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Pedestrian Movement on Ramps - A Preliminary Investigation

George E. Turner
Belinda L. Collins

Environmental Design Research Division
Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, DC 20234

March 1979

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

<u>Corrections to NBSIR 79-1729</u>

Page v - The table of contents section 4.2 should read:
4.2 Differences Between Variables

Page 7 - Under section 1.5 Ramps, the second paragraph, seventh line, the word confirm is misspelled. In line 9, closing quotation marks should be inserted after the word <u>grades</u>.

Page 8 - In the second paragraph, the fifth line, the word preferable is misspelled.

Page 9 - In the third paragraph, the ninth line, the word descent is misspelled.

Page 15 - In the fourth paragraph, the eighth line should read:
........heights (±48ft) above the..................

Page 24 - In the second paragraph, third and fourth lines should read:
sampled segments and were not sufficiently clear for continuous and accurate counting.

Page 32 - Under section 4.2, the first paragraph, the twelfth line, the number 339.23 should be 509.06.

Page 33 - In criteria 3, the word diminishes is misspelled.

Page 42 - In the first paragraph, the first complete sentence, Flow,............and egress., should be deleted.

Page 47 - In reference 17, the word <u>Exits</u> in the title is misspelled.

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Our thanks go to the Baltimore Colts and the Baltimore Memorial Stadium management for their permission to videotape ramp use at the Stadium and their help in making arrangements that made our job easier.

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.

Length

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

Area

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

Volume

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

Equivalent Terms

Density: Persons/square foot = 10 persons/square meter

Area: Square feet/person = 0.1 square meters/person

Flow: persons/foot width/minute = .05 persons/meter width/second

Speed: feet/minute = .005 meters/second

The data in this report are given in English units because they are directly compared with data collected by other researchers which were reported in English units. Where researchers presented their data in metric units, these units are retained.

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ABSTRACT

The research described in this report was a preliminary investigation of pedestrian movement characteristics on two specific building ramps. Variables of pedestrian movement such as speed, flow, and area were studied, as well as the relationships between these variables. In addition, the specific measurements of speed, flow, and area were compared with similar measurements determined by other researchers not only for ramps, but also for stairs and level surfaces. Finally, suggestions were made for additional research into the characteristics of pedestrian movement on various elements of the building circulation system.

Key Words: Building circulation, building ramps, pedestrian circulation, pedestrian flow, Pedestrian movement, pedestrian ramps, ramps.

1. INTRODUCTION

1.1 BUILDING CIRCULATION AND PEDESTRIAN MOVEMENT

The characteristics of pedestrian movement that are critical for the effective design of circulation systems include speed, density, and flow. Determination of these characteristics is essential for the design of a pedestrian passageway which will facilitate movement. Knowledge of the basic characteristics of human movement also requires an understanding of the effects of different building circulation elements, such as stairs, ramps, and level surfaces.

The entire building circulation system determines the characteristics of pedestrian movement for each element. Movement on ramps, stairs, and level surfaces affects circulation throughout the total building. Furthermore, each circulation element has important consequences for the flow of traffic within a building. Thus, Tregenza (1976) noted that the basic shape of a building determines the effectiveness of its internal circulation system. Variations in building form, building height, and dispersion over a site can alter the amount of space occupied by circulation elements and affect the time required to travel within the building (Tregenza, 1976).

Fruin (1974) commented that the pedestrian system in a building is comprised of three elements. These include the vertical (stairs, elevators, and escalators), the horizontal (corridors, passageways, etc.), and the horizontal/vertical interface facilities (transit stations, sidewalks, lobbies, etc.). The goal of the designer is to facilitate pedestrian movement throughout each of these elements. First, however, the characteristics of pedestrian movement upon each must be determined, beginning with the horizontal and vertical elements.

Pedestrian movement characteristics have been extensively observed and even modeled mathematically for both stairs and level surfaces. As for ramps, it has been suggested that they are so similar to level surfaces that there should be no difference in pedestrian movement patterns between the two types of elements. Yet, ramps have typically been used to replace stairs and accomplish a change in elevation. Consequently, the use of ramps may have physiological and behavioral consequences that are more similar to those found for stairs than for level surfaces. As a result, there is a great need to determine the pedestrian movement characteristics for a variety of ramp grades, and to compare these data with those for stairs as well as with those for level surfaces.

This report reviews previous reseach on pedestrian movement for ramps, stairs, and level surfaces. It also presents detailed findings of pedestrian movement recorded on two ramps before and after a football game at the Baltimore Stadium. These results are then compared with previous research to determine the extent to which pedestrian movement on ramps is similar to that on other circulation elements. Finally, recommendations for further research are suggested.

1.2 RATIONALE FOR RESEARCH

The Architectural Barriers Act (PL 90-480) of 1968 and the Rehabilitation Act (PL 93-112) of 1973, are evidence of the Federal Government's interest in designing and maintaining environments that are free from architectural barriers. A prevalent form of architectural barrier for the handicapped is the stair, whether only one step, a curb, or an entire flight of stairs. One of the most common solutions to the problem of stairs as barriers is the provision of ramps. These provide access for those in wheelchairs, as well as for non-handicapped persons. Yet, the optimum design characteristics of ramps which would facilitate movement are not well documented.

In addition to the need to remove architectural barriers for the handicapped, three other factors prompted the present investigation of ramps. The first was that of safety. Because of the high incidence of accidents on stairs reported by the United States Consumer Product Safety Commission (CPSC), the use of ramps may be a good alternative for reducing the number of stair accidents. A second factor was the knowledge that the National Research Council (NRC) of Canada had recorded pedestrian movement on ramps at the Montreal Stadium during the 1976 Olympics. It was hoped that this effort would provide a data base for comparison. At this point, however, NRC has not published its data. The third factor was the lack of movement data specifically for ramps, which makes them the least understood of all circulation system components and, therefore, a weak element in the understanding of circulation system performance.

While the use of a ramp may solve the problem of access for those in wheelchairs, there is little information on what the substitution of ramps for stairs will do to total building circulation or to general pedestrian movement. There is, for example, some indication that ramps may provide greater potential egress capacity than do stairs. Aside from stadia, there are few building types in which ramps are used exclusively (no doubt because of the greater area required for ramps). As a result, it is difficult to determine what are "normal" movement characteristics for ramps. Data gathered in circumstances where the pedestrian is forced to choose between a ramp and a stair do not provide sufficient information on normal circulation patterns, because the pedestrian is forced to stop or slow down at the choice point, thus changing his speed and that of those behind him.

Consequently, the best place for studying pedestrian movement on ramps is in a building where the ramp is used as the primary element for changing elevation. Such a situation occurs in stadia where ramps are used so extensively that "normal" pedestrian movement and circulation patterns can be easily studied. Data collected on ramps in stadia can also be compared with data collected on stairs and level surfaces in other building types. Such data represent a baseline against which ramp data collected in other building types may be compared.

Pedestrian movement characteristics on ramps such as speed, flow, and density should be determined as input to guidelines for the design of ramps. These movement characteristics should include consideration of human convenience and ease of movement as well as maximum flow and capacity. Although many authorities use the maximum possible capacity as the primary determinant of the dimensions of circulation elements, "no evaluation or consideration of human convenience was made in developing these standards" (Fruin, 1971) p. 71. Thus, the maximum capacity of a circulation element is attainable only when dense crowding occurs. Yet, this "crowding results in reduced pedestrian convenience significantly as normal speeds are restricted due to a loss of freedom to maneuver within the traffic stream" (Fruin, 1971) p. 71. Consequently the evaluation of pedestrian movement on ramps should include an evaluation of optimal as well as maximum capacity, as well as a comparison with other circulation elements. In the next sections, the characteristics of pedestrian movement on all circulation elements will be reviewed.

1.3 TECHNICAL TERMS

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 parameters 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).

Density is the number of persons per unit of area, expressed as pedestrians per square foot (ft^2). Because this measure results in fractions of people, Fruin (1971) chose to use its reciprocal, area, defined as square foot 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 of passageway per unit time or as pedestrians per foot-width per minute (pfm). Flow is also equal to the average speed times the average density - or 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 foot-width per minute, 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.

1.4 GENERAL CHARACTERISTICS OF PEDESTRIAN MOVEMENT

Much of the research on pedestrian movement has centered around the measurement of speed, flow and density for level surfaces. Thus, numerous researchers reported mean walking speeds on level surfaces ranging from about 140 fpm to 470 fpm for level surfaces (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 & Azar, 1964; Tregenza, 1976; Henderson, 1971; Hoel, 1968; Henderson & Lyons, 1972).

After establishing a range of walking speeds under free-flow circumstances, researchers turned to a consideration of the effects of crowding or increased pedestrian density upon walking speed. They found a decrease in the range of walking speeds with increasing density (Fruin, 1971; Tregenza, 1976; Hankin & Wright, 1958; O'Flaherty & Parkinson, 1972). In fact, once an area of 2-3 ft^2 per pedestrian is reached, movement stops for all practical purposes and density is close to maximum (Fruin, 1971; Tregenza, 1976; Hankin & Wright, 1958). Yet, at areas only slightly larger than these, 4-5 ft^2 per pedestrian, maximum flow rates are found (Navin & Wheeler, 1969; Hankin & Wright, 1958; Fruin, 1974).

Observation of the close relationship between speed and density -- and consequently, flow (which is 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 per pedestrian to restricted flow conditions at the lowest level of 5-10 ft^2 per pedestrian. On the other hand, O'Flaherty and Parkinson (1972) recommended that a density of about 18 ft^2 per pedestrian would provide adequate service.

1.5 RAMPS

The research discussed in the previous section refers primarily to level surfaces. It is also important to determine whether the characteristics of pedestrian movement on ramps and stairs vary from those for level surfaces, and if so, in what ways. The data for ramps will be discussed first.

The most significant effect of ramps upon movement might be expected to be that of the grade or incline of the ramp. Yet, Fruin (1971) noted that within limits ramp grade appeared to have little effect on free-flow 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. Other studies comfirm 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. 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. 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). Tregenza (1976) noted that ramps steeper than eight percent can be dangerous for the handicapped.

Steinfeld (1975) recommended that ramps designed for the disabled should have a slope of four to eight percent, with five percent preferred. Handrails should be provided on both sides. Walter (1971) found that when the various categories of wheelchair users were considered, a gradient of about 7 percent was found to be preferrable, although there was a range of 6 to 11 percent. Foot (1973) found that for pedestrians who walk, the velocities on a 10 percent ramp vary from 0.35 to 1.40 m/sec. Velocity is heavily dependent upon the density of 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 stairways.

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 on the Illinois Central Railway system had shown that flow rate was about equal for level surfaces and ramps (around 27 pfm) but slower for stairs (18 pfm for ascent and 19 pfm for descent). Again, the area per person under uncrowded conditions was about equal for level surfaces and ramps (11.1 ft^2 and 10.5 ft^2) but much smaller for stairs (5.7 ft^2). The NBS study itself found an average of about 8.0 ft^2 per person on ramps at Grand Central Station with a minimum of about 6.2 ft^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 length 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 gradient of five percent or less have little effect upon walking speed. Yet, he pointed out also that some data from the Road Research Laboratory suggest that a ten percent ramp gradient could reduce upward 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).

The Traffic Engineering Handbook (Evans, 1950) estimated that while the rate of egress (flow) is about thirty persons/minute/traffic lane of 22 inch width for stairs, this figure increases to thirty-seven persons/minute/traffic lane (22 inch wide) for ramps. The Handbook also suggested that users generally prefer ramps and find them safer. The Handbook indicated further that ramps of six to twelve percent are safer and more commonly used. At these gradients, speed on ramps does not appear to vary much with slope. Thus, the range of average speeds for ascent, was found to be about 252 fpm for a twelve percent ramp and 282 fpm for a two percent ramp. For desceat, the average speed was 270 fpm for the twelve percent ramp and 288 fpm for the two percent ramp. These figures may be compared with a range of average speed of 210 to 270 fpm for a level passageway (Evans, 1950).

1.6 STAIRS

The pattern of movement on stairs is rather different from that on ramps and level surfaces. Perhaps because the change in elevation is much more pronounced than that for ramps or because the steps restrict the pace distance, both flow rate and speed are slower. Thus, typical speeds for ascent are about 100-125 fpm with a range of 40-164 fpm (Fruin, 1971). In descent, speeds are somewhat faster, around 130-150 fpm (Galbreath, 1969). (Furthermore, Templer (1974) noted that more severe accidents occur in descent than ascent.) Yet, although speeds are lower than on level surfaces, density is not increased. In fact, people tend to occupy a smaller area on stairs, around 7-8 ft^2 per person (Fruin, 1971). 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 & Booth, 1975). (The effects of small amounts of counterflow are much less apparent for horizontal surfaces, and center around a ten percent or less decrease in speed.)

1.7 ENERGY EXPENDITURE

For stairs, Fruin (1971) indicated that human energy consumption increases with increasing riser height. For example, an increase in riser height from 6 inches to 8.25 inches resulted in an increased energy cost of ninety-six percent in ascent and fifty-eight percent in descent. There were also significant increases in pulse rate and blood pressure with greater stair angles. As a result, the ANSI Standard A117.1 (1961) recommends a maximum riser height of 7 inches where stairs must be provided in a "barrier free" design.

In contrast, Corlett, Hutcheson, Beluga, and Rogozuski (1972) noted that the use of ramps may require even more energy consumption than stairs and suggest that the cardiac cost of climbing a stair of equal height is always less than that of climbing 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.

Both Tregenza (1976) and Templer (1974) found that energy expenditure can be lower for ramps of small grade but greater for ramps of larger angular grade. More energy may be required to ascend a ramp than a normal flight of stairs of the same height. Templer (1974) noted that as the pitch of the ramp increases to around ten to fifteen percent a gait is adopted which closely duplicates the energy expended in climbing stairs. Yet, 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 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. Nevertheless, the overall characteristics of pedestrian movement such as flow and density on ramps remain much less well documented than those for stairs or level surfaces.

1.8 MODELS OF PEDESTRIAN FLOW

Despite the gaps in the knowledge about pedestrian movement on level surfaces, ramps, and stairs, a number of attempts have been made to model such movement mathematically. Successful models are a critical element in predicting movement for design purposes. Again, the bulk of the modeling effort has focused upon data for level surfaces.

Henderson (1971) and Henderson and Lyons (1972) collected data on pedestrian flow on level surfaces in an attempt to use equations of gaseous diffusion rates as a model of flow. While they were moderately successful in their attempt, there is some question about the applicability of these models to human behavior. Henderson and Lyons (1972) commented that their data on student movement and flow rates did not suitably fit these equations.

They found that the diffusion equations applied only if the crowd was relatively homogeneous in terms of sex, age and similarity of environment and activity. Thus, in order to apply these equations, one must be sure that a homogeneous population exists with a more-or-less common trip purpose.

Elkington, et. al., (1976, p. 17) noted that mathematical models can be useful in predicting pedestrian movement, particularly for areas of high activity. "The effects on pedestrian activity of change in traffic management and pedestrian facility provisions can be examined once a suitable model has been developed and calibrated. However, sophisticated models, capable of predicting flows in a network, are demanding in both data collection and computation and are of questionable value in town centres. Simpler models relating numbers of pedestrians on footways to planning parameters, may be adequate for most central area planning purposes."

However, there is a need to develop sophisticated mathematical tools for planning routes for total building circulation and methods of transportation -- stairs, ramps, level surfaces, escalators, elevators, and people movers -- which are designed specifically to improve pedestrian movement.

1.9 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 reasonably adequate for predicting pedestrian movement characteristics on level surfaces -- at least for crowded conditions. However, the characteristics of pedestrian movement on ramps are much less understood. The range of speeds, densities, and flows is documented in only one study for a transit station where ramps formed one element of the circulation system. Consequently, the effects of ramps upon movement in a variety of built environments for a variety of crowd densities have not been extensively assessed.

In the study to be reported here, a range of flows, densities, and speeds were measured for pedestrians on ramps in a stadium. These movement characteristics were compared with the reported data for level surfaces and stairs. An attempt was then made to determine the extent to which the use of a ramp (of a particular grade) would alter speed, flow, and density. Although there is a need to assess other building types, crowd conditions, and similar factors, these data do represent an initial step in the development of predictive models of pedestrian flow on ramps. Such models are needed so that building circulation systems can serve the needs of both handicapped and non-handicapped populations under normal and emergency conditions.

2. AN INVESTIGATION OF MOVEMENT CHARACTERISTICS ON TWO RAMPS

2.1 METHOD OF INVESTIGATION

2.1.1 Data Collection Site

The data collection site for the project was the Baltimore Memorial Stadium in Baltimore, Maryland. This site was selected because: 1) it is within easy driving distance of the Bureau of Standards; 2) spectator vertical circulation is accomplished exclusively by ramps on the inside of the stadium; 3) 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 during the 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. 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 ($\pm$ 12 ft) 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 ($\pm$ 18 ft) above the lower level and is reached by walking up seven ramp lengths.

2.1.2 Data Collection Procedure and Equipment

The data collection occurred at the Baltimore Colt-Detroit Lion football game on Sunday, December 11, 1977. The game started at 2:00 p.m. and ended at about 5:10 p.m. (The game was close until the final seconds when the Detroit Lions won.) Videotaping locations on the west side of the stadium were selected. The first location (lower level) was at the top of and looking down on the bottom length of a one story ramp located inside the stadium (Figure 1). The second location (upper level) was at the top of and looking down on the next-to-last length of ramp of one of the ramp towers (Figure 2).

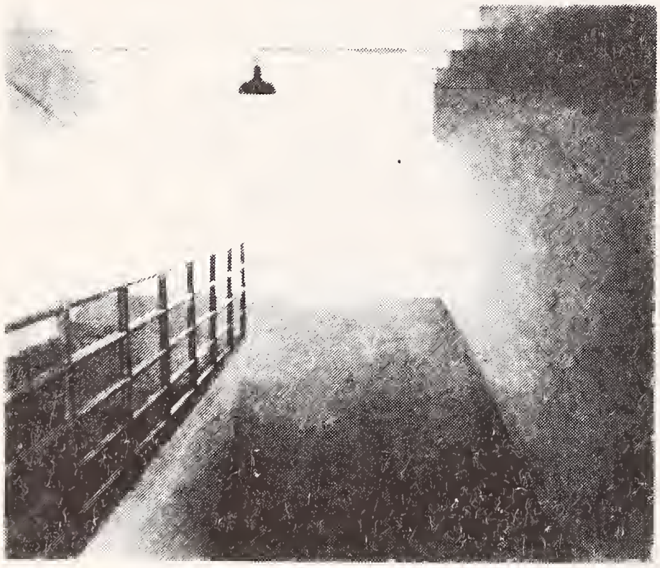

FIGURE 1. LOWER LEVEL RAMP (VIEW FROM VIDEO TAPING POSITION)

FIGURE 2. UPPER LEVEL RAMP (VIEW FROM VIDEO TAPING POSITION)

Each of the two ramps selected for study was observed during both egress (down) and ingress (up) for a total of four samples. For the ramp on the upper level, a 17.33 ft long section was selected, while for the lower ramp, a length of 10 ft was chosen. The difference in ramp length was deliberate, intended to assess the effects of length upon the accuracy of timing walking speed. Both ramps were just about equal in width, with the upper ramp being 5.58 ft wide, and the lower ramp 5.62 ft wide. Both ramps also had a slope of about 16%. Because the

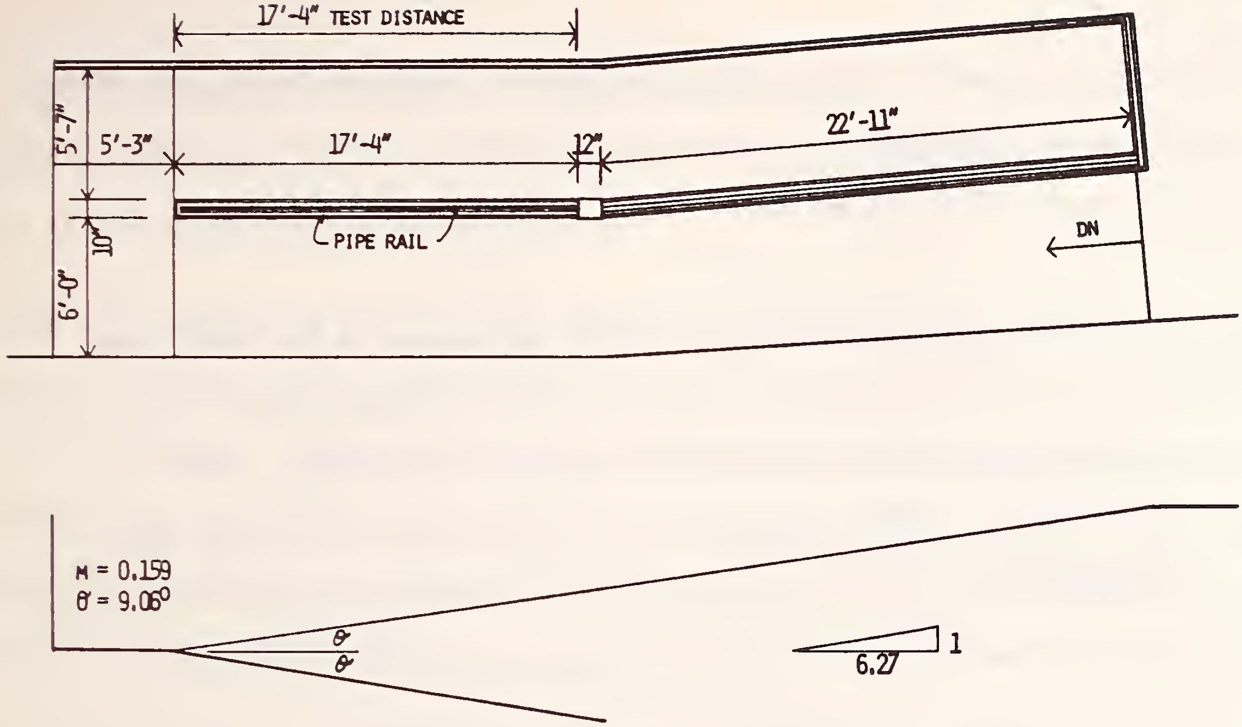

FIGURE 3. UPPER LEVEL RAMP PLAN AND SECTION

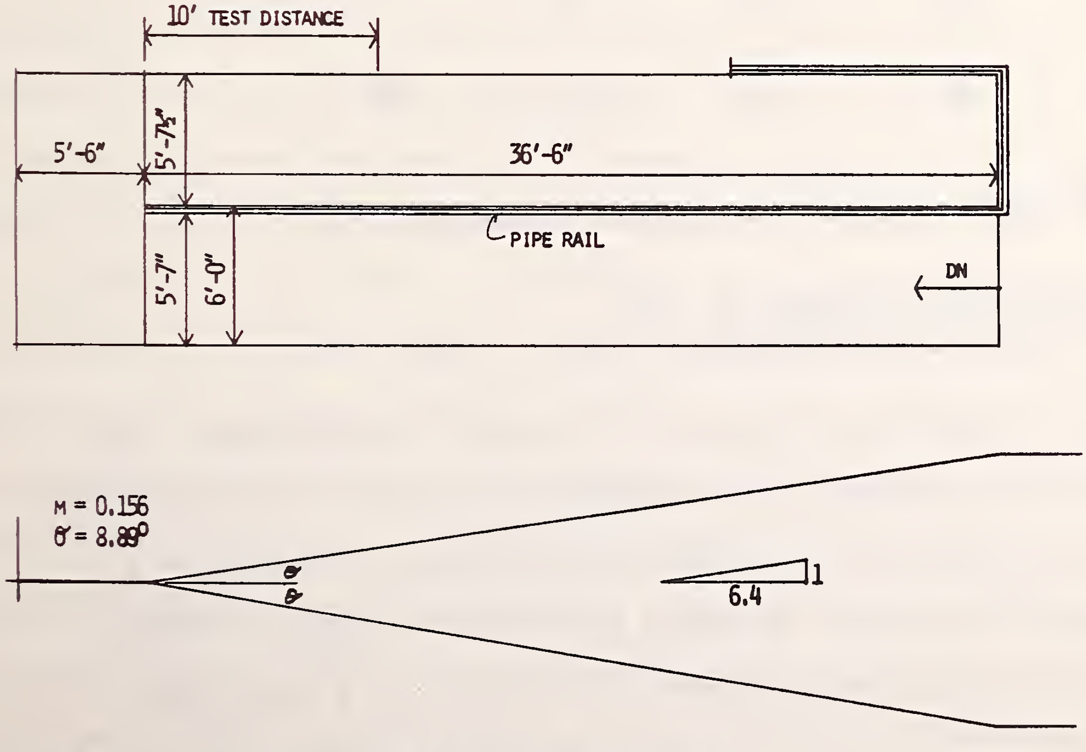

FIGURE 4. LOWER LEVEL RAMP PLAN AND SECTION

two ramps were equivalent dimensionally in terms of width and slope, the effects of variations in ramp length, as well as in the user's direction of travel, could be readily compared (see Table 1).

During the filming, the distance being studied was marked on the lower ramp with two tape strips. The first strip was placed at the beginning of the ramp while the second strip was located 10 ft from the beginning. The markers were visible on the videotapes. On the upper ramp, the first tape mark was placed at the top of the ramp while the second was placed at a large column located about 17 ft down the ramp (see Figures 3 and 4).

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
FLOW/AREA	S	S	S	S
SPEED/AREA	NS	NS	NS	S
SPEED/FLOW	NS	NS	NS	NS

TABLE 11. X^2 TESTS OF INTERACTIONS BETWEEN VARIABLES

NOTE: S = SIGNIFICANT DIFFERENCE AT .05
NS= NO SIGNIFICANT DIFFERENCE AT .05

Two identical portable video cameras and recorders, battery-powered, were mounted on tripods overhead at the videotaping locations. Since the portable recorders required the use of thirty-minute videotapes and because of a limited number of batteries, 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. Egress was taped continuously over a period of approximately 30 minutes using the same equipment and at the same location as for ingress.

There are a number of advantages to the use of film or videotape as a data collection method (Foot, 1973). Data can be collected at one time and analyzed at a later date. Furthermore, the record is permanent so that subsequent reanalysis is possible. With videotape, there is the extra advantage that there is a monitor so that the data record can be immediately observed for picture quality and content.

2.1.3 Data Collection Constraints

Several important lessons were learned prior to, during, and after collecting the data. The first lesson concerned the availability and condition of equipment. Because it was necessary to borrow some equipment from other reserach units, scheduling for its use and checking its operating condition was more of a challenge than had been anticipated. Another lesson learned had to do with the need to understand the impact of environmental characteristics on the proper functioning of equipment. The videotaping took place at temperatures below freezing (around -3°C). The temperature had a dramatic effect on the service life of the battery packs and caused even the back-up supply of batteries to be completely exhausted just prior to the termination of egress at one of the camera locations. In addition, because the sun was setting at the beginning of egress, the main light sources were the stadium lighting fixtures which were at less than desirable locations and light levels. In the absence of prior data collection experience at a particular site, it is extremely helpful to walk through a practice collecting effort when such is feasible.

A very valuable lesson learned had to do with understanding the relationship between data collection and analysis. Since ingress to sporting events usually occurs over a longer period than does egress, the taping/non-taping intervals chosen turned out to be a very appropriate approach. Approximately thirty hours of analysis were required for each thirty minute tape; therefore, a time relationship was established that will be useful when collecting data in the future.

3. ANALYSIS OF THE DATA

3.1 VIDEOTAPE ANALYSIS

When the videotapes were analyzed, horizontal lines indicating the area 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 in a crowd, a method was devised to measure the point at which a typical person's head would cross the two lines. In this method, a person of moderate height was selected from the first portion of each of the four videotapes (for each ramp and direction). Once his/her feet were aligned with the beginning of the ramp, a horizontal line was drawn just touching his/her head. The same procedure was repeated at the end of the ramp. In this way, head height could be consistently used as a marker point. 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 marked lines were counted. Their transit time was also determined. A procedure somewhat akin to that used by Hankin and Wright (1958) was employed in the counting and timing phase. As they had done, a person was chosen to mark the end of a group. He/she was timed with a stopwatch as he/she passed between the two marker lines. At the same time, all persons who were 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 the persons 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 occurring group separated by an obvious gap from the next group.

For ingress, definition of the marker person was much easier than for egress, due to the clarity of the videotapes. In addition, the whole ingress process lasted much longer than egress. Because people began to arrive from as much as one hour before game time to fifteen minutes after the kick-off, flow densities were much lower. Egress occurred in about one-half hour with considerable crowding.

Two observers were used to transfer the data from videotape to recording sheets. As the first step, they selected a marker person for each group. They recorded some identifying characteristics and the videotape marker numbers on the data sheet so that the marker person could easily be re-identified. Then, after one observer had timed the marker person, the other observer recorded his/her transit time. Once the transit time of the marker person was recorded, then 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 form a group for purposes of data analysis. 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.

For ingress, once the overall count had been made, several subsequent refinements were made. The first involved determination of the total flow (see Figure 5). In this, all persons who were visible between the two marker lines during each three minute taping interval were counted. Because of battery problems, ingress on ramp 2 was not recorded as long as on ramp 1. The tape segment was also retimed using a stopwatch. In this way, the number of people per unit area per unit time could be determined. The second count was an attempt to determine the number of women and children. Because of the bulky winter clothing, it was somewhat difficult to differentiate women from men, so that the assignment of people to male/female groups is not reported with overwhelming confidence. Children were defined as anyone whose head was at least one head below the upper marking line. Again, this categorization is not perfect; it may include short women or men while excluding tall children. Nevertheless, an estimate was made of the numbers of women and children using the ramp. These data are reported in Table 2.

In the third count, a more detailed determination was made of some unique behavior patterns. Two categories were selected; counterflow and crossover. Counterflow was defined as movement in the opposite direction from the marker person. All persons moving between the two marker lines at the same time as the marker person were included in the count. Although counterflow is a common term in the circulation literature, whether pedestrian or vehicular, crossover is not. It is defined here as the movement of a particular person from one side of the ramp to the other for no apparent reason. Crossover appeared to occur primarily at transition points, such as landings and was characterized by the crossing of one person behind another. The reasons for such "crossover" behavior are unclear; yet because it can slow or impede flow and speed on the ramp, the phenomenon is of interest.

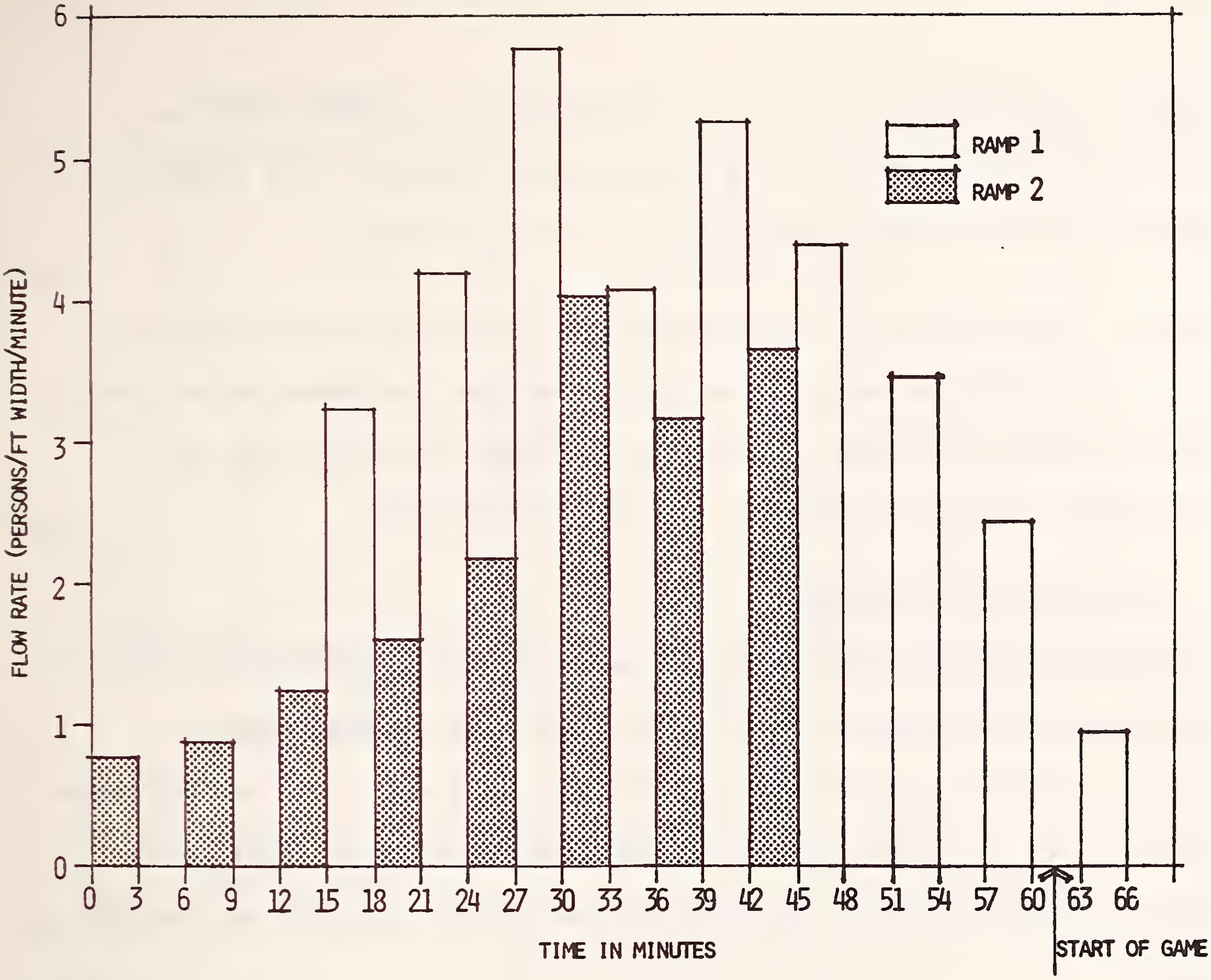

FIGURE 5. INGRESS FLOW RATES

	RAMP 1 INGRESS	RAMP 2 INGRESS
MEN	71.95%	76.23%
WOMEN	20.48%	16.98%
CHILDREN	7.57%	6.79%
TOTAL	100.00%	100.00%

TABLE 2. POPULATION COMPOSITION

Because of the limited instances of counterflow and crossover, they will not be reported in further detail at this time. However, it is intended that they will be examined more closely in future research.

Similar detailed counts of women and children, crossover, and counterflow could not be made for egress because the tapes were continuous rather than sampled segments and because of battery and lighting problems were not sufficiently clear for continuous and accurate counting.

3.2 DATA ANALYSIS PROCEDURES

Statistical analyses were made on data points that were derived from the original individual raw counts and times taken from the videotapes. A computer program was written for transforming the raw data to four variables: density, area per person, flow rate, and walking speed (see Appendix A). These variable values were the basis for the analysis and findings reported herein.

The second edition of the Statistical Package for the Social Sciences (SPSS) [Nie, et. al., 1975] was used for all statistical analyses. In particular, the subprograms, Frequencies and Scattergram were used. In addition, Dataplot, an interactive graphical data analysis program, [Filliben, 1978] was used for fitting models to the data.

4. FINDINGS

4.1 THE DISTRIBUTION AND CENTRAL TENDENCY OF THE TRANSFORMED VARIABLES

Frequency distributions were created for the following variables: area per person (area), flow rate (flow), and walking speed (speed). Since area is the reciprocal of density, density was not used in this data

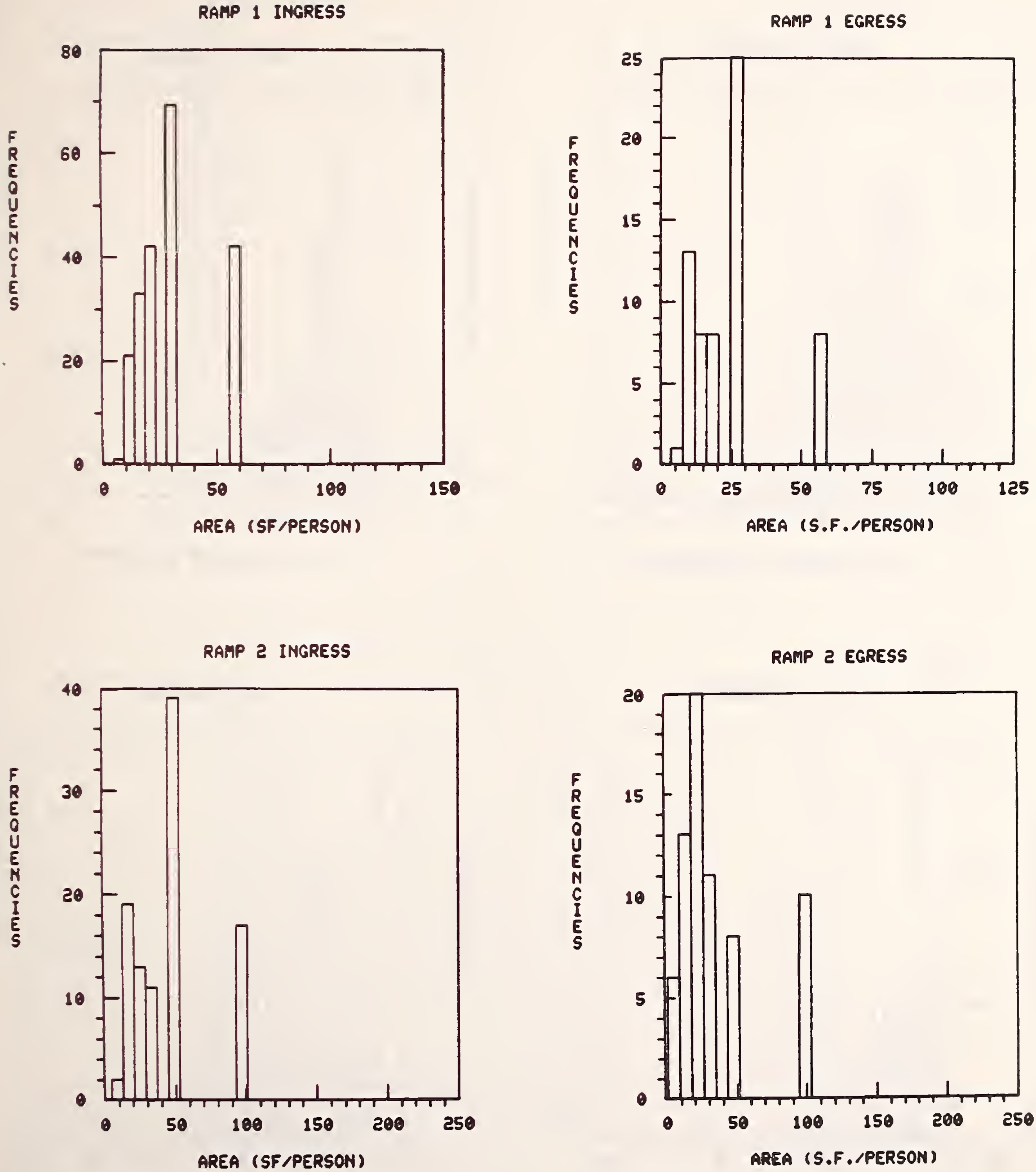

FIGURE 6. AREA PER PERSON

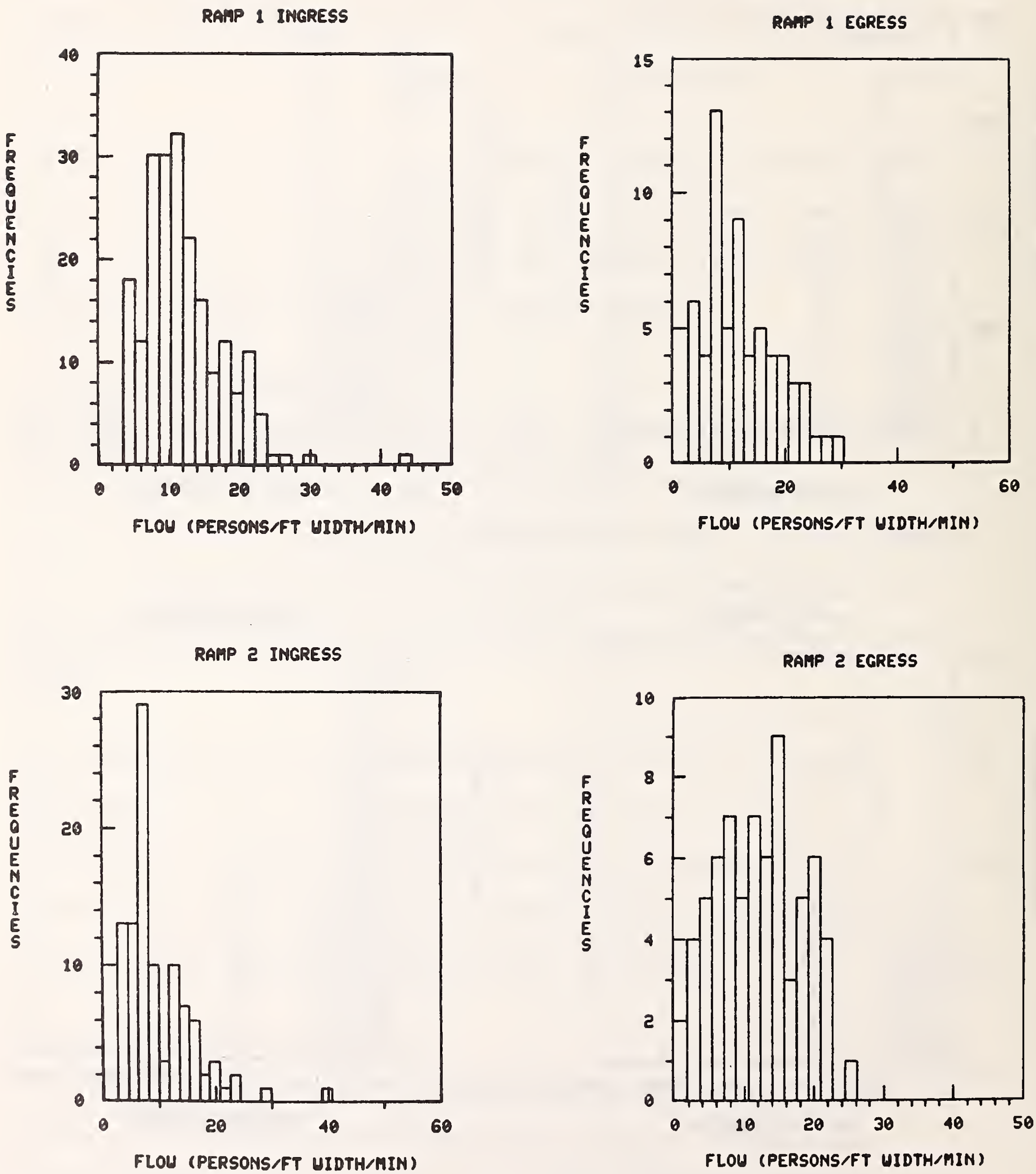

FIGURE 7. FLOW RATE

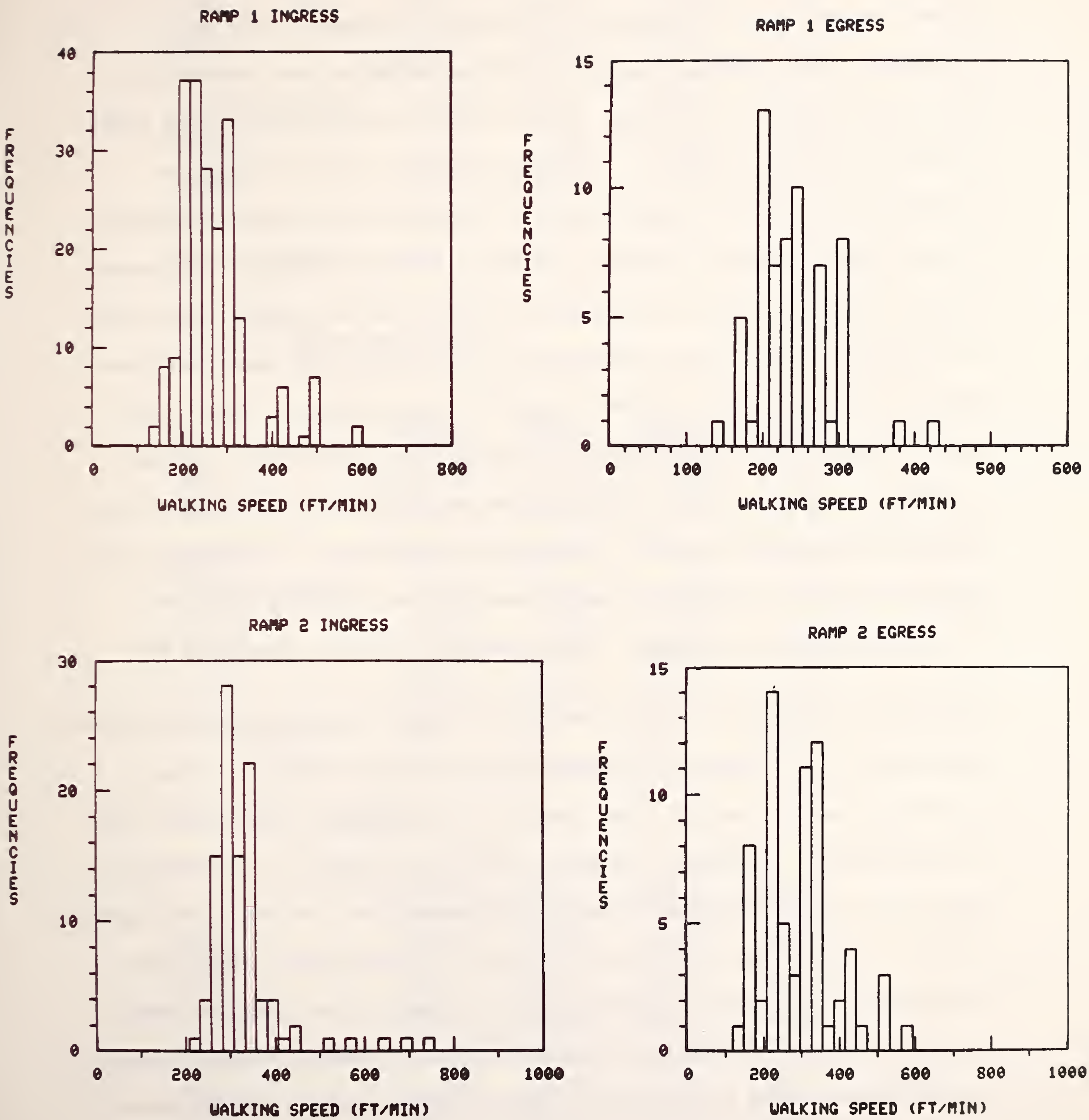

FIGURE 8. WALKING SPEED

analysis because area per person is a more useful measure in building circulation system design. Each of the three variables were analyzed for both entry (ingress) and exiting (egress) and for both the lower ramp (Ramp 1) and the upper ramp (Ramp 2). Figures 6 through 8 are histograms of the distributions of the variables of both ramps during ingress and egress. Note that area comprises a discrete condition so that there is a gap between the area occupied by one person and that occupied by two persons (see Figure 6). Tables 3, 4, and 5 give the statistics associated with each condition. Areas per person for both ingress and egress were similar for Ramp 1 such that a Chi square (X^2)-Test revealed no significant difference. For Ramp 2, however, area per person during ingress was significantly different from and larger than during egress. Furthermore, comparisons of both egress and ingress revealed a difference between Ramp 1 ingress and Ramp 2 ingress but no difference between Ramp 1 egress and Ramp 2 egress (see Table 8).

Comparisons of mean flow data between the two ramps did reveal some additional similarities. Both ingress and egress flow rates were similar for Ramp 1. In addition, egress flow rate was similar for both ramps. Ingress flow rate was significantly different from egress flow rate for Ramp 2. In addition, ingress flow rates were significantly different between the ramps (see Tables 6 and 9). The average speed on both ramps in both directions ranged from 238 fpm to 333 fpm. Both ingress and egress tended to be slower for Ramp 1 than for Ramp 2. In addition, ingress speed was faster than egress speed for both ramps. Both T-tests and X^2-tests revealed that all comparisons of mean pedestrian speed were significant beyond the .05 level. (See Tables 7 and 10). The average speed on both ramps in both directions ranged from 238 fpm to 333 fpm.

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
MEAN	27.79	24.71	44.98	34.72
MODE	28.13	28.13	48.35	24.17
VARIANCE	244.01	201.22	706.01	805.78
STANDARD DEVIATION	15.62	14.19	26.57	28.39
MINIMUM	7.03	7.03	8.79	7.44
MAXIMUM	56.25	56.25	96.7	96.7
RANGE	49.22	49.22	87.91	89.26
N OF OBSERVATIONS	208	63	101	68

TABLE 3. AREA PER PERSON

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
MEAN	12.02	12.65	10.01	12.29
MODE	10.67	10.67	7.17	14.34
VARIANCE	32.03	43.57	36.4	33.4
STANDARD DEVIATION	5.66	6.6	6.03	5.78
MINIMUM	3.56	3.56	2.83	2.34
MAXIMUM	42.67	29.87	39.43	25.09
RANGE	39.11	26.31	36.6	22.75
N OF OBSERVATIONS	208	63	101	68

TABLE 4. FLOW RATE

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
MEAN	268.91	237.87	333.06	295.96
MODE	300	200	346.6	346.6
VARIANCE	6334.73	2474.55	6885.15	9686.69
STANDARD DEVIATION	79.59	49.75	82.98	98.42
MINIMUM	142.86	142.86	231.07	138.64
MAXIMUM	600	428.57	742.71	577.67
RANGE	457.14	285.71	511.64	439.03
N OF OBSERVATIONS	208	63	101	68

TABLE 5. WALKING SPEED

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
RAMP 1 INGRESS	-	NS	S	NS
RAMP 1 EGRESS		-	S	NS
RAMP 2 INGRESS			-	S

TABLE 6. t-TEST OF FLOW RATE

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
RAMP 1 INGRESS	-	S	S	S
RAMP 1 EGRESS		-	S	S
RAMP 2 INGRESS			-	S

TABLE 7. t-TEST OF WALKING SPEED

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
RAMP 1 INGRESS	-	NS	S	NS
RAMP 1 EGRESS		-	S	NS
RAMP 2 INGRESS			-	S

TABLE 8. X^2 TEST OF AREA PER PERSON

NOTE: S = SIGNIFICANT DIFFERENCE AT .05
NS= NO SIGNIFICANT DIFFERENCE AT .05

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
RAMP 1 INGRESS	-	NS	S	S
RAMP 1 EGRESS		-	S	NS
RAMP 2 INGRESS			-	S

TABLE 9. X^2 TEST OF FLOW RATE

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
RAMP 1 INGRESS	-	S	S	S
RAMP 1 EGRESS		-	S	S
RAMP 2 INGRESS			-	S

TABLE 10. X^2 TEST OF WALKING SPEED

	RAMP 1 INGRESS	RAMP 1 EGRESS	RAMP 2 INGRESS	RAMP 2 EGRESS
FLOW/AREA	S	S	S	S
SPEED/AREA	NS	NS	NS	S
SPEED/FLOW	NS	NS	NS	NS

TABLE 11. X^2 TESTS OF INTERACTIONS BETWEEN VARIABLES

NOTE: S = SIGNIFICANT DIFFERENCE AT .05
NS= NO SIGNIFICANT DIFFERENCE AT .05

Both ingress and egress tended to be slower for Ramp 1 than for Ramp 2. In addition, ingress speed was faster than egress speed for both ramps. Both T-tests and X^2-tests revealed that all comparisons of mean pedestrian speed were significant beyond the .05 level. (See Tables 7 and 10).

4.2 DIFFERENCES BETWEEN VARIABLES

In order to test some of the differences between variables, each variable (speed, flow, area) was divided into three classes. Thus, three levels of area were chosen: "Small" (less than 10 ft^2), "medium" (10-25 ft^2) and "large" (greater than 25 ft^2). Three levels of speed and flow were also chosen representing slow, moderate, and rapid. Because the speed and flow were much higher for ingress than egress, different cut-off points were selected for the three classes for ingress and egress. Consequently, for flow, for ingress, "slow" was less than 15.7 pfm, "moderate" was 15.7-28.3 fpm, and "fast" was greater than 28.3 fpm, while for egress, the cut-off values were 10.73 fpm and 17.9 fpm. Similarly for speed, for ingress, "slow" was less than 348.4 fpm, "moderate" was 348.4-509.06 fpm and "fast" was greater than 339.23 fpm. Three by three contingency tables were set up and each of the three relationships was tested using a X^2 analysis. Table 11 lists the results of the tests for differences.

Based on the curvilinear bivariate relationships that have been reported by Henderson (1971), Henderson and Lyons (1972), Hankin and Wheeler (1969), Older (1969), and Fruin (1971), an attempt was made to fit curves to certain of the relationships. The walking speed/area, flow/area, and speed/flow relationships were modeled (see Figures 9 to 12).

The criteria for fitting curves were as follows:

1. If a curve is found that satisfies the speed/area relationship such that speed equals some geometric conditions of area, then the curve for the flow/area relationship must express flow in terms of the speed/area curve (flow = speed/area).

2. The curve must pass a lack of fit test involving determining an F-ratio. The ratio follows an F-distribution and must satisfy that distribution at the five percent level of significance. [Draper & Smith, 1966, pp. 29 & 63.]

3. The curve must be logical in terms of the way zero speed or flow is approached. In other words, it has been shown by others and is intuitively logical that as the area per person diminshes, the walking speed and the consequent flow is diminished.

With the given criteria, no curves were found that were capable of satisfying all three criteria. Most curves would satisfy only criterion 2. Figures 9 through 12 show the data points through which an attempt was made to fit the curves. While the data indicated certain curvilinear relationships between variables, no generalizable curve was found that could be applied across relationships, ramps, or direction of movement (ingress and egress).

5. DISCUSSION

5.1 BASIC MOVEMENT VARIABLES IN PREVIOUS RESEARCH: SPEED, FLOW AND AREA

5.1.1 Walking Speed

The mean speeds reported in this report tended to be somewhat faster than the mean speed of 265 fpm for level surfaces found by Fruin (1971). Only Ramp 1 egress was slower (238 fpm). Mean speed for all four situations was

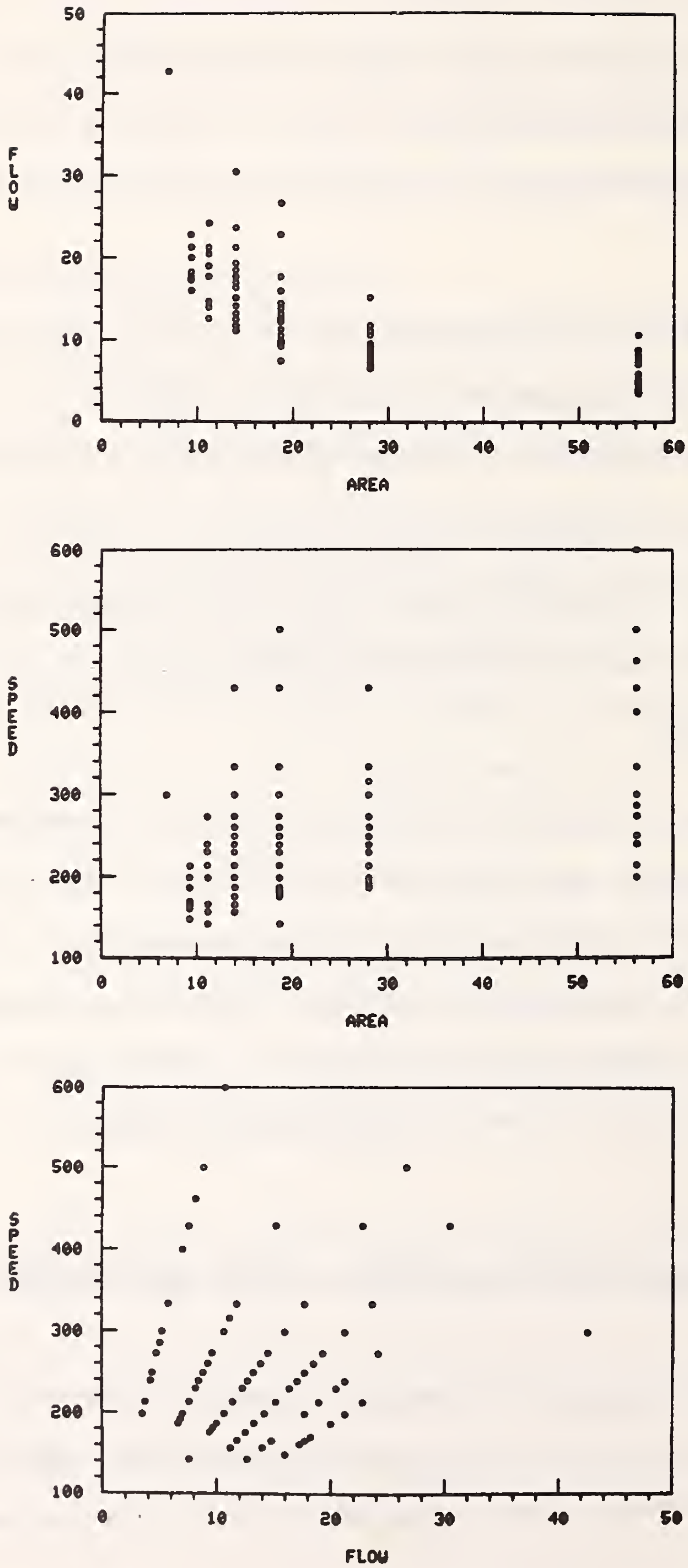

FIGURE 9. RAMP 1 INGRESS

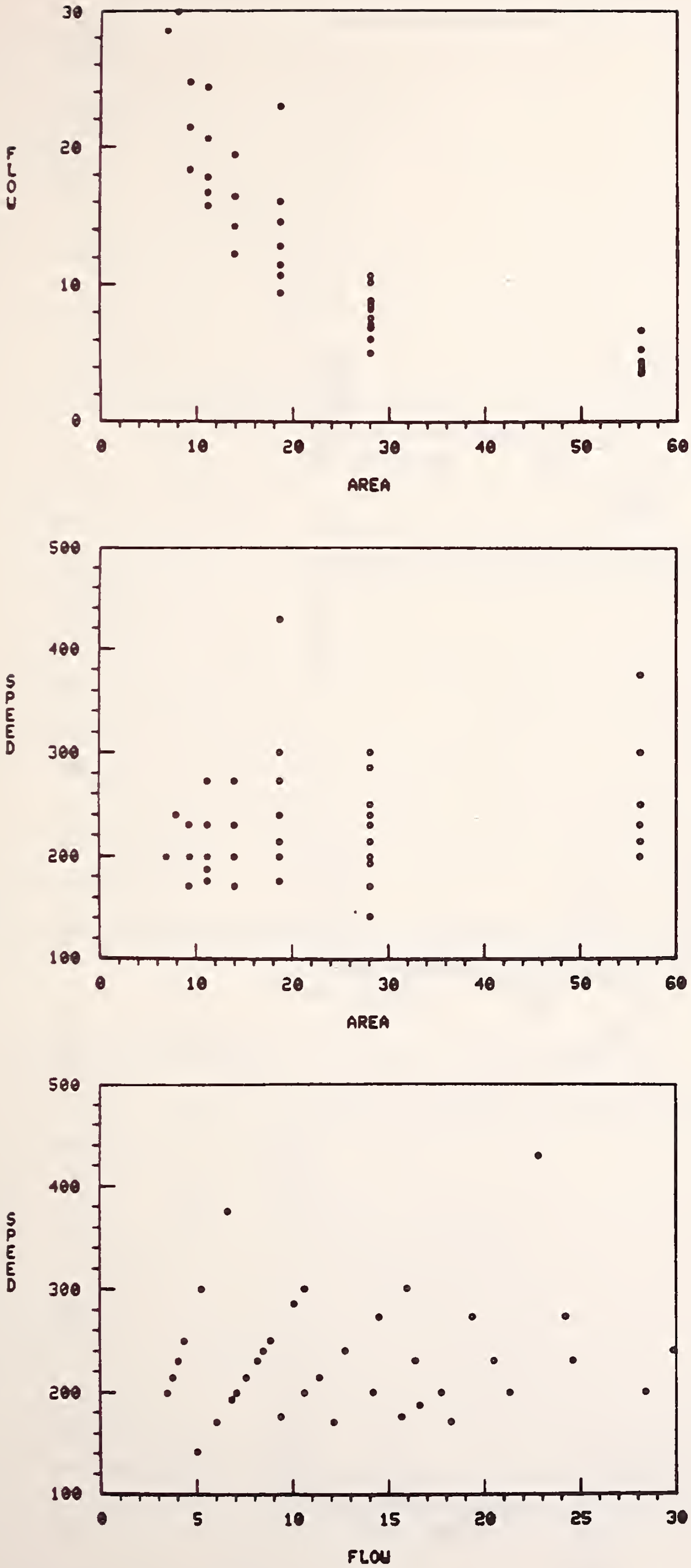

FIGURE 10. RAMP 1 EGRESS

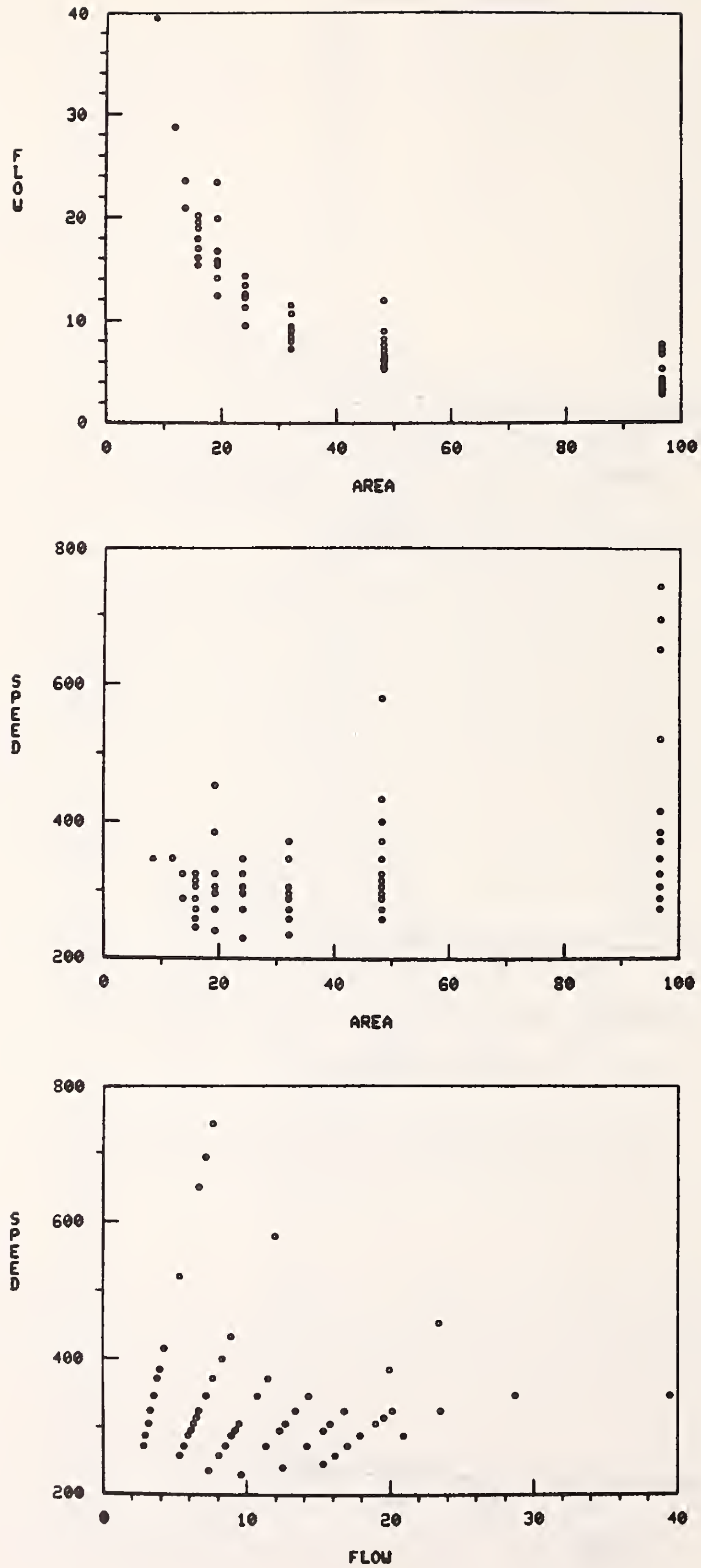

FIGURE 11. RAMP 2 INGRESS

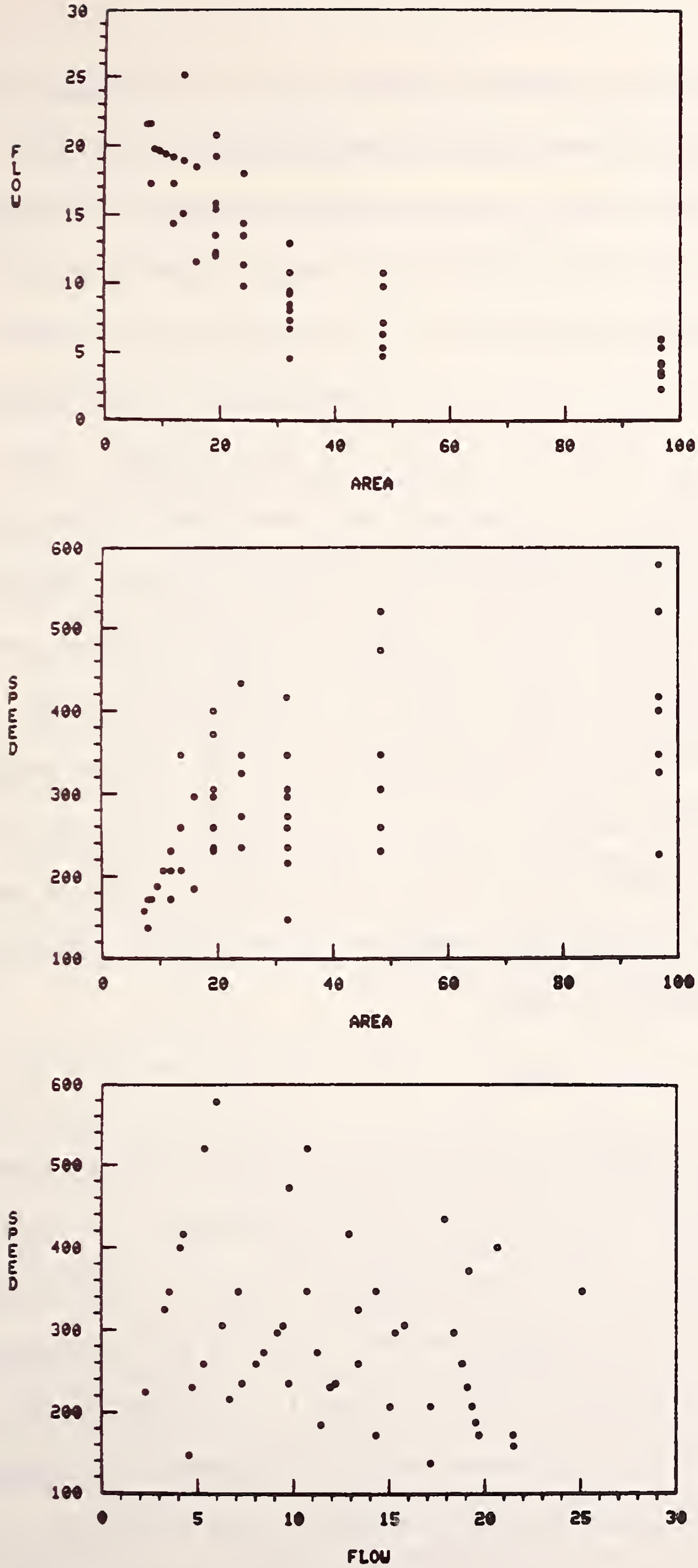

Figure 12. Ramp 2 Egress

calculated to be about 284 fpm. Pignataro (1973) reported mean speeds of 267 fpm for men and 245 fpm for women with a combined range of 204-315 fpm. Elkington et al., (1976) noted, however, that the Ministry of Transport reported an average speed of 300 fpm (5 fps) for adults. Navin & Wheeler (1969) reported an average walking speed of 4.3 fps (158 fpm) while Hoel (1968) reported an average speed of 288 fpm for pedestrians in Pittsburgh, with a mean speed for men of 296 fpm and one of 278 fpm for women. Thus, the range of speeds calculated for the various ramp measurement situations was within that reported by other researchers for level surfaces. Nevertheless, Ramp 1 ingress does appear to have a higher speed (333 fpm) than that generally reported. This is higher than the speed data for ramps reported in the Traffic Engineering Handbook (1950) which suggested that the average speeds range from 252 fpm to 288 fpm depending upon gradient and direction of movement. Needless to say, the variations in speeds should be expected because the experimental conditions (circulation component, temperature, lighting, etc.) differed widely between the studies.

5.1.2 Area Per Person

Comparison of the mean area occupied by pedestrians on the Baltimore ramps with previous research also revealed some interesting findings. The average area per person calculated for these ramps ranged from 25-27 ft^2 for ingress and egress on Ramp 1 to 45 ft^2 for ingress on Ramp 2 and 35 ft^2 for egress. The minimum area was calculated to be 7 ft^2 for Ramp 1. For Ramp 2, the minimum area was 7.44 ft^2/person for egress and 8.79 ft^2/person for ingress. These calculated areas are somewhat larger than those found by previous researchers. For example, previous NBS research (1935) reported an average area of about 8 ft^2/person on ramps in Grand Central Station with a minimum area of 6.2 ft^2. Finally, measures of area per person on level surfaces range upwards from an absolute minimum of 2-3 ft^2/pedestrian (Fruin, 1971). Clearly, the condition assessed for the Baltimore ramps did not reflect the extremes of pedestrian density which have been found for transportation facilities.

5.1.3 Flow

Similarly, average flow rates determined for the Baltimore ramps were much lower (10-12.5 pfm) than those (20-25 pfm) suggested by Fruin as the optimum for achieving maximum flow volumes. Nevertheless for Ramp 2 ingress, high flow rates of 20-39 pfm occurred for a small percent of the samples. For Ramp 2 egress, high flow rates of 20-25 pfm occurred for several samples. For Ramp 1 egress the range of high flow rates was much slower, from 11-20 pfm. Finally for ingress Ramp 1, the high range was from 20 to 43 pfm. It should be noted that for Ramp 1 the minimum area was 7.03 ft^2/person. This is very close to the 7 ft^2 that Fruin (1971) suggested for peak flows.

Fruin (1971) noted that to achieve a flow of 30 pfm requires extremely favorable walkway conditions and traffic composition. Hankin & Wright (1958) recommended that level passageways be designed for about 27 pfm and stairs for 12-31 pfm. Navin and Wheeler (1969, p. 33) found that for flow: "starting from the point of maximum speed, the flow increases rapidly with minimum reduction in average stream speed to a critical flow at approximately 26.4 pfm. The speed at this point is four feet per second. The flow and speed reduce rapidly until complete congestion occurs at zero flow and velocity." Complete congestion did not occur during data collection on the Baltimore ramps. It should be noted that the extent to which metering of flow caused by turnstiles and ticket taking at ingress, and metering of flow by cross circulation and aisle congestion at egress will have a direct effect on the figures obtained.

5.2 MOVEMENT BIVARIATE RELATIONSHIPS

As noted earlier, a number of researchers developed mathematical models or curves which relate speed, flow, area, and density data (Henderson, 1971; Hankin & Wright, 1958; Older, 1968; Navin & Wheeler, 1969; and O'Flaherty and Parkinson, 1972). In addition, Fruin (1971) plotted his data in a curvilinear form from which a general mathematical model could be derived. Since none of these models or curves were developed from data collected on ramps, the data from the current project offered an opportunity to apply such models and compare ramp data with similar relationships found on other circulation system elements.

In general, the following relationships were determined. Fruin (1971) found for horizontal surfaces that as area increased, speed also increased until a maximum speed was achieved. Beyond that speed, increasing area made little or no difference. The ramp data collected in this investigation showed the same relationship between speed and area as that described by Fruin. However, densities on the ramps were not sufficiently high to produce areas of less than 7 ft^2 per person. Therefore, there were no data points in the range where Fruin showed a rapid reduction toward zero for walking speed. Nevertheless, the ramp data does correspond very closely to Fruin's curve for areas greater than 7 ft^2 person.

Fruin also determined that the relationship between flow and area is distinctive. There is low flow at small areas, followed by a rapid increase in flow to a maximum at around 7 ft^2/person, followed by a gradual decline in flow as area increases. Once again the ramp data show this same relationship between flow and area. As was the case with speed, there were no data points for the smaller areas; therefore, the rapid increase in flow between 2 and 7 ft^2/person was not indicated. Hankin & Wright (1958), Older (1968), and O'Flaherty and Parkinson (1972) all found a decrease in speed with increasing density.

Finally, Navin and Wheeler (1969) and Older (1968) found that when speed and flow were plotted together, speed had a wide range of values at lower flows and tended toward an average as flow increased. The smaller range of speeds at higher flows is due to pacing and passing restrictions at a higher density. The ramp data appear to have this same tendency when speed and flow are plotted together.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

While it is not intended that definitive conclusions should or can be drawn on the strength of this project, the findings do suggest certain characteristics of pedestrian movement on ramps that merit elaboration. Contrary to expectation, the results of both the T-tests and X^2 tests did not indicate that there is a significant difference between ingress and egress in a stadium for a sporting event. Nevertheless, the data do suggest that there is a significant difference in walking speeds betweeen ingress and egress and for each ramp. One of the more interesting aspects of the findings has to do with the results of the X^2 tests of the relationships between flow and area, speed and area, and speed and flow. According to the tests, there is no statistically significant relationship between speed and flow, and speed and area. However, the results indicated a very strong interaction between flow and area. This interaction was the same for both ramps and for both ingress and egress. Flow, was the same for both ramps and for both ingress and egress. Since flow, defined as the ratio of speed, to area, is associated more strongly with area than with speed this has environmental design and management implications. Area is the physical component that the designer controls, while speed is the user's response to the environment. If this suggested relationship proves to be the case in subsequent research, then the designer can manipulate the environment to provide the desired rates of flow.

The characteristics of pedestrian movement outlined for ramps raise further questions to be answered and point to numerous potential research designs. However, these findings represent the requisite first step to understanding the part that individual circulation elements play in the movement of people throughout buildings.

6.2 RECOMMENDATIONS

In order to develop a more generalized understanding of pedestrian movement on ramps, there are several areas of research which should be investigated. The research reported in the previous section has indicated that some of the basic relationships between flow, speed, and area uncovered for other elements appear to hold for ramps. The lack of data for high density flow conditions, however, makes it difficult to determine both maximum and minimum flows for the areas studied. In addition, the lack of clarity in the egress tapes makes any conclusions drawn about differences between ingress and egress somewhat tentative at this time. Therefore, there is a need to collect additional high density data on ramps. In addition, such data should be collected for different outdoor temperatures, for different sporting events, and different populations. Because of the bitter cold during the data collection effort, egress movement, in particular, may have been affected.

Once the basic variables of speed, flow, and density have been established for a particular ramp grade, 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 on 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 has indicated that both flow and speed are lower for stairs than for horizontal surfaces. Because sufficiently low densities were not obtained with the present ramp data, it is not yet clear whether flow and speed are more similar to stairs or to 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 particular, 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. It has already been mentioned that the people studied on the

Baltimore ramps were primarily adult males -- females and children accounted for only ten to twenty percent of the pedestrians sampled. Yet Henderson and Lyons (1972) have 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 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 conditions 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.

6.3 SUMMARY

In summary, the research described in these pages represents a preliminary investigation of the pedestrian movement characteristics on building ramps. Variables of pedestrian movement, speed, flow, and area and the relationships between them are reported. In addition, the specific measures of these variables and their relationships are compared with similar measures determined by other researchers. Finally, suggestions for further research into pedestrian movement on ramps and other building circulation elements are made.

7. REFERENCES

1. Basic Building Code, Sixth Edition, Building Officials and Code Administrators International, Inc., Chicago, Illinois, 1975.

2. Corlett, E. N., Hutcheson, F., De Lugan, W. A., & Rogozenski, J. Ramps or Stairs - The Choice Using Physiological and Bio-mechanical Criteria. Applied Ergonomics, 1972, 34, 195-201.

3. Draper, N. R., & Smith, H. Applied Regressing Analysis, New York: John Wiley & Sons, Inc., 1966.

4. Elkington, J., McGlynn, R., & Roberts, J. The Pedestrian: Planning and Research - A Literature Review and Annotated Bibliography. London: Transport and Environment Studies (Test), 1976.

5. Evans, H. K. (Ed). Traffic Engineering Handbook. New Haven, Connecticut: Institute of Traffic Engineerings (Second Edition), 1950, 98-112.

6. Filiben, J. J. "Dataplot - An Interactive System for Graphics, Fortran Functions, and Linear/Non-Linear Fitting." Proceedings of the Statistical Computer Sections of the American Statistical Associations, 1978.

7. Foot, N. I. S. Pedestrian Traffic Flows, DMG-DRS Journal: Design Research and Methods. 1973, 7 (2), 162-167.

8. Fruin, J. J. Pedestrian Planning and Design. New York: Metropolitian Association of Urban Designers and Environmental Planners, Inc., 1971.

9. Fruin, J. J. Pedestrian System Planning for High Rise Buildings. Transportation Engineering Journal, August 1974, 675-686.

10. Galbreath, M. Time of Evacuation by Stairs in High Buildings. (Fire Research Note No. 8). Ottawa: National Research Council of Canada, May 1969.

11. Hankin, B. D., & Wright, R. A. Passenger Flow in Subways. Operational Research Quarterly, 1958, 9 (2), 81-88.

12. Henderson, L. F. The Statistics of Crowd Fluids, Nature, 1971, 229, 381-383.

13. Henderson, L. F., & Lyons, D. J. Sexual Differences in Human Crowd Motion, Nature, 1972, 240, 353-355.

14. Hoel, L. A. Pedestrian Travel Rates in Central Business Districts. Traffic Engineering, January 1968, 10-12.

15. Lawton, A. H., & Azar, J. Some Observations of Behavior of Older Pedestrians. Medical Times, 1964, 92 (1), 69-74.

16. Melinek, S. J., & Booth, S. An Analysis of Evacuation Times and the Movement of Crowds in Buildings. (Building Research Establishment Current Paper). 96/75, October 1975.

17. National Bureau of Standards. Design and Construction of Building Exists. NBS Miscellaneous Publication, M151, October 1935.

18. Navin, F. P. D., & Wheeler, R. J. Pedestrian Flow Characteristics. Traffic Engineering, June 1969, 30-36.

19. Nie, N. H., Hull, C. H., Jenkins, J. G., Steinbrenner, K., & Brent, D. H. Statistical Package for the Social Sciences. (Second Edition). New York: McGraw-Hill Book Co., 1975.

20. O'Flaherty, C. A., & Parkinson, M. H. Movement on a City Centre Footway. Traffic Engineering and Control, February 1972, 435-438.

21. Older, S. J. Movement of Pedestrians on Footways in Shopping Streets, Traffic Engineering and Control, August 1968, 160-168.

22. Pignataro, L. J. Traffic Engineering: Theory and Practice. Englewood Cliffs, New Jersey: Prentice-Hall, Inc. 1973, 252-257.

23. Preiser, W. Analysis of Pedestrian Velocity and Stationary Behavior in a Shopping Mall. Unpublished doctoral dissertation, Pennsylvania State University, March 1973.

24. Specifications for Making Buildings and Facilities Accessible to and Usable by the Physically Handicapped. New York: American National Standards Institute, ANSI A117.1-1961.

25. Standard Building Code, Southern Building Code Congress International Incorporated, Birmington, Alabama, 1976 Edition.

26. Steinfeld, E. Interim Report: Barrier-free Access to the Man-made Environment. A Review of Current Literature. U.S. Department of Housing and Urban Development, Contract N. H.-2200R, October 1975.

27. Templer, J. A. Stair Shape and Human Movement. Unpublished doctoral dissertation, Columbia University, 1974.

28. Tregenza, P. The Design of Interior Circulation. New York: Van Nostrand Reinhold Co., 1976.

29. Uniform Building Code, 1976 Edition, International Conference of Building Officials, Whittier, California, 1976.

30. Walter, F. Four Architectural Movement Studies for the Wheelchair and Ambulant Disabled. London: The Disabled Living Foundation, April 1971.

Appendix A

```
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C       PED.MOV -- PEDESTRIAN MOVEMENT VARIABLES
C
C       THIS VERSION WAS WRITTEN FOR AND USED ON A
C       DEC SYSTEM-10
C
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C       WRITTEN BY GEORGE E. TURNER, RESEARCH ARCHITECT
C       ARCHITECTURAL RESEARCH PROGRAM
C       ENVIRONMENTAL DESIGN RESEARCH DIVISION
C       CENTER FOR BUILDING TECHNOLOGY
C       NATIONAL ENGINEERING LABORATORY
C       NATIONAL BUREAU OF STANDARDS
C       WASHINGTON, D.C. 20234
C
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C
C       THIS PROGRAM CALCULATES THE PEDESTRAIN MOVEMENT
C VARIABLES DENSITY (PERSONS/SQUARE FOOT), AREA (SQUARE
C FEET/PERSON), FLOW (PERSONS/FOOT WIDTH/MINUTE), AND SPEED
C (FEET/MINUTE) FROM TWO BASIC VARIABLES, TIME (WALKING TIME
C BETWEEN TWO POINTS IN SECONDS) AND COUNT (THE NUMBER OF
C PERSONS WITHIN A PARTICULAR SQUARE FOOTAGE).  IN ADDITION,
C THE PROGRAM CAN BE USED TO NORMALIZE THE TWO BASIC VARIABLES
C TO A STANDARD TIME MEASURING DISTANCE AND COUNTING AREA.
C THE NORMALIZED BASIC VARIABLES CAN BE USED FOR CALCULATING
C THE PEDESTRIAN MOVEMENT VARIABLES.
C
C       THE PROGRAM ALSO OFFERS THE OPTION OF CONVERTING THE
C CALCULATED VARIABLES DENSITY, AREA, FLOW, AND SPEED TO METRIC
C UNITS.
C
C
C       FIRST ENTER THE NUMBER OF OBSERVATIONS, CASES, ETC. OR
C SOME LARGE NUMBER FOR SITUATIONS WITH UNEQUAL N'S.
C
        N = (SOME NUMBER)
C
C       IF THE BASIC VARIABLES ARE TO BE NORMALIZED, GIVE NBAS
C A VALUE OF 1 OR IF NOT, A VALUE OF 0.
C
        NBAS = (1 OR 0)
C
C       IF THE NORMALIZED BASIC VARIABLES ARE TO BE USED IN THE
C CALCULATION OF THE PEDESTRIAN MOVEMENT VARIABLES, GIVE NNORM A
C VALUE OF 1 OR IF NOT, A VALUE OF 0.
C
        NNORM = (0 OR 1)
C
C       IF ORIGINAL (NON-NORMALIZED) BASIC VARIABLES ARE TO BE
C USED IN THE CALCULATION OF THE PEDESTRIAN MOVEMENT VARIABLES,
C GIVE JREG A VALUE OF 1 OR IF NOT, A VALUE OF 0.
C
        JREG = (0 OR 1)
C
```

```
C       IF THE PEDESTRIAN MOVEMENT CALCULATIONS ARE TO BE CON-
C VERTED TO METRIC UNITS, GIVE MNORM (CALCULATIONS MADE FROM
C NORMALIZED BASIC VARIABLES) AND/OR MREG (CALCULATIONS MADE
C FROM THE ORIGINAL BASIC VARIABLES) A VALUE OF 1 OR IF NOT, A
C VALUE OF 0.
C
        MNORM = (0 OR 1)
C
        MREG = (0 OR 1)
C
C       DECLARE THE REAL NUMBER VARIABLES AND DIMENSION ARRAYS
C WITH THE VALUE ASSIGNED TO N EARLIER.
C
        REAL SQFT,LENGT,TIME(N),COUNT(N),DENSI(N),AREA(N),
     1  FLOW(N),SPEED(N),NTIME(N),NCOUN(N),MDENS(N),MAREA(N),
     1  MSPEE(N),MFLOW(N),NDENS(N),NAREA(N),NSPEE(N),NFLOW(N),
     1  MDEN(N),MARE(N),MSPE(N),MFLO(N)
C
C       ENTER THE DISTANCE, IN FEET, BETWEEN THE TWO POINTS
C USED FOR TIMING A PERSON WALKING.
C
        LENGT = (SOME NUMBER)
C
C       ENTER THE AREA, IN SQUARE FEET, OF THE LOCATION WHERE
C COUNTS OF THE NUMBER OF PEOPLE WERE MADE.  THIS WOULD BE THE
C AREA BETWEEN THE TWO POINTS USED FOR TIMING.
C
        SQFT = (SOME NUMBER)
C
C       ENTER THE ORIGINAL DATA, TIME IN SECONDS AND A COUNT
C OF SOME NUMBER OF PEOPLE.  THIS PROGRAM IS WRITTEN TO READ
C THE DATA FROM A DISK, HOWEVER, CARDS, TAPES, OR ANY MEANS
C DESIRED CAN BE USED.
C
        CALL IFILE(1,'PED.DAT')
C
        DO 10 I=1,N
C
        READ(1,5,END=15)TIME(I),COUNT(I)
C
5       FORMAT(F3.1,1X,F2.0)
C
10      CONTINUE
C
C       A TEST IS MADE TO DETERMINE IF THE BASIC VARIABLES
C ARE TO BE NORMALIZED.
C
15      IF(NBAS.EQ.0)GO TO 35
C
C       IF NORMALIZATION IS TO BE DONE, THE FOLLOWING CALCU-
C LATIONS ARE MADE.
C
        DO 20 I=1,N
C
```

```
      NTIME(I) = TIME(I)*(A CORRECTION FACTOR DERIVED FROM
     1                    A PROPORTIONAL RELATIONSHIP OR
     1                    OTHERWISE)
C
      NCOUN(I) = COUNT(I)*(A CORRECTION FACTOR DERIVED FROM
     1                     A PROPORTIONAL RELATIONSHIP OR
     1                     OTHERWISE)
C
20    CONTINUE
C
C     THE RESULTING NORMALIZED VARIABLES ARE FILED FOR
C FUTURE USE.
C
      CALL OFILE(21,'NBAS.DAT')
C
      DO 30 I=1,N
C
      WRITE(21,25)NTIME(I),NCOUN(I)
C
25    FORMAT(F3.1,1X,F3.0)
C
30    CONTINUE
C
C     A TEST IS MADE TO DETERMINE IF THE NORMALIZED VARIABLES
C ARE TO BE USED IN THE CALCULATION OF THE PEDESTRIAN MOVE-
C MENT VARIABLES.
C
      IF(NNORM.EQ.0)GO TO 35
C
C     IF THE NORMALIZED VARIABLES ARE TO BE USED, THE FOLLOW-
C ING CALCULATIONS ARE MADE:
C
      DO 31 I=1,N
C
      NDENS(I)=NCOUN(I)/SQFT
C
      NAREA(I)=SQFT/NCOUN(I)
C
      NSPEE(I)=(60/NTIME(I))*LENGT
C
      NFLOW(I)=NSPEE(I)/NAREA(I)
C
31    CONTINUE
C
C     THE RESULTING PEDESTRIAN MOVEMENT VARIABLES ARE FILED
C FOR FUTURE USE.
C
      CALL OFILE(21,'NORM.DAT')
C
      DO 33 I=1,N
C
      WRITE(21,32)NDENS(I),NAREA(I),NFLOW(I),NSPEE(I)
```

```
C
32       FORMAT(F3.2,1X,F5.2,1X,F5.2,1X,F6.2)
C
33       CONTINUE
C
C        A TEST IS MADE TO DETERMINE IF THE BASIC VARIABLES
C ARE TO BE USED IN THE CALCULATION OF THE PEDESTRIAN MOVEMENT
C VARIABLES.
C
35       IF(JREG.EQ.0)GO TO 45
C
C        IF THE BASIC VARIABLES ARE TO BE USED, THE FOLLOWING
C CALCULATIONS ARE MADE:
C
         DO 40 I=1,N
C
         DENSI(I)=COUNT(I)/SQFT
C
         AREA(I)=SQFT/COUNT(I)
C
         SPEED(I)=(60/TIME(I))*LENGT
C
         FLOW(I)=SPEED(I)/AREA(I)
C
40       CONTINUE
C
C        THE RESULTING PEDESTRIAN MOVEMENT VARIABLES ARE FILED
C FOR FUTURE USE.
C
         CALL OFILE(21,'REG.DAT')
C
         DO 42 I=1,N
C
         WRITE(21,41)DENSI(I),AREA(I),FLOW(I),SPEED(I)
C
41       FORMAT(F3.2,1X,F5.2,1X,F5.2,1X,F6.2)
C
42       CONTINUE
C
C        A TEST IS MADE TO DETERMINE IF THE PEDESTRIAN
C MOVEMENT VARIABLE OBTAINED FROM NORMALIZED BASIC VARIABLES
C ARE TO BE CONVERTED TO METRIC UNITS.
C
45       IF(MNORM.EQ.0)GO TO 66
C
C        IF METRIC CONVERSION IS DESIRED, THE FOLLOWING
C CALCULATIONS ARE MADE:
C
         DO 50 I=1,N
C
         MDENS(I)=NDENS(I)/0.0929
C
```

```
          MAREA(I)=NAREA(I)*0.0929
C
          MSPEE(I)=NSPEE(I)*0.3048
C
          MFLOW(I)=MSPEE(I)/MAREA(I)
C
50        CONTINUE
C
C         THE RESULTING CONVERTED VARIABLES ARE FILED FOR
C FUTURE USE.
C
          CALL OFILE(21,'MNORM.DAT')
C
          DO 65 I=1,N
C
          WRITE(21,60)MDENS(I),MAREA(I),MFLOW(I),MSPEE(I)
C
60        FORMAT(F4.2,1X,F4.2,1X,F6.2,1X,F6.2)
C
65        CONTINUE
C
C         A TEST IS MADE TO DETERMINE IF THE PEDESTRIAN
C MOVEMENT VARIABLES OBTAINED FROM THE BASIC VARIABLES ARE
C TO BE CONVERTED TO METRIC UNITS.
C
66        IF(MREG.EQ.0)GO TO 80
C
C         IF METRIC CONVERSION IS DESIRED, THE FOLLOWING
C CALCULATIONS ARE MADE:
C
          DO 70 I=1,N
C
          MDEN(I)=DENSI(I)/0.0929
C
          MARE(I)=AREA(I)*0.0929
C
          MSPE(I)=SPEED(I)*0.3048
C
          MFLO(I)=MSPE(I)/MARE(I)
C
70        CONTINUE
C
C         THE RESULTING CONVERTED VARIABLES ARE FILED FOR
C FUTURE USE.

          CALL OFILE(21,'MREG.DAT')
C
          DO 75 I=1,N
C
          WRITE(21,73)MDEN(I),MARE(I),MFLO(I),MSPE(I)
C
73        FORMAT(F4.2,1X,F4.2,1X,F6.2,1X,F6.2)
C
75        CONTINUE
C
C         THIS ENDS THE PEDESTRIAN MOVEMENT VARIABLES PROGRAM.
C
80        STOP
C
          END
```

APPENDIX B

RAMP REGULATIONS IN THE MODEL BUILDING CODES

The Uniform Building Code (1976) requires that ramps should not exceed a slope of one vertical to eight horizontal (twelve percent). Ramps with slopes of greater than 1:15 six percent are required to have landings at both top and bottom as well as handrails. Furthermore, the surface of all ramps should be roughened or made of non-slip material.

The BOCA Basic Building Code (1975) allows ramps with a gradient of not more than one in twelve (eight percent) to be used as an exit way component. Steeper ramps of one and one-half in twelve (twelve percent) may be used except for special occupancies. All ramps with a slope greater than one in twelve, or wherever there is danger of slipping, should be surfaced with non-slip materials. Handrails are required for all ramps on at least one side. Landings are required at all entrances, exits, turns and doors to ramps.

The Standard Building Code (1976) limits the slope of ramps to one in ten (ten percent) and requires a non-slip surface. As with the other two codes, all requirements for stairways apply insofar as they are applicable. For all public buildings (where access for the handicapped is essential), the slope cannot be greater than one in twelve. Handrails and landings are also required.

FEDERAL INFORMATION PROCESSING STANDARD SOFTWARE SUMMARY

01. Summary date (Yr. Mo. Day)	78 11 09
02. Summary prepared by (Name and Phone)	George E. Turner (301) 92]-2102
03. Summary action: New / Replacement / Deletion	[X] New [ ] Replacement [ ] Deletion
Previous Internal Software ID	
04. Software date (Yr. Mo. Day)	78 04 21
05. Software title	Pedestrian Movement Variables
06. Short title	PED.MOV
07. Internal Software ID	
08. Software type	[ ] Automated Data System [X] Computer Program [ ] Subroutine/Module
09. Processing mode	[ ] Interactive [X] Batch [ ] Combination
10. Application area — General	[ ] Computer Systems Support/Utility [X] Scientific/Engineering [ ] Bibliographic/Textual [ ] Management/Business [ ] Process Control [ ] Other
10. Application area — Specific	Calculation of movement variables
11. Submitting organization and address	Architectural Research Program Environmental Design Research Division Center for Building Technology National Bureau of Standards Washington, D.C. 20234
12. Technical contact(s) and phone	George E. Turner (301) 921-2102

13. Narrative

PED.MOV is used to calculate the pedestrian movement variables density, area per person, flow rate, and walking speed from two basic variables, time (walking time between two points) and count (the number of persons within a particular square footage between the previous two points). In addition, the program can be used to normalize the two basic variables to a standard time measuring distance and counting area. The program also offers the option of converting the calculated variables density, area, flow, and speed to metric units. Input/output is via punched cards and line printer, or via terminal.

14. Keywords

Pedestrian circulation; Pedestrian flow; Pedestrian movement

15. Computer manuf'r and model	16. Computer operating system	17. Programing language(s)	18. Number of source program statements
Digital Equipment Corporation	DECsystem-10	Fortran V	
19. Computer memory requirements	**20. Tape drives**	**21. Disk/Drum units**	**22. Terminals**
10.5k 1024 words/K 32 Bit Words			

23. Other operational requirements

24. Software availability	25. Documentation availability
[ ] Available [ ] Limited [X] In-house only	[X] Available [ ] Inadequate [ ] In-house only contact: George E. Turner (301) 921-2102

26. FOR SUBMITTING ORGANIZATION USE

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1974 July
U.S. Dept. of Commerce—NBS
(FIPS. Pub. 30)

INSTRUCTIONS

01. **Summary Date.** Enter date summary prepared. Use Year, Month, Day format: YYMMDD.

02. **Summary Prepared By.** Enter name and phone number (including area code) of individual who prepared this summary.

03. **Summary Action.** Mark the appropriate box for new summary, replacement summary or deletion of summary. If this software summary is a replacement, enter under "Previous Internal Software ID" the internal software identification as reported in item 07 of the original summary, and enter the new internal software identification in item 07 of this form; complete all other items as for a new summary. If a software summary is to be deleted, enter under "Previous Internal Software ID" the internal software identification as reported in item 07 of the original summary; complete only items 01, 02, 03 and 11 on this form.

04. **Software Date.** Enter date software was completed or last updated. Use Year, Month, Day format: YYMMDD.

05. **Software Title.** Make title as descriptive as possible.

06. **Short Title.** (Optional) Enter commonly used abbreviation or acronym which identifies the software.

07. **Internal Software ID.** Enter a unique identification number or code.

08. **Software Type.** Mark the appropriate box for an **Automated Data System** (set of computer programs), **Computer Program**, or **Subroutine/Module**, whichever best describes the software.

09. **Processing Mode.** Mark the appropriate box for an **Interactive**, **Batch**, or **Combination** mode, whichever best describes the software.

10. **Application Area.**
    General: Mark the appropriate box which best describes the general area of application from among:
    - Computer Systems Support/Utility
    - Management/Business
    - Scientific/Engineering
    - Process Control
    - Bibliographic/Textual
    - Other

    Specific: Specify the sub-area of application; e.g.: "COBOL optimizer" if the general area is "Computer Systems Support/Utility"; "Payroll" if the general area is "Management/Business"; etc. Elaborate here if the general area is "Other."

11. **Submitting Organization and Address.** Identify the organization responsible for the software as completely as possible, to the Branch or Division level, but including Agency, Department (Bureau/Administration), Service, Corporation, Commission, or Council. Fill in complete mailing address, including mail code, street address, city, state, and ZIP code.

12. **Technical Contact(s) and Phone:** Enter person(s) or office(s) to be contacted for technical information on subject matter and/or operational aspects of software. Include telephone area code. Provide organization name and mailing address, if different from that in item 11.

13. **Narrative.** Describe concisely the problem addressed and methods of solution. Include significant factors such as special operating system modifications, security concerns, relationships to other software, input and output media, virtual memory requirements, and unique hardware features. Cite references, if appropriate.

14. **Keywords.** List significant words or phrases which reflect the functions, applications and features of the software. Separate entries with semicolons.

15. **Computer Manufacturer and Model.** Identify mainframe computer(s) on which software is operational.

16. **Computer Operating System.** Enter name, number, and release under which software is operating. Identify enhancements in the Narrative (item 13).

17. **Programing Language(s).** Identify the language(s) in which the software is written, including version; e.g., ANSI COBOL, FORTRAN V, SIMSCRIPT II.5, SLEUTH II.

18. **Number of Source Program Statements.** Include statements in this software, separate macros, called subroutines, etc.

19. **Computer Memory Requirements.** Enter minimum internal memory necessary to execute software, exclusive of memory required for the operating system. Specify words, bytes, characters, etc., and number of bits per unit. Identify virtual memory requirements in the Narrative (item 13).

20. **Tape Drives.** Identify number needed to operate software. Specify, if critical, manufacturer, model, tracks, recording density, etc.

21. **Disk/Drum Units.** Identify number and size (in same units as "Memory"—item 19) needed to operate software. Specify, if critical, manufacturer, model, etc.

22. **Terminals.** Identify number of terminals required. Specify, if critical, type, speed, character set, screen/line size, etc.

23 **Other Operational Requirements.** Identify peripheral devices, support software, or related equipment not indicated above, e.g., optical character devices, facsimile, computer-output microfilm, graphic plotters.

24. **Software Availability.** Mark the appropriate box which best describes the software availability from among: **Available to the Public, Limited Availability** (e.g.: for government use only), and **For-In-house Use Only.** If the software is "Available", include a mail or phone contact point, as well as the price and form in which the software is available, if possible.

25. **Documentation Availability.** Mark the appropriate box which best describes the documentation availability from among: **Available to the Public, Inadequate for Distribution,** and **For In-house Use Only.** If documentation is "Available", include a mail or phone contact point, as well as the price and form in which the documentation is available, if possible. If documentation is presently "Inadequate", show the expected availability date.

26. **For Submitting Organization Use.** This area is provided for the use of the organization submitting this summary. It may contain any information deemed useful for internal operation.

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7. AUTHOR(S) George E. Turner and Belinda L. Collins	8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, DC 20234	10. Project/Task/Work Unit No.
	11. Contract/Grant No.
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	14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

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

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

The research described in this report was a preliminary investigation of pedestrian movement characteristics on two specific building ramps. Variables of pedestrian movement such as speed, flow, and area were studied, as well as the relationships between these variables. In addition, the specific measurements of speed, flow and area were compared with similar measurements determined by other researchers not only for ramps, but also for stairs and level surfaces. Finally, suggestions were made for additional research into the characteristics of pedestrian movement on various elements of the building circulation system.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Building circulation; building ramps; pedestrian circulation; pedestrian flow; pedestrian movement; pedestrian ramps; ramps

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