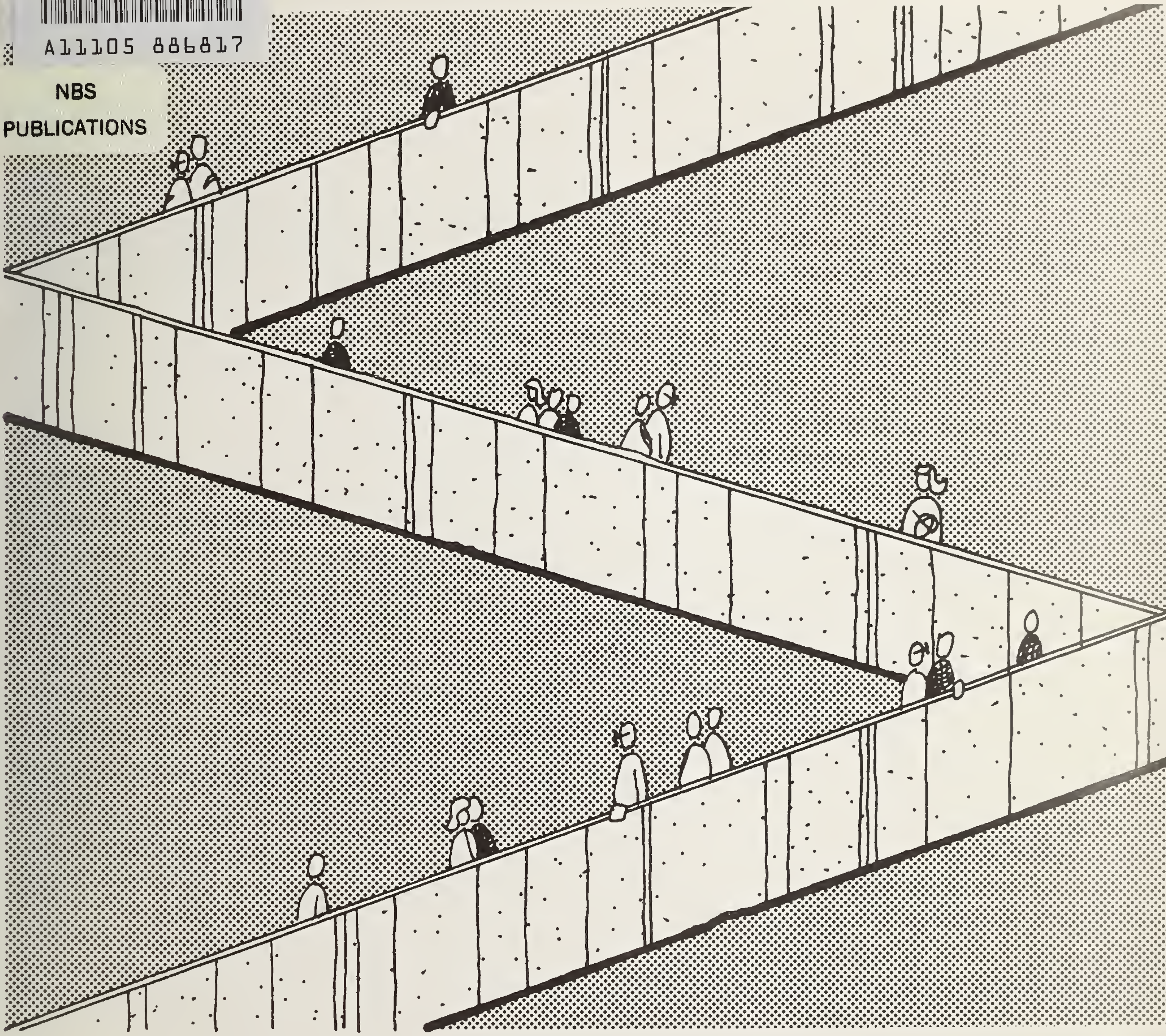

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Pedestrian Movement Characteristics on Building Ramps

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U.S. DEPARTMENT OF COMMERCE

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

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SI CONVERSION

In recognition of the position of the U.S.A. as a signatory to the General Conference on Weights and Measures, which gave official status to the Metric SI System of units in 1960, the following conversion factors are provided to assist readers.

<u>Length</u>

1 inch (") = 0.0254 meter
1 foot (') = 0.3048 meter

<u>Area</u>

1 square foot (ft^2) = 0.0929 $meter^2$

<u>Volume</u>

1 cubic foot (ft^3) = 0.0283 $meter^3$

<u>Equivalent Terms</u>

Density: Persons/square foot = 10.76 persons/square meter

Area: Square feet/person = 0.0929 square meters/person

Flow: Persons/foot width/minute = 0.051 persons/meter width/second

Speed: Feet/minute = 0.0051 meters/second

The data in this report are given in metric units. However in citations where researchers presented their data in English units, these units are retained.

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1. INTRODUCTION

1.1 BUILDING CIRCULATION PLANNING

Increased knowledge of the characteristics of pedestrian circulation is a critical necessity in building planning and design. An understanding of pedestrian movement characteristics in the various component parts that comprise a building circulation system is the key to effective planning and design. However, movement characteristics for one component type, the ramp, have escaped detailed research study.

Pedestrian circulation systems are made up of vertical, horizontal, transitional, and indicative components. The vertical components are those that are specifically designed, located, and used for changes in elevation or level (elevators, stairs, ramps, etc.) The horizontal components are those that are specifically designed, located, and used for movement on a specific elevation or level (corridors, aisles, walkways, etc.). The transitional components are those that are specifically designed, located, and used to control access to, movement through, and egress from the circulation system (doors, gates, turnstiles, etc.). Finally, the indicative components are those that are specifically designed, located, and used for displaying information, indicating direction, and identifying elements throughout the circulation system.

To be effective, a building layout must support all the interrelated activities that occur within it [Willoughby, 1975]. The pedestrian circulation system is the primary means by which building activities are interrelated. Tabor [1969] points out that the effect of the built form on pedestrian movement in office buildings is a central relationship between the office function and its physical environment. According to Tregenza [1976], the basic shape of a building determines the effectiveness of its internal circulation system -- and hence the effectiveness of the activities which occur within the building.

In addition to determining internal activity relationships, the pattern of pedestrian circulation can be a significant tool for developing overall building form [White, 1973; 1975]. Many buildings clearly emphasize their circulation patterns in both their plan layouts and overall form. Examples of some of the most commonly known buildings that visibly express their circulation designs are the Pentagon in Washington, the Guggenheim Museum in New York, the McGill University Medical Building in Montreal, the Pompidou (Beaubourg) Center in Paris, and the Carpenter Center for the Visual Arts at Harvard University.

According to Fruin [1974], the pedestrian system planning problem is readily defined as the need to balance the vertical and horizontal components in a way that improves pedestrian movement. Turner and Collins [1979] suggest that all four component parts of the circulation system should be balanced to facilitate movement throughout the building. Nevertheless, the elements of building circulation have rarely been assessed as a total system, perhaps because the performance of the individual elements is at best, imperfectly understood.

1.2 BUILDING CIRCULATION RESEARCH

Despite the need to study all activities occurring in components of the circulation system, most research in building circulation has been and remains directed toward the problem of emergency egress. Stahl and Archea [1977] report that such egress research falls into three distinct areas: studies of "carrying capacity" (pedestrian density along passageways, walking speeds of pedestrians on passageways, and pedestrian flow rate in passageways); studies of signage, lighting and visibility under fire conditions; and studies of occupant responses to, and experiences in, fires. An additional area of building circulation research is directed toward defining and accommodating "movement patterns" in circulation systems [Whitehead and Eldar, 1964; Tabor, 1969].

An earlier review of the literature [Turner and Collins, 1979] suggests that there are three basic or generic categories of building circulation research. The first category can be termed "movement capacity" and contains those investigations where pedestrian movement* rates (flow, walking speed, density) over various circulation elements are measured [Fruin, 1971; Older, 1968; Navin and Wheeler, 1969]. The second category, termed "movement patterns", contains investigations where locations of activities and frequencies of movement between them are recorded [Tabor, 1969; Willoughby, 1975; Horizontal and Vertical Circulation..., 1962]. The third category is termed "movement psychology and physiology" and contains experiments in which cognitive and perceptual behaviors and physiological responses of pedestrians are investigated relative to circulation system components [Stahl, 1978; Corlett, Hutcheson, DeLugan, and Rogozenski, 1972].

Although researchers have investigated movement capacities and patterns for all circulation components, their primary focus has been upon the movement characteristics for horizontal elements such as walkways, or for vertical elements such as stairs. Because building circulation systems contain elements from all four basic components, complete information is needed about the performance of these components to evaluate, simulate, or design a complete and effective circulation system. Within the vertical, horizontal and transitional components, pedestrian movement characteristics such as flow rate, walking speed, and density have been extensively investigated for elements such as stairs, walkways and entry ways. Furthermore, the characteristics of pedestrian circulation have been extensively observed and even modeled mathematically for both stairs and walkways.

On the other hand, ramps, one part of the vertical component, have received little research attention. It has been suggested that ramps are so similar to level surfaces that there should be no difference in pedestrian movement patterns between the two types of elements. However, ramps are typically used to replace stairs and accomplish a change in elevation. Consequently, ramps may have movement characteristics that are more similar to those found for stairs than those for level surfaces. Therefore, there is a need to determine the pedestrian movement characteristics for ramps, and to compare them with data obtained for stairs and for level surfaces.

1.3 RATIONALE FOR RAMP RESEARCH

The need to determine detailed movement characteristics for ramps led to the present investigation of pedestrian movement on ramps in a free-flow situation. This investigation was designed to expand the existing research base.

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* See appendix A for a definition of the movement terms.

The current lack of sufficient research attention to ramps may have occurred because of their apparent similarity to level surfaces, or because of their infrequent use within buildings. Yet there are at least three major reasons for studying pedestrian movement on ramps. First, the lack of movement data specifically for ramps makes them the least understood of all vertical circulation components. As such, they are therefore a weak element in the understanding of overall circulation system performance. Secondly, there are new new legal requirements which mandate the design and maintenance of environments that are free from architectural barriers to the disabled. Since ramps can provide access for both able and disabled persons, they have the potential for being an alternative to stairs is some situations. As a result, the carrying capacity of ramps for normal and emergency situations must be understood. The third impetus behind the study of ramps is their potential for greater safety. The other major non-mechanical element of the vertical component, the stair, has a very high incidence of accidents [Archea, Collins & Stahl, 1979]. An improved understanding of movement on ramps could result in their wider use and could therefore be effective in reducing accidents on vertical circulation components. However, issues of safety are not addressed in this report.

1.4 SUMMARY

An increased knowledge of the design parameters responsible for more effective pedestrian circulation remains one of the main needs for building planning. While an understanding of pedestrian movement characteristics on the various components that make up a building circulation system is the key to effective planning, one component, the ramp, has rarely been the subject of building circulation research. Yet, in order to design an effective circulation system, an understanding of the movement characteristics for all the components is necessary. In this report, a description of some of the characteristics of pedestrian movement on ramps is presented, in the hope that it will increase understanding of the ramp as an element of the vertical circulation system.

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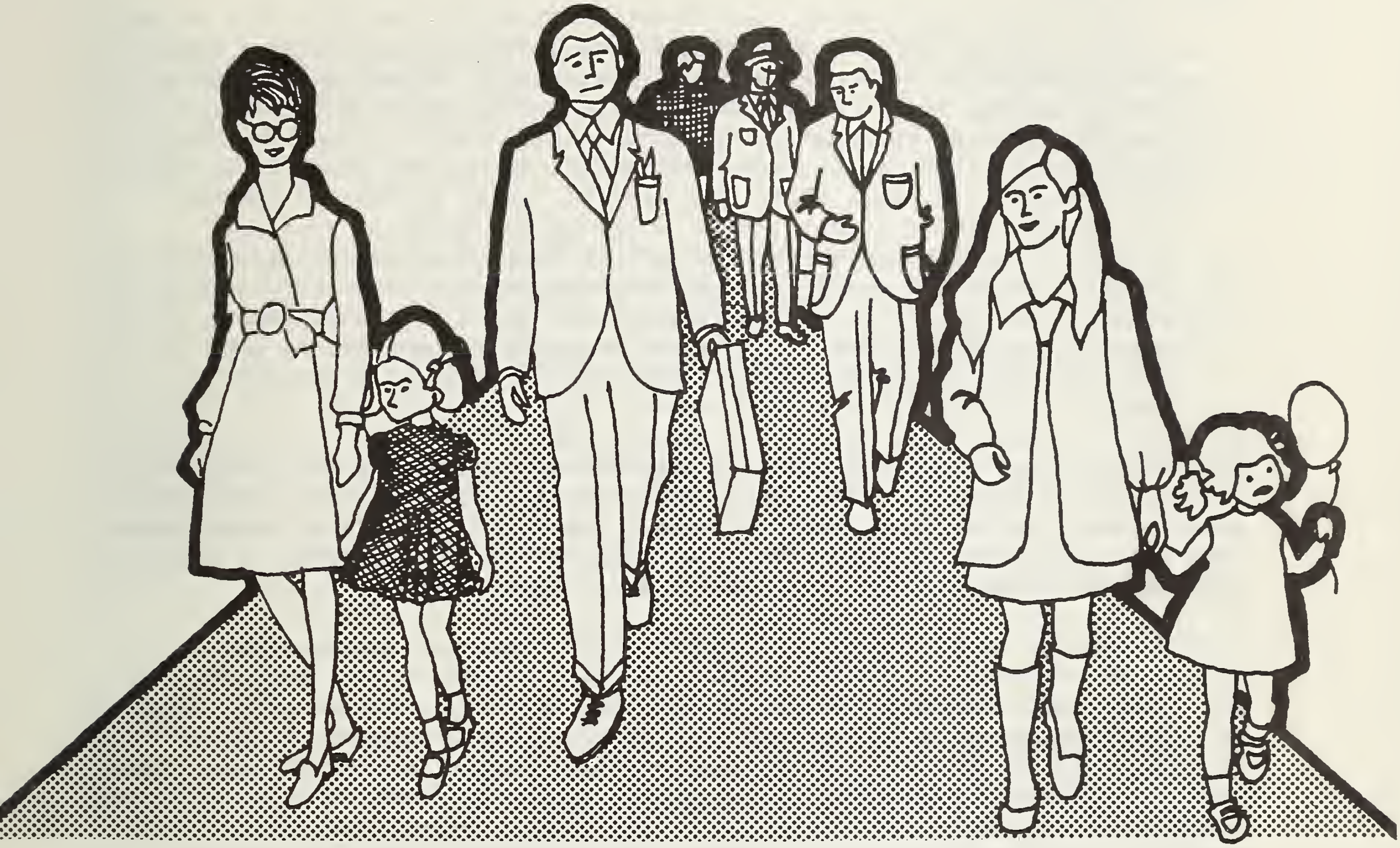


2. THE LITERATURE ON PEDESTRIAN CIRCULATION

The literature cited in the sections that follow focuses on movement characteristics on ramps, level surfaces, and stairs, as well as on energy expenditures on ramps and stairs. It is intended to provide a suitable framework within which to compare the building ramp data obtained in this study with other ramp and building circulation data in general.

2.1 RAMPS

The most significant effect of a ramp on pedestrian movement might be expected to be its grade or incline. Yet, Fruin [1971] noted that, within limits, ramp grade appeared to have little effect on freeflow walking speed on ramps. He commented that:

> "There were no statistically significant differences in walking speed due to grades of up to six percent, according to a survey of walking speeds by age, sex, and (ramp) grade categories in the Central Business District of Washington, D.C. [MacDorman, 1957]. Other studies confirm that there is no measurable effect on walking speed of up to five percent, but that there is a gradual linear decline in speeds for steeper grades [Hoel, 1968]. A controlled study of soldiers walking on a variable-grade treadmill revealed that an increase in positive treadmill grade, from five to ten percent, decreased average walking speeds by 11.5 percent [Evans, 1962]. A further increase in grade to twenty percent, a slope not normally encountered in most urban areas, decreased normal walking speeds by only 25 percent" [Fruin, 1971, p. 41].

Foot [1973] found that pedestrian walking speeds on a 5.7° slope grade vary from 0.35 to 1.40 m/sec. with speed being heavily dependent upon the density of the flow. He also mentioned a tendency for people to walk up ramps faster than they walk down. Finally, Foot asserted that pedestrian flow on stairs is considerably lower than that on ramps and level passageways.

In 1935, the National Bureau of Standards (NBS) reported measurements of pedestrian movement on stairs, ramps, and level surfaces. Although the work was concerned primarily with exit design, NBS did note a number of differences in pedestrian movement between the various circulation elements. The NBS report indicated that previous studies at the Illinois Central Railway system terminal had shown that flow rate was about equal for level surfaces and ramps (around .14 pms) but slower for stairs (.09 pms for ascent and .10 pms for descent). Again, the area per person under uncrowded conditions was about equal for level surfaces and ramps (1.03 m^2 and .98 m^2) but much smaller for stairs (.53 m^2). The NBS study itself found an average of about .74 m^2 per person on ramps at Grand Central Station with a minimum of about .58 m^2. The study also determined that: "given similar conditions, the discharge rate on ramps is faster than on stairways. Naturally, the width of stairway treads reduces the normal 30-inch (.76 m) stride more than a ramp with a slope of one in ten or less, and would therefore result in effecting a slower discharge rate for the stairway" [NBS, 1935, p. 38].

Tregenza [1976] indicated that ramps with a slope of 3° or less should have little effect upon walking speed. Yet, he pointed out also that data from the British Road Research Laboratory [Research on Road Traffic, 1965] suggest that a 5.7° slope could reduce upward walking speed by forty percent. "The effect of a downward gradient is similar; it has been found that under some circumstances people walk more slowly downhill than uphill, but this generally has not been observed. Less energy is used in moving downwards, but the greater control necessary is difficult for the frail and elderly" [Tregenza, 1976, p. 95].

Tregenza [1976] noted, furthermore, that ramps steeper than 4.6° can be dangerous for the handicapped, while Steinfeld [1975] recommended that ramps designed for the disabled should have a slope of 2.5° to 4.6°, with 3° preferred. Handrails should be provided on both sides. On the other hand, Walter [1971] found that when various categories of wheelchair users were considered, a slope of about 4° was preferrable, although there was an acceptable range of 3.4° to 6.3°.

The Traffic Engineering Handbook [Baerwald, 1965] reports from a study by the Portland Cement Association that while the rate of egress (flow) is about thirty persons/minute/traffic lane (.5 persons/sec.) of 22 inch (.56 m) width for stairs, this figure increases to thirty-seven persons/minute/traffic lane (22 inch wide) (.62 persons/sec./.56 m wide) for ramps. The Handbook also suggested that users generally prefer ramps and find them safer. Based on the Portland Cement study, the Handbook indicated further that ramps 7.1° to 9.5° are commonly used in stadia or grandstands. From data collected by the Chicago surface lines, the Handbook points out that at slopes less than 7° speed on ramps does not appear to vary much. Thus, based on the Chicago surface lines figures, the range of average speeds for ascent was found to be about 4.2 fps (1.31 m/s) for a 6.8° ramp and 4.7 fps (1.43 m/s) for a 1° ramp. For descent, the average speed was 4.5 fps (1.37 m/s) for the 6.8° ramp and 4.8 fps (1.46 m/s) for the 1° ramp.

To summarize, there have been a number of studies which have assessed the effect of ramp slope upon walking speed. These studies have suggested that slopes of less than 3.4° do not affect speed [MacDorman, 1957; Hoel, 1968; Tregenza, 1976]. In fact, the Traffic Engineering Handbook [Baerwald, 1965] reports slopes less than 7° appear not to affect walking speed. However, the British Road Research Laboratory [1965] points out that a slope of 5.7° can reduce walking speed by forty percent.

Although there are discrepancies in the reported ramp slope below which there is no effect on walking speed, the majority of research findings indicate that at very small slopes walking speed is not affected. Because the conditions surrounding the measurement of walking speed varied between the different research studies, there may have been many unreported variables other than slope that affected the results.

2.2 LEVEL SURFACES

Much of the research on pedestrian movement has centered around the measurement of speed, flow, and density for level surfaces. Researchers have reported mean walking speeds on level surfaces ranging from about 2.33 fps (.71 m/s) to 7.88 fps (2.40 m/s) [Fruin, 1971; Pignataro, 1973; Elkington, McGlynn and Roberts, 1976; and Tregenza, 1976]. Factors which can influence mean walking speed include those of surface characteristics, age, sex, counterflow, carried objects, etc. [Preiser, 1973; Lawton and Azar, 1964; Tregenza, 1976; Henderson, 1971; Hoel, 1968; Henderson and Lyons, 1972].

Researchers have reported a decrease in the range of walking speeds with increasing pedestrian density [Fruin, 1971; Tregenza, 1976; Hankin and Wright, 1958; O'Flaherty and Parkinson, 1972]. In fact, once an area of 2-3 ft^2 (.19-.28 m^2) per pedestrian is reached, movement stops for all practical purposes and density is close to maximum [Fruin, 1971; Tregenza, 1976; Hankin and Wright, 1958]. Yet, at areas only slightly larger than these, 4-5 ft^2 (.37-.45 m^2) per pedestrian, maximum flow rates are found [Navin and Wheeler, 1969; Hankin and Wright, 1958; Fruin, 1974]. Observation of the close relationship between speed and density -- and consequently, flow (a measure derived from both speed and density that considers passageway width) -- led to the development of mathematical models which could predict flow volume characteristics for a given passageway. In addition, the relationships between speed, area, flow, and density led Fruin [1971] to the development of a level-of-service concept in which different passageway widths for a given volume provide different levels of crowding and, hence, comfort or discomfort for the pedestrian. Fruin [1971] suggested six levels of service, ranging from complete free-flow conditions at 35 ft^2 (3.26 m^2) per pedestrian to restricted flow conditions at 5-10 ft^2 (.46-.93 m^2) per pedestrian. On the other hand, O'Flaherty and Parkinson [1972] recommended that a density of about 18 ft^2 (1.67 m^2) per pedestrian would provide adequate service.

2.3 STAIRS

The pattern of movement on stairs is rather different from that on ramps and level surfaces. Perhaps because the method of movement on stairs is related more to climbing than walking, both flow rate and speed are slower. Thus, typical speeds for ascent are about 100-125 fpm (.51-.64 mps) with a range of 40-164 fpm (.2-.83 mps) [Fruin, 1971]. In descent, speeds are somewhat faster, around 130-150 fpm (.66-.76 mps) [Galbreath, 1969]. The slower speeds on stairs were not accompanied by high densities. Nevertheless, "As with walkway volume, maximum stairway flow occurs in the region of minimum pedestrian area occupancy, about at the point of a two tread length and one shoulder breadth area, or approximately three square feet per person" [Fruin, 1971, p. 59]. A small flow in the opposite direction (counterflow) of the main flow can almost halve the capacity of a narrow stair [Melinek and Booth, 1975]. (The effects of small amounts of counterflow are much less apparent for horizontal surfaces, and result in only a ten percent or less decrease in flow.)

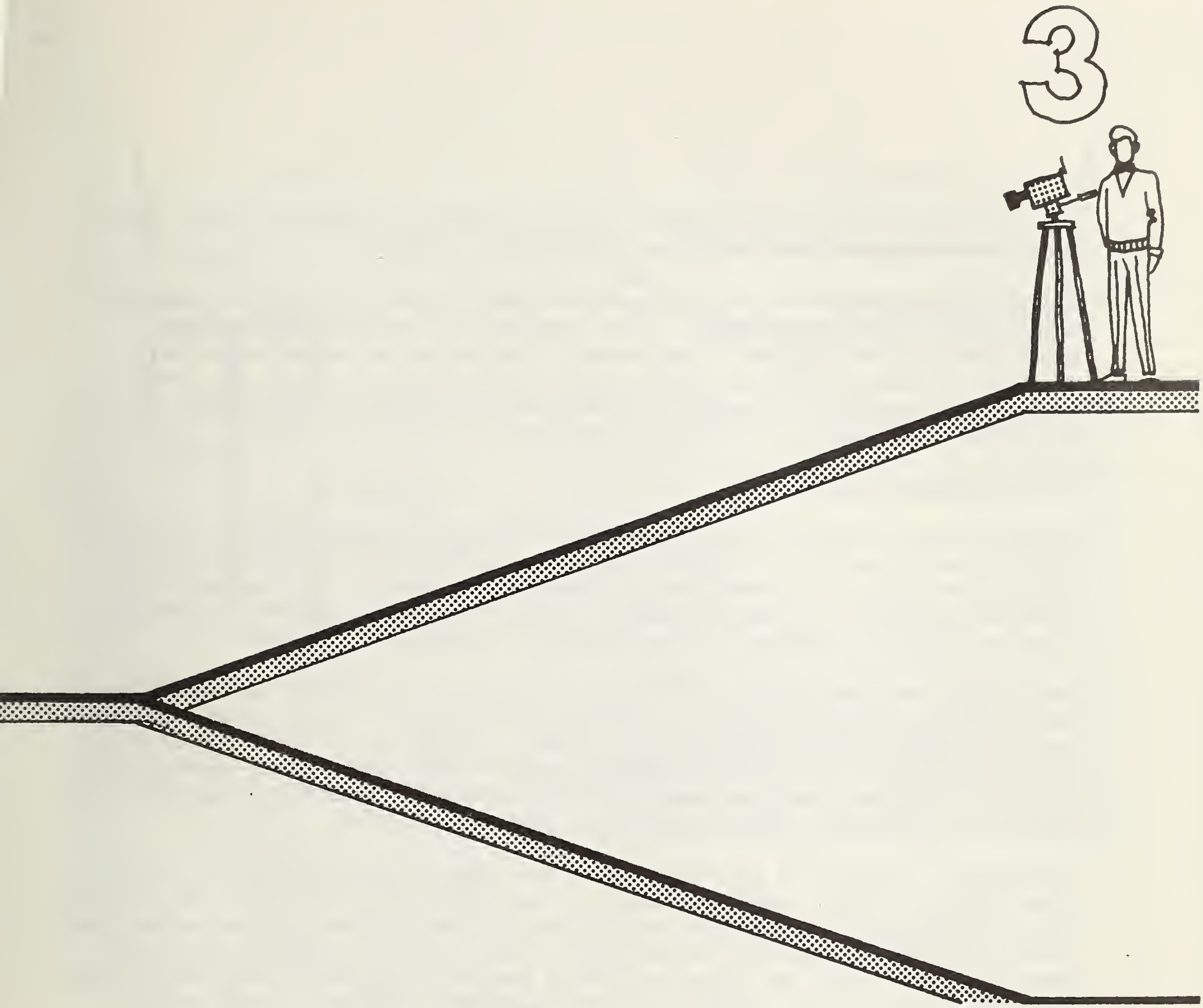
2.4 ENERGY EXPENDITURE

Corlett, Hutcheson, DeLugan, and Rogozenski [1972] noted that the use of a ramp may require even more energy consumption than a stair and suggested that the cardiac cost of climbing a stair of equal height is always less than that of walking a ramp. Energy consumption is not the whole picture, however. "Where knee angle (and probably ankle angle) is important as in old or lame people, it would appear that a ramp will be easier to negotiate for a given slope, than any form of fixed stairway, although the maximum ramp angle requires further study to specify. Where joint rotation and muscle strength are not limiting factors, however, it would seem that stairs are more efficient from a physiological cost point of view and that high steps are less costly to negotiate than low ones. It also appears that the higher step is negotiated more quickly for a given height of climb" [Corlett, et al., 1972, p. 200]. Thus, from a physiological point of view, joint flexion must be considered along with energy expenditure for a particular user group in any choice between stairs and ramps.

However, using a ramp can be physiologically more efficient than climbing a stair and walking the remaining distance on the level when total distance is considered [Tregenza, 1976; Templer, 1974]. Templer [1974] reported that the average pedestrian speed of 3 mph (1.34 m/s) on ramps appears to be such that energy expenditure is at a minimum. This speed is also about the same as that found for level surfaces.

2.5 SUMMARY OF PREVIOUS RESEARCH

The preceding review of the literature on pedestrian movement on level surfaces, ramps, and stairs has indicated that characteristics of movement such as speed, density, and flow have been established for level surfaces under many different circumstances. The knowledge base appears to be reasonably adequate for predicting pedestrian movement characteristics on level surfaces. The knowledge base for pedestrian movement on ramps appears to be restricted to determinations of speed with no assessment of flow or density effects. Furthermore, the bulk of the data was collected over 40 years ago [Baerwald, 1965; NBS, 1935]. Consequently, the effects of ramps upon all movement variables for a variety of built environments and for a variety of crowd densities remains to be assessed. Although there is a need to assess the effects of other building types, crowd conditions, and similar factors upon movement characteristics for ramps, data from the present investigation do represent an initial step in the development of information about pedestrian movement on ramps. Such information is needed to design building circulation systems to serve the needs of both able-bodied and disabled populations under normal and emergency conditions.



3. THE RESEARCH DESIGN

3.1 METHOD OF INVESTIGATION

The descriptive method of research was used for this study [Isaac and Michael, 1971]. Descriptive research as used here is defined as the systematic delineation of the facts and characteristics of a given population or area of interest, factually and accurately. It is the accumulation of a data base that is primarily representative and does not necessarily attempt to determine or explain relationships, test hypotheses, make predictions, or explain meanings and implications although research aimed at these more powerful purposes may include descriptive methods [Issac and Michael, 1971].

A descriptive method was used because the lack of existing data on ramps and limitations in the scope of the study prohibited a more elaborate quasi-experimental investigation. The research design was intended to collect factual information that describes pedestrian movement on ramps; to identify problems if possible or justify current design practices; and to make comparisons with the work of other researchers.

3.2 DATA COLLECTION SITE

The data collection site for the project was the Baltimore Memorial Stadium in Baltimore, Maryland. This site was selected because: (1) spectator vertical circulation is accomplished exclusively by ramps on the inside of the stadium; and (2) it is used virtually year-round since it serves as the home playing field for both major league baseball and football teams.

The stadium was dedicated in 1954 and is typical of stadium construction at that time. The basic structure and seating tiers are cast-in-place concrete, and the exterior and interior walls or wall facings are of brick and concrete block. Because of the horseshoe-like configuration, the seating capacity for football is larger than for baseball. Football game capacity is approximately 60,700, while baseball game capacity is just over 58,300.

The stadium seating can be entered from two levels, upper and lower. Each level is ringed by a promenade having concession stands and toilet facilities. Ramp towers located around the outside face of the stadium are the primary vertical circulation elements for gaining access to the two levels. The lower level occurs at grade on the east side of the building and is entered directly from the ticket gates. However, on the west side, the lower level occurs at about one story-height (3.6 m) above grade and is reached by walking up two ramp lengths after passing through the ticket gates. In addition to the ramp towers, one story ramps are located inside of the stadium on the west side and serve as alternative means for reaching the lower level from the ticket gates. The upper level is about three-and-one-half story heights (5.4 m) above the lower level and is reached by walking up seven ramp lengths. See figures 1 and 2.

3.3 DATA COLLECTION PROCEDURE AND EQUIPMENT

Data were collected at a Baltimore Colt football game on Sunday, December 11, 1977 and at Baltimore Orioles baseball game on Sunday, September 17, 1978. Both games were played in the afternoon. The temperature during the football game was about -3°C and about 21°C during the baseball game. Attendance at the football game was 45,124 while attendance at the baseball game was only 4,436. Videotaping locations were on the west side of the stadium. A different, but similar, pair of ramps was investigated for each game. (See figures 1 and 2.) The ramps were different because, upon the advice of the stadium management,

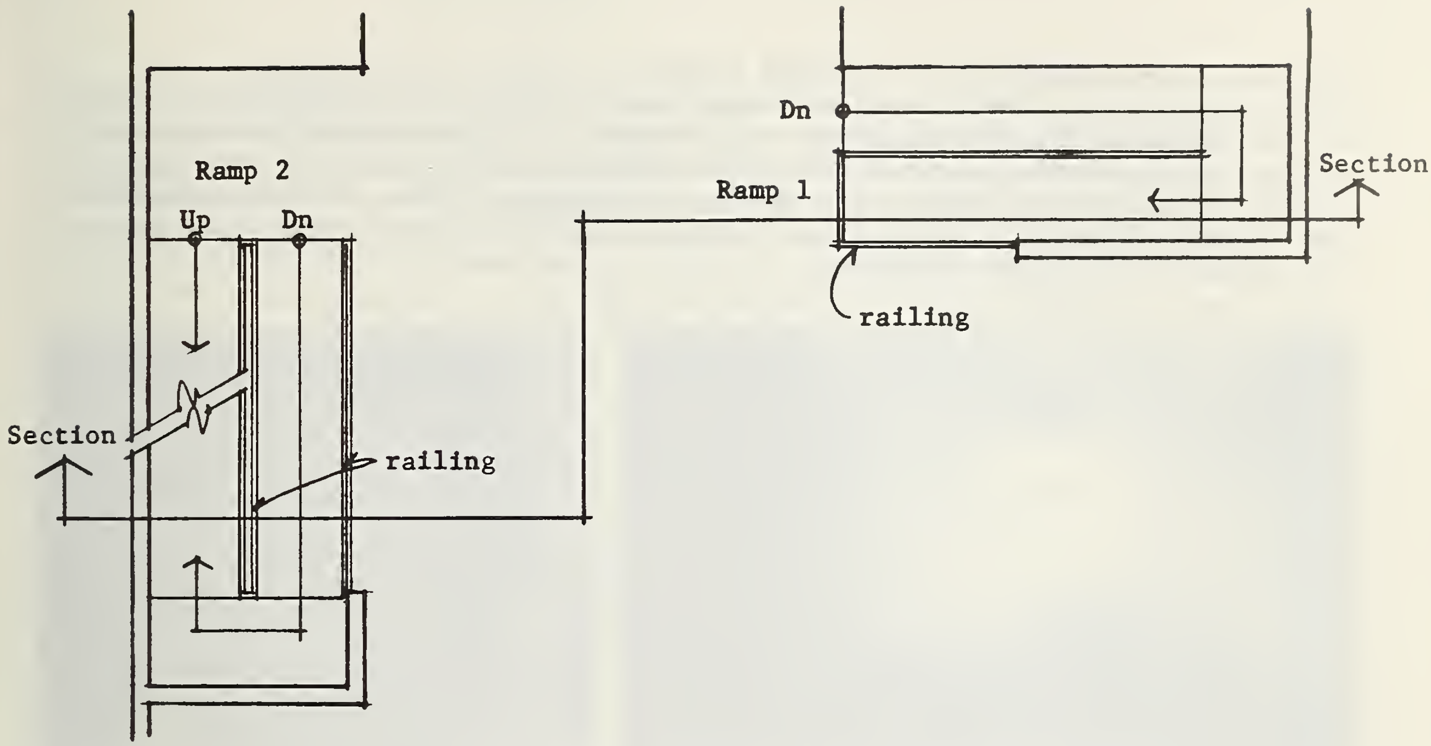


Figure 1. Plan at lower level promenade showing the relationship between ramps (not to scale)

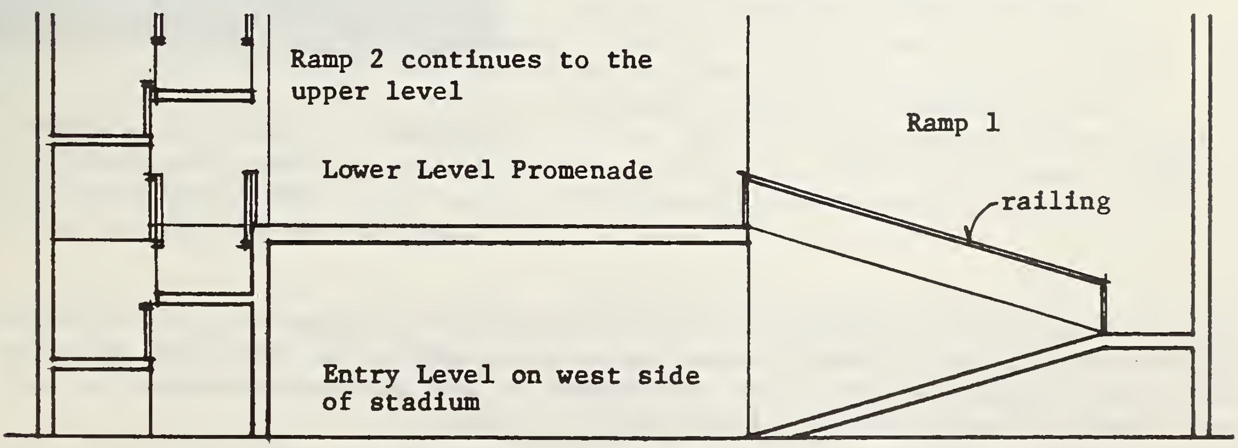


Figure 2. Partial section through ramps (not to scale)

locations were selected where maximum numbers of users were expected. The interior locations (lower level or ramp 1) were at the top of and looking down on the bottom length of a one story ramp (figure 3). These ramps led directly to lower level seats. Perimeter locations (upper level or ramp 2), were at the top of and looking down on the next-to-top length of ramp of the perimeter ramp towers (figure 4). These ramps provided access to lower level seats and sole access to upper level seats.

Figure 3. Typical lower level ramp (view from video taping position).

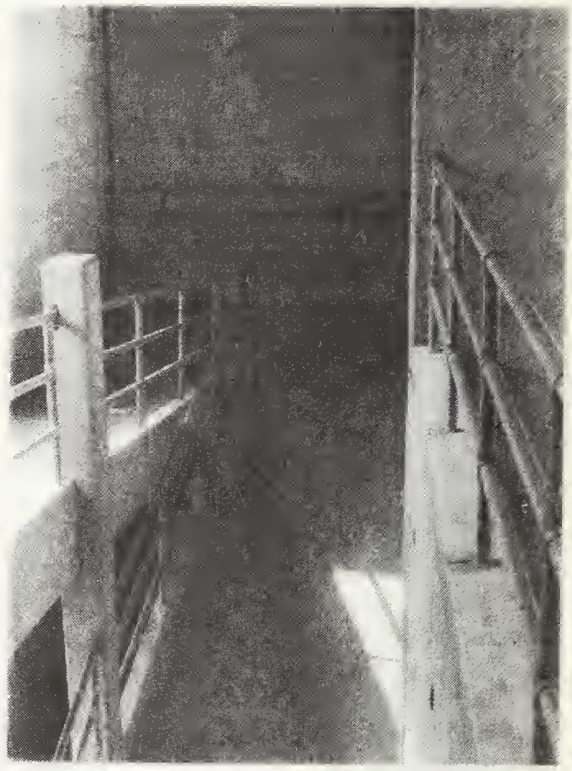


Figure 4. Typical upper level ramp (view from video taping position).

The west side of the stadium was selected because its exposure to the afternoon sun provided higher lighting levels inside the stadium for video taping. The actual ramps selected were those recommended by the stadium management as the most likely to reach high densities and flow rates.

Each of the four ramps selected for study was observed during both ingress (up) and egress (down) for a total of eight samples. The ramps were similar dimensionally and table 1 gives a dimensional comparison. Data were collected by means of video cameras and recorded on videotape for later analyses.

There are a number of advantages to the use of film or videotape as a data collection method [Foot, 1973]. The data can be preserved intact and transcribed at a later date, making analysis more flexible. Furthermore, the record is permanent so that subsequent reanalysis is possible. With videotape, there is the extra advantage of a monitor in the camera that allows the data record to be immediately observed for picture quality and content. However, the primary disadvantage to videotape is the need for large numbers of batteries if there is no electrical power available and if videotaping is done over long periods of time.

	Football Game		Baseball Game	
	Ramp 1	Ramp 2	Ramp 1	Ramp 2
Width	1.72 m	1.70 m	2.13-2.51 m	1.69 m
Length	3.00 m	5.20 m	3.95 m	6.50 m
Area	5.23 m^2	8.98 m^2	9.83 m^2	11.15 m^2
Slope	1:6.4(8.9°)	1:6.3(9.1°)	1:6.4(8.9°)	1:6.4(8.9°)

Table 1. Dimensions for Portions of the Ramps Used in the Study

Identical battery-powered, portable video cameras and recorders were mounted on tripods overhead at the videotaping locations. Since the portable recorders required the use of thirty-minute videotapes, the entire ingress was not taped. Instead, a sample of the ingress was obtained by taping alternating three minute intervals, starting approximately one hour before game time. Because ingress to scheduled events such as athletic games has been reported to be a gradual, long, and continuous process [Roytman, 1975], alternating, evenly spaced, time intervals were believed to be a valid means of reducing the length of the process while maintaining its basic structure. Egress was taped continuously over a period of approximately 30 minutes using the same equipment at the same location as for ingress.

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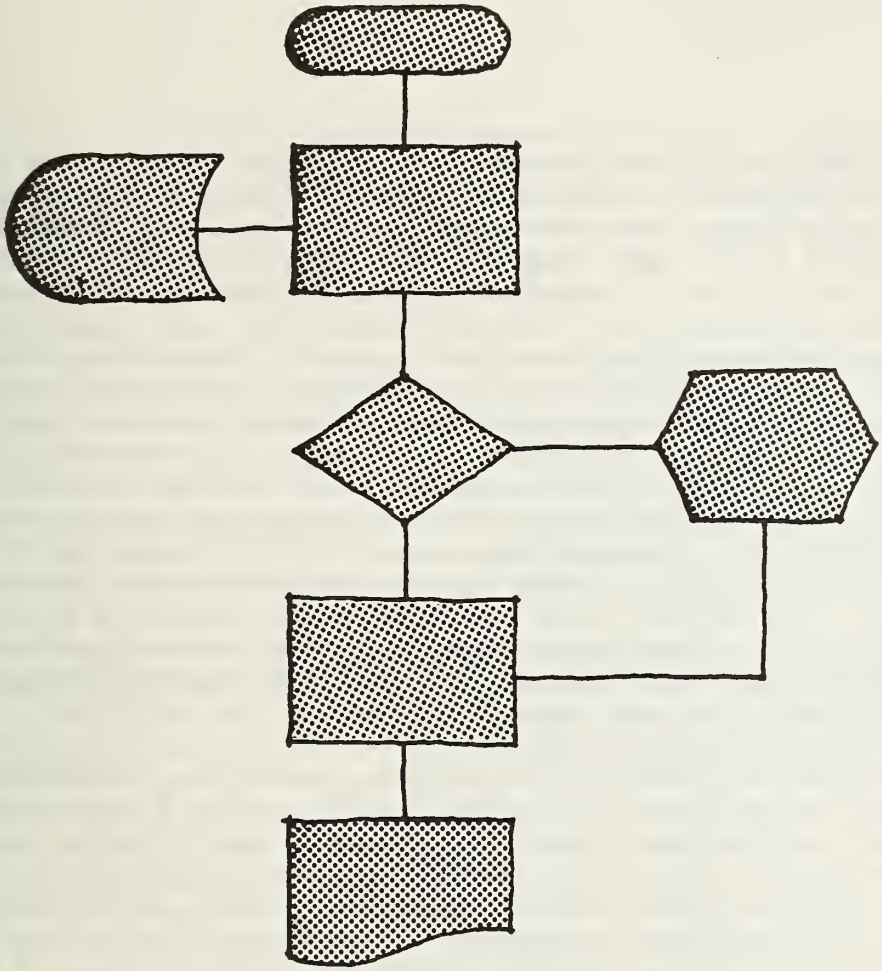

4. TRANSFORMATION OF THE DATA

4.1 VIDEOTAPE CONVERSION

The test distances on the ramps over which pedestrian movement data were collected were indicated on the videotapes during taping. When the videotapes were analyzed, horizontal lines indicating the length of the ramp studied were drawn on the monitor screen with a felt-tip pen. Because of the difficulty in determining when a person's feet crossed these lines on the ramp in a crowd, the location of the floor lines were projected up so that the estimated point at which a person's head would cross the two lines could be observed. A person of average height was selected from the first portion of each of the videotapes (for each ramp and direction). When the person's feet were aligned with the beginning and end points of the test length of the ramp, horizontal lines were drawn just touching his/her head. Once the horizontal lines representing head-height above the predetermined marker lines on the ramp had been drawn, the number of people passing between the lines were counted. Their transit time was also determined. In the counting and timing phases, a procedure somewhat akin to that used by Hankin and Wright [1958] was employed in which a single person was chosen to mark the end of a group. This person was timed with a stopwatch as he/she passed between the two marker lines. At the same time, all other persons between the two lines and in front of the marker person at any time during his/her transit were counted as a group. Unlike Hankin and Wright, the marker person was selected from people on the videotape and was not a member of the research staff. The marker person was arbitrarily defined as being the last person in a naturally occuring group separated by an obvious gap from the next group. The procedure for identification of the marker person was the same for both ingress and egress for both games.

Two observers transferred the walking time and group counts from the videotapes to recording sheets. As the first step, they jointly selected a marker person for each group. They recorded some identifying characteristics and the video-recorder counter number on the data sheet so that the marker person could easily be re-identified. Once the transit time of the marker person was recorded, the number of people in each group was determined. In this count, all of the people in front of the marker person whose heads were between the two horizontal lines were counted. These people were considered to constitute the density associated with the marker person's walking speed. Each observer counted the people independently. Then, any difference in counts was resolved in a simultaneous recount. Both the independent and the combined count were recorded.

Once the overall count had been made, several subsequent refinements were made. The first involved determination of the proportion of adult men, adult women, and children in the observed samples. Because of the bulky winter clothing worn at the football game, it was somewhat difficult to differentiate women from men. Furthermore, the videotapes of football egress were not as clear as for ingress due to fading light conditions. However, the baseball game attire did not present any particular difficulty in assigning people to male/female groups. Children were defined as anyone whose head was at least one head height below the marker lines. Again, this categorization is not perfect; it may include very short adults while excluding tall children. The number of women at the football game is reported with a 95 percent confidence of being within $\pm$ 2.6 percent of the actual number. The numbers of children at both the football and baseball game are reported with a 95 percent confidence of being within $\pm$ 1.8 percent and $\pm$ 3.5 percent of the actual numbers respectively.

The number of observations varied between ingress and egress for each ramp. The variation was relatively slight for the baseball game but particularly pronounced for the football game. Since each "observation" is for a group of people (as defined earlier), differences in the number of observations may be due to a difference in the manner in which pedestrians group, as well as to a difference in the absolute number of people.

Ingress occurred over a longer time period than did egress, people arrived individually and generally in small groups. The individuals and small groups were all counted and timed for walking speeds. Because egress occurred more quickly than ingress, many of the individuals and small groups observed during ingress became members of larger groups during egress. In addition, it is possible for people to chose to leave by a different ramp than used for entering. Furthermore, the below freezing temperatures at the football game may have caused some people to leave prior to egress video taping.

For the baseball game however, slightly more observations were made during egress than during the football game egress despite the overall smaller attendance. People may have chosen a different ramp for ingress than for egress or the smaller overall attendance may not have produced larger groupings of people during egress.

5

5. RESULTS

Statistical analyses were made on data points that were derived from the original individual raw counts and times taken from the videotapes. Area per person was determined by dividing the area of the portion of the ramp used by the individual groups of people. Walking speeds were derived by dividing the transit time for the marker person by the length of the portion of the ramp used. Finally, flow rate was calculated by dividing speed by area. A computer program was written for transforming the raw data and creating data files containing four variables: density, area per person, flow rate, and walking speed [Turner and Collins, 1979]. Values for these variables form the basics statistics for the analyses and findings reported herein.[1]

The results include: an analysis of the relationships between movement variables, ramp location, and game type; and descriptive statistics for three movement variables (area per person, flow rate, and walking speed). Additional examinations focused on: the composition of the population in terms of men, women, and children; comparison of the distributions of movement variables; and a determination of the physical location of people on the ramps.

5.1 ANALYSIS OF COVARIANCE

The first statistical relationship to be considered is the effect of ramp location, movement direction and game type upon both flow and speed. Two analyses of covariance was conducted for: flow or speed as dependent variables; ramp (1 or 2), direction (ingress or egress), and game (football or baseball) as independent variables; and area per person as the covariate.[2] Area was used as a covariate in order to remove, to the extent possible, the extraneous variation in flow resulting from the different dimensions of the portions of the ramps used in the study.

The main effects of ramp, direction, and game were significant for speed, while only game showed a significant effect upon flow. There was a significant 2-way interaction for direction and game for both flow and speed although the other 2-way interactions, ramp-direction, and ramp-game, were not significant. The 3-way interactions were not significant. Table 2 gives a summary of the results of the analyses.

5.2 DESCRIPTIVE STATISTICS FOR THE MOVEMENT VARIABLES

Descriptive statistics including mean, mode, standard deviation and range were computed for three movement variables: area per person (area), flow rate (flow), and walking speed (speed). Each of the three variables was analyzed for: entry (ingress) and exiting (egress); for the lower ramp (ramp 1) and the upper ramp (ramp 2); and for the football game and the baseball game.

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[1] The second edition of the Statistical Package for the Social Sciences (SPSS) [Nie, et al., 1975] was used for all statistical analyses. In particular, procedures entitled "Frequencies" and "Scattergram" were used.

[2] The analyses were two separate univariate tests, nonorthogonal (unequal cell) three-way analyses of variance using SPSS Subprogram ANOVA [Nie, et al., 1975] with the default option (classic experimental approach) analysis method.

Source of Variation	Flow	Speed
Covariate		
Area	S	S
Main Effects		
Ramp	NS	S
Direction	NS	S
Game	S	S
2-Way Interactions		
Ramp-Direction	NS	NS
Ramp-Game	NS	NS
Direction-Game	S	S
3-Way Interactions		
Ramp-Direction-Game	NS	NS

S = significant, $\alpha \leq 0.05$
NS = non-significant $\alpha > 0.05$

Table 2. Results of Two Analyses of Covariance

Area per person was reported instead of its reciprocal, density, because area per person is a more useful measure for building circulation system design. However, descriptive statistics for density are given in appendix B. Tables 3, 4, and 5 give summaries of the descriptive statistics for each variable across all conditions. Differences in the descriptive statistics between ramps and between games for area per person and flow are influenced by differences in the dimensions of the portions of the ramps used in the study (see table 1). The dimensional differences resulted from differences in ramp widths and camera viewing angle caused by practical necessities encountered at the site. Since walking speed was measured over a linear dimension rather than being derived from an area, it can be readily compared across conditions.

5.3 CHI-SQUARE TESTS

Further analysis consisted of examinations of the differences between the distributions of the movement variables with respect to the ramp location, direction of movement, and type of game. The distributions were tested by collapsing them to five categories proportioned to the overall range of values

	Football Game				Baseball Game			
	Ramp 1 Ingress	Ramp 1 Egress	Ramp 2 Ingress	Ramp 2 Egress	Ramp 1 Ingress	Ramp 1 Egress	Ramp 2 Ingress	Ramp 2 Egress
Mean	2.58	2.30	4.18	3.23	5.07	4.29	6.74	4.48
Mode	2.61	2.61	4.49	2.25	2.46	4.91	5.58	5.58
Variance	2.11	1.74	6.08	6.95	8.69	6.62	10.40	12.34
Std. Dev.	1.45	1.32	2.47	2.63	2.95	2.57	3.22	3.51
Minimum	0.65	0.65	0.82	0.69	1.97	0.76	1.59	0.86
Maximum	5.23	5.23	8.98	8.98	9.83	9.83	11.15	11.15
Range	4.58	4.58	8.16	8.29	7.86	9.07	9.56	10.29
N of Obs.	208	63	101	68	44	58	38	39

Table 3. Area Per Person (m^2/person)

	Football Game				Baseball Game			
	Ramp 1 Ingress	Ramp 1 Egress	Ramp 2 Ingress	Ramp 2 Egress	Ramp 1 Ingress	Ramp 1 Egress	Ramp 2 Ingress	Ramp 2 Egress
Mean	0.66	0.69	0.55	0.67	0.26	0.37	0.25	0.48
Mode	0.58	0.58	0.39	0.78	0.23	0.20	0.16	0.14
Variance	0.10	0.13	0.11	0.10	0.02	0.04	0.02	0.10
Std. Dev.	0.31	0.36	0.33	0.32	0.14	0.19	0.14	0.31
Minimum	0.19	0.19	0.15	0.13	0.04	0.08	0.09	0.12
Maximum	2.33	1.63	2.16	1.37	0.63	0.88	0.77	1.18
Range	2.14	1.44	2.01	1.24	0.59	0.80	0.68	1.06
N of Obs.	208	63	101	68	44	58	38	39

Table 4. Flow Rate (persons/meter-width/second)

	Football Game				Baseball Game			
	Ramp 1 Ingress	Ramp 1 Egress	Ramp 2 Ingress	Ramp 2 Egress	Ramp 1 Ingress	Ramp 1 Egress	Ramp 2 Ingress	Ramp 2 Egress
Mean	1.36	1.21	1.69	1.50	1.02	1.19	1.35	1.32
Mode	1.52	1.02	1.76	1.76	1.00	1.00	1.22	1.10
Variance	0.16	0.06	0.18	0.25	0.15	0.09	0.09	0.11
Std. Dev.	0.40	0.25	0.42	0.50	0.38	0.30	0.30	0.33
Minimum	0.73	0.73	1.17	0.70	0.40	0.32	0.61	0.73
Maximum	3.05	2.18	3.77	2.93	2.67	2.23	1.94	2.20
Range	2.32	1.45	2.60	2.23	2.27	1.91	1.33	1.47
N of Obs.	208	63	101	68	44	58	38	39

Table 5. Walking Speed (meters/second)

of the movement variable under consideration. Since the technical literature on pedestrian movement gave no guidance as to an appropriate number of categories, five classes were arbitrarily selected. Appendix C gives the tables used in the Chi-square tests.

Examination of the distributions of area per person and flow was limited to comparisons of ingress and egress on each ramp. As discussed in the previous section, differences in area and flow between ramps were due to differences in the dimensions of the portions of the ramps used in the study.

Table 6 shows the results of the examination of area. The results indicate that area per person does not differ significantly between ingress and egress for ramp 1, but does differ significantly between ingress and egress for ramp 2.

Table 7 shows the results of the examination of flow rate. The results indicate a significant difference in flow rates between ingress and egress, for ramp 2 but not for ramp 1.

In table 8, results of the examination of walking speed are given. The consistent differences between movement direction and ramp location obtained for the football game do not all occur for the baseball game. Table 9 gives the results of a further analysis which tests differences between the football and baseball games. The results indicate that there is a significant difference in ingress walking speeds between the football and baseball games, but that there is no difference in egress speeds.

	Area per Person	X^2
Football Game	Ramp 1 Ingress - Ramp 1 Egress	NS
	Ramp 2 Ingress - Ramp 2 Egress	S
Baseball Game	Ramp 1 Ingress - Ramp 1 Egress	NS
	Ramp 2 Ingress - Ramp 2 Egress	S

S = significant, $\alpha \leq 0.05$
NS = non-significant, $\alpha > 0.05$

Table 6. Tests of Differences in Area

	Flow Rate	X^2
Football Game	Ramp 1 Ingress - Ramp 1 Egress	NS
	Ramp 2 Ingress - Ramp 2 Egress	S
Baseball Game	Ramp 1 Ingress - Ramp 1 Egress	NS
	Ramp 2 Ingress - Ramp 2 Egress	S

S = significant, $\alpha \leq 0.05$
NS = non-significant, $\alpha > 0.05$

Table 7. Tests of Differences in Flow

	Walking Speed	X^2
Football Game	Ramp 1 Ingress - Ramp 1 Egress	S
	Ramp 2 Ingress - Ramp 2 Egress	S
	Ramp 1 Ingress - Ramp 2 Ingress	S
	Ramp 1 Egress - Ramp 2 Egress	S
Baseball Game	Ramp 1 Ingress - Ramp 1 Egress	S
	Ramp 2 Ingress - Ramp 2 Egress	NS
	Ramp 1 Ingress - Ramp 2 Ingress	S
	Ramp 1 Egress - Ramp 2 Egress	NS

S = significant, $\alpha \leq 0.05$
NS = nonsignificant, $\alpha > 0.05$

Table 8. Tests of Differences in Speed

	Football vs Baseball	X^2
Walking Speed	Ramp 1 Ingress - Ramp 1 Ingress	S
	Ramp 1 Egress - Ramp 1 Egress	NS
	Ramp 2 Ingress - Ramp 2 Ingress	S
	Ramp 2 Egress - Ramp 2 Egress	NS

S = significant, $\alpha \leq 0.05$
NS = non-significant, $\alpha > 0.05$

Table 9. Tests of Differences in Speed Between Games

5.4 POPULATION COMPOSITION

The composition of the population in terms of adult men, adult women, and children was estimated for ingress on both ramps during the football game. The same observation was made for both ingress and egress on both ramps during the baseball game. Table 10 summarizes the results of the counts per category in terms of percentages of the total. It is apparent from the table that adult males accounted for approximately three quarters of the population of the football game but less than one half of the population of the baseball game. Although the percentage of adult women attending the baseball game was only slightly higher, the number of children attending the baseball game was 20 percent higher than at the football game. More elderly people and individuals with walking handicaps were observed at the baseball game, although formal counts were not made for these categories.

	Football Game		Baseball Game	
	Ramp 1	Ramp 2	Ramp 1	Ramp 2
Number of Observations	581	265	391	228
Men	71.95%	76.23%	44.00%	47.80%
Women	20.48%	16.98%	28.10%	26.80%
Children	7.57%	6.79%	27.90%	25.40%
Total	100.00%	100.00%	100.00%	100.00%

Table 10. Population Composition

5.5 PEDESTRIAN LOCATIONS ON RAMPS

Building regulations use a standard 22-inch unit of width as the basis for sizing circulation system components. It is assumed that 22 inches will allow for the passage of a single file of people. The widest and most narrow ramps used in the study (see figure 1) were divided by 0.55 m (22 inches) in order to determine the number of single files that each ramp could accommodate. From the videotapes for the two ramps, the number of single files (alone and side-by-side walking) occurring during ingress and egress were counted.

Table 11 shows the frequencies of alone and side-by-side walking. Since the area of study for ramp 1 was a trapezoid shape and varied between just under 4 and just over 4 1/2 single files, it was treated as being able to accommodate four files.

A record was also made of the location on the ramps where people positioned themselves while walking. Alone and side-by-side walking were examined for the location of individuals relative to the center line of the ramp. The intention of the observation was to examine the extent to which the right hand lane driving rule applied to pedestrian walking. Table 12 shows the results of walking location counts for lone individuals.

Table 13 shows the results of walking location counts for pairs of people.

Ramp 1 (3.87 to 4.56 units of width*)			Ramp 2 (3.07 units of width)		
Number of persons walking abreast per observation	Frequency	%	Number of persons walking abreast per observation	Frequency	%
1	63	72	1	54	70
2	19	22	2	22	29
3	6	6	3	1	1
4	0	0	4	0	0
1	80	58	1	64	52
2	49	36	2	53	43
3	7	5	3	6	5
4	1	1	4	0	0

* Unit of width = 22 in.

Table 11. Side-by-Side Walking on Ramps

	Ingress Ramp 1	Ingress Ramp 2	Egress Ramp 1	Egress Ramp 2
RC	32%	17%	63%	61%
C	33%	33%	31%	33%
LC	35%	50%	6%	6%

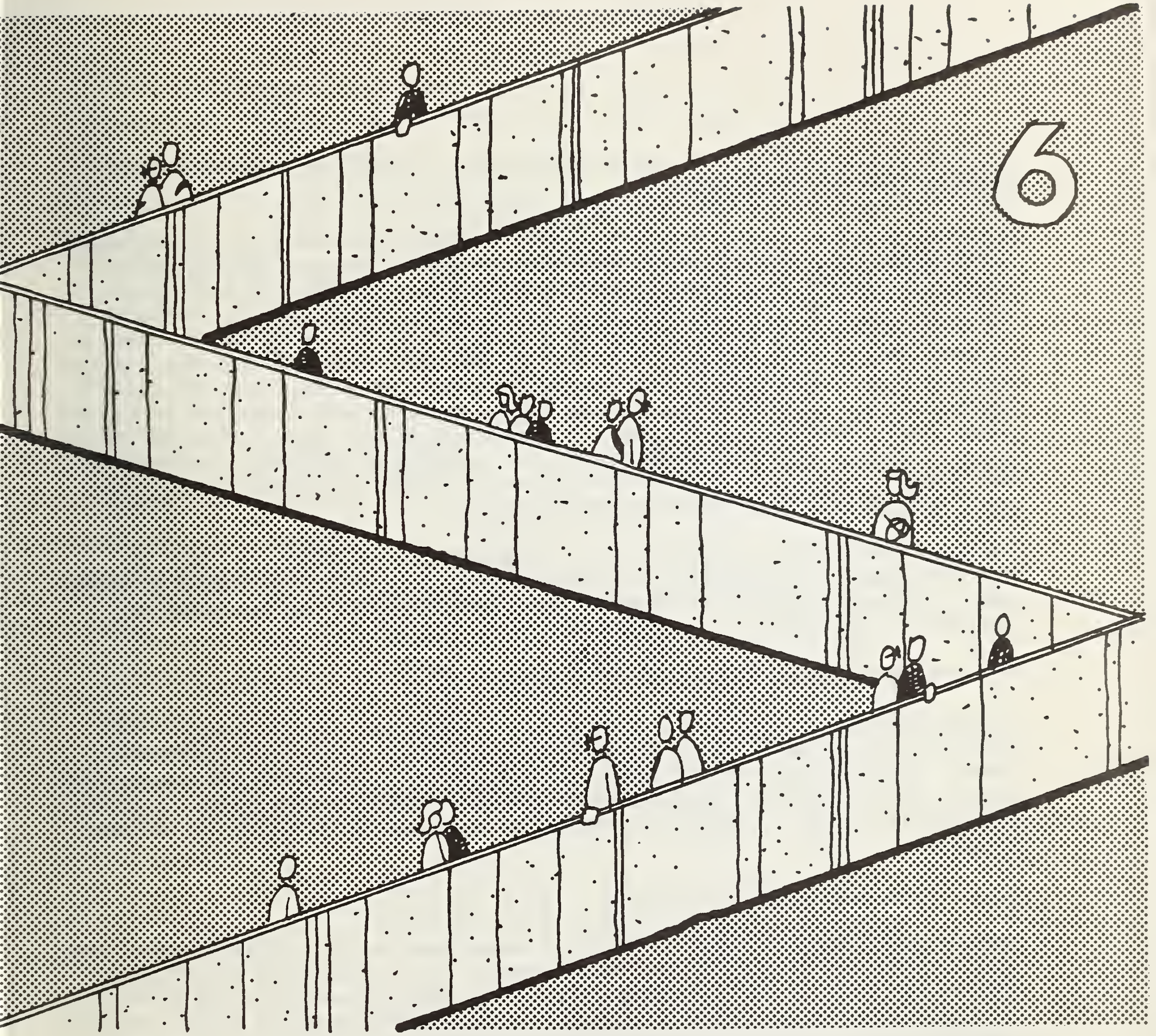
RC = right of center
C = center
LC = left of center

Table 12. Walking Locations of Lone Individuals

	Ingress Lower level ramp	Ingress Upper level ramp	Egress Lower level ramp	Ingress Upper level ramp
RC/C	31%	10%	54%	61%
RC/LC	50%	30%	39%	37%
C/LC	19%	60%	7%	2%

RC/C = right of center and center
RC/LC = right of center and left of center
C/LC = center and left of center

Table 13. Walking Locations for Pairs of People



6. DISCUSSION

6.1 RESULTS OF THE ANALYSIS OF COVARIANCE

By removing, to the extent possible, extraneous variation caused by the covariate area per person, the effects of variations in ramps, direction of movement, and type of athletic game were examined for flow rate and walking speed. The variables studied do not by any means acccount for all of the variation found in flow rates and walking speeds. They merely represent variables for which some comparison can be made. Since many factors can confound the results of an observational study such as this, any interpretation of the findings must be speculative.

Walking speed was significantly different for ramp, direction, and game, while flow showed a significant difference only for game. Because walking speed is a function of area per person, it tends to be nearly uniform at very small areas and variable or unrestricted at larger areas [Fruin, 1971]. Plots of the relationships of the standard deviations of walking speeds on the ramps at varying areas per person appear similar to the functional relationship reported by Fruin (see appendix D). Fruin reports areas at or below 0.465 m^2/person on level surfaces and 0.372 m^2/person on stairs as being representative of crowded conditions. However, areas below 0.65 m^2/person did not occur at either of the games. In addition, since variations were calculated for fewer observations at the larger areas than at the smaller areas, the results are speculative and point out the need for further investigation.

The only two-way interaction showing a significant difference was that of direction-game. Consequently, the differences that can be attributed to either game or direction separately must be qualified by specifying the level or category of the other.

6.2 DESCRIPTIVE STATISTICS FOR THE MOVEMENT VARIABLES

The descriptive statistics for each ramp for both games can be compared with similar information for other field investigations of pedestrian movement on ramps. Table 14 gives a comprehensive overview of the movement parameters from several other studies. Ramp dimensions and the environmental context are also provided in order to illustrate both the differences and similarities of the studies.

6.2.1 Area Per Person

Comparison of the mean area occupied by pedestrians on the Baltimore ramps with that reported by previous researchers revealed some interesting differences. The average area per person for the Baltimore ramps ranged from 2.58-6.74 m^2 for ingress and 2.30-4.48 m^2 for egress. Previous NBS research [1935] reported average areas of 0.753 m^2 for ingress (movement up) and 0.734 m^2 for egress (movement down) on ramps in Grand Central Station. The average areas observed on the Baltimore ramps were generally much larger with even the smallest being over twice as large as the Grand Central average. According to Fruin [1971], it is possible to have areas as small as 0.27 m^2/person before total immobilization occurs. If 0.27 m^2 is considered to be the approximate minimum area required for movement, it is obvious that the observed areas per person for the Baltimore ramps were very large by comparison.

	Dimensions			Context			Movement Parameters						
Code	Width (meters)	Length (meters)	Slope	Site	Time	Temp. (°C)	Avg Area (m^2/p)	Avg Volume (p/min)	Avg Flow (p/m/s)	Average Speed (m/s) Men	Women	Combined	No of Obs.
A	1.715	11.125	8.9°	Stadium	PM	-3	2.582	-	0.657	-	-	1.363	208
B	1.702	12.573	9.1°	Stadium	PM	-3	4.178	-	0.547	-	-	1.691	101
C	3.0-2.1	11.303	8.9°	Stadium	PM	29.5	5.071	-	0.264	-	-	1.022	44
D	1.689	12.573	8.9°	Stadium	PM	29.5	6.739	-	0.247	-	-	1.348	38
E	1.943	41.808	5.9°	RR Stat.	-	-	0.753	-	1.148	-	-	-	-
F	3.581	-	6.7°	RR Stat.	AM	-	-	46.6	-	1.341	1.250	1.280	138
G	5.004	-	5.7°	Office B.	AM	-	-	72.6	-	1.433	1.280	1.341	275
H	6.401	-	5.7°	Stadium	-	-	-	190.6	-	-	-	1.158	25
I	3.353	-	2.1°	Sidewalk	-	-	-	39.6	-	1.889	1.555	1.615	15
J	9.449	-	1.7	Sidewalk	-	-	-	-	-	1.55	1.341	1.433	101
A	1.715	11.125	1:6.4	Stadium	PM	-3	2.295	-	0.692	-	-	1.209	63
B	1.702	12.573	1:6.3	Stadium	PM	-3	3.225	-	0.672	-	-	1.503	68
C	2.1-3.0	11.303	1:6.4	Stadium	PM	29.5	4.294	-	0.365	-	-	1.186	58
D	1.689	12.573	1:6.4	Stadium	PM	29.5	4.478	-	0.479	-	-	1.324	39
E	1.943	41.808	1:9.7	RR Stat.	-	-	-	-	0.820	-	-	-	-
F	3.581	-	1:8.5	RR Stat.	PM	-	-	39.8	-	1.463	1.311	1.372	321
G	5.004	-	1:10	Office B.	PM	-	-	68.2	-	1.494	1.372	1.433	212
J	4.449	-	1:35	Sidewalk	-	-	-	-	-	1.555	1.372	1.463	113
K	1.943	41.808	1:9.7	RR Stat.	-	-	0.734	-	1.039	-	-	-	-

Code: A ,B ,C ,D [Turner and Collins, 1979 and this report], E, K [NBS, 1935], F, G, H, I, J [Baerwald, 1965].

Table 14. Ramp Research Findings Comparison Table

The average flow rates observed on the Baltimore ramps varied from 0.25 pms to 0.69 pms. Fruin [1971] reports that on level surfaces a flow rate of 1.10 pms is possible under a variety of walkway and traffic conditions. He further points out that a flow rate of 1.39 pms can be attained under favorable conditions, and a rate of 1.65 pms is possible under the most favorable conditions of walking and traffic composition. Either much higher flow rates are possible on the Baltimore ramps or there may be a real difference in possible movement between ramps and level surfaces.

The average flow rates for ramps reported by NBS [1935] based on observations at Grand Central Station are very similar to the typical rate of 1.10 pms for level surface reported by Fruin [1971]. It is possible that the areas observed for the Grand Central ramps were similar to those for level surfaces observed by Fruin. If the areas on the Grand Central ramps were similar to those reported by Fruin for level surfaces, much higher flow rates are possible on the Baltimore ramps. If the Grand Central areas were lower than Fruin's, the higher flows may have resulted from the greater widths of the ramps. The Baltimore ramps were about one half the width of the Grand Central ramps.

6.2.3 Walking Speed

The measure most common to all the studies is mean walking speed. The mean speed varies from 1.022 meters per second to 1.691 meters per second across all studies. Although characteristics of the environmental context vary a good deal, as do ramp dimensions, the majority of the mean walking speeds are between approximately 1.3 and 1.4 meters per second. Variations in reported walking speed may be attributable to variations in environmental conditions. For example, Hoel [1968] found that walking speeds on level surfaces decreased as ambient temperature increased and Evans [1962] found that walking speed decreased as slope increased on treadmills.

The average walking speed on the Baltimore ramps ranged from 1.02 - 1.6 mps for ingress and from 1.19 - 1.50 mps for egress. The slopes of the Baltimore ramps, approximately 9°, are greater than the slopes for other ramps where walking speeds have been observed. The traffic Engineering Handbook [Baerwald, 1965] reports the range of average speeds walking up ramps to be from 1.28 mps on 6.8° inclines to 1.48 pms on 1.1° inclines. The range of average speeds walking down ramps is reported to be from 1.37 mps on 6.8° slopes of 1.46 mps on 1.1° slopes [Baerwald, 1965].

Although there are differences in the slopes of ramps and various other conditions between the studies reporting average walking speeds, the reported difference between minimum and maximum average speeds for all studies is about .66 meters per second or a little over 1 mile per hour.

Various researchers have reported average walking speeds on level surfaces ranging from about 0.71 mps to 2.37 mps [Fruin, 1971; Pignataro, 1973; Elkington, et al., 1976; and Tregenza, 1976]. While the range of average walking speeds on ramps is within in the range of average walking speeds on level surfaces, the range on ramps tends not be as large because of a lower maximum value. This might be an indication that the slope of the surface can affect the frequency of, or tendency for, fast walking. Yet the range of average speeds on ramps far exceeds that reported for stairs (0.51-.76 mps). Thus, unlike stairs, ramps appear to allow more rapid speeds of movement while accomplishing a change in elevation.

6.3 POPULATION COMPOSITION

Although the populations (ramp users) for the two games appeared to be quite different in terms of the proportions of adult males and children, the proportion of adult females was only slightly larger for the baseball game. Research by Henderson and Lyons [1971, 1972] has suggested that males and females behave as though they belong to different populations in otherwise homogeneous crowds. They determined that walking speed distributions were different for males and females within the same crowd. Although not specifically investigated in this project, variations in population composition such as sex or age may result in differences between movement variables. It is possible, however, that the greater percentage of children at the baseball game may have accounted for the significant difference in walking speed observed for baseball ingress.

6.4 CHI-SQUARE TESTS

The Chi-square test results indicated that the distributions of area per person differed significantly between ingress and egress only on ramp 2 during both games. Ingress at sports events tends to occur over an extended time period as people gradually arrive from the time the gates are open until the start of game. Egress, on the other hand, tends to be of relatively short duration with the simultaneous departure of large numbers of spectators. Thus, differences in the distributions of area per person between ingress and egress are to be expected. The lack of significant differences in area for ramp 1 suggests that the use of the ramp may not have corresponded with the model of gradual ingress and quick egress.

The distributions of flow rates differed significantly between ingress and egress for both the football and baseball games for ramp 2. The lack of significant differences between ingress and egress flows for ramp 1 can be attributed to the lack of difference in areas because flow is derived from area.

Although the flow rates discussed herein are derived from and represent discrete points, actual flow on a circulation system component is continuous over any time interval of use. The derived flow rates merely represent flows that are possible if the area per person and walking speed remains constant.

Tests for differences in the distributions of walking speeds were significant for both the ramp and the direction of movement in all but two out of eight tests. No significant difference was found between ramp 2 ingress and ramp 2 egress and ramp 1 egress and ramp 2 egress for the baseball game. Walking speeds tend to be variable or unrestricted when area per person is not a limiting factor. As a result, the data suggest that people were free to walk at a speed of their own choosing, unaffected by crowd movement or density.

Chi-square analyses were also made between walking speed distributions on the same ramp locations for both games. A significant difference in the distribution of walking speeds occurred only for ingress between the two games. While walking speed for ingress varied on the same ramp locations between games, egress did not. This difference may have occurred because ingress lasted for a much longer time than egress. As a result, ingress could allow greater differences in walking speeds that the short duration and simultaneous nature of egress prohibited.

6.5 PEDESTRIAN LOCATIONS ON RAMPS

The observation of walking patterns indicated that the majority of the people using the ramps were walking alone. There is no obvious reason why most people would walk alone, particuarly since in many instances it was obvious that although the individual was part of a group or pair, he/she chose to walk in a single file fashion. There were no obvious advantages to single file walking such as a commonly used hand rail. Where side-by-side walking occurred, it never exceeded the calculated number of files based upon the 22-in width unit used as the basis for current building circulation requirements. As noted earlier, though, the area per person was typically large with high densities occurring in very few instances.

An analysis of the position of lone individuals walking on the ramps indicated that during ingress a majority of people walked to the left of center and ignored the right of center convention used by vehicular traffic. However, during egress the right of center convention predominated. Since the position of most individuals agreed with the direction of wind of the ramp during ingress and egress, an "inside track" type of behavior was being exhibited. It appears that most people tend to take the shortest physical distance.

The locations of pairs of people did not indicate a tendency for any one location in either direction to be used more frequently. It may be that simultaneous effects of two or more individuals on the walking location of each other prevents the more regularized positioning observed for lone individuals.

6.6 RAMP SLOPE

Ramp slope was not one of the conditions that could be varied in this study. Slope was a constant 9° ($\pm$ 0.1°) for all ramps in the Baltimore Stadium. However, the review of the literature suggested several interesting means for evaluating the effects of slope upon movement parameters and human positioning.

One method for determining the maximum slope that will permit normal walking is based on the premise that the equilibrium of a person walking down a ramp will be maintained if an associated retaining moment is equal to or greater than a tilting moment due to the ramp slope [Roytman, 1975]. Calculations of the moments are made using the following equations:

$$M_r = P(\cos a)s, \quad M_t = P(\sin a)h$$

where: M_r is the retaining moment in kg meters
M_t is the tilting moment in kg meters
P = weight of the person in kg
h = height of the center of gravity above the ramp floor in meters
s = arm of the retaining moment in meters (length of the shod foot)
a = angle of the ramp relative to the horizontal

There is to an underlying fallacy with the tilting moment equation in that the height of the whole body center of gravity was measured perpendicular to the ramp. Observation of the videotapes, showed that people compensate for slope by leaning forward when walking up a ramp and backwards when walking down. Therefore, calculations were made using the retaining and tilting moment equations with center of gravity measured from the ramp floor but perpendicular to the horizontal, and using the anthropometric dimensions of the 50 percentile adult male [Dreyfuss, 1967], the maximum slope for a ramp should be 17°.

A study by Corlett, et al. [1972] concluded that where knee angle and ankle angle are important, a ramp is easier to use than a stair. Consequently, a biomechanical method for determining maximum slope was used. Murray, et al. [1964] reported the rotation angles of ankle, knee, and hip joints for normal men during the walking cycle for horizontal surfaces. Based on the assumption that the walking gait is used on ramps, ramp slopes were added to the normal flexions and extension of ankle, knee, and hip joints until a governing maximum was reached for the 50th percentile adult male [Dreyfuss, 1967]. It was calculated that the ankle extension was the governing rotational limit with a ramp of 17° being maximum. In other words, a normal walking gait would have to be changed for ramps above 17° to an augmented gait in order to compensate for joint rotation limits. However, there is no evidence to indicate that other aspects of gait such as the heel to toe action of the foot and the variation in the rate of forward movement of the body center of gravity are not more critical considerations than joint rotation.

6.7 RAMP FLOW CAPACITIES

The maximum flow rate observed on the Baltimore ramps was 2.33 pms at an area of 0.5 square meters per person. (See Appendix E.) Fruin [1971] reported maximum flow rates on stairs and level surfaces at areas of approximately 0.23 m^2 and 0.45 m^2 respectively. Various other researchers [Togawa, 1955; Older, 1968; Navin and Wheeler, 1969; Fruin, 1971] have shown that as the area per person decreases the flow rate will increase, until the area is so small that all movement stops. Since maximum flow rates for both stairs and level surfaces [Fruin, 1971] occur at smaller areas per person than those at which the maximum flow rates on the Baltimore ramps occurred, these ramps may be capable of a much higher flow rate than observed. If the maximum average speed of 1.69 pms observed at Baltimore (ramp 2 ingress), is divided by the areas at which Navin and Wheeler [1961] observed maximal flow (.37-.45 m^2), then a maximum possible flow rate of 3.8 to 4.6 pms is possible. It should be noted that this theoretical flow rate is greater than that prescribed by the Life Safety Code [Sharry, 1978] (The Life Safety Code prescribes flow capacities for ramps such as those in the Baltimore stadium to be 100 persons per unit of exit width per minute both up and down the ramp. This translates to a flow rate of 3 persons per meter width per second (pms), with density unspecified). These calculations suggest that it may be possible to achieve much higher flow rates on ramps than those specified by the Code.

The NBS report [NBS, 1935] dealing with the design of building exits places ramps between level surfaces and stairs in terms of flow rate with stairs having the lowest rate. Fruin [1971] reported average flow rates for level surfaces at between 0.82 pms and 0.66 pms for areas per person between 1.39 m^2 and 1.86 m^2. He reported average flow rates for stairs at between 0.33 pms and 0.26 pms in the up direction and between 0.38 pms and 0.31 pms in the down direction for areas between 1.39 m^2 and 1.86 m^2. Average flow rates on the Baltimore ramps were equal to or greater than Fruin's data for level surfaces and were consistently greater than those for stairs in both the up and down directions for areas per person between 1.39 m^2 and 1.86 m^2. This suggests that, at similar densities of pedestrians, ramps having slopes up to 9° can allow flow rates in either the up or down direction that are equal to or greater than flow rates for level surfaces, and far greater than those for stairs reported by Fruin.

6.8 FURTHER RESEARCH NEEDS

In order to develop a comprehensive understanding of pedestrian movement on ramps in general, there are several areas of research that remain to be addressed. The research reported herein describes variables of pedestrian movement and the relationships between them on one design of a ramp. Once the basic variables of speed, flow, and density have been established for a particular ramp design, and a good set of experimental procedures developed, other variables pertaining to ramps should be assessed. These include ramp width, slope, interactive effects such as counterflow and direction of travel, and effects of pedestrian gait. Eventually, the investigation should be extended to other building types--particularly those in which ramps handle a high volume of pedestrian traffic. Additional research on ramps is needed to compare movement characteristics on them with that on other elements of building circulation systems. The most obvious comparison is with stairs, which are also used for vertical circulation within a building. Previous research by Fruin (1971) and others had indicated that both flow and speed are lower for stairs than for horizontal surfaces. Furthermore, counterflow has a marked effect upon flow on stairs, quickly reducing it to half the normal volume--yet a similar amount of counterflow on a horizontal surface may only reduce it by ten percent. A closer examination of the relationship between counterflow and flow-volume for ramps is needed, in partiuclar, when the potential for using ramps as a major element of the vertical circulation system is considered.

The previous paragraph has dealt with the need to determine and compare pedestrian movement characteristics for all forms of vertical and horizontal circulation within a building. There is also a need, however, to determine the effects of population differences upon movement, particularly for ramps and stairs. While the proportions of adult males, adult females and children using the Baltimore ramps were reported, there is no indication as to how this population affected movement rates. Yet, Henderson and Lyons (1972) pointed out that female/male pedestrian populations differ significantly in their movement characteristics. Still another research question is that of the relative ease of movement for different population groups on both stairs and ramps. There are two questions here. The first is that while ramps clearly facilitate access for the handicapped in wheelchairs, is this facilitation also true for the elderly, those on crutches or those with ankle/knee movement problems? A stair may in fact be easier to negotiate for some--but not for all handicapped persons. Conversely, limited observation has suggested that many non-handicapped persons tend to choose a ramp over a stair.

Thus, a second research question is the condition under which ramps are used instead of stairs. There is, consequently, the need to research a design in which both handicapped and non-handicapped persons are asked to use both a ramp and a stair, and their choices as well as the movement characteristics for each element/population type are experimentally determined. Finally, ensuring optimal performance for all circulation systems depends upon knowledge not only of basic movement variables such as speed, flow, and area but also of fundamental environmental characteristics such as illumination, surface texture, and signage.

6.9 SUMMARY

An effective pedestrian circulation system is one of the primary requirements in building planning. Circulation system design requires an understanding of the characteristics of pedestrian movement in buildings. Pedestrian movement throughout an entire building can be characterized by movement rates on each of the individual circulation system components. Ramps are one of the variety building component parts designed and used exclusively for circulation. Consequently, movement rates on ramps are important in their design and regulation.

In order to satisfy the requirement for continuity of movement rates throughout the circulation system, it is necessary to understand the differences in movement rates between different components and between different sizes or designs of the same component. This report has presented the results of observations of pedestrian movement on ramps as a step in developing an understanding of pedestrian movement in buildings in general.

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APPENDIX A

As a background for the review of pedestrian movement research, it is important to define and understand a number of the technical terms and parameters that are used. These parameeers are used as the input to design criteria for pedestrian movement. The four major movement characteristics that are most often studied include: speed, flow, area, and density. The following definitions of these pedestrian movement parameters are paraphrased from those given by Fruin [1971].

Speed is defined as the distance traveled by the pedestrian per unit time and is expressed as feet per minute (fpm), feet per second (fps), miles per hour, (mph), or meters per second (mps). On ramps, the distance traveled is measured along the inclined or sloped surface and does not represent speed with respect to either the horizontal or vertical component of the slope.

Density is the number of persons per unit of area, expressed as pedestrians per square foot (ft^2) or pedestrians per square meter (m^2). Because this measure results in fractions of people, Fruin [1971] chose to use its reciprocal, area, defined as square feet or square meters per pedestrian.

Flow or flow rate is defined as the number of persons passing a point in a unit of time. It is expressed as pedestrians per foot-width or meter-width of passageway per unit time or as pedestrians per foot-width per minute (pfm) or pedestrians per meter-width per second (pms). Flow is also equal to the average pedestrian speed divided by the average pedestrian area.

Fruin [1971] noted further that flow is one of the most important traffic characteristics because it determines the width of the passageway. Since flow has been defined as pedestrians per unit-width per time, a reduction in width will impede movement. Predicting flow rate accurately is thus important in determining the width of a particular circulation element, whether it be a ramp, a stair, a corridor, a doorway, or the like.

APPENDIX B

	Football Game				Baseball Game			
	Ramp 1 Ingress	Ramp 1 Egress	Ramp 2 Ingress	Ramp 2 Egress	Ramp 1 Ingress	Ramp 1 Egress	Ramp 2 Ingress	Ramp 2 Egress
Mean	0.53	0.61	0.33	0.51	0.26	0.34	0.19	0.40
Mode	0.43	0.43	0.22	0.32	0.41	0.20	0.18	0.18
Variance	0.07	0.10	0.04	0.12	0.02	0.06	0.01	0.08
Std. Dev.	0.26	0.31	0.20	0.35	0.13	0.25	0.12	0.28
Minimum	0.22	0.22	0.11	0.11	0.10	0.10	0.09	0.09
Maximum	1.51	1.51	1.18	1.40	0.51	1.32	0.63	1.17
Range	1.29	1.29	1.07	1.29	0.41	1.22	0.54	1.08
N of Obs.	208	63	101	68	44	58	38	39

Table 1-B. Descriptive Statistics for Density

APPENDIX C

Area Classes	Football Ramp 1 Ingress	Football Ramp 1 Egress	Area Classes	Football Ramp 2 Ingress	Football Ramp 2 Egress
0.65 - 1.56	55	22	0.69 - 2.34	34	39
1.57 - 2.48	42	8	2.35 - 4.00	11	11
2.49 - 3.39	69	25	4.01 - 5.66	39	8
3.40 - 4.31	0	0	5.67 - 7.32	0	0
4.32 - 5.23	42	8	7.33 - 8.98	17	10

Area Classes	Baseball Ramp 1 Ingress	Baseball Ramp 1 Egress	Area Classes	Baseball Ramp 2 Ingress	Baseball Ramp 2 Egress
0.76 - 2.57	15	20	0.86 - 2.91	4	20
2.58 - 4.38	6	10	2.92 - 4.97	5	4
4.39 - 6.20	12	20	4.98 - 7.03	17	8
6.21 - 8.01	0	0	7.04 - 9.09	0	0
8.02 - 9.83	11	8	9.10 -11.15	12	7

Figure 1-C. Area (m^2 per person) Frequency Tables used for Chi-square Tests

Flow Classes	Football Ramp 1 Ingress	Football Ramp 1 Egress	Flow Classes	Football Ramp 2 Ingress	Football Ramp 2 Egress
0.19 - 0.61	116	35	0.13 - 0.53	65	27
0.62 - 1.04	66	15	0.54 - 0.94	26	25
1.05 - 1.47	24	11	0.95 - 1.34	8	15
1.48 - 1.90	1	2	1.35 - 1.75	1	1
1.91 - 2.33	1	0	1.76 - 2.16	1	0

Flow Classes	Baseball Ramp 1 Ingress	Baseball Ramp 1 Egress	Flow Classes	Baseball Ramp 2 Ingress	Baseball Ramp 2 Egress
0.04 - 0.20	17	14	0.09 - 0.30	30	23
0.21 - 0.37	17	21	0.31 - 0.52	6	6
0.38 - 0.54	9	14	0.53 - 0.74	1	6
0.55 - 0.71	1	5	0.75 - 0.96	1	5
0.72 - 0.88	0	4	0.97 - 1.18	0	4

Figure 2-C. Flow (pms) Frequency Tables used for Chi-square Tests

Speed Classes	Football Ramp 1 Ingress	Football Ramp 1 Egress
0.73 - 1.19	70	35
1.20 - 1.65	106	26
1.64 - 2.12	16	1
2.13 - 2.58	14	1
2.59 - 3.05	2	0

Speed Classes	Football Ramp 2 Ingress	Football Ramp 2 Egress
0.70 - 1.31	5	25
1.32 - 1.92	84	32
1.93 - 2.54	7	7
2.55 - 3.15	2	4
3.16 - 3.77	3	0

Speed Classes	Football Ramp 1 Ingress	Football Ramp 2 Ingress
0.73 - 1.33	121	12
1.34 - 1.94	68	77
1.95 - 2.55	17	7
2.56 - 3.16	2	2
3.17 - 3.77	0	3

Speed Classes	Football Ramp 1 Egress	Football Ramp 2 Egress
0.70 - 1.14	27	17
1.15 - 1.59	34	23
1.60 - 2.03	1	19
2.04 - 2.48	1	5
2.49 - 2.93	0	4

Figure 3-C. Speed (mps) Frequency Tables used for Chi-square Tests

Speed Classes	Baseball Ramp 1 Ingress	Baseball Ramp 1 Egress
0.32 - 0.79	10	2
0.80 - 1.26	26	39
1.27 - 1.73	7	14
1.74 - 2.20	0	2
2.21 - 2.67	1	1

Speed Classes	Baseball Ramp 2 Ingress	Baseball Ramp 2 Egress
0.61 - 0.92	4	5
0.93 - 1.24	11	13
1.25 - 1.56	10	12
1.57 - 1.88	12	6
1.89 - 2.20	1	3

Speed Classes	Baseball Ramp 1 Ingress	Baseball Ramp 2 Ingress
0.40 - 0.85	13	3
0.86 - 1.30	23	14
1.31 - 1.76	7	18
1.77 - 2.21	0	2
2.22 - 2.67	1	0

Speed Classes	Baseball Ramp 1 Egress	Baseball Ramp 2 Egress
0.32 - 0.70	2	0
0.71 - 1.08	20	10
1.09 - 1.46	28	15
1.47 - 1.84	6	11
1.85 - 2.23	2	3

Figure 4-C. Speed (mps) Frequency Tables used for Chi-square Tests

Speed Classes	Football Ramp 1 Ingress	Baseball Ramp 1 Ingress
0.40 - 0.93	13	20
0.94 - 1.46	130	20
1.47 - 1.99	46	3
2.00 - 2.52	10	0
2.53 - 3.05	9	1

Speed Classes	Football Ramp 1 Egress	Baseball Ramp 1 Egress
0.32 - 0.70	0	2
0.71 - 1.08	20	20
1.09 - 1.46	33	28
1.47 - 1.84	8	6
1.85 - 2.23	2	2

Speed Classes	Football Ramp 2 Ingress	Baseball Ramp 2 Ingress
0.61 - 1.24	3	15
1.25 - 1.87	82	22
1.88 - 2.50	11	1
2.51 - 3.13	2	0
3.14 - 3.77	3	0

Speed Classes	Football Ramp 2 Egress	Baseball Ramp 2 Egress
0.70 - 1.14	17	14
1.15 - 1.59	23	18
1.60 - 2.03	19	6
2.04 - 2.48	5	1
2.49 - 2.93	4	0

Figure 5-C. Speed (mps) Frequency Tables used for Chi-square Tests

APPENDIX D

Standard deviations were calculated for distributions of walking speeds at different classes of area per person and are listed in table 1-E. The calculations were made in order to examine the relationship of walking speed as a function of area per person. If there is the freedom to walk at many different speeds as more space is available to an individual, and if the freedom to walk at increasingly different speeds is exercised by individuals, variance in walking speeds should increase as the area per person increases.

Classes of Area	Football Ramp 1 Ingress	Football Ramp 1 Egress	Football Ramp 2 Ingress	Football Ramp 2 Egress	Baseball Ramp 1 Ingress	Baseball Ramp 1 Egress	Baseball Ramp 2 Ingress	Baseball Ramp 2 Egress
0.01- 1.00	0.207	0.114	-	0.118	-	0.247	-	0.164
1.01- 2.00	0.302	0.286	0.261	0.335	-	0.141	-	0.219
2.01- 3.00	0.237	0.226	0.182	0.327	0.268	0.176	0.200	0.307
3.01- 4.00	-	-	-	-	0.308	0.164	0.295	0.272
4.01- 5.00	-	-	0.276	0.458	0.249	0.338	-	-
5.01- 6.00	0.577	0.288	-	-	-	-	0.241	0.313
6.01- 7.00	-	-	-	-	-	-	-	-
7.01- 8.00	-	-	-	-	-	-	-	-
8.01- 9.00	-	-	0.753	0.548	-	-	-	-
9.00-10.00	-	-	-	-	0.627	0.387	-	-
10.01-11.00	-	-	-	-	-	-	-	-
11.01-12.00	-	-	-	-	-	-	0.266	0.278

Table 1-D. Walking Speed Standard Deviations at Various Classes of Area Per Person

The standard deviation of walking speeds is always greater at the largest area per person than at the smallest area for each ramp and direction of movement. However, the standard deviation did not continuously increase from the lowest to highest area as might be anticipated.

The results of the calculations are not intended to provide the basis for drawing inferences of any sort, but rather are intended to provide a description of the relationship between walking speed and area per person with respect to the Baltimore Stadium ramps.

APPENDIX E

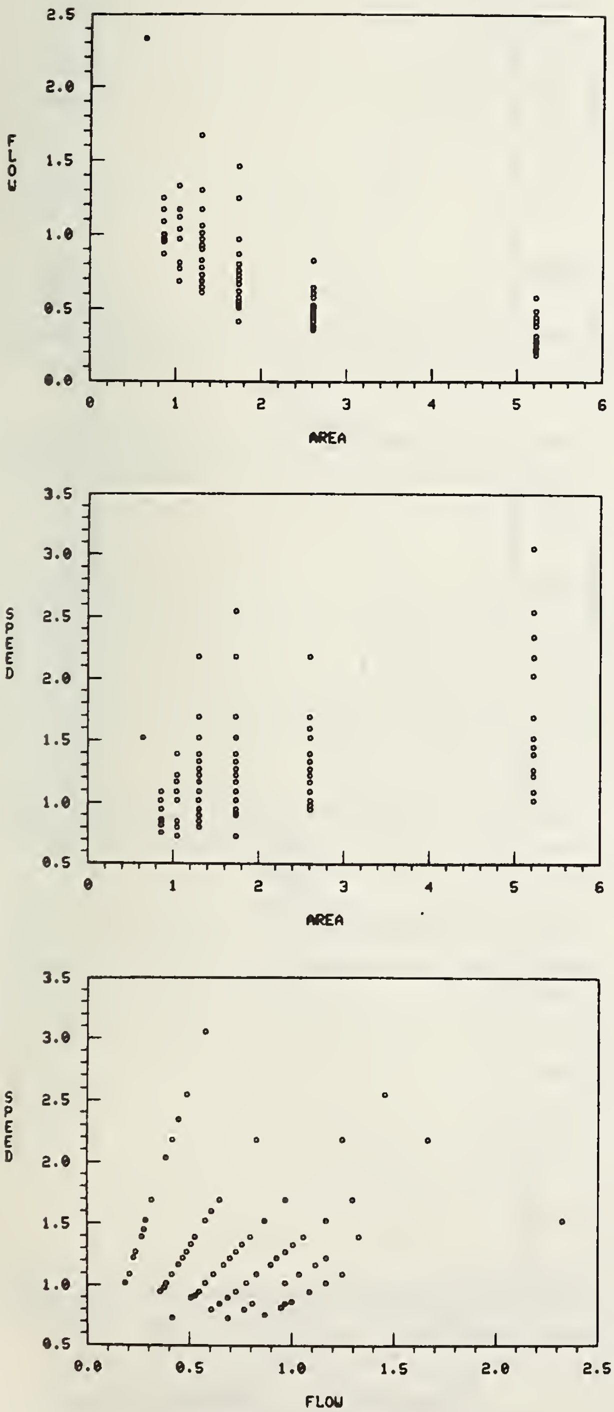

Figure 1-E. Football Game
Ramp 1 Ingress

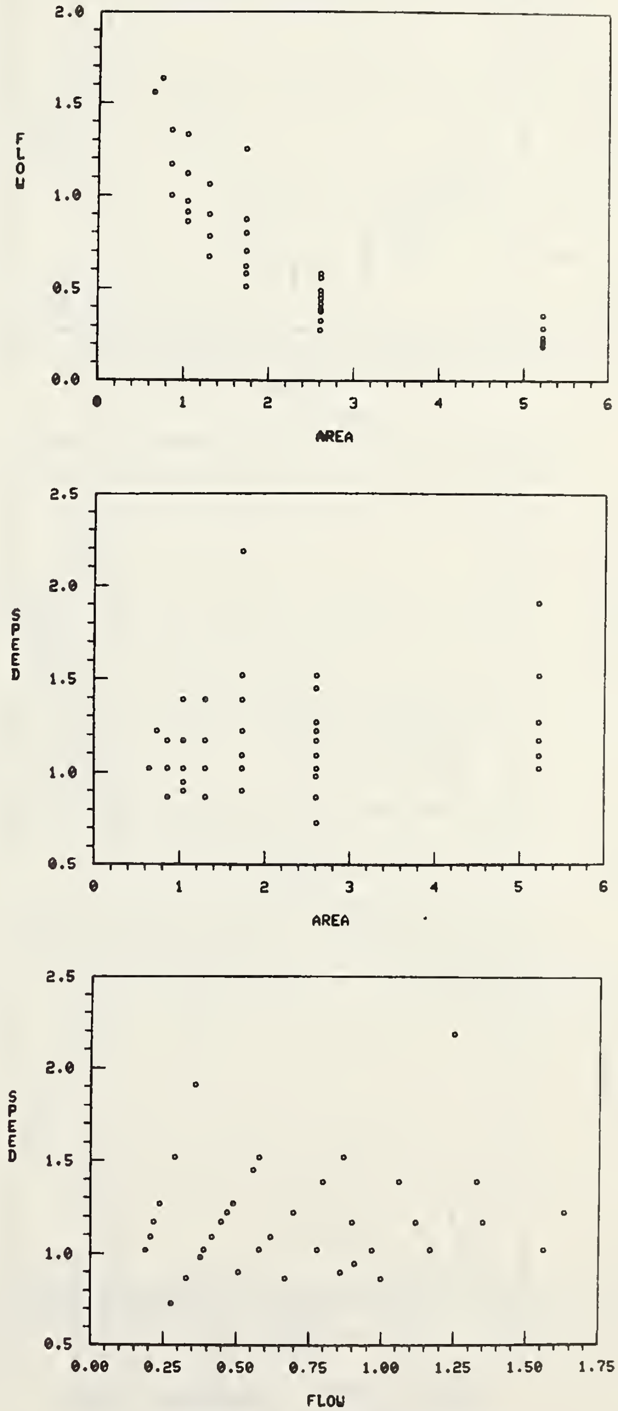

Figure 2-E. Football Game
Ramp 1 Egress

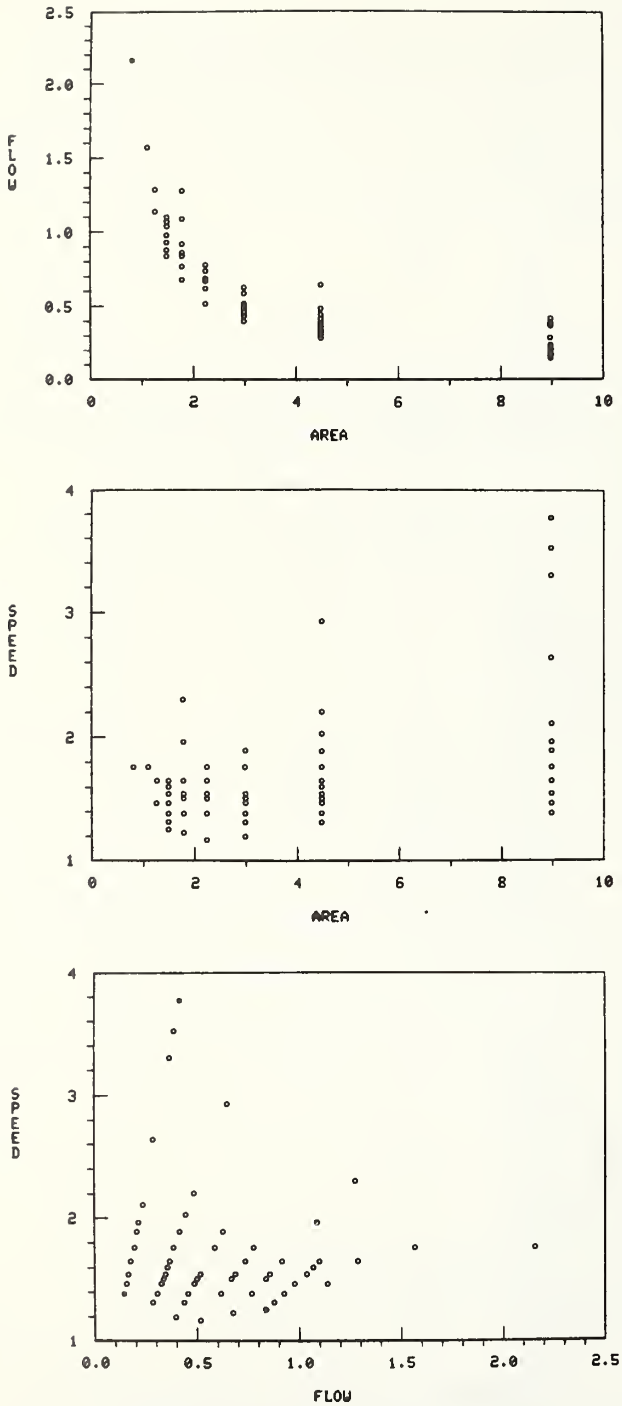

Figure 3-E. Football Game
Ramp 2 Ingress

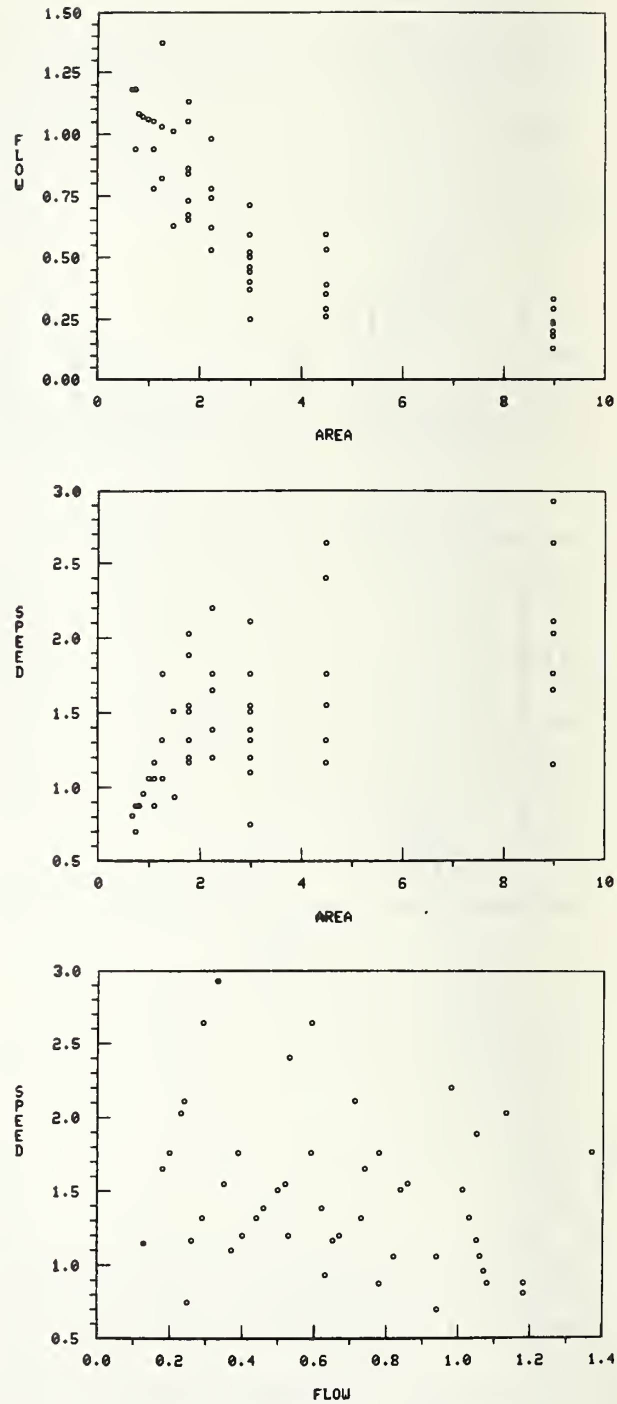

Figure 4-E. Football Game
Ramp 2 Egress

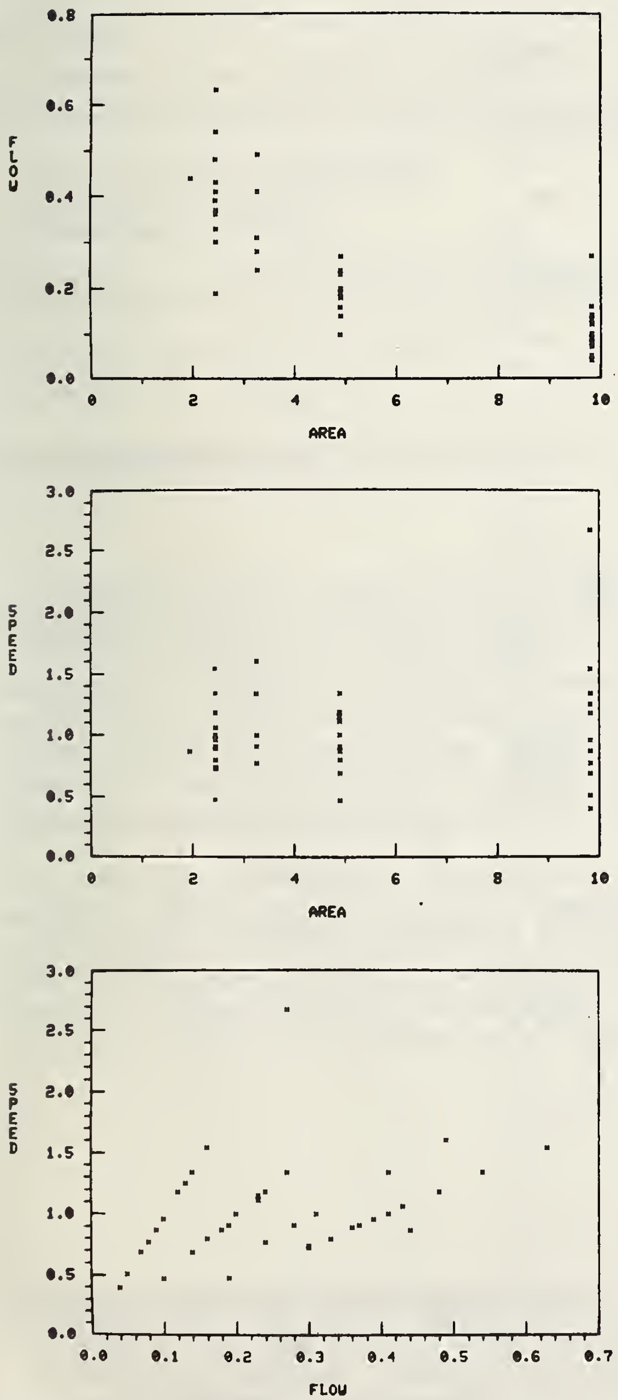

Figure 5-E. Baseball Game
Ramp 1 Ingress

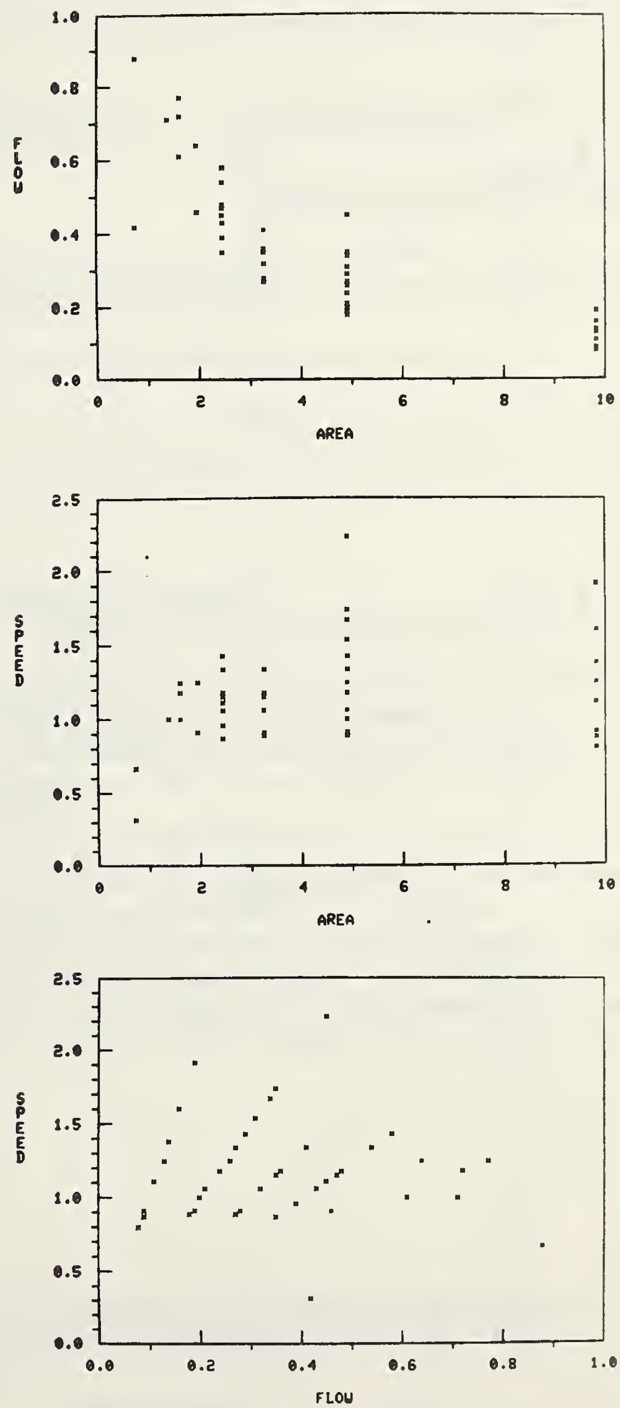

Figure 6-E. Baseball Game
Ramp 1 Egress

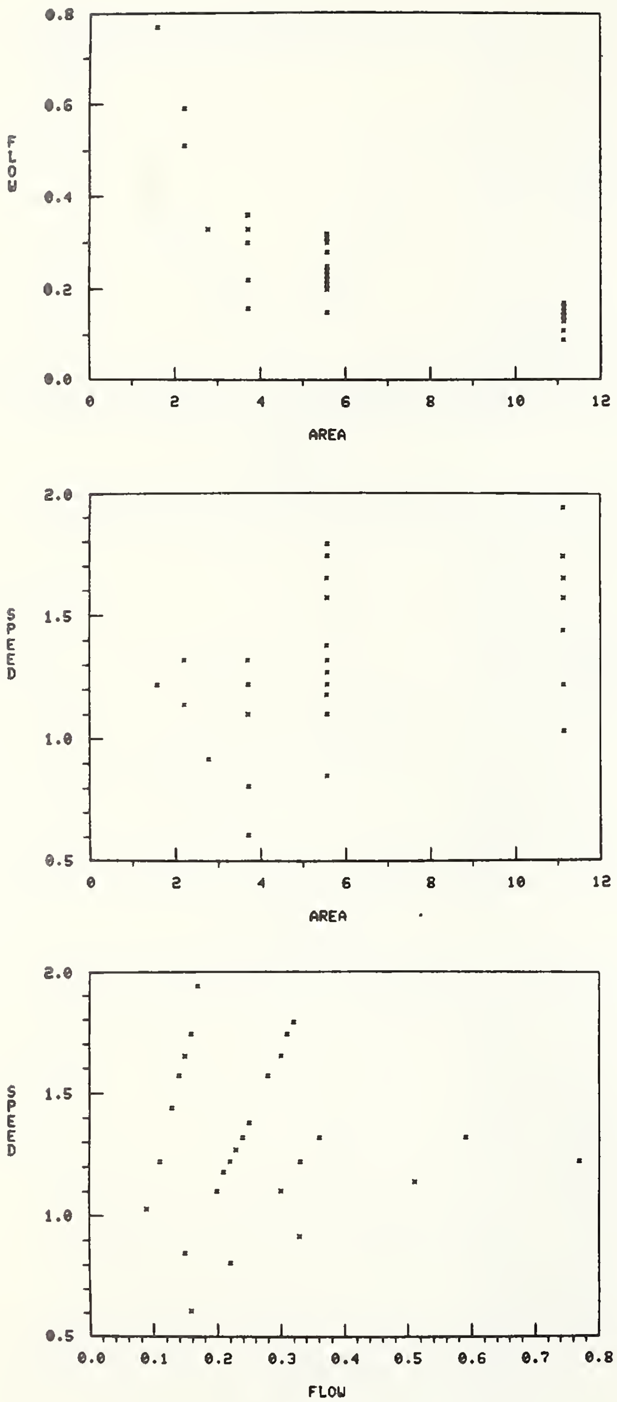

Figure 7-E. Baseball Game
Ramp 2 Ingress

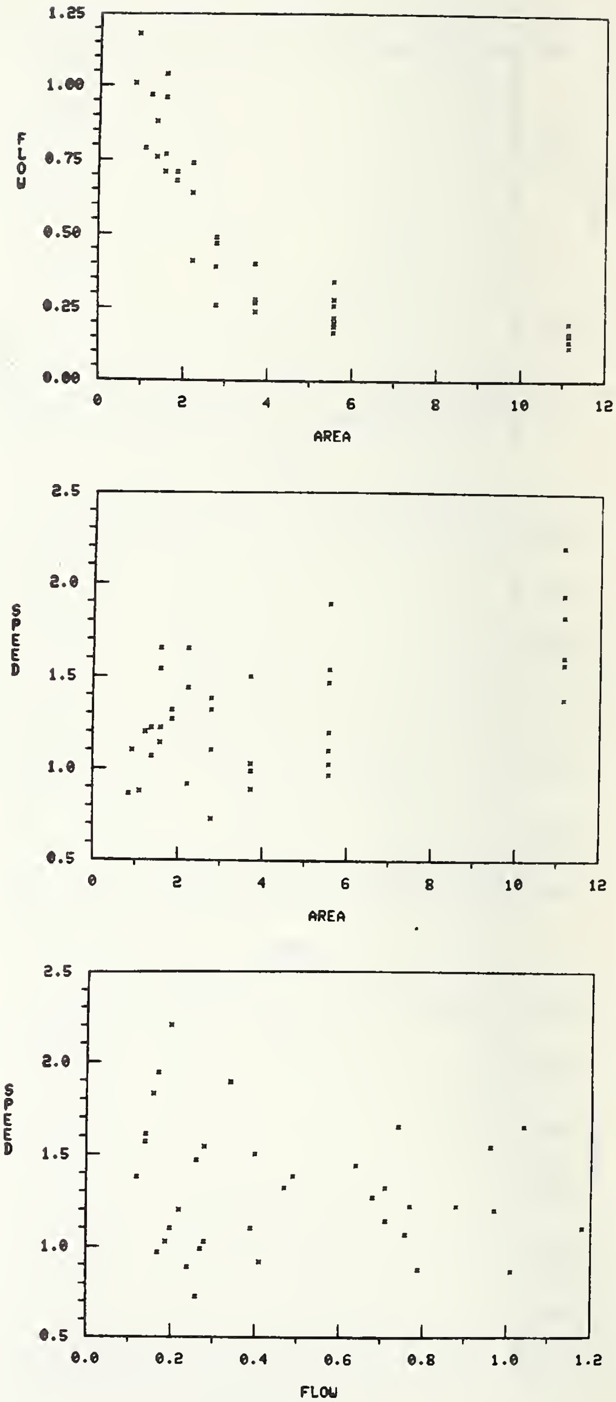

Figure 8-E. Baseball Game
Ramp 2 Egress

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Knowledge of design for effective predestrian circulation is one of the main requirements in building planning. While an understanding of pedestrian movement characteristics on the various component parts that make up a building circulation system is the key to effective planning, one component type, the ramp, has rarely been the subject of building circulation research.

The research described in this report is the result of an investigation of pedestrian movement characteristics on four specific building ramps during two different professional athletic contests. Variables of pedestrian movement such as speed, flow, and density were studied as well as the relationships between them. In addition, counts of pedestrians by sex were made. Results were compared for the specific ramps and with previously reported data obtained for ramps, stairs, and level surfaces.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Building circulation, building ramps, pedestrian circulation, pedestrian flow, pedestrian movement, pedestrian ramps, ramps.

13. AVAILABILITY

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