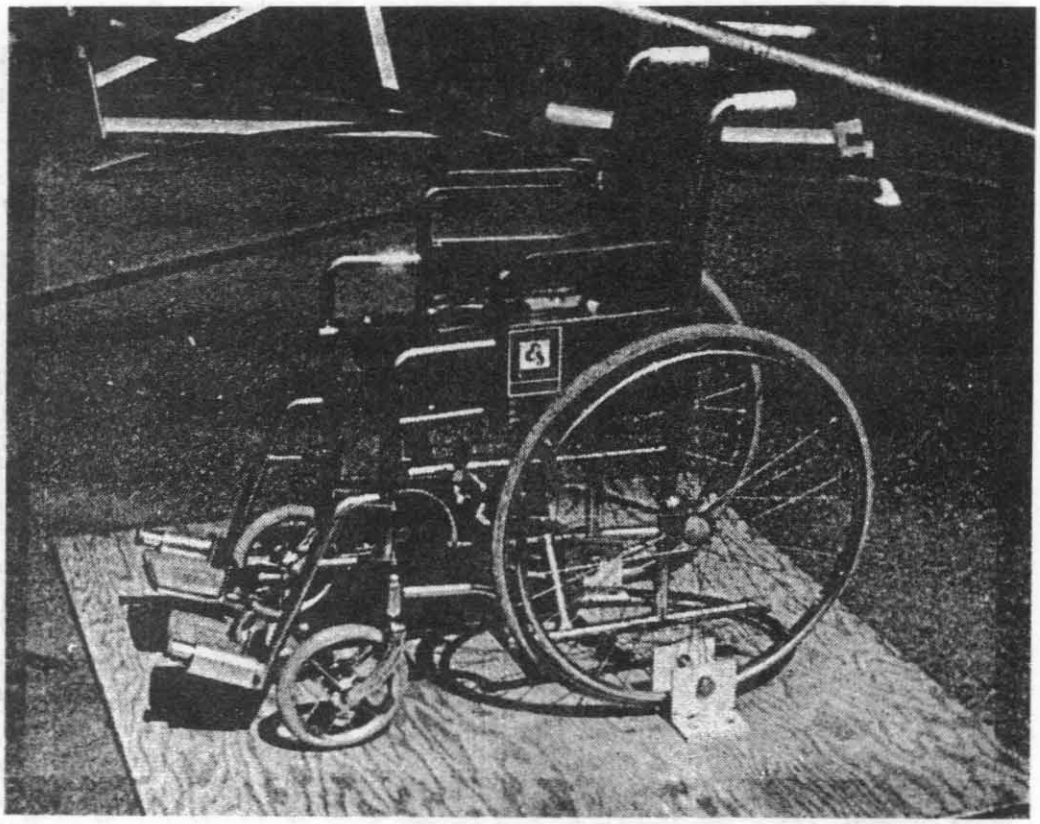


Figure 11. Floor mounted rim pin securement system.

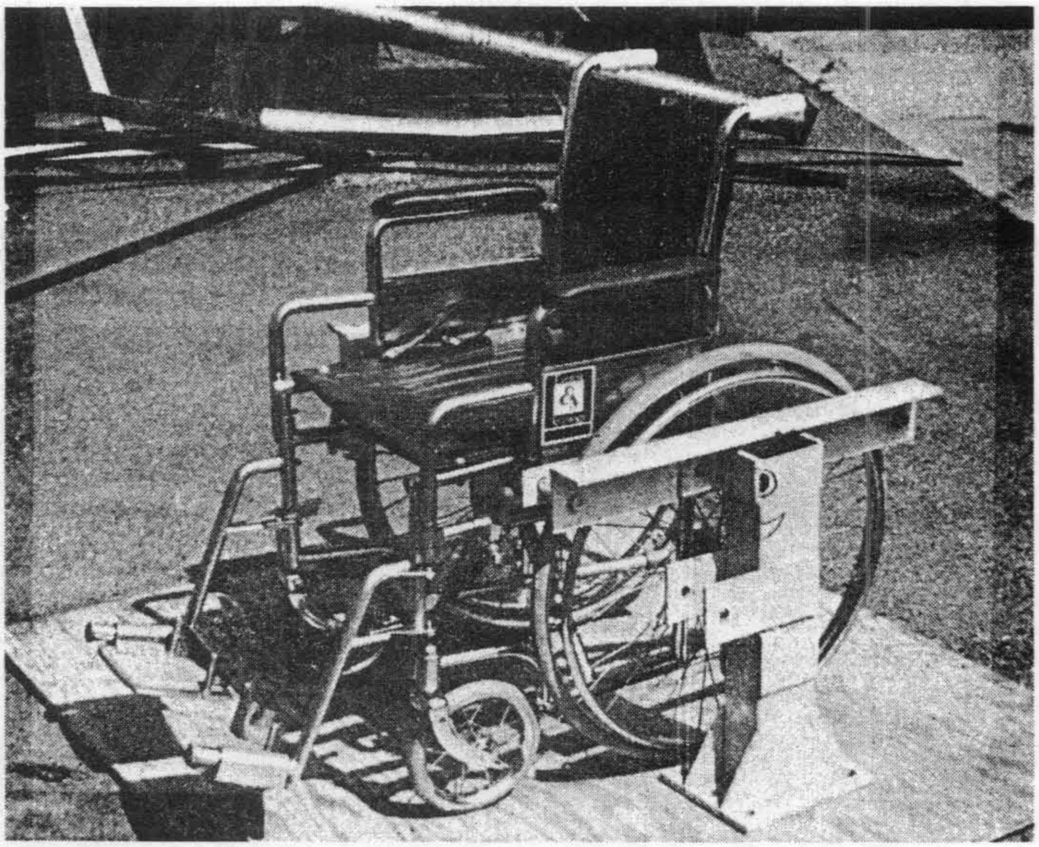


Figure 12. Fender brackets securement system.

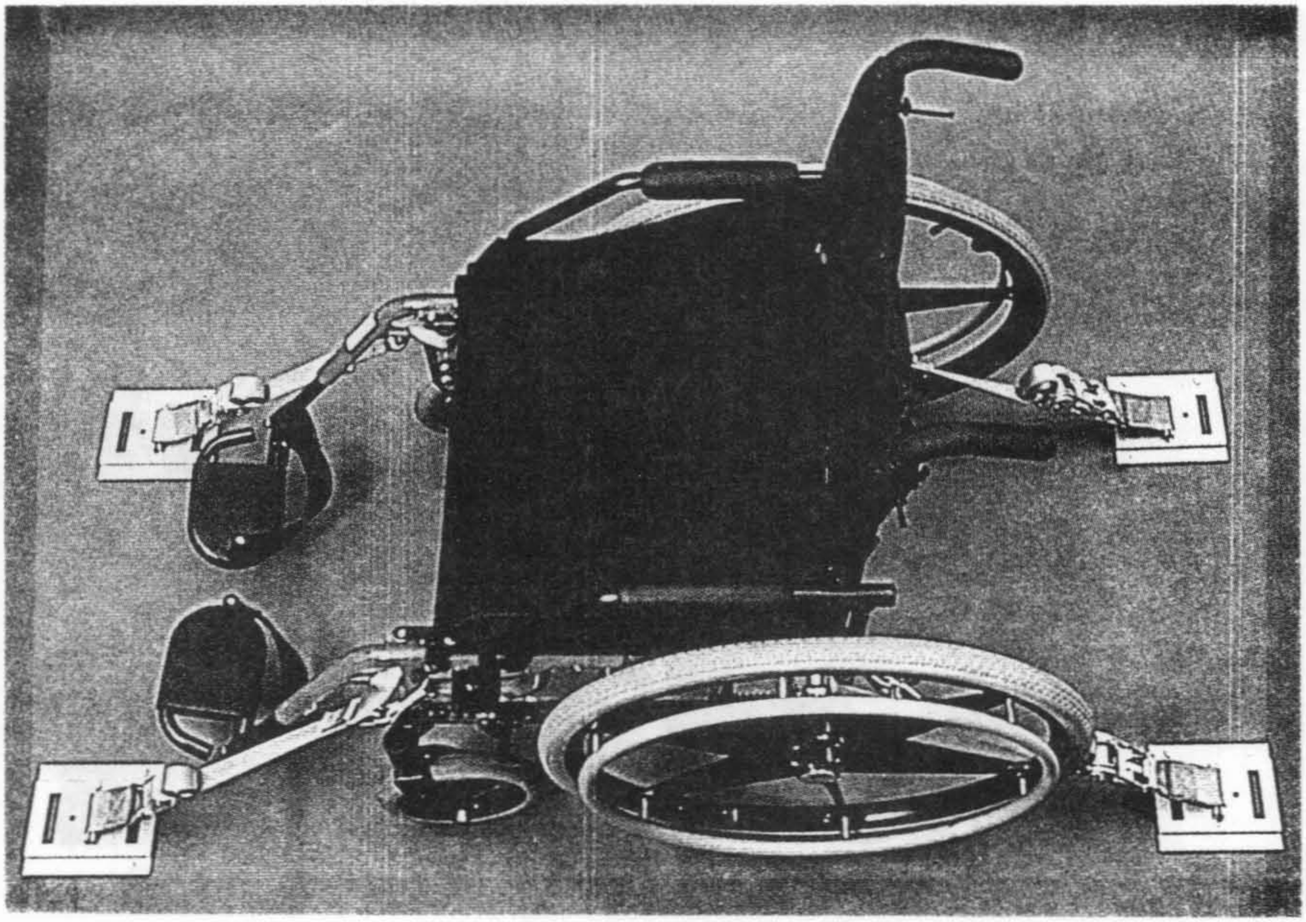


Figure 13. Cargo belt securement system.

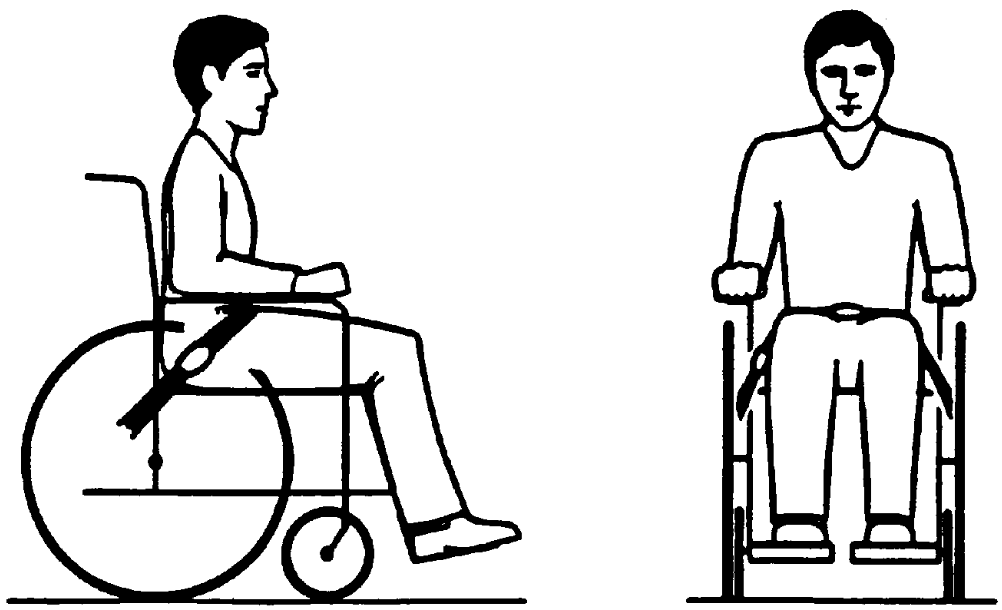


Figure 14. Lap belt system.

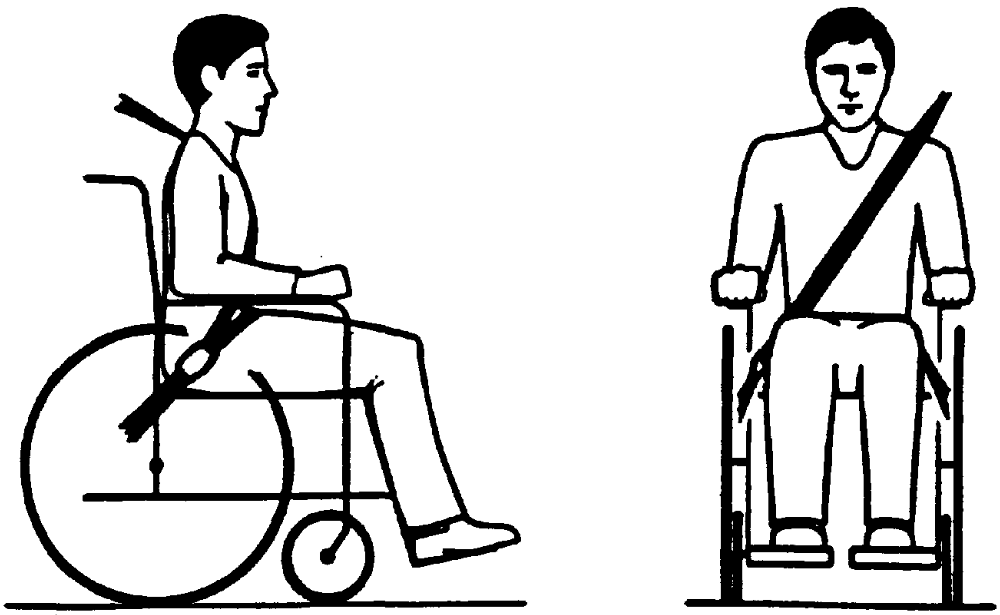


Figure 15. Lap and shoulder belt system.

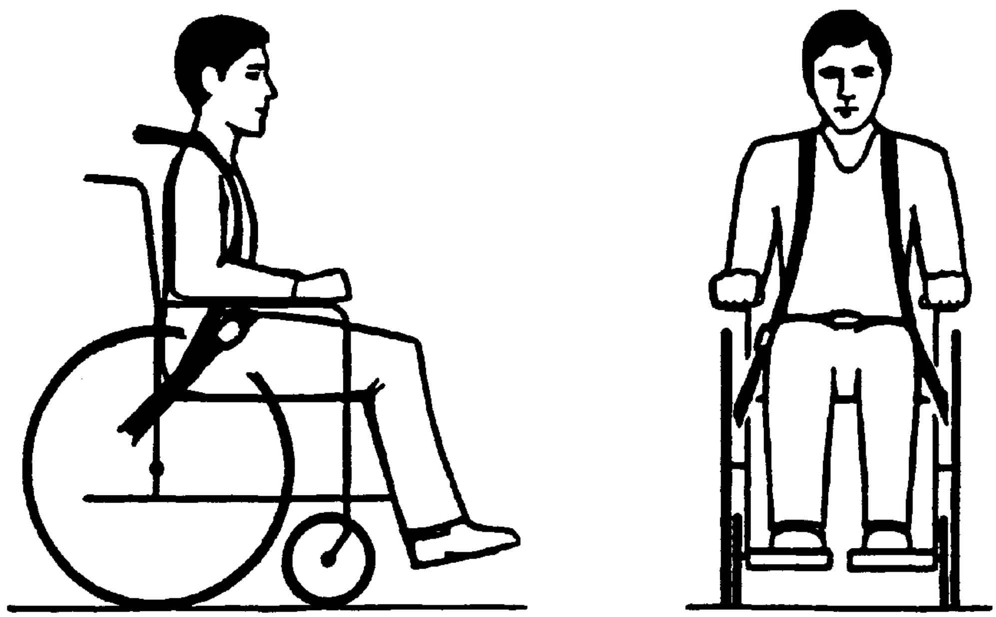


Figure 16. Harness belt system.

IV. RESEARCH ON WHEELCHAIR SECUREMENT AND OCCUPANT RESTRAINT SYSTEMS

Research and test reports gathered reveal that many studies have been conducted since the mid 1970's to evaluate and develop wheelchair securement and occupant protection systems. Most of these studies were sponsored by federal or state agencies. This section presents a brief summary of these studies. The studies reviewed are presented in chronological order.

Student Wheelchair Transportation - Loading and Securement, State of California business and Transportation Agency, Division of Mass Transportation, August 1974.

This study was performed to assist the California Department of Education in developing specifications for school buses carrying wheelchairs. The study addressed wheelchair loading and securement equipment. The equipment was evaluated based on engineering judgement.

Wheelchair securement systems investigated include those that anchor the rear wheels to the vehicle with rim pin or rim clamp, and those that anchor the frame of the wheelchair to the vehicle with T-bar, chains or belts. The study found that all devices which locked through the rear wheels provided a loose securement and would allow some movement of the wheelchair. The effectiveness of many wheelchair securement devices that attach to the rear wheels depends on the strength of the wheels. The study found that the four belt system, two belts connected to the rear axle and two belts connected to the front casters, provided positive wheelchair securement, even in the case of wheel collapse. The four belt system was considered to be highly adjustable to various size wheelchairs.

The study also examined three types of restraint systems for the wheelchair occupant: belt to wheelchair, belt to vehicle, and belt to both wheelchair and vehicle. The belt to chair arrangement is used primarily to prevent the occupant from falling out of the wheelchair during loading and unloading. Restraint of the occupant during transit depends on the integrity of the wheelchair and its securement. In the belt to vehicle arrangement the occupant is secured by safety belts to the floor or sidewall of the vehicle. The study emphasized the importance of proper securement of the wheelchair in this type of arrangement to prevent the occupant from sustaining impact with the wheelchair in the event of an accident.

The study recommended, among other suggestions, the adoption of statewide hardware component specifications for wheelchair and occupant securement and action to obtain physical test data on the hardware components. The study advocated crash tests of prototype vehicles containing simulated wheelchair students to obtain body reactions during the test.

<u>Estimation of the Size of the Transportation Handicapped Population</u>, Report No. 75-116, Contract No. DOT-UT-50030, ABT Associates Inc., October 1975.

This study was performed for the Urban Mass Transportation Administration (UMTA), U.S. Department of Transportation. The study examined the characteristics of the market for services for the urban transportation of handicapped persons at the national level. Available studies and supporting data were reviewed to estimate the number of persons regarded as transportation handicapped. The study found that information on mobility and travel behavior patterns of the transportation disabled to be extremely limited.

The study defined the transportation disabled to be: all persons with mobility limitations due to chronic conditions, the acutely disabled, and residents of a number of types of institutions. Based on this definition, the total transportation disabled population was estimated to be 5,526,000 in 1975. This number consisted of 244,000 under 18 years of age, 2,383,000 between 18 and 64, and 2,899,000 over age 64. ABT stated that the estimation procedure established for this study could be employed to obtain rough approximations of the transportation disabled population in any metropolitan area using only Census data. The study also provided a brief analysis of travel patterns of the transportation disabled.

An Evaluation of Several Commercially Available Automotive Wheelchair Restraints, Project 3671, Contract #V5244P-1523, Texas A&M University, November 1978.

This study was conducted for the Veterans Administration to evaluate the performance of wheelchair restraints used to secure a wheelchair and its occupant in a passenger motor vehicle. A limited human factors evaluation was also made to determine the ability of a disabled person to use these restraint systems.

Static tests were performed for a number of wheelchair restraint devices considered to be representative of the different design concepts being marketed at the time of this study. Restraint devices tested include both manually operated and electrically powered. Devices tested were: Medicab T-Bar clamp, Collins W-40 and W-49 rear wheel rim clamps, General Teleoperators fender clamp, Speedy Wagon vertical side clamp and electric restraint, Para-Quad electric restraint, Fred Scott restraint, and Medicab restraint. The wheelchair used for these tests was the Everest and Jennings "Universal" manual model weighing 50 pounds. The tests were based on the test requirements specified in FMVSS No. 207 and

FMVSS No. 210 for seat belts, seat structures, and seat-to-vehicle attachment components.

The static tests included: horizontal loading of a force through the center of gravity of the wheelchair; a horizontal force applied to the seat back at the upper crossmember to produce a moment loading about the seating reference point; a horizontal force applied through the center of gravity of the wheelchair together with a horizontal force applied to the seat belt fastened around a pelvic body block; and a force applied through the combined center of gravity of the wheelchair and the 50th percentile anthropomorphic dummy in the direction parallel to the surface of the platform on which the wheelchair was restrained. The human factors evaluation employed two paraplegic subjects to test several wheelchair restraints to determine suitability of the devices to be used by an unassisted paraplegic. The restraints chosen were those which could conceivably be used by a person intending to drive a vehicle while seated in a wheelchair.

The study concluded that none of the wheelchair restraint devices evaluated performed satisfactorily. The wheel rim type of restraint was considered to be totally inadequate, while the T-bar clamp was judged to come close to satisfactory performance. It suggested that:

1. appropriate performance standards for wheelchair restraints should be adopted and reflected in state and federal law,

2. adequate installation and operating instructions should be required to accompany all wheelchair restraints sold,

3. all wheelchair restraint devices sold should include a satisfactory seat belt as an integral part of the wheelchair restraint system, and

4. additional dynamic tests be required before final approval is given to a particular wheelchair restraint system.

Impact Testing of Restraint Devices Used with Handicapped Children in Bus Seats and Wheelchairs, Final Report, UM-HSRI-78-52, Highway Safety Research Institute, University of Michigan, November 1978.

This study was performed for the Department of Public Instruction of the State of Wisconsin to evaluate, through sled impact tests, the effectiveness of restraint systems used for the transport of disabled children in wheelchairs and bus seats.

A series of 16 sled tests were conducted using an impact pulse having a deceleration of 16 g's and a velocity differential of 20 mph. Eight tests involved dummies seated in wheelchairs in forward facing and side facing orientations for head-on and 33 degree oblique impacts. Another eight tests involved dummies seated on bus seats for head-on and 33 degree oblique impacts.

Two sizes of Everest & Jennings wheelchairs were used in the tests: the Tiny-Tot Universal model for a six-year-old dummy, and the Junior Premier model for a 5th percentile female dummy. The dummy was restrained to the wheelchair by a Collins Saf-T-Straint padded belt in all tests. The restraint belt was wrapped around the wheelchair back just above the armrests and buckled in front. Wheelchair restraint systems tested included the Collins Saf-T-Lock which was bolted to the bus floor and held the wheelchair by the rear wheel rims, and the Rupert Industries safety belts which were anchored to the bus wall and wrapped around the front of the wheelchair.

In the tests with the dummy restrained to the bus seat, two seats were bolted to the sled with a distance of 27 inches from the back of the rear seat to the back of the front seat. The dummy was restrained in the rear seat for all tests with belt, harness, or restraint vest.

The study found that many of the restraint systems tested were generally ineffective in protecting the children in the event of a school bus collision. Systems that provided adequate protection for children in forward-facing wheelchairs and head-on impacts were found to be ineffective when the wheelchairs were placed sideways in buses. In six of the eight bus seat tests the dummy's head struck the back of the seat in front.

The study pointed out that wheelchairs were not designed with vehicle transportation in mind, and until appropriate structural modifications were made, one must consider their structural weakness in providing for restraint and occupant protection. It indicated that most restraint devices had not been adequately impact tested and that the designers of these restraints systems had little understanding of basic crashworthiness design concepts. The study recommended that restraint systems be dynamically tested under realistic impact conditions prior to marketing and/or use.

Dynamic Testing of Restraint Systems and Tie-downs for Use with Vehicle Occupants Seated in Powered Wheelchairs, Interim Report, UM-HSRI-80-61, Highway Safety Research Institute, University of Michigan, August 1980.

This study was conducted for the Massachusetts Rehabilitation Commission to evaluate the effectiveness of restraint systems for powered wheelchairs and their occupants. This interim report described 22 of 30 sled tests completed at the time of the report. Of these 22 tests, one was for a side impact, one was for a 45 degree impact, and the remaining were for frontal impacts.

All tests were conducted using a rectangular deceleration pulse of 16 g's for an impact velocity differential of 20 mph. Each test used an Everest & Jennings Model 3P powered wheelchair frame with appropriate masses attached to simulate a complete powered wheelchair. A 50th percentile male dummy was used as the wheelchair occupant. Wheelchair tie-down systems tested included: rim pin, T-bar, power lock-down, 3- or 4-point Aeroquip straps, and a lap belt anchored to the vehicle floor encircling both the chair and the occupant with a single belt. Occupant restraints used were lap belt, chest belt, and various combinations of lap and chest belts.

The tie-down system by Creative Control, Inc. was found to provide the most effective wheelchair securement. The Aeroquip straps were also found to provide good wheelchair securement for frontal impacts. Belt systems by Bud and Falcon Industries offered good occupant restraint when used with a chair lap belt and when the wheelchair is effectively secured by other means.

The study revealed materials and hardware in use for securing wheelchairs generally did not have sufficient strength to withstand the forces generated in a crash. However, the wheelchair was found to have sufficient strength to be secured if tie-downs were place at appropriate points. The study suggested that for occupant crash protection, the wheelchair should be secured independent of the occupant restraint.

The Need for Wheelchair Fastening Equipment in Rail Rapid Transit, Issue Paper, Alan J. Warshawer Associates, October 1980.

This issue paper was prepared for the UMTA under the research and development plan for improving transit accessibility for the elderly and disabled. This study examined the need for wheelchair fastening equipment for rail rapid transit vehicles. The following three topics were addressed in this study:

1. Current travel by wheelchair users on rapid rail transit systems.

2. The force envelope (acceleration, braking, and lateral "g" forces) of the transit systems.

3. The stability and holding power of current wheelchairs.

The study presented anecdotal evidence from actual experiences of wheelchair users in three (MARTA of Atlanta, BART of San Francisco/Oakland, and WMATA of Washington D.C., all considered accessible to wheelchair users) of the ten operating rapid rail transit systems. Most wheelchair users stated that securement equipment was not necessary for rail rapid transit vehicles and that they felt it was undesirable and would not use it. The consensus among wheelchair users interviewed in this study was that they would learn how to overcome forces generated by the movement of a rail vehicle after a brief training session or a few actual trips. The study found no reported case of injury to a wheelchair user or to another passenger due to wheelchair movement in a transit vehicle in the three transit systems accessible to wheelchair users.

The study examined the envelope of the "g" forces of transit operations that acted on the wheelchair. These forces were generated by acceleration, braking, and track curves and were elements of transit design. The study found that all U.S. transit systems except CTA (Chicago) were within the force envelope of the accessible systems. The study inferred that since accessible systems were transporting wheelchair users effectively without wheelchair tie-down equipment, all systems except CTA had force characteristics suitable for travel by wheelchair patrons without tie-down equipment in normal operation.

The study found no specific information available on the stability of wheelchairs for rail rapid transit travel. Based on test data from bus studies conducted by Texas A&M University and by CALTRANS, the study inferred that wheelchairs would not lose stability until forces in excess of 0.19 g were exerted. Since this level of force was found to be greater than the maximum force exerted in normal rapid rail operations and emergency brake applications, the study concluded that there was no need for tie-down equipment to provide wheelchair stability.

<u>Crash Protection Systems for Handicapped School and Transit Bus Occupants, Volumes I to V, Interim Report</u>, DOT HS-805-821 to DOT HS-805-825, Minicars, Inc., December 1980.

This study was conducted for the National Highway Traffic Safety Administration (NHTSA), U.S. Department of Transportation. The study included:

1. state-of-the-art survey of the equipment, practices and procedures used by operators of school and transit busses for the transportation of disabled passengers,

2. analysis and evaluation of available accident data involving school and transit buses, and

3. development of deceleration crash pulses for full-scale buses to be used for sled tests in a follow-up study.

The survey revealed that approximately 6.6 percent of the U.S. population was disabled in some way. About 3 percent of these persons were confined to wheelchairs. The report stated that, according to research conducted at Wayne State University, no existing wheelchair securement system was able to provide adequate protection for disabled passengers on buses. The study found that performance standards for the securement devices and standards on crash protection for bus passengers were almost nonexistent. Through the survey the study also defined desirable characteristics of transportation equipment for the disabled.

From accident data the study found that frontal impacts (11, 12, and 1 o'clock directions) accounted for the majority of the fatal and serious bus accidents and that single vehicle rollover and rollover after initial impact were involved in a large percentage of the fatal bus accidents. However, the study could not find a single case for which a wheelchair occupant suffered a serious or fatal injury. The primary components of the bus which caused injuries to the passengers were seat backs, stanchions, windows and structural deformation resulting from the accident.

To develop the deceleration crash pulses eight buses were tested under this study. These buses were subjected to frontal impact with a stationary barrier at speeds ranging from 15 to 30 mph. After the frontal tests were completed, five of these buses were subjected to a second test for either rear or side impact. In these tests, dummy trajectories and injury levels were also measured. Each bus had up to seven instrumented dummies on board. The wheelchairs used in the tests were the standard Everest & Jennings manual wheelchairs (Model T8A) representative of 85 percent of the wheelchairs in use at the time of this study. These wheelchairs were placed at various locations and in various orientations in the buses and secured by a variety of commercially available wheelchair securement systems. Each occupant was restrained to the wheelchair with a lap belt.

Crash Protection Systems for Handicapped School Bus Occupants, Volumes I to III, Final Report, DOT HS-805-826 to DOT HS-805-828, Minicars, Inc., March 1981.

This study was a continuation of the research program for the National Highway Traffic Safety Administration described above. In this study the work was concentrated primarily on the sled test parametric investigation portion of the program. The objective of this portion of the program was to establish the influence of various characteristics of crash protection systems on the effectiveness of available crash protection. Bus crash pulses developed in the previous part of this program were used in this study for conducting sled tests.

Thirty-two sled tests were performed to determine the influence of five major parameters on the occupant protection of disabled school bus passengers in wheelchair or in side facing seat. The selected parameters were: bus crash pulse, dummy size, wheelchair orientation, wheelchair securement type, and passenger protection system. These parameters were established through the previous work as described in the Interim Report.

These tests simulated front, side, and rear impacts at 20 and 30 mph with the wheelchair facing either forward or sideways. Dummy sizes included 6-year-old child, 5th percentile female, 50th percentile male and 95th percentile male. Passengers were protected by belts or padding. Wheelchairs were secured to the sled with cargo belts, U-bracket to the frame, or securement attached at the T-junction.

Test results showed that the higher 30 mph pulse put more strain on the wheelchair securement devices and the occupant restraint systems. As a result, some of the tested protection systems caused structural failures. A rigid securement attached to the wheelchair frame was found to reduce the deformation of the wheelchair. The T-junction securement and the U-bracket both kept the wheelchair deformation to a minimum. The cargo belts were unable to limit deformation and dummy excursion under heavy loading conditions.

The orientation of the wheelchair was found to affect the performance of the securement devices. The securement systems worked best when the wheelchair was placed in a forward facing direction since the wheelchair was inherently stronger in this direction. When placed sideways, the wheelchair showed a tendency to collapse, due in part to the folding feature of most wheelchairs. A wheelchair held by cargo belts was found to be particularly vulnerable. The use of a U-bracket reduced this tendency because it increased the lateral strength of the wheelchair.

Four-point and backpack belts were found to be most effective when placed on a forward facing passenger facing the direction of impact. They were less effective when tested in a side facing orientation with respect to the direction of impact. The study recommended that the orientation of the wheelchair should determine the type of securement system and the design of the securement systems must account for the extra load of an occupant belted directly to the wheelchair. The study suggested that the main frame members of the wheelchair should be utilized for the attachment of the securement devices.

Wheelchair Securement on Bus and Paratransit Vehicles, Interim Report No. 1, UMTA-CA-06-0098-81-1, California Department of Transportation, April 1981.

This study was conducted for the Urban Mass Transportation Administration (UMTA), U.S. Department of Transportation, to evaluate the safety of loading and securement hardware for transporting passengers in wheelchairs. This interim report documented the results for the first segment of wheelchair securement research.

Under this study 42 dynamic sled tests were conducted to determine the performance of wheelchairs using 12 different types of securement systems. Both manual and battery powered wheelchairs were used in these tests. All tests simulated a frontal crash. The speed of the sled at impact varied from 5.7 to 23.3 mph with deceleration rates ranging from 5 to 12 g's. A combination of forward, rearward, or sideways wheelchair orientations were used. The 50th percentile male dummy was restrained either to the wheelchair or to the sled with lap belt or lap and shoulder belts.

The study found that the wheelchair orientation with respect to the direction of impact and the point of attachment of the securement system to the wheelchair were primary variables affecting the crashworthiness of the wheelchair. In frontal crashes, the rearward facing orientation resulted in the least damage to the wheelchair and the least injury to the occupant when the head and body were fully supported. The next best wheelchair orientation was found to be forward facing. Side facing provided the least resistance to wheelchair damage and the least protection for the dummy. However, a side support, such as a wall or seat back, would increase the ability of side facing wheelchair to withstand frontal impacts.

At 20 mph and 10 g's, representative of a severe crash of the bus at 20-30 mph into a solid barrier, the rear wheels of the wheelchair were found to be strong enough to restrain a forward facing wheelchair and its occupant in a frontal impact when both wheels were held by the securement system. When the rear wheels of a forward facing wheelchair were secured with a wall rim pin device, they tended to roll upward during a frontal impact which resulted in tip over for a wheelchair without footrests.

Wheelchair restraint systems that depended on tension for securement, such as T-bar, horizontal bar, etc., tended to come free when the wheelchair deformed. The forward placed T-bar was found to be ineffective in restraining the wheelchair during frontal crashes over 10 mph and 10 g's. Securement by a belt around the occupant's waist and the back of the wheelchair was found to be unsatisfactory for high speed impacts because of the high potential for internal injury to the occupant and disengagement of the belt as the back of the wheelchair bent.

Occupant excursion was found to vary widely with the systems tested. It was suggested that the available clear space and the removal, or padding of, obstructions should be major concerns in the selection and placement of the securement systems.

The space needed for a forward facing wheelchair varied considerably depending on the size of the wheelchair and the type of wheelchair/occupant securement system used. This study found that a minimum clear space of 30 inches wide by 53 inches long was required for the average sized wheelchair, when the occupant had to position the wheelchair himself.

Because of the multiplicity of disabilities and limited dexterity of a large percentage of wheelchair users, the study suggested that it would be beneficial for the wheelchair users to provide their own securement equipment which best fit their needs if the user was expected to operate the device without assistance.

Multimodal Wheelchair Securement/Passenger Restraint - Prototype Development, Report No. TP 3057E, Douglas Ball Inc., May 1981.

This study presented the work on the second phase of a program initiated by the Transportation Development Centre (TDC) of Transport Canada to develop a prototype wheelchair securement and passenger restraint system for disabled travellers on various transportation modes. The concept of the modular system was defined in the first phase of this program. Work for the second phase included the construction of the prototypes, laboratory strength testing and in-service operational evaluation.

The wheelchair securement/passenger restraint system consisted of four modular elements: a wedgetrack, a bulkhead, a shoulder rest incorporating a shoulder belt, back and head support, and a special seat suitable for use by ambulatory passengers. This system was designed as a steel structure bolted to the floor or to the wall of a vehicle with specific consideration for use in a van. Four prototype units were constructed, one was static tested for strength and three were used for an in-service performance evaluation in a van. Several components failed the static tests because of deficiency in fabrication and assembly. The response to the in-service performance evaluation was generally favorable.

Wheelchair Securement on Bus and Paratransit Vehicles, Final Report, UMTA-CA-06-0098-82-2, California Department of Transportation, July 1981

This study was a continuation of the work reported in the Interim Report UMTA-CA-06-0098-81-1 which summarized 42 tests in Phases I and II. This study covered 17 dynamic tests at various velocity and deceleration levels for Phases III and IV. Head Injury Criteria, Chest Severity Index and head excursion were measured on a 50 percentile male dummy. Conclusions given in the final report were drawn from all four phases of testing (59 tests).

All of the securement systems used in the Phase III tests were the same as those used in the first two phases. Phase IV repeated testing for two securement devices and included testing for two new securement systems. These tests were run at velocities of 5 and 20 mph and decelerations of 5 and 10 g's with a 50th percentile male dummy.

The authors of this study concluded that a wheelchair and its occupant could survive a 20 mph/10 g crash in a bus when properly secured. It was found that the securement system should be symmetrically attached to the wheelchair in at least two places and be designed to keep the wheelchair secured under crash loads. The occupant should be restrained with an upper torso belt and a lap belt.

The study found that all wheelchair securement systems available at the time of this study suffered some deficiency. Some were awkward to use, others did not provide sufficient protection to the wheelchair or to the occupant. It was found that wheelchairs were designed to withstand the level of forces generated during a crash.

Test results showed that impact velocity had a greater effect on wheelchair damage and occupant injury than the deceleration. The reduction in occupant head excursion and CSI (Chest Severity Index) was greater by decreasing impact velocity than by decreasing deceleration. Occupant's HIC (Head Injury Criteria) data were found to be dependent on head contact and showed no correlation with head excursion.

Occupants of electric powered wheelchairs were shown to have higher head excursion than occupants of manual wheelchairs. Tests showed the extent of occupant body movement and the degree of wheelchair damage were greater with the electric powered wheelchairs because of their greater weight. No spilling of battery liquid was found in tests performed with the electric powered wheelchairs.

<u>An Assessment of Wheelchair Restraint Systems Used Onboard Transit Buses, Draft Project Memorandum</u>, Project No. 2464, Ketron, Inc., January 1982.

This study was conducted for the Transportation Systems Center (TSC), U.S. Department of Transportation to provide an assessment of the experience with the onboard wheelchair restraint systems. Restraint systems, including prototype and development systems, were reviewed and site visits were made to equipment manufacturers.

The study found that little thought had been given by many transit bus operators to the interior arrangement such as non-skid flooring and providing room to accommodate powered wheelchairs. The operators appeared to accept whatever arrangement and equipment the bus manufacturer offered. Though on-board security had not been a problem, some major problem situations were found to exist. These problems included unsecured wheelchairs due to inadequate or broken restraints and backward facing occupants without head restraints to prevent whiplash injury. The study also pointed out that the powered wheelchair user must be taken into consideration as a major factor in accessible bus system design. The study recommended the establishment of a definition of a universal wheelchair restraint system.

<u>National Workshop on Bus Wheelchair Accessibility, Proceedings</u>, UMTA, May 1986.

The National Workshop on Bus Wheelchair Accessibility was held on May 7-9, 1986 in Seattle, Washington, sponsored by UMTA. The goal of this workshop was to provide a forum for discussion to establish greater awareness and understanding of the accessibility issues, to identify and resolve the key problems experienced in providing accessible service, and to develop a workable set of industry guidelines for wheelchair lifts, securement devices and ramps. This proceedings was prepared by TSC for UMTA.

Presentations of the workshop participants were organized into two general sessions and six workshop sessions. The subjects of general sessions were the components of successful wheelchair accessible transit, and safety and policy issues. The workshop sessions covered the following topics: wheelchair lift equipment problems, issues, and solutions for fixed-route accessible buses and for alternative service (small buses and paratransit), reliability and cost of wheelchair lift equipment, community input and service integration, and performance guidelines on wheelchair lift and securement systems for fixed-route accessible buses and for alternative services.

Major recommendations from the workshop participants were:

1. Need to conduct future workshops with broad-based participation to review progress and address needs.

2. Extend the work on equipment guidelines to address non-equipment areas such as operations and maintenance procedures, policies regarding accessible service, and the training of drivers and passengers.

3. Develop design guidelines for small buses and paratransit vehicles used for accessible transportation.

4. Need for research and development of wheelchair securement systems, especially automatic securement systems.

5. Need for better and more effective communications between transit agencies and the disabled community.

National Workshop on Bus-Wheelchair Accessibility, Guideline Specifications for: Active Wheelchair Lifts, Passive Wheelchair Lifts, Wheelchair Ramps, and Wheelchair Securement Devices, UMTA-IT06-0322-87, UMTA, May 1986.

This report is a collection of four separate guideline specifications for active wheelchair lifts, passive wheelchair lifts, wheelchair ramps, and wheelchair securement devices. These guideline specifications were developed by the Advisory Panel sponsored by UMTA. Inputs developed during the Workshop and written comments submitted following the Workshop were incorporated in the development of these guideline specifications. The intention was to provide transit agencies with a model that they could use in the development of their specifications for wheelchair accessibility.

Each guideline specification covered, in general, the following areas: general, technical requirements, testing, certification, inspection, warranties, maintenance, training, and service.

These guideline specifications focused only on the technical requirements of a specific piece of equipment. They were developed for use throughout the United States to assist in the purchase of such equipment. However, these guideline specifications are advisory in nature. Unique local conditions could make an item suggested for inclusion inappropriate and a local public transportation provider would be required to make appropriate changes.

Development of a Standard Interface Concept for Securing Wheelchairs in Accessible Vehicles, TP9734E, T E S Limited, January 1989.

This study was sponsored by the Transportation Development Centre (TDC), Transport Canada, to develop and evaluate a concept for a standard interface between wheelchair and vehicle. Such a standardized interface would provide a solution to the problems associated with the incompatibility of the securement systems used for a wide variety of size and shape of wheelchairs.

Design criteria for the standard interface were established to define the physical performance and ergonomic requirements. These design criteria included the performance requirement for a securement system to withstand a 20 g load in a frontal collision, to resist a 2500 pound force applied in any direction for a period of 20 seconds, and to limit the motion of the occupied wheelchairs to 3/8 inch at any point of contact with the vehicle floor. Neither the crashworthiness of the wheelchair nor the attachment of a passenger restraint were considered in the development of the interface.

Several design concepts were developed based on the design criteria established. One system was selected and approved by TDC for fabrication. This system consisted of a set of opposing hooks installed under the vehicle floor. When activated these hooks would rise out of the floor, catch onto mating pins fixed to the bottom of the wheelchair, and pull down to secure the wheelchair. The hooks were spring loaded and actuated with hydraulic cylinders. A control panel installed on the vehicle allowed the wheelchair occupant or attendant to engage or disengage the interface system.

Several trials were conducted with various wheelchairs to evaluate the system activation, interface connection, and wheelchair securement in accordance to the design criteria. In each case the wheelchair was secured firmly to the floor allowing no movement of the wheelchair. The securement time was determined to be 1.5 minutes. Wheelchair ownership costs were estimated to be $200 to $350 per wheelchair and the vehicle ownership costs were estimated to be $2,000 per wheelchair position.

The study recommended the development of a standard for transportable wheelchairs to solve the problem of incompatibility between wheelchairs and securement systems. This standard would define the performance requirements and dimensional limitations for any wheelchair which would be accepted for transport by a transportation system.

<u>Development of a Wheelchair Securement System for Vans and Small Buses</u>, TP9758E, TES Limited, February 1989.

Under a contract from TDC, Transport Canada, a wheelchair securement system for vans and small buses was developed by TES Limited. This securement system was expected to provide two essential functions: wheelchair securement to prevent wheelchair movement and to transfer loads from the wheelchair to the vehicle structure, and occupant restraint to restrain basic movement of a wheelchair occupant during transportation and, in some cases, to provide crash protection.

The developmental task was divided into two phases. Under Phase 1, a review of documents pertaining to wheelchairs, specialized vehicles, and wheelchair securement systems, including standards and guidelines, was conducted to establish evaluation criteria for a wheelchair securement system. Generic securement systems were evaluated against these criteria in order to determine the desirable and undesirable features of the different models. Then two conceptual designs were developed. After evaluation by operators of transportation services for the disabled, one concept was selected for fabrication.

The selected concept was a system of retractable belts and hooks for securing the wheelchair to the floor of the vehicle at four points. The belts were stored inside a floor mounted structure containing the tensioning mechanism. The occupant restraint was provided by retractable lap and torso belts. This securement system could adapt to many wheelchair types and could be used in any bus or van model.

Phase 2 consisted of detailed design of the conceptual design, prototype construction, and performance evaluation. The in-house and in-service evaluation of the prototype by operators revealed several operational deficiencies. Though some deficiencies were eliminated through modification, the prototype was found to have insufficient vertical hold down force.

<u>Development of a Test Program to Determine the Crashworthiness of Wheelchairs, Working Paper</u>, T E S Limited, February 1989.

This test program was developed for TDC, Transport of Canada, to determine the crashworthiness of wheelchairs secured in specialized transportation vehicles. The development of this test program included the selection of wheelchairs and securement systems, identification of test requirements and facilities, and the estimation of costs for the program.

The study identified five generic categories of wheelchairs: standard manual, standard electric, 3-wheeled chairs, 4-wheeled chairs, and other. A selection process resulted in the following list of wheelchairs for the proposed test program.

Wheelchair Type	Manufacturer	Model
Standard Manual	Everest & Jennings	Premier
	Canadian Wheelchair Mfg.	Voyager
	Invacare	#5000
Powered	Invacare	Power Rolls
	Fortress Scientific	655FS
	Everest & Jennings	Marathon
Sport	Motion Designs	Quickie
	Quadra Wheelchair	Esprit
	Invacare	ETS
	Everest & Jennings	Ultralight
Scooter	Fortress Scientific	2000FS
	Orthokinetics	Lark
	Everest & Jennings	Mobie
	Amigo	Amigo
Child	Orthokinetics	Travel Chair (6300)

A four-point belt system, such as the Q'Straint, was selected for the securement of the wheelchairs. A lap belt independent of the wheelchair securement was selected for restraining the occupant because the lap belt was considered to represent the worst case scenario in occupant protection.

Test requirements to determine the crashworthiness of wheelchairs were identified based on CSA (Canadian Standards Association) Standard D409 and recommendations from many studies and guidelines. The requirements identified include:

1. Each wheelchair shall be properly assembled.

2. The four-point belt system shall be installed on the test sled.

3. The wheelchair shall be oriented in the desired direction for the test - either forward or rearward facing.

4. The wheelchair securement shall be fastened or attached to the wheelchair according to the manufacturer's instructions.

5. A 50th percentile male dummy shall be used to represent a typical adult occupant and a six-year-old child dummy shall be used for the child-sized chair. The dummy should be restrained by a lap belt positioned underneath the armrests and over the pelvic area.

6. Instrumentation to record the following test data shall be installed and verified:
   a. velocity of the sled immediately prior to impact,
   b. deceleration of the sled,
   c. wheelchair securement loads,
   d. occupant restraint loads,
   e. wheelchair deformation and excursion, and
   f. occupant contact with any part of the wheelchair.

7. Visual equipment such as high speed motion picture cameras shall be used to record the impact event.

8. The sled control should be set to obtain a 30 mph velocity differential and a 20 g deceleration pulse.

Sled testing facilities were contacted to determine the suitability of these facilities to conduct the dynamic test program. Two testing facilities, the Defence and Civil Institute of Environmental Medicine (DCIEM), Downsview, Ontario and the University of Michigan Transportation Research Institute (UMTRI) Ann Arbor, Michigan, were highlighted in this study.

The study recommended the development of a database of information, such as that resulting from the proposed program, to assess the test results.

<u>Study of Transportation of Medically Fragile Children, Volume 2 -Adaptive and Assistive Equipment and Hardware</u>, Special Transportation, Inc., April 1989.

This study was sponsored by the Michigan State Board of Education to examine issues related to the transportation of technology dependent students. Volume 2 summarized the results of a review of existing or proposed standards and guidelines, as well as interview and consultation with experts and engineers, on the following concerns regarding the equipment and hardware used in providing the transportation services for these technology dependent students:

1. Structural integrity and crashworthiness of wheelchairs.

2. Orientation or positioning of wheelchairs on buses.

3. Strength, attachment, and practical use of wheelchair securement systems and hardware.

4. Attachment, strength, and positioning of occupant protection systems and hardware.

5. Safe seating construction of wheelchairs.

6. Attachment and positioning of life support systems.

The study pointed out that the International Standards Organization (ISO) had been studying the issue of wheelchair construction and testing for several years. Specific areas with regard to wheelchair safety under the ISO consideration included wheelchair dynamic stability, seating dimensions, static strength and stability, fatigue characteristics, climate testing, burning behavior, power controls for powered wheelchairs, and definition of a wheelchair. Based on the interview of many of the members of the ISO studying committee, the definition would be restricted to that of the "traditional" wheelchair, and would not include three-wheeled carts and many other types of mobile seating devices used for the transportation of technology dependents. There was also no indication of any effort for the design or manufacture of a wheelchair to be used specifically for transportation.

The study recommended courses of action in many areas for the Michigan Department of Education and other state agencies. Major recommendations are summarized below.

1. Petition the National Highway Traffic Safety Administration (NHTSA) to:

   a. Repeal the exemption of handicapped and convalescent passengers from compliance with Federal Motor Vehicle Safety Standard (FMVSS) 222 school bus seating requirements.

   b. Establish uniform national safety standards for mobile seating devices used for student transportation.

   c. Provide test criteria guidelines for equipment manufacturers to use in meeting the standard.

   d. Require equipment manufacturers to certify that their devices meet the requirements of the standard.

   e. Adopt a standard for power lifts used on buses.

2. Direct the state resource team to:

   a. Review mobile seating devices, new and in use, and issue advisory opinions regarding the safety of use for student transportation.

   b. prepare a list identifying those mobile seating devices which are considered safe for student transportation.

3. Require that pupil transportation providers shall:

   a. Transport only mobile seating devices which have been identified.

   b. Not transport mobile seating devices that have obvious breaks, tears, or other defects which could present a safety risk to the occupant.

4. Require pupil transportation providers to:

   a. Only provide transportation for students seated on, or placed on, mobile assistive devices pursuant to written authorization.

b. Only use student vests, harnesses, and other assistive or supportive equipment when authorized and approved.

c. Only use student vests, or harnesses which are tested and certified by the manufacturers to meet impact forces at 30 mph and 20 g's.

5. Require pupil transportation providers, on all new buses purchased after July 1, 1990, to:

   a. Position all occupied mobile seating devices so as to be facing in the direction of forward travel of the bus, or;

   b. Position and secure mobile seating devices opposite the direction of forward travel when: i) required by a student's Individual Education Plan Committee (IEPC), ii) the mobile seating device provides adequate occupant protection, including head and back support, or iii) the transporter can provide a safe securement system for the seating device and the occupant.

   c. Secure mobile seating devices with a four-point tie-down system that has been tested to meet minimum impact forces of 30 mph and 20 g's, and can be operated by an adult person without the use of tools.

   d. Use an occupant securement system which provides the ability to safely restrain the occupant in a mobile seating device in the event of a 30 mph and 20 g's force impact.

   e. Require the manufacturer of the mobile seating device and occupant securement system to furnish information and instructions regarding the maximum weight capacity and installation and use of the system.

6. Require that vehicles used for the transportation of disabled students meet the federal standards established for school buses over 10,000 lbs GVW, and prohibit

the use of passenger vans purchased after July 1, 1990, for transportation of all disabled students.

7. Prohibit the use of acid batteries on electrically powered mobile seating devices when used for bus transportation.

8. Issue guidelines regarding the use and transportation of oxygen and ventilator equipment.

<u>Crash Test of a Three-Wheeled Scooter</u>, HICKLING Reference 3060, HICKLING, September 1989.

This crash test was carried out by HICKLING at the Transportation Research Center (TRC) in East Liberty, Ohio, for the Transportation Development Centre (TDC) of Transport Canada.

In this test an Amigo Classic three-wheeled scooter was positioned facing forward in the front passenger area of a 1989 Dodge Caravan. The vehicle was impacted from the rear by a moving barrier at 30 mph. The scooter was secured at four points by an Aeroquip system. The occupant of the scooter, a 50th percentile dummy, was secured with lap and shoulder belts to the vehicle. For ballast, a standard wheelchair was placed facing forward in the rear driver's side of the van, secured with two Aeroquip belts from the rear of the wheelchair frame to the vehicle floor. The wheelchair dummy was restrained with a lap belt to the floor of the vehicle.

During the crash the bolts fastening the seat pedestal to the scooter base broke and the dummy and the seat/pedestal assembly flew to the back of the van. The three-point occupant restraint remained intact. Despite a relatively low HIC value of 342, the authors concluded, "The dummy incurred potentially fatal head and/or neck injuries upon impact with the interior structures of the vehicle." The battery box broke away from the scooter, posing a threat as a projectile. There was a slight bending of the scooter base and bumpers.

The standard wheelchair, with its occupant, fell over backwards during the test. The motion of the dummy was such that, in the opinion of the authors of this report, a human occupant would have suffered a severely broken neck due to head impact with the van interior. The report stated that if the wheelchair had been tied down in the front, it would likely not have fallen over backwards, however in that case the neck injuries could have been even worse, due to the immovable nature of the backrest of the wheelchair.

This test demonstrated that a 30 mph rear impact was potentially fatal to the occupant of an Amigo Classic scooter secured in a van with the system described. The test result provided no clue as to what would happen to the occupant of the scooter in a frontal vehicle crash.

V. EXISTING STANDARDS AND PRACTICES

Copies of the standards or code of practice for the transportation of persons in wheelchairs have been obtained from the countries and organizations listed below. None of these is specific to children on school buses.

Australia - Australian Standard 2942-1987 "Wheelchair Occupant Restraint Assemblies for Motor Vehicles"

International Standards Organization - ISO DRAFT Standard "Wheelchair Tie-down and Occupant Restraint Systems for Motor Vehicles" (Oct. 31, 1989). This is also the Society of Automotive Engineers (SAE) DRAFT Standard.

Canada - Canadian Standards Association CAN3-D409-M84 "Motor Vehicles for the Transportation of Physically Disabled Persons"
amended December 1986.

Sweden - Swedish Board of Transport "Regulations for Adapting Public Transport Vehicles for Use by Disabled Persons" Preliminary Edition 5/10/89.

United Kingdom - Code of Practice VSE 87/1 "The Safety of Passenger in Wheelchairs on Buses".

This section summarizes each of the above standards as to:

1. under what conditions the standard applies,

2. design requirements for the vehicle, securement device, or wheelchair, and

3. the different levels of compliance permitted under the standard.

Technical reports could not be found describing the research testing, if any, conducted to support the development of these standards. Depending on the process used in these countries, there may not have been any testing done specifically for standards development.

Table 4 contains very brief descriptions of each standard for comparison.

TABLE 4

Standards Compared

COUNTRY/ ORGANIZATION	VEHICLE TYPES	OCCUPANT RESTRAINTS	EVALUATION CRITERIA	PERFORMANCE STANDARDS
Australia	All motor vehicles	Lap and torso under most conditions	Sled test: Front, side, and rear impacts each with their own delta V and deceleration range specified.	Horizontal excursion of the dummy hip point.
International Standards Organization DRAFT	All motor vehicles	Lap and torso	Sled test: Front impact del V=30mph decel 18-22g's	Not yet established. Horizontal hip excursion, chest g's under discussion.
Canada	Motor vehicles, other than passenger cars, converted specifically for transporting disabled persons.	Lap belt required. Torso belt recommended.	Extreme driving manuevers.	Motion of the wheelchair must be limited to 3/8" in any direction.
Sweden	Adaption of buses built after 1989, equipped to seat max. 12 adults, used to transport passengers in wheelchairs.	Lap and torso belts with inertia reels under most conditions.	Static tests on restraints: 5kN for manual chair, 50kN for power chair. Strength of the brackets given by ref. to a cargo securement standard.	Wheelchair must be held steady.
United Kingdom	Motor vehicle for more than 8 seated passengers, including those in wheelchairs.	Lap and torso.	Static tests applied to restraints: 4400N to chair restraints, 8800N to occupant restraints.	The restraints should withstand these applied forces without failing or separating from the attachment. Movement of chair should not exceed 200mm.

AUSTRALIA

"Wheelchair Occupant Restraint Assemblies for Motor Vehicles"

The Australian standard is by far the most rigorous and complete standard for the transportation of persons in wheelchairs. It covers:

1. design of wheelchair securement devices,

2. design of occupant restraints,

3. the test procedure and performance requirements for wheelchair occupant restraint assemblies,

4. corrosion protection and surface finish,

5. installation of restraint assemblies, and

6. guidelines (not requirements) for vehicle reinforcement at the anchor attachment points, types of vehicles to use for transporting persons in wheelchairs, and types of wheelchair to avoid in transport.

However, no technical reports could be found which described the research testing, if any, that supported the development of this standard and described the process by which the test procedure and performance requirements were decided upon. It is quite possible that no testing was done specifically to support or develop the standard [5].

Conditions

All motor vehicles where "suitable anchorages can be installed and where sufficient space is available" must comply. The standard specifically excludes the restraint of wheelchair occupants who are driving the vehicle.

Requirements

Orientation

Side facing orientation of the wheelchair is not allowed.

Securement Devices

The standard specifies that the securement device shall be attached to the frame of the wheelchair and not to the wheels, axles, chair back, arm rests, or foot rests. If the device uses webbing, these belts shall comply with the Australian standards for webbing, webbing components, and adjustment devices. The standard specifies that the wheelchair securements shall capture the wheelchair frame in such a manner that the wheelchair cannot come free if the frame, or other wheelchair components deform, or if one or more tires deflate.

Occupant Restraint

Securement of the occupant must be independent of the wheelchair. However, the wheelchair securement device shall be designed to carry loads from the occupant restraints. The occupant restraint shall either be anchored directly to the vehicle or be mounted at suitable points on the wheelchair tie-downs which are anchored to the vehicle. With the wheelchair correctly secured, belt anchor points shall fall within the permitted zones as shown in Figures 17 to 19 for lap belts, torso belts, and harness belts, respectively. The shaded areas in these figures indicate permitted zones on either side of the seating reference plane. All dimensions are in millimeters.

Testing

A minimum of three tests is required: one each front, side and rear impact under the following conditions:

	Front	Rear	Side
Velocity change	22mph +/-.7mph	20mph +/-.7mph	10mph +/-.7mph
Deceleration range	20-24g's	14-20g's	8-15g's
Duration of decel. within range	not < 15msec	not < 15msec	not < 10msec
Duration decel. > 2 g's	not > 100msec	not > 90msec	not > 70msec

Performance

A "wheelchair occupant restraint assembly" is the combination of the securement device which holds the wheelchair to the vehicle and the device which holds the occupant to the vehicle (not the chair). The requirements for the entire system subjected to the above tests are:

1. After the test the dummy must remain in the chair and the chair must remain upright and facing within 20 degrees of the original orientation.
2. There must be no "fragmentation or complete separation of any load carrying part".
3. All chair and occupant restraints must be able to be released without tools.
4. If a head restraint is used head acceleration should not exceed 75 g's during contact with any part of the restraint assembly.
5. Limits for horizontal excursion of the dummy during the test are shown in Table 5 and are measured from the hip reference point P shown in Figure 20 [6].

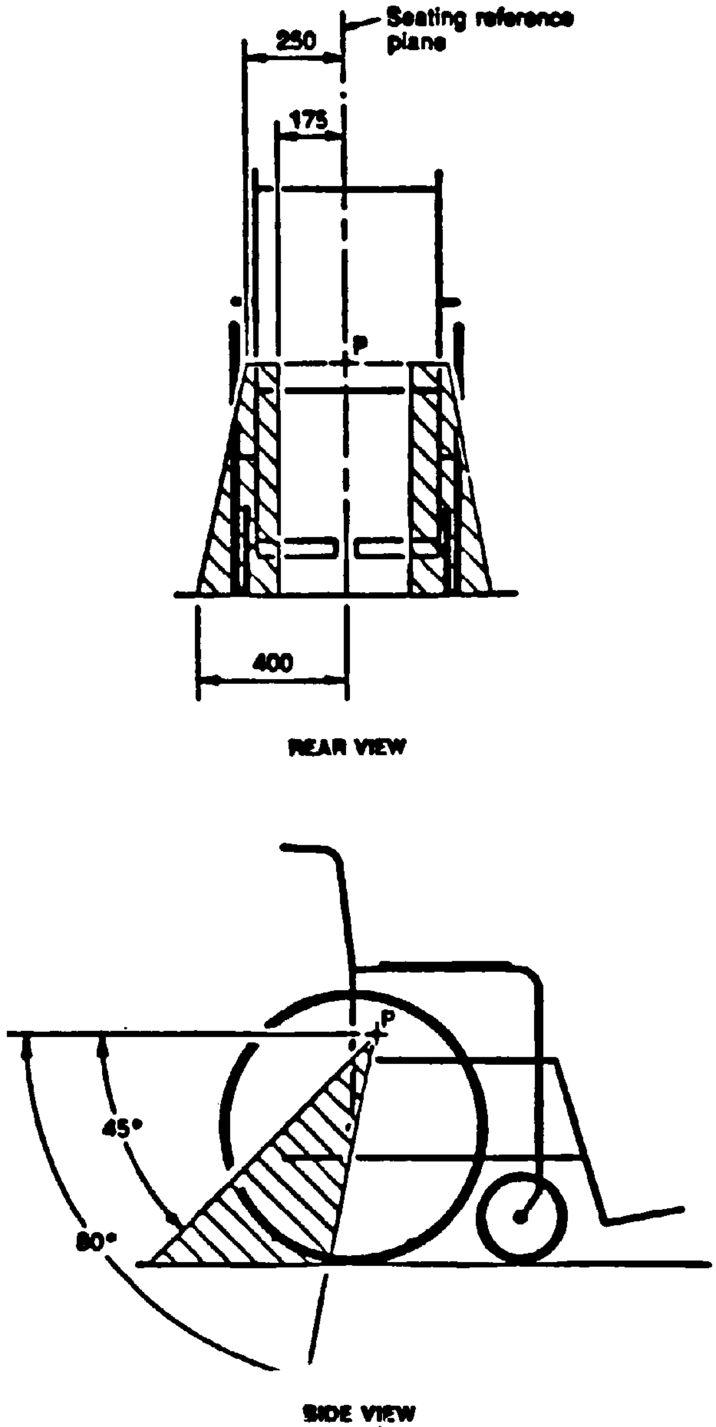


Figure 17. Location of anchor points for a lap belt.

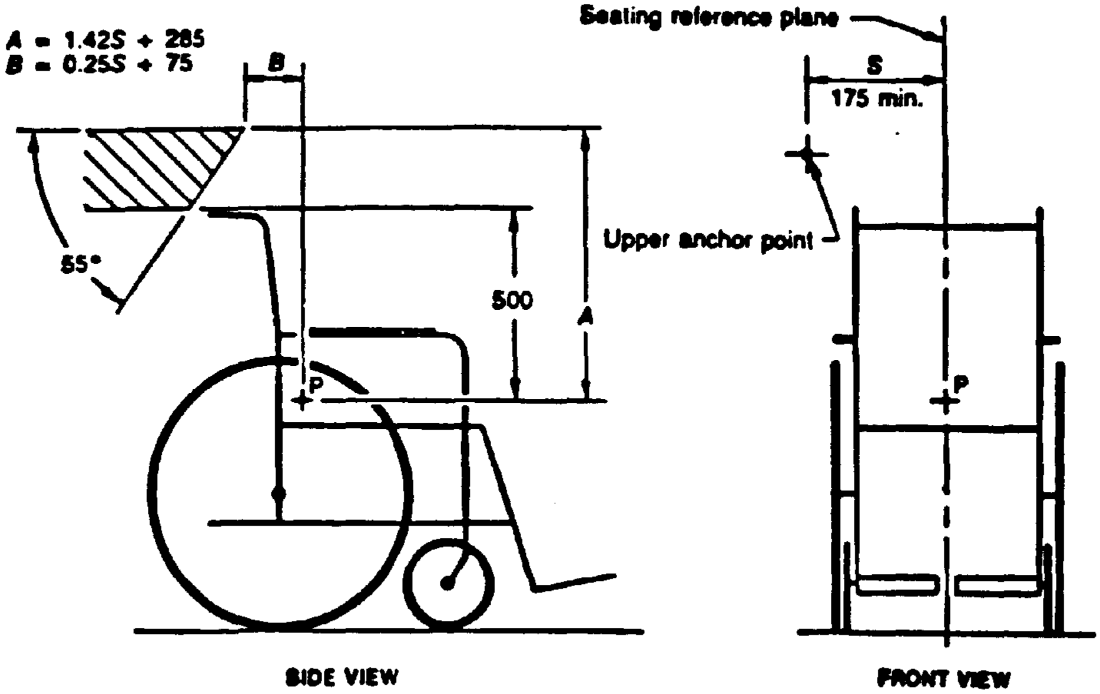


Figure 18. Location of anchor points for a torso belt.

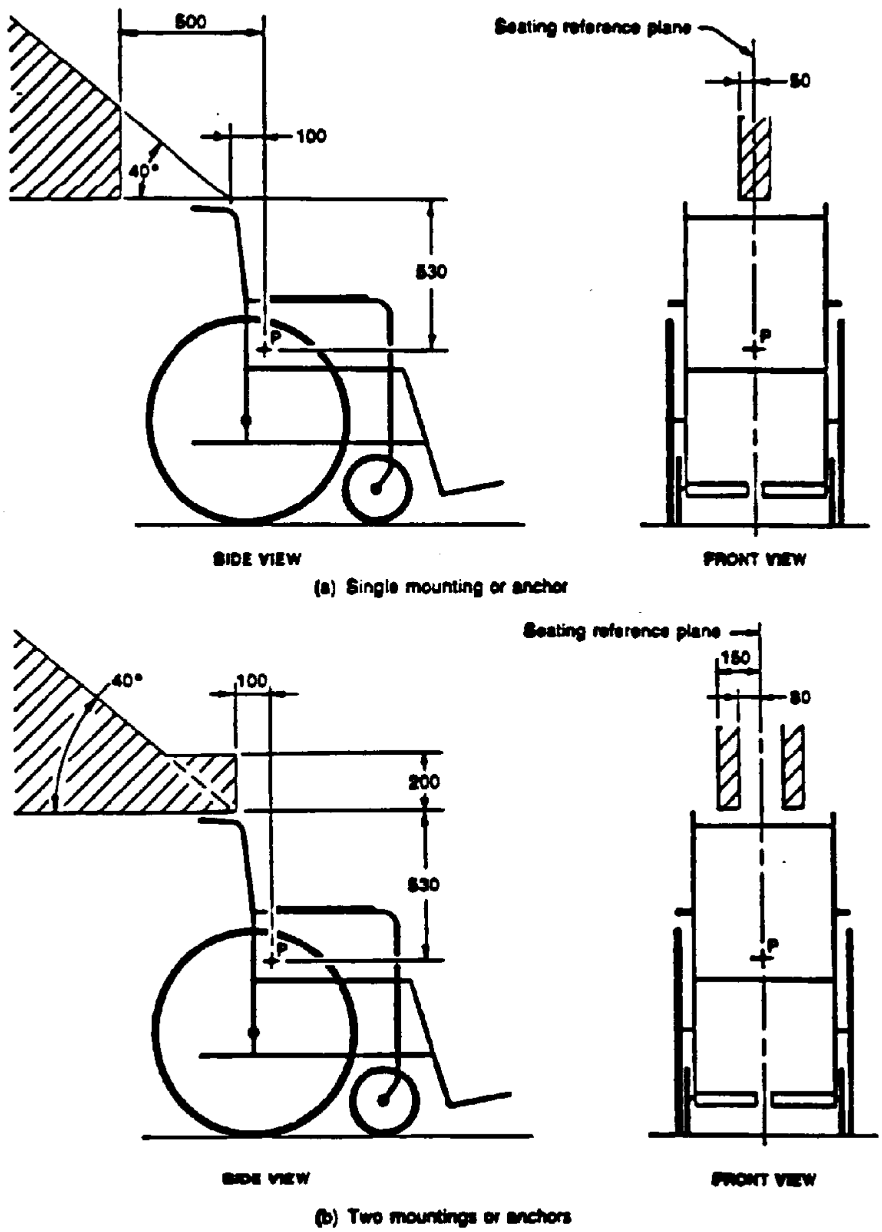


Figure 19. Location of anchor points for harness belts.

TABLE 5

Allowable horizontal dummy excursion.
(inches)

Impact Direction	Chair Orientation	Occupant Restraint	Excursion: Hip w.r.t. Pt. P	Excursion: Hip w.r.t. Frame	Excursion: Shoulder w.r.t. Frame
Front	Forward	Lap	9.8	15.7	not spec.
	Forward	Lap & Torso	9.8	15.7	25.6
	Rearward	All	not spec.	15.7	15.7
Rear	Forward	All	not spec.	7.9	7.9
	Rearward	Lap	not spec.	7.9	not spec.
	Rearward	Lap & Torso	not spec.	7.9	13.8
Side	No requirements specified.				

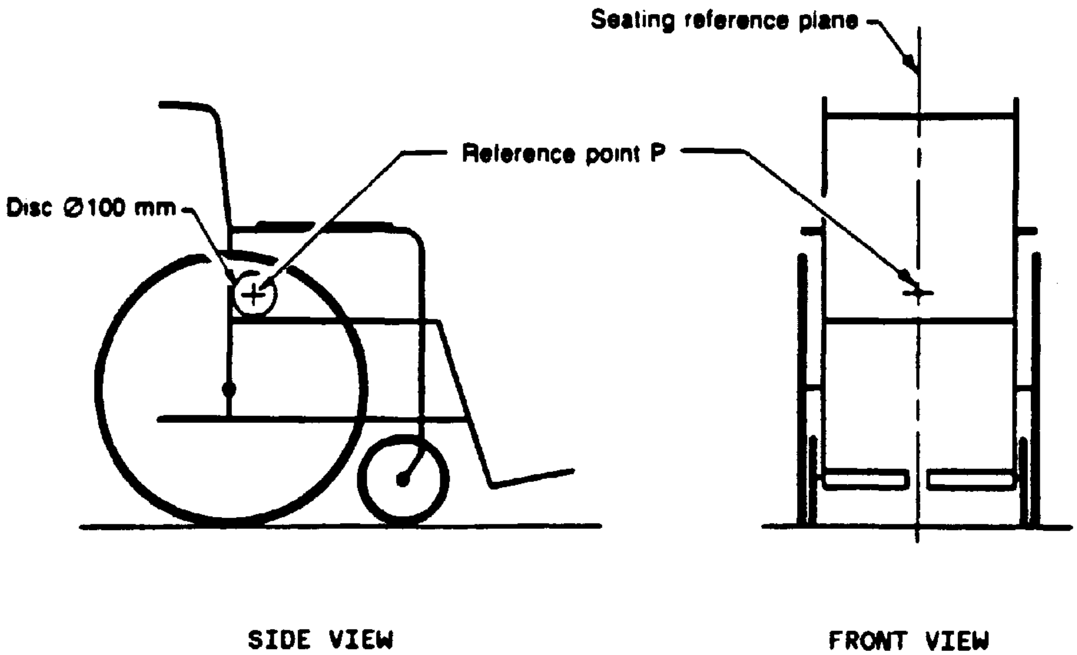


Figure 20. Position of reference point P and seating reference plane.

INTERNATIONAL STANDARDS ORGANIZATION DRAFT STANDARD

as of Oct. 31, 1989
"Wheelchair Tie-down and Occupant Restraint
Systems for Motor Vehicles"

The International Standards Organization (ISO) and the Society of Automotive Engineers (SAE) are working together on a standard for the transportation of persons in wheelchairs. This DRAFT Standard (as of October 1989) is based on the Australian standard. Therefore, presented below are the differences between the Australian standard (above) and the ISO/SAE Draft.

Testing

1. Only a frontal impact is required.

2. The velocity change required in the test is 30 mph.

3. The deceleration range is 18 to 22 g's.

Performance

No performance requirements have yet been established. Excursion limits are under discussion as well as whether or not to include a requirement on chest accelerations.

As of the October 1989 Draft, no guidelines are included for vehicle reinforcement at the anchor attachment points, types of vehicles to use for transporting persons in wheelchairs, or types of wheelchair to avoid in transport.

CANADA

"Motor Vehicles for the Transportation
of Physically Disabled Persons"

Canadian standards are scheduled to be updated in the 1990's. Below is a summary of the current standards.

Conditions

"Motor vehicles, other than passenger cars, designed and manufactured or converted for the purpose of transporting physically disabled persons."

Requirements

Sections 6.13.1 and 7 deal with the placement and securement of wheelchairs and their occupants in the vehicle.

Orientation

Section 6.13.1, "Wheelchair Passenger Seating," requires the wheelchair to be forward or rearward facing. If facing rearward a back and head restraint must be provided which is designed to withstand a 20g acceleration in the forward direction.

Space Requirement - floor space 27 x 44 inches. The 44 inches being parallel to the vehicle longitudinal centerline.

Securement Devices

There must be a securement device at every wheelchair position.

Every securement device must withstand a force of 200 lbs applied forward or rearward relative to the longitudinal direction of the chair.

The securement device must limit forward and backward rotational, lateral, and vertical motion to 3/8 inch "in any direction at any point of contact with the floor" under 3 conditions (assuming wheelchair + occupant = 250 lbs)

1. full throttle acceleration on dry pavement from 0 to 25mph with vehicle at curb weight plus weight of one chair and curb weight plus weight of the design number of chairs,

2. maximum braking from 22 to 0 mph on dry pavement with the vehicle at curb weight plus weight of one chair and curb weight plus weight of the design number of chairs, and

3. driving with the outer front wheel around a 50 ft diameter circle at 12mph, an 75 ft diameter circle at 14mph, or 100ft diameter circle at 16mph.

These are not crash conditions, but rather examples of extreme driving manuevers.

Occupant Restraint

At least a lap belt must be provided at every wheelchair position. A torso belt is not allowed without a lap belt.

Wheelchair securement force must not be cumulative to the occupant restraint system.

The restraint system must comply with the strength requirements for seat belts under CMVSS 209 (covers bolts, buckles, retractors, webbing, and attachment hardware) and seat belt anchors under CMVSS 210.

SWEDEN

"Regulations for Adapting Public Transport Vehicles for Use by Disabled Persons"

This standard governs the transportation of all disabled persons, not just wheelchair users, on all forms of public transport. We will discuss here only those sections which deal with transport of persons in wheelchairs on buses.

Conditions

Section 20: "Adaption of buses ... built 1989 or later, equipped to seat a maximum of 12 adults and used to transport passengers in wheelchairs"

Requirements

Space

Space required for each wheelchair position at floor level is 800 x 1300 mm (31.5 x 51.2 inches) and "from a maximum height of 300 mm [11.8 in] above floor level shall have an extra width upwards of at least 50 mm [2 in] on each side."

Orientation

The Swedish standard does not prohibit side facing placement of wheelchairs.

Securement Devices

The standard does not require a specific design for the wheelchair or the securement device. "The anchorage and fastenings shall be able to hold a wheelchair steady when exposed to directional pressure from the direction in which the vehicle is travelling, amounting to 5 kN [1,124 lbs] for manually driven, and 50kN [11,240 lbs] for heavy electric driven wheelchairs." "The wheelchair must not overturn, twist or shift position when exposed" to vertical or horizontal forces. "Anchorage shall be symmetrically affixed to the wheelchair, and attached to the chassis or another robust part. The anchorage must hold the wheelchair steady even under such pressure that the wheel chair becomes deformed. Anchorage shall fit any of the usual types of wheelchairs." The securement device may consist of belts attached to the wheelchair in a downward-backward and downward-forward fashion. The webbing should also be angled slightly to the side if possible. Section 19.10 states, "The space for a wheelchair shall be fitted with fixed anchorage which meets the relevant requirements as stipulated in National Road Safety regulations (TSVFS 1978:9) on equipment for securing cargo. The weight of the wheelchair (cargo) is thereby assumed to be 150kg [330 lbs]."

Occupant Restraints

Separate torso and lap belts fitted with inertia reels are required for the wheelchair positions. Lap belts only are allowed "if the upper fastening bracket for a diagonal belt cannot be fitted without considerable inconvenience." The positions of the anchors for the lap and torso belts are proscribed in detail:

Anchor	Distance from the plane of the floor	Distance from vertical plane thru longitudinal center of chair	Distance from vertical plane behind rear wheels of chair
Lap	0	min. 120mm	max. 400mm
Torso:			
Upper	1100-1400mm adjustable	140-500mm	250-550mm behind adjustable
Lower	0 opposite side of the center line from the upper anchor	min. 120mm	max. 400mm

The Swedish standard requires that the anchor brackets for the occupant restraints be placed on the vehicle chassis. The lap belt shall form an angle of 30 to 80 degrees, preferably as close to 60 degrees as possible, from a horizontal level. The anchor points for the lap and the torso belts shall be so placed to achieve a belt geometry as shown in Figure 21. Plane A is a horizontal plane at vehicle floor level. Plane B is a vertical plane parallel with the longitudinal axis of the vehicle. Plane C is a vertical plane perpendicular to Plane B. The wheelchair is to be placed on Plane A with its center line on Plane B and the intersecting line between the seat and the seat back on Plane C. Anchor points for the lap belts shall be positioned within the space of the two triangular blocks and the anchor point for the torso belt shall be positioned within the space of the rectangular block. All dimensions in Figure 21 are given in millimeters.

Levels of compliance

Buses manufactured in 1989 and 1990 are exempt from the belt anchorage requirements.

Certifications

Securement device manufacturers must show by test or calculation that the device will withstand the proscribed applied load and must "state the resultant bearing pressure on the fastening brackets in the vehicle." The vehicle or chassis manufacturer must certify that the securement device can withstand this bearing pressure. Certification of the belt requirements must "be done by the vehicle or chassis manufacturer or by the person or persons undertaking the adaptation of the vehicles."

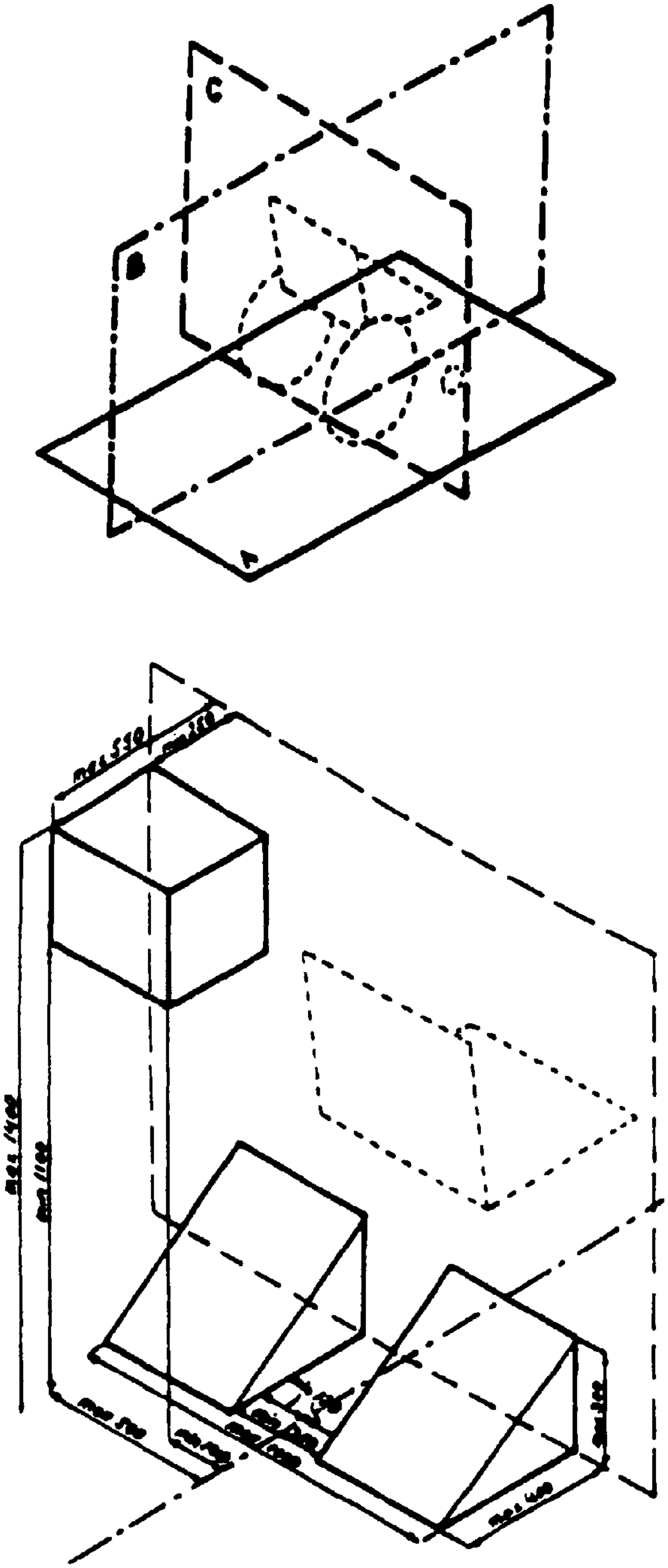


Figure 21. Allowable zones for anchor points.

UNITED KINGDOM

"The Safety of Passengers in Wheelchairs on Buses "

As a code of practice, not a regulation, this document is used as a guide "to offer advice to bus manufacturers and operators on the safe carriage of passengers in wheelchairs."

Conditions

This code of practice covers any vehicle for more than eight seated passengers, including wheelchairs.

Recommendations

Space - 1200mm long by 700mm wide with minimum headroom of 1400 mm. If only small wheelchairs are carried 900mm long by 500mm wide.

Orientation - Wheelchairs should not be carried facing sideways.

Securement devices - should withstand a forward (with respect to the vehicle) force of 8800N (1,978 lbs) and side and rearward forces of 4400N (989 lbs) at 250mm at 250mm +/- 50mm above the floor of the vehicle without failing or becoming separated at its attachment. The movement of the wheelchair should not exceed 200mm.

Occupant restraints - should withstand a forward force of 8800N at a height of 700mm +/- 50mm without failing or becoming separated at its anchors and should be able to be released after the load is removed.

Where any part of the securement device is also used as part of the occupant restraint system the following forces should be applied and then the occupant restraint system should be tested separately as above.

Forward or rearward facing wheelchair: Forward force of 8800N applied at 250mm +/- 50mm and 700mm +/- 50mm above the floor simultaneously.

Wheelchair in any direction: Rearward and side force of 4400N at 250mm +/-50mm above the floor.

Attachments to the vehicle - Both securement devices and occupant restraints should be attached to parts of the vehicle capable of withstanding the above forces.

VI. CONCLUSIONS

Upon review of the literature and in conversations with experts in the field the consensus appears to be:

1. When transporting persons in wheelchairs on buses the wheelchairs should preferably be placed in the forward facing orientation.

2. The wheelchair and its occupant should be restrained to the vehicle independently.

3. A combination torso and lap belt is one means of effective occupant restraint.

4. A tie-down system attaching the frame of the wheelchair to the floor of the vehicle with straps at four points (two rear and two front) is the most universally adaptable securement system currently available.

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2. Letter from Dr. Jan Baxter, Michigan Department of Education, Special Education Services to Gayle Dalrymple, DOT/RSPA/TSC, March 1, 1990.

3. Study of Transportation of Medically Fragile Children, Special Transportation, Inc., April 1989.

4. Crash Protection Systems for Handicapped School and Transit Bus Occupants, Volume II, Interim Report, DOT HS-805-822, Minicars, Inc., December 1980.

5. Conversation with Dr. Larry Schnieder and Dr. Roger Koppa ISO and SAE standards development task group members.

6. Australian Standard 2942-1987 "Wheelchair Occupant Restraint Assemblies for Motor Vehicles",

Section 1.4.7.4. Reference point P - with a wheelchair viewed in side view, point P lies at the centre of a disc of 100mm diameter lying in the seating reference plane and touching the backrest and the upper surface of the seat, assuming any sling seat and back rest to be taut.

Section 1.4.7.6. Seating reference plane - a vertical plane in a vehicle, being the plane of symmetry of the seat of a wheelchair correctly positioned in wheelchair occupant restraint assembly.

APPENDIX A

Wheelchair and Securement Device Manufacturers and Distributors

Wheelchair and Securement Device Manufacturers and Distributors

Accurtron Tool & Instrument Co.
505 Howmet Dr.
Hampton, VA

Action Products Inc.
22 N. Mulberry St.
Hagerstown, MD

Aeroquip Corp.
1225 W. Main St.
Van Wert, OH

American International Medical Equipmemnt Sales, Inc.
788 E. 138th St.
Bronx, NY

Amigo Sales, Inc.
6693 Dixie Hwy.
Bridgeport, MI

ATD-American Co.
139 Greenwood Ave.
Wyncote, PA

The Braun Corp.
1014 S. Monticello
Winamac, IN

Britax-Excelsior Ltd.
1 Churchill Way West
Andover, Hampshire, Great Britain

Century Mfg. Co.
Industrial Pike
Aurora, NE

Cheney Co.
2445 S. Calhoun Road
New Berlin, WI

Colson Equipment, Inc.
Harry S. Truman Blvd.
Caruthersville, MO

Dunlap Export Co., Inc.
P.O. Box 5357
Akron, OH

Emron Corp.
20650 Enterprise Ave.
Brookfield, WI

Everest & Jennings, Inc.
3233 E. Mission Oak Blvd.
Camarillo, CA

Falcon Rehabilitation Products
4404 E. 60th Ave.
Commerce City, CO

Fortress Scientific Ltd.
1100 Finch Ave. W.
Downsville, Ont., Canada

Funcraft Vehicles Ltd.
165 Sheldon Dr.
Cambridge, Ont., Canada

Gendron, Inc.
890 Lugbill Road
Archbold, OH

Golf & Western Health Care, Inc.
927 Lake Road
Medina, OH

Hand Crafted Metals
13710 49th St., N.
Clearwater, FL

Huntco Healthcare Inc.
1180 Central Industrial Ave.
St. Louis, MO

Invacare Corp.
899 Cleveland St.
Elyria, OH

Kendall-futuro Co.
5801 Mariemont Ave.
Cincinnati, OH

La Bac Systems Inc.
8955 S. Ridgeline Blvd.
Highlands Ranch, CO

LaBerne Mfg. Co., Inc.
4668 Franchise St.
Charleston, SC

Lumex
100 Spence St.
Bay Shore, NY

Med Covers Inc.
1639 Green St.
Raleigh, NC

Milwaukee Machine & Eng. Corp.
2244 S. Calhoun Road
New Berlin, WI

Mini-Matic Engineering Mfg.
1313 Tyler St., N.E.
Minneapolis, MN

Mobilizer Medical Products
13710B 49th St., N.
Clearwater, FL

Ortho Kinetics, Inc.
P.O. Box 436
Waukesha, WI

Orthopedic Appliance Co., Inc.
2101 8th Ave. S.
Birmingham, AL

Ortho Safe System, Inc.
P.O. Box 9435
Trenton, NJ

Palmer Industries
P.O. Box 7079
Endicott, NY

Pekay Machine & Engineering Co., Inc.
2520 W. Lake St.
Chicago, IL

J.T. Posey Co.
5635 Peck Road
Arcadia, CA

Pryor Products
420 N. Cedros
Solana Beach, CA

Q'Straint
4248 Ridge Lea Road
Buffalo, NY

Rosenthal Mfg. Co., Inc.
5035 N. Kedzie Ave.
Chicago, IL

S & D Medical Products, Inc.
Airport Road
Festus, MO

Stainless Medical Products
P.O. Box 955986
St. Louis, MO

Sunrise Medical
2842 Business Park Ave.
Fresno, CA

Wright-Way, Inc.
P.O. Box 460907
Garland. TX

Yung Technologies International, Inc.
P.O. Box 68
Lake Placid, NY

Appendix B

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Appendix C

Experts in the Field

Experts in the Field

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