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STAIRWAY AND HANDRAIL DESIGN FOR REDUCING FALL INJURIES

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EXECUTIVE SUMMARY

The first of two reports included in this document describes an analysis of existing occupational injury data concerning stair-related falls. Injury data based on reports obtained from the Ohio and California workers' compensation agencies were analyzed to identify common stair injury patterns. Frequency tabulations are provided for the following factors:

1. Location (indoors vs. outdoors, on vs. off employer's premises, site category).
2. Task (ascending vs. descending, body movement on the stair, task being attempted).
3. Events (precipitating actions and conditions).

One of the most outstanding findings is that 92 percent of the injuries occurred when the worker was descending the stair, i.e. 636 of the 688 cases in which direction of travel was indicated. Additionally, injury records from the New York and Ohio workers' compensation agencies were used to prioritize industries in terms of combined frequency and severity rates of stair-related injuries.

The second report describes a study of stairway risk factors based on video tape recordings of workers using 31 flights of stairs selected from among the industries with the highest frequency and severity rates for stair-related injuries. The video tapes were reviewed to identify all incidents, i.e. falls, trips, slips, missteps, and moments of temporary instability. The characteristics of the 98 stair users who were involved in an incident were compared to the characteristics of a matched group of stair users who did not have incidents. The matched sample was obtained by selecting the third person traveling on the same stairway in the same direction prior to the person who had the incident. The factors which best discriminate between the incident group and the non-incident group were:

1. The incident group tended to be those whose movement was impeded by others and who were older.
2. The non-incident group tended to be those who were wearing glasses and those who were very large or heavy individuals.

The influence of stairway physical features on the risk of injury was examined using correlation analysis. The measure of risk was the incidence rate (observed incidents per number of observed uses) for each flight as well as for each tread. Among the several variables significantly correlated with higher incidence rate, some of the more important design factors are:

1. Considering ascents and descents together, higher effective riser height, and less effective tread depth were both significant. These results indicate that the safest stairs have an effective riser height not greater than 7 inches, and an effective tread depth no less than 11 inches.
2. Considering descent only because this was associated with 92% of the injuries, the size of the nosing projection was significantly correlated with incidence rate. Since the mean nosing projection on the 31 flights in the sample was 11/16 inches, it would appear that nosing projections that exceed this dimension were associated with higher incident rates.

These two reports were submitted by the Georgia Tech Research Institute and Safety Sciences, Inc. in fulfillment of Contract No. CDC 210-79-0020 for the National Institute for Occupational Safety and Health.

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AN ANALYSIS OF OCCUPATIONAL STAIR ACCIDENT PATTERNS

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INTRODUCTION

Accidents related to work surfaces are responsible for a large percentage of U.S. occupational injuries. One of the more complete tabulations of occupational injuries, that for workers' compensation cases in New York State during 1966-1970, reported that 120,682 injuries related to work surfaces occurred during that period (20% of the total). Almost 14% of these involved stairs. These cases accounted for about 3% of all injuries and all awarded compensation indemnity costs. A recent analysis of 3,270 fall injury reports (Cohen and Compton, 1982) collected from a broad range of industry types, sizes, and geographical distributions indicated that approximately 10% were stair-related.

Despite the magnitude of the problem, little research has been performed to define the characteristics and etiological factors related to occupational stair accidents. However, the work load demands and hazards inherent in the task of stair climbing in public and private residential settings are well documented (Fitch, et al., 1974; Templer, et al., 1976; Archea, et al., 1979). For example, Archea et al. suggest that a greater likelihood of misstepping and falling exists on stairs because of the unusual gait and excessive energy expenditure required by stair climbing. Added to this is the increased human information processing load related to negotiating many sequential changes in elevation. Templer (1974) points to the opportunity for increased severity of accidents on stairs as compared with accidents on other work surfaces. According to Templer, this is a function of the elevation in a stairwell coupled with the sharp edges of the stair tread nosings to which falling persons are exposed. Add to this the fact that overall employee exposure to stairs is considerably greater than other elevated work surfaces, i.e., ladders, scaffolds, catwalks, and platforms (Cohen and Compton, 1982) and it becomes apparent that understanding the factors associated with occupational stair accidents remains an important area for detailed study.

The present paper describes the results of the first phase of an in depth study of the factors associated with accident occurrence during the use of stairways in industry. It describes an analysis of available workplace injury data related to falls on stairs. The purposes of this analysis are to: (a) identify those industries which experience the highest injury rates from falls on stairs, and (b) characterize predisposing factors and precipitating events which are commonly associated with falls on stairs in the workplace. The results of in depth video analysis of select industrial and commercial stairs and employee stair use, comprising later phases of the study, are presented in a companion paper.

METHODS

Precoded Injury Data Tapes

As a first step to understanding the factors associated with occupational stair accidents, an analysis was undertaken of precoded injury data tapes available from both the Ohio and New York workers' compensation agencies. These data tapes were made available to SAFETY SCIENCES through arrangements with the U.S. Bureau of Labor Statistics (BLS), Department of Labor. This data, available for all "closed" cases in the year 1977, was particularly advantageous for several reasons:

1. It represented a readily available, precoded source of broadly representative and recent data on occupational stair accidents.

2. Although precoded for certain limited select factors, it could be used for identifying high risk industries.

A major advantage of this data over other available tabulations, such as that which could be derived from the Bureau of Labor Statistics' Supplementary Data System (SDS), is that the New York and Ohio data is coded for "agency of accident," not "source of injury." According to the American National Standards Institute (ANSI) Z16.2 (1969) method of coding occupational injuries, the "source of injury" is defined as the object or substance that directly injures the worker. In the case of a fall from a defective stairway to a floor, the "source of injury" would not be the stairs; rather, it would be the floor. The "agency of accident," on the other hand, is defined as the object about which a hazardous condition exists. In the above example, the "agency of accident" is the stairway. Clearly, then, the "agency of accident, as opposed to the "source of injury," is more appropriate for purposes of identifying injuries associated with stairs from precoded workers' compensation data.

The first step in the data analysis process was to extract all cases coded as "agency of accident" from the master New York and Ohio tapes onto working data tapes. The working tapes, one each for Ohio and New York, were then used to generate a series of matrices through a computer program available from the Statistical Package for the Social Sciences (Nie et al., 1975). The matrices yielded measures of frequency and severity, i.e., number of cases by industry and average lost workdays per lost-workday case by industry for both the Ohio and New York data. However, number of cases and average days lost alone do not take into account differences in exposure, i.e., relative risk. An index of relative risk, suitable for such aggregated data, can be obtained by utilizing published Bureau of Census data, which provided population figures for each industry in each state (New York and Ohio) for the 1977 calendar year. Frequency and severity rates were then calculated using the following standard formulas:

$$\text{Frequency Rate} = \frac{\text{No. of Cases} \times 100}{\text{No. of Employees}}$$

$$\text{Lost Workday Rate} = \frac{\text{Total Lost Workdays} \times 100}{\text{No. of Employees}}$$

The following steps were then taken in order to derive a single index representing the combined data from both states:

1. Both the New York and Ohio frequency and lost workday (LWD) rates were normalized, yielding four separate normalized rates.

2. The New York rates were then weighted by 1.2 to account for an approximately 20% greater number of cases.

3. The four normalized and weighted rates were then summed and averaged, thus yielding a single, average adjusted rate for each industry.

4. These rates were then ranked, from the highest to the lowest, for all reported industries.

Injury Reports

In order to study actual case reports, copies of "Employer's First Reports of Injury" with an ANSI Z16.2 accident type code "035: Falls on Stairs" were requested from the workers' compensation agencies of California, Georgia, and Ohio. These were the states in which video observations were to be taken in the subsequent phases of the study described in the companion paper. The reports from Georgia, however, proved to be impossible to access, since their records system was not automated at the time of the study. The request to each of these agencies specified all such cases from the most recent calendar year prior to data analysis, i.e., 1979. Ohio provided 308 and California provided 522 usable reports. All personal and company identifying information (that is, name of employer, name of employee, and social security number) were deleted by agency personnel upon request.

A prior NIOSH study performed by SAFETY SCIENCES (1977) to determine whether the data on occupational injury records presently used are of sufficient research value found that this data source was substantially reliable and accurate. That study also found that the quantity of data provided on reports varied widely as a function of several influences, such as the open-ended nature of form items and lack of training of persons completing the forms, but that there is much more information relevant to hazard and countermeasure identification available on injury records than is conventionally being utilized.

The procedures for analyzing these data involved accessing the information contained on the injury reports and performing frequency tabulations of selected factors. In addition, the Ohio data included "workdays lost," a measure of severity. These factors were chosen on three bases:

1. Relevance to stair accidents as identified from previous stair research in settings other than occupational.

2. Relevance to the types of information that are appropriate for injury report data analysis as suggested by a generalized model of types of injury data relevant to safety research (SAFETY SCIENCES, 1977).

3. Availability of information on the specific reports analyzed.

TABLE 1 shows a list of the factors that were analyzed and the availability of data related to these factors on the injury reports. "Precipitating events/conditions" do not result in injury but lead to the injuring event. Some cases indicated the presence of more than one precipitating event or condition. The analysis included all identified events and conditions, not a judgment of "the single most important cause."

TABLE 1
AVAILABILITY OF DATA FROM INJURY REPORTS
RELEVANT TO STAIR ACCIDENT ETIOLOGY *

ANALYSIS FACTORS	PERCENT AVAILABLE FROM DATA BASE	
	CALIFORNIA	OHIO
I. Location		
1. Standard Industrial Classification	98	83
2. Indoors/outdoors	88	61
3. On/off premises	99	96
4. Site	> 99	81
II. Task		
1. Direction of travel	94	64
2. Body position	99	97
3. Work activity	59	62
III. Events		
1. Accident (fall) types	80	63
2. Precipitating events/conditions	64	64

*Factors recommended in NIOSH model (SAFETY SCIENCES, 1977).

RESULTS AND DISCUSSION

Injury Reports

TABLE 2 presents a breakdown of the number of stair falls by general environment (inside/outside). These data show that, overall, twice as many accidents occurred at indoor locations than at outdoor ones. This is probably because overall more work is performed indoors than outdoors. However, regional differences between the two states are reflected in these data. Nearly twice the percentage of outdoor accidents were recorded in Ohio than in California. It is apparent from reading the accident report narratives that this difference is more related to environmental conditions (e.g., rain and ice) than to other factors, such as differences in task exposure. Despite the opportunity for more outdoor work activity in California, exterior stair users in Ohio are likely to be confronted with more weather-induced work surface hazards, such as work surfaces slippery from rain, snow and ice, than are the majority of California stair users.

TABLE 2
STAIR ACCIDENTS BY GENERAL ENVIRONMENT

	CALIFORNIA		OHIO		TOTAL	
ENVIRONMENT	No.	%	No.	%	No.	%
Inside	362	69	85	29	447	54
Outside	94	18	103	33	199	24
Unspecified	64	12	120	39	184	22
Total	522		308		830	

Given the wide variance of staircase designs and environments, another type of data related to location that is important to consider is that which indicates an employee's familiarity with the features of the location of the accident occurrence. A factor that is available from injury report data and bears a strong relationship with familiarity is "on/off employer's premises," as described in TABLE 3. A check of the occupations of employees involved in the "off" category showed that most were of a service nature (e.g., route drivers, bottled water deliverers, case workers, public health inspectors, etc.).

These occupations typically involve both a high task exposure to stairway use and a high exposure to new and unfamiliar staircase features, located away from the employer's premises.

TABLE 3
STAIR ACCIDENTS BY GENERAL LOCATION
(ON/OFF EMPLOYER'S PREMISES)

LOCATION	CALIFORNIA		OHIO		TOTAL	
	No.	%	No.	%	No.	%
Inside	442	85	228	74	670	81
Outside	75	14	69	22	144	17
Unspecified	5	1	11	4	16	2
Total	522		308		830	

TABLE 4 presents a categorization of types of stairway sites where stair accidents occurred. Such information can be useful for pinpointing types of areas with high exposure or unusual concentrations of hazards. Fifteen percent of all accidents occurred on stairs at entrances or exits (both at employer's premises and at field locations). The unique problems faced by users at such architectural constructs include: 1) abrupt change of environment and visual cues from inside to out, 2) abrupt change in level, surface materials and conditions (many of the Ohio cases involved slips on ice and snow while leaving work), 3) increased traffic volume as a result of funneling at entrances and exits, and 4) haste due to lateness in reporting to work or eagerness to leave. The incidence of falls on basement and attic stairs may be related to several typical features characteristic of these locations: 1) limited usage and, therefore, limited familiarity; 2) stair design inconsistent with other facility stairs (typically with a steeper angle of incline), resulting in unexpected or more difficult to negotiate circumstances; and 3) poor lighting conditions.

In the category designated as "industry specific areas," it is interesting to note the high percentage of cases occurring in office and manufacturing areas (20% and 13% overall, respectively). Other analyses, to be discussed, indicate that this high concentration of accidents is not only due to high relative exposure, but to several important inherent hazards as well.

TABLE 4

STAIR ACCIDENTS BY TYPES OF SITES

SITES	CALIFORNIA No.	CALIFORNIA %	OHIO No.	OHIO %	TOTAL No.	TOTAL %
Structural Types	103	20	122	40	225	27
Entrance/exits	37	7	60	19	97	12
Basement/attic	26	5	25	8	51	6
Lunchroom/lounge	15	3	6	2	21	3
Parking structure/lot	8	2	1	< 1	9	1
Machine steps	6	1	21	7	27	3
Restroom stairs	5	1	--	--	5	< 1
Loading dock	4	1	5	2	9	1
Trailer steps	2	1	4	1	6	1
Industry Specific Areas	341	65	89	29	430	52
Office areas	140	27	29	10	169	20
Manufacturing	75	14	31	10	106	13
Retail stores	40	8	5	2	45	5
Schools	32	6	6	2	38	4
Restaurants	22	4	13	4	35	4
Hospitals	26	5	2	1	28	3
Warehouse	6	1	3	1	9	1
"Field" Locations	68	13	57	19	125	15
Construction sites	21	4	18	6	39	5
Private residences	10	2	4	1	14	2
Private residence entrances	10	2	15	5	25	3
Miscellaneous job site	25	5	12	4	37	4
Emergency response sites	2	< 1	8	3	10	1
Others	8	2	13	4	21	3
Unspecified	2	< 1	27	9	29	3
Total	522		308		830	

The "field locations" category represents another indication of familiarity because such locations are described as typically being used by the accident victim only once or infrequently. Conditions and circumstances leading to falls in these areas cannot always be controlled in the same manner as those in more captive locations, i.e., the employer's premises. The subcategory "construction sites" also suggests the presence of inherent hazards, such as incomplete stairway construction (e.g., loose floor boards, handrail not in place, etc.) and task-related overextending (e.g., reaching with paint brush or dry wall knife) and prolonged exposure while working on stairs.

Information on activities being performed at the time of accident occurrence is extremely valuable to safety research. It not only assists in understanding how accidents happen, but also allows countermeasure development to go beyond mere physical guarding of hazards, suggesting changes in work design, training and work supervision. TABLE 5 shows the direction of travel of the victim at the time of the accident occurrence. It is suspected that the difference in reported accident frequency between going up and coming down stairs (6% and 77%, respectively) is related less to design or behavioral factors than to reporting differences. A fall while ascending stairs is generally of lower severity because forward momentum is arrested by the staircase structure itself, while a fall down a staircase is likely to result in higher severity because there is a greater distance to fall. Injury reports, because of reporting criteria based on minimal severity levels, are skewed toward the selection of higher severity incidents. Previous research on public and private household stairs (Templer et al., 1978; Archea et al., 1979) confirms that while missteps would be expected to be more frequent in ascent, serious accidents resulting in injuries are more common in descent.

TABLE 5
STAIR ACCIDENTS BY VICTIM'S DIRECTION
OF TRAVEL

	CALIFORNIA		OHIO		TOTAL	
DIRECTION	No.	%	No.	%	No.	%
Down	474	91	162	53	636	77
Up	18	3	34	11	52	6
Unspecified	30	6	112	36	142	17
Total	522		308		830	

Generally, injury report data on body position or movement is not definitive because, on most report forms, information related to the position of body parts (i.e., head, hands, feet, trunk) and force and direction of movements is not specifically requested. TABLE 6 classifies stair accidents by available data on body position. Nearly 90% of the cases are reported as involving "walking" as the body position. This proportion may not be unusually high, but may indicate that other important information (e.g., objects carried, etc.) is missing. The other categories shown are somewhat indicative of the commission of gross, often intentional, errors and are consistent with expectations of body positions associated with falls on stairs, but the low reported frequencies suggest that performance errors that lead to the majority of stair accidents are not the obvious "gross" ones, but minute or subtle missteps, etc. Many of the movements appear to be related to overextending the body's mass beyond its base of support (e.g., "bending/reaching" and "pushing/pulling"), resulting in unbalancing.

Activity being performed at the time of the accident could be determined in every case, but some of the information may be overly generalized (about 40% stated that the victim was "walking on stairs" and were categorized as "transit, unspecified"). Activity being performed is specifically requested on the California report form, but not on the one used in Ohio. The work activity data studied does, however, indicate specific recurring accident patterns (see TABLE 7).

Sixty-four percent of all cases were related to the activity of "transit". This is an unexpected finding, since a staircase is a specialized walking surface intended for transit from one elevation to another. The other broad categories in TABLE 7 show the types of secondary task performance that were found in the injury report data. Workers who "make rounds" probably have a higher exposure to stairs because their jobs require them to "rove" around the premises. They may also be exposed to more poor lighting conditions (e.g., security patrol) and diversion of attention (e.g., inspection, escorting persons). Materials handling subcategories attempt to classify types of loads as they may be related to accident occurrence (e.g., "visual encumbrances," a subcategory used to describe loads that obstruct vision and/or require attention-sharing). Workers "working on stairs" are specifically not involved in transit, yet are attempting to use the staircase with its inherent hazards as a regular, i.e., level, working surface.

TABLE 6
STAIR ACCIDENTS BY BODY POSITION
AT TIME OF ACCIDENT

BODY POSITION	CALIFORNIA		OHIO		TOTAL	
	No.	%	No.	%	No.	%
Walking	468	90	266	86	734	88
Walking, holding handrail	11	2	3	1	14	2
Sweeping, mopping movements	11	2	3	1	14	2
Bending/reaching	9	2	4	1	13	2
Running	6	1	13	4	19	2
Stepping backwards	5	1	5	2	10	1
Pushing/pulling (e.g., handcart)	4	1	3	1	7	1
Turning around	4	1	2	1	6	1
Unknown	4	1	9	3	13	2
Total	522		308		830	

TABLE 7
STAIR ACCIDENTS BY WORK ACTIVITY

WORK ACTIVITY	CALIFORNIA No.	CALIFORNIA %	OHIO No.	OHIO %	Days Lost	Days per Case	TOTAL No.	TOTAL %
Transit	343	66	191	62	1369	7.1	534	64
Leaving work	50	10	35	11	313	8.9	85	10
On break	41	8	5	2	29	5.8	46	6
Changing work area	30	6	17	6	82	4.8	47	6
Reporting to work	21	4	21	7	149	7.0	42	5
Unspecified	201	39	113	37	896	7.9	314	38
Making Rounds	52	10	20	6	118	5.9	72	9
Inspecting	17	3	7	2	56	8.0	24	3
Security patrol	16	3	5	1	26	5.2	21	3
Domestic/custodian	10	2	6	2	22	3.7	16	2
Escorting persons	9	2	2	1	14	7.0	11	1
Materials Handling, Types of Loads or Methods	82	16	47	15	302	6.4	129	16
Visual and balance encumbrance	17	3	14	5	83	6.0	31	4
Balance encumbrance (i.e., weight distributed off base of support)	14	3	9	3	69	7.7	23	3
Multiple objects	14	3	7	2	22	3.1	21	2
Visual encumbrance (e.g., visual obstruction, attention sharing)	11	2	6	2	61	10.2	17	2
Light to moderate	11	2	1	< 1	3	3.0	12	1
With coworker	3	1	2	1	2	1.0	5	1
With device (e.g., handcart)	2	1	5	1	50	10.0	7	1
Unspecified load	10	2	3	1	12	4.0	13	2

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WORK ACTIVITY	CALIFORNIA No.	CALIFORNIA %	OHIO No.	OHIO %	Days Lost	Days per Case	TOTAL No.	TOTAL %
Working on Stair	19	4	15	5	73	4.9	34	4
Construction	8	2	7	2	13	1.9	15	2
Cleaning	7	1	4	1	34	8.5	11	1
Other	4	1	4	1	13	3.3	8	1
Field-Related tasks (e.g., Route Delivery, Visiting Client)	26	5	35	11	242	6.9	61	7
Total	522		308			6.8	830	

TABLE 8 shows the reported frequencies for various precipitating events or conditions found in stairway injury reports. Only conditions or events that were directly related to the accident occurrence were tallied. Four broad categories of events were identified: 1) design-induced conditions, 2) environmentally related conditions, 3) inherent user characteristics, and 4) performance factors. Under "design conditions," problems with surface materials accounted for a fairly high proportion (11%) of the total events/conditions. Metal and cement materials (reported as slippery) made up almost two-thirds of these, while carpet and brick involved "tripping" incidents amounted to one-fourth of the problems related to surface materials. Protruding nosings related to trips while ascending, open risers resulting in distraction while ascending, and doors that opened abruptly onto staircase tops or bottoms were the most prominent design-induced problems that emerged from these data. About 1% of the cases specifically reported the involvement of missing or slippery handrails.

Environmental conditions, which can largely be corrected through improved housekeeping and maintenance, probably have the greatest potential for immediate correction. Many of the low-COF conditions on exterior staircases (e.g., "wet from rain"), which are beyond the purview of improved housekeeping, can be approached by "surface modification" types of corrective actions to increase the COF of the surface material by, for example, providing an adequate "wash" to ensure proper water run-off, acid-etching of concrete and application of non-skid tread material. A glance at the difference between the two states found in the category of "low coefficient conditions" supports the earlier contention that increased occurrence of accidents out of doors in Ohio was related to climatic differences. While the percentages of slips in rain puddles was approximately equivalent, a possible difference may be attributed to 42 cases (19%) specifically related to snow and ice in Ohio, compared with only one such case in California.

Stairway user characteristics accounted for about 8% of the total reported events/conditions. About half of these were related to design, condition, and/or maintenance of shoes, and the other half to predisposing physiological impairments generally not related to stairway usage, e.g., weak knee or ankle from previous injury "gave out." Several cases, however, involved fainting or dizziness due to fumes from industrial processes near the staircase.

Fully 50% of all events/conditions were classified as due to performance factors. Design interface problems may have played a more significant role than these data indicate. However, even with very high quality data sources, such as accident investigation reports involving victim interviews and site surveys, it is not easy, or necessarily desirable, to identify a single cause related to either design or behavior. On the contrary, it is likely that in most cases multiple factors interact to result in an accident. For example, one-third of "misarticulated foot placements" can be attributed to patterns that may be design-related, e.g., "foot placed off edge of step" and "caught heel on step." Twenty percent of "misarticulated foot placements" can be confidently attributed to purely behavioral or judgmental errors (e.g.,

TABLE 8

PRECIPITATING EVENTS/CONDITIONS IDENTIFIED FROM STAIR INJURY REPORTS

TYPES OF CONDITIONS	CALIFORNIA		OHIO				TOTAL	
	No.	%	No.	%	Days Lost	Days per Case	No.	%
Design Conditions	64	17	27	12	108	4.0	91	16
Surface materials (e.g., slip on metal step, trip on carpet)	46	13	17	8	176	4.5	63	11
Physical design features (e.g., protruding nosing, narrow tread)	15	4	9	4	30	3.3	24	4
Handrail missing/slippery	3	1	1	< 1	2	0.2	4	1
Environmental Conditions	82	22	90	40	670	7.4	172	31
Low coefficient of friction conditions (e.g., wet, oily, rain, ice, snow)	45	12	63	28	414	6.6	108	19
Object/obstruction on stairs (e.g., hoses, refuse, etc.)	16	4	13	4	145	11.0	29	5
Maintenance problems (e.g., broken step, loose nosing)	8	2	6	3	49	8.2	14	2
Poor lighting, dark	13	1	8	< 1	62	7.8	5	1
User Characteristics	36	10	9	4	45	5.0	45	8
Footwear/clothing (e.g., high heel caught in step, shoe broke)	20	5	4	2	22	5.5	24	4
Physiological dysfunction	16	4	5	2	23	4.6	21	4

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TYPES OF CONDITIONS	CALIFORNIA No.	CALIFORNIA %	OHIO No.	OHIO %	Days Lost	Days per Case	TOTAL No.	TOTAL %
Performing Factors	184	50	99	44	667	6.7	283	50
Misarticulated foot placement*	94	26	55	24	364	6.6	149	27
Inattention/preoccupation (e.g., looking away from staircase)	46	13	15	7	114	7.6	61	11
Extending mass beyond base of support (e.g., reaching)	30	8	21	9	136	6.5	51	9
Haste (i.e., running)	14	4	8	4	53	6.6	22	4
Total	366		225		1490	6.6	561	

*Possibly includes some types of events/conditions that may be design- or environment-related, but insufficient information was provided in order to confidently make the determination.

skipping steps, changing direction of travel on midstairs, and stepping backward). More than half of the cases in this category occurred while victims were transferring from stair to level surface or vice versa, at the top or bottom of the staircase. It is likely that many of these occurrences are related to the user having not yet changed gait or walking behavior required when approaching or leaving the stairs.

"Inattention/preoccupation" cases involved such problems as directly looking away from the stairs, juggling multiple objects, and concentrating on not spilling open containers of hot liquids (often coffee). "Extending mass beyond base of support," which resulted in unbalancing, involved both excessive reaching and carrying large and bulky objects, which effectively increased and extended the user's weight beyond the base of support provided by the feet. This can be especially dangerous while descending stairs because of the forward and downward momentum and the opportunity for misstepping off the end of a step if the step edge is visually obscured by the large object being carried, or if attention is momentarily drawn away from the task of stair descent by any number of distractions in the workplace, many of which can be eliminated by improved workplace layout and stair design (Archea et al., 1979). Undue haste, particularly when reporting to or leaving work, is a problem more amenable to training and work practice reinforcement type countermeasures.

Precoded Injury Data

TABLE 9 presents a summary of overall industry ranking with respect to combined frequency and severity of stair-related injuries derived from analysis of the precoded Ohio and New York injury data tapes. As can be seen, a broad range of general industry is represented on this list. Miscellaneous manufacturing industries show by far the highest overall rate of stair-related injuries, over 50% greater than the next two industry groupings. A number of highly ranked industries are noted to involve service functions or transitory conditions away from the employer's premises and, hence, not directly controllable by the employer through structural design changes. This follows from the injury reports data analysis as well. Some examples include: police and fire protection; public health inspection; building construction; trucking; membership organizations (social, fraternal, religious, etc.); laundry services; etc. Other highly ranked industries identified from the New York and Ohio tapes are probably over-represented, or even peculiar, to those states. Examples include: motion pictures - production, distribution (New York) and foundries (Ohio).

TABLE 9
OVERALL INDUSTRY RANKING WITH RESPECT TO
STAIR-RELATED INJURIES

RANK	SIC NUMBER	SIC INDUSTRY DESCRIPTION	AVERAGE OF ADJUSTED
1	399	Miscellaneous Manufacturing Industries	6.437
2	94	Admin. of Public Health; Social & Income Maint.	4.262
3	9221 & 9224	Police & Fire Protection	4.022
4	83	Membership Organization; Social Fraternal & Rel.	2.967
5	421	Trucking--Local & Long Distance	1.997
6	331, 332, 336	Blast Furnaces; Rolling Mills, Iron, Steel & Nonferrous Foundries	1.964
7	78	Motion Pictures--Production, Distribution, Theaters	1.712
8	70	Hotels, Motels, Rooming Houses, Camps & Lodgings	1.688
9	82	Educational Services; Elementary through College (Public & Private)	1.659
10	91	General Local & State Government	1.617
11	01 & 02	Agricultural Products--Crops & Livestock	1.611
12	20	Food & Kindred Products; Meat, Diary, Bakery, Beverages, Canned Fruits & Vegetables	1.526
13	281 & 286	Industrial Inorganic & Organic Chemicals	1.390
14	56	Apparel & Accessory Stores	1.250
15	47	Transportation Services	1.102
16	7211-7215	Laundries & Laundry Services	1.074
17	95	Air & Water Resources, Solid Waste Management	1.028
18	15 & 17	Bldg. Construction; General Bldg. Contractors	0.973
19	801	Offices of Physicians; Health Practitioners, Labs, Nursing Facilities	0.964
20	581	Eating & Drinking Places	0.889
21	59	Miscellaneous Retail	0.839
22	372	Aircraft Parts	0.830
23	57	Furniture, Home Furnishings, & Equipment Stores	0.808

CONCLUSIONS

The findings of the injury data analyses indicate several accident-related patterns associated with occupational stair use. One of these patterns involves the occurrence of a variety of design and environmentally induced hazards that stair users frequently encounter. Such hazards appear to be especially troublesome when they are unexpected by the user. If the user encounters a characteristic of the stair site that is different from his normal expectation, an adaptation in stair-use behavior must be made or an accident may occur. If a stair user is familiar with the characteristics of a stair site, then the inherent hazards are already recognized and can be more easily avoided.

The data show two general types of unfamiliar stair situations: 1) sudden changes on a familiar, routinely used staircase, such as transient housekeeping and maintenance problems; and 2) those which are more or less permanent features of a particular stair that is not routinely used by the victim and that is different from other staircases with which the victim is familiar. The occurrence of events fitting the latter case is indicated by the frequency of reports listed in categories such as, "off" employer's premises, "field locations," and "field-related tasks." The environmental conditions reported in TABLE 8 indicate some transient hazardous situations common to stairs and other work surface types that are often easily remedied by improved maintenance and housekeeping practices. Design conditions listed in TABLE 8 describe some of the more or less permanent structural problems, the solutions to which are generally more difficult, but must be ultimately approached through improved design criteria, such as those obtainable from detailed user observations. (Archea, et al., 1979).

The other major problem associated with stair use is that of user performance errors. While the activities of stair ascent and descent are commonly taken for granted and not typically thought of as specific structured tasks per se, the negotiation of multiple sequential changes in elevation requires continual information processing and complex biomechanical activity. Although the stair structure enhances the opportunity for performance errors, people can usually perform the negotiation of elevation changes without incident when their limited information processing capability can be focused on that task. When their work duties require sharing attention with the simultaneous performance of other, secondary tasks, such as materials handling, or their limited attention is momentarily diverted, information overload and the opportunity for errors in performance of the primary task can occur, particularly in the presence of an unexpected hazard or unfamiliar setting. The problem of task overload in accident-producing situations is well demonstrated by Saari (1977), who showed that accident rates tend to be higher for tasks that are nonrepetitive and unpredictable. Types of work that are not preplanned or in the same location fall into this category and stair-related examples include workers who "make rounds (e.g., security patrol), "constructions sites", "field", and other unfamiliar and/or unpredictable stair hazard locations.

Accidents are generally the result of system failures. Typically, multiple factors interact, resulting in a series of events leading to an injury. Such is the case with the data reported here. Often, a reported performance error (e.g., running or inattention) preceded and placed the victim in a position wherein a hazardous, environmentally related situation (e.g., ice on a stairstep) could not be recognized or easily avoided. In other cases, performance errors (e.g., missteps resulting in a fall injury) were clearly design-induced (e.g., due to doors opening abruptly onto staircase tops or bottoms). This was particularly true in unfamiliar or otherwise task-loaded situations.

The industrial setting has the unique opportunity of having an almost wholly "captive" stair user population. This introduces the possibility of implementing additional types of countermeasures that cannot be readily applied to public and private residential stairways. Such countermeasures are performance or behaviorally oriented. They include: training (e.g., manual materials handling on stairs, specific hazard awareness, etc.) and work reinforcement (e.g., no running on or skipping stairs). Often, such behaviorally oriented countermeasures are the only type of corrective actions that can be applied, such as with locations remote from the employer's premises, as is the case with the relatively high proportion of service and delivery personnel who are injured each year from falls on stairways.

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STUDY OF FACTORS ASSOCIATED WITH RISK OF WORK-RELATED STAIRWAY FALLS

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INTRODUCTION

It has long been recognized that stairs are among the most serious accident hazards that individuals encounter in the everyday environment (Merrill, M.H., et al., 1957; Brill and See 1971, 1974; H.U.D. 1972). The magnitude of the stair accident problem has become even more apparent since 1973 when the U.S. Consumer Product Safety Commission (CPSC) began issuing systematic reports of the frequency and severity of accidental injuries resulting from the use of a wide range of products and environments. According to the data reported by CPSC's National Electronic Injury Surveillance System (NEISS) there are over 500,000 injuries resulting from stair accidents each year that are serious enough to require hospital treatment (NEISS News, 1974). As a consequence, stairs have consistently ranked at or near the top of the NEISS hazard priority ranking. Further, it is believed that there are close to two million temporarily or permanently disabling injuries attributable to stair accidents in the United States each year (McGuire, 1971; H.U.D., 1972) and conservative estimates attribute approximately 3,800 deaths to stair accidents each year (H.U.D., 1972). Again, using conservative estimates, the total annual cost of stair accidents in terms of compensation paid, workdays lost, and direct medical expenses exceeds $2,000,000,000 (Alessi & Brill, 1979).

In an attempt to identify ways to reduce the frequency and severity of residential stair accidents, the Consumer Product Safety Commission funded a major research project on stair, ramp, and landing hazards at the National Bureau of Standards (NBS) (Archea, Collins, & Stahl, 1979). In addition to an exhaustive review of previous research and existing standards pertaining to stair safety, NBS conducted a thorough examination of over 500 field reports of stair accidents which had been gathered by NEISS investigators, and then conducted its own survey and inventory of stair use and stair quality in a stratified sample of residences in Milwaukee (Carson, Archea, Margulis, and Carson, 1978).

In addition, one of the most significant aspects of the work at NBS was the development of unobtrusive techniques for gathering and subsequently analyzing detailed videotape and film records of stair users in naturalistic settings (Archea, et al., 1979; Templer, et al., 1978). Records of over 32,000 stair users were obtained in various parts of the country, including approximately 120 who had noticeable missteps and almost 20 who had uncontrolled falls or accidents. From a detailed time-series analysis of these records, it was determined that visual perception is a major factor in successful stair use and that visual deceptions or distractions which disrupt the typical visual scans associated with stair use are a major factor in stair accidents (Archea, et al., 1979).

Using a matched sample of stair users who did and did not have accidents recorded on the NBS videotapes, Templer attempted to identify precipitating environmental and behavioral factors such as a handrail use, items carried, speed of movement and type of clothing. The results of this analysis reinforced the importance of visual factors in stair accidents and shed additional light on the importance of abrupt changes in stair conditions (sudden distractions, changing light levels, etc.) in determining precisely where accidents would occur on each flight (Templer, et al., 1978).

Because of the richness of these videotape data, it became possible to pool incident rates with those reported in the Milwaukee survey and by NEISS to give a first approximation of the frequency of missteps, accidents, injuries, and deaths on stairs as a function of use (Archea, et al., 1979).

In earlier laboratory studies of energy expenditure and gait on stairs Templer established an acceptable range of riser and tread dimensions for stairs using subjective user comfort ratings and observed rates of missteps as the major criteria. In a related observational study of stair use in public settings, Templer also determined typical patterns of handrail use and channel selection on flights of stairs having different widths and configurations (Templer, 1974; Fitch, Templer, and Corcoran, 1974).

In 1982, Cohen and Compton reported the results of a study performed for the National Institute for Occupational Safety and Health (NIOSH). The study included detailed field investigation of work surface characteristics in the vicinity of 50 accidents in nine industrial or semi-industrial organizations. One of the major conclusions from this study was the important role that local variations in slip-resistance characteristics may play in work surface accidents--including stair accidents. This sheds new light on the role of slip-resistance in pedestrian accidents and was consistent with some of the implications of the CPSC-NBS research, but which had not been investigated in detail.

As a result of the NBS, Templer, and Cohen/Compton studies it became apparent that making a successful transition from walking on a level landing to walking down a flight of stairs requires a person to (a) look directly at the stair as they approach and step onto it, and (b) to cautiously "get the feel" of the treads while descending the first two or three steps. In effect, one must visually estimate the most appropriate initial placement of their foot on the first tread, and then confirm the accuracy of both their estimate and their foot placement kinesthetically. Once assured that they are placing their feet within the limits imposed by the design and dimensions of the stair treads, users are free to attend to other portions of their visual surroundings as they continue their descent.

Within this framework, accidents were found to occur when this process was disrupted and the user abruptly encountered a nonconforming condition which they failed to anticipate from their prior visual and kinesthetic cues. Such conditions could include changes in the level of slip-resistance or subtle variations in riser heights or tread depths. Visual deceptions built into the design of the stair and distractions that drew the user's attention away from the stair were found to be two of the leading causes of stair accidents (Templer, et al., 1978; Carson, et al., 1978; Archea, et al., 1979; Archea, 1983).

The intent of the present study, which was funded by NIOSH, was to apply the type of analysis used in the NBS studies to the conditions encountered on industrial stairs. More specifically the NIOSH study set out to identify design strategies for reducing the frequency of stair accidents at industrial sites.

METHODOLOGY

SELECTION OF STAIR SITES

The selection of sites for the study involved a focusing procedure to identify high risk locations that (a) would be a better representation of the injury-causing potential of industrial stairs than could have been obtained by a random sample, and (b) would enable a higher than average yield of incidents for each hour of videotape recorded. To do this, industries were selected which had a high incidence of stair-related accidents.

Selection of Specific Industries

Based on an analysis of state workers' compensation records for New York and Ohio (Cohen, Templer, and Archea, 1985), overall industry priorities were established with respect to the combined frequency and severity of stair-related injuries. These priorities are presented in the first two columns of Table 1.

In addition to prioritizing the frequency and severity of stair-related incidents, Table 1 reflects several other factors relevant to the conduct of detailed behavioral observations. For example, most of the "priority industries," that were initially identified, involve service functions or transitory conditions away from the employer's premises and, hence, were not controllable through structural design changes. Some examples included: police and fire protection, public health administration, building construction, trucking, membership organizations (social, fraternal, religious, etc.) and laundry services. Other "priority industries" initially identified from the New York and Ohio tapes were deemed to have been peculiar to those states. Examples included: motion picture production and distribution in New York and foundries in Ohio.

Table 1: Industries Prioritized According to the Combined Frequency and Severity of Stair-Related Injuries.

Industry Priorities	Frequency-Severity Index	Number of Candidate Establishments	Number of Flights Observed
Miscellaneous Manufacturing	6.437	13	10
Administration of Public Health	4.262	*	*
Police and Fire Protection	4.022	*	*
Membership Organizations	2.967	*	*
Local and Long Distance Trucking	1.997	*	*
Blast Furnaces and Foundries	1.964	*	*
Motion Picture Distribution	1.712	*	*
Hotels and Motels	1.688	3	2
Educational Services	1.659	7	3
Local and State Government	1.617	7	3
Agricultural Products	1.611	*	*
Food and Kindred Products	1.526	11	4
Industrial Chemicals	1.390	*	*
Apparel Stores	1.250	2	2
Transportation Services	1.102	*	*
Laundry Services	1.074	*	*
Air and Water Management	1.028	*	*
Building Construction	.973	*	*
Medical Offices	.964	*	*
Eating and Drinking Places	.889	5	5
Miscellaneous Retail	.889	6	2

* Industries dropped from consideration for reasons cited in the text.

Selection of Specific Establishments

The following criteria were then used to identify the specific establishments at which observations were to be made:

1. Selected industries should be broadly representative of the nine major Standard Industrial Classification (SIC) division (O.M.B., 1972).
2. Industries represented in the sample should involve a relatively high frequency and severity of stair-related accidents.
3. They should not include establishments which serve primarily as a home-base for workers predominantly involved in service or transitory functions remote from the employer's premises.
4. They should not include installations peculiar to a particular state; rather, they should represent types of establishments that can be found almost anywhere in the country.
5. Selected establishments should include generalized settings (e.g., offices, manufacturing areas, eating places, etc.) where a high volume of employee stair usage is likely.

The task of selecting specific candidate sites began with a survey of professional organizations to identify a representative sample of the various industries within each of the SIC classifications. Two consumer organizations, five professional organizations, three governmental agencies, and nine industrial organizations were contacted by telephone in California, Georgia and Ohio.

From these sources and the California, Georgia and Ohio Manufacturing Directories, a number of candidate establishments were identified. The safety engineer, plant manager, and/or personnel director at each candidate site was contacted to solicit their potential interest in participating. Agreement was reached with 15 potential sites in California, 24 sites in Georgia, and 15 sites in Ohio. The number of candidate establishments selected in each industry category is shown in the 3rd column of Table 1.

Selection of Specific Stairs

Each candidate site was visited by members of the research team and selected characteristics of all candidate stair flights were recorded. Stair characteristics recorded included: location; the number of flights; flight lengths; effective stair widths; riser and tread dimensions; traffic density; percentage of usage by employees; flooring materials; lighting; and, potentials for unobtrusive videotape recording. In addition, 35 mm slides fully illustrating each stair and its setting were taken.

Preliminary field observations revealed that an average of 600-750 employee uses could be expected on each flight during a typical work week. Based on an incident rate of one per 175 uses (Archea, et al., 1979) it was determined that a minimum of 30 flights would have to be observed in order to yield 100-125 incidents. The number of flights required for each industry classification was then adjusted in proportion to the frequency/severity index for that industry, as shown in the 2nd column of Table 1. The number of flights observed in each category is shown in the last column of Table 1.

The final selection of flights was based upon (a) the widest range of dimensional and configurational characteristics, (b) the highest volume of employee usage, (c) potentials for good camera angles and (d) proportional representation within each industry category. Note that several of the candidate staircases had "composite" layouts. This means that they were composed of several straight flights coupled to landings in various configurations. In such cases, individual sections were selected as if they were independent flights with different settings.

VIDEOTAPE METHODOLOGY

The data collection phase involved the recording of the characteristics and actions of people using each of the 31 flights of stairs that had been selected by the procedures presented above. After the final selection of locations had been completed, a notice of the study was posted to inform employees of the nature and purpose of the study. Employees were given the option to not participate in the study by informing the field researcher of his/her desire not to be taped. Although the vast majority of users videotaped were employees of the company, occasional visitors to the company may have been videotaped as well.

It was originally intended that Super-8 movie cameras would be utilized for the data collection. However, after a thorough examination of the available technology, videotape was chosen as a superior collection instrument for the following reasons:

1. Recordings could continue for up to 2 hours without reloading - as compared to 10 minutes for film.
2. Recordings could be instantly replayed to ensure that clear images had been obtained.
3. Recorded information could be edited and transferred electronically to master tapes as required for analysis purposes.

Setting up recording equipment. The recording equipment was located where it would be as unobtrusive as possible, yet would provide a clear view of the users from head to foot, as they negotiated each flight. Two cameras were used for most flights. From previous work, it was found that the top and the bottom of flights were the loci of a disproportionately high percentage of incidents (Templer, et al., 1978). Therefore, on long flights the cameras were focussed on these points.

Recording Time. Because it was necessary to consider the possibility that stair incidents occur more frequently at certain times of the day, or on certain days of the week, the videotape recordings were made throughout the workday, five days a week. Every stair use was recorded and analyzed for the duration of the study. Data were collected between 24 and 40 hours at each stair site.

Physical Measures. As stated earlier, all of the physical conditions of the stair were recorded in detail. Any changes in environmental condition during the recording process were fully recorded.

ANALYSIS

All tapes were studied by trained encoders to identify all conceivable stair incidents. Any abnormal behavior associated with the use of the stair was noted. This included such behaviors as a misstep or slip, bumping into another person on the stair, suddenly reaching for the handrail and any form of hesitation or disruption in the subject's forward progress.

Thirty percent of the tapes were rechecked to ensure reliability. A total of 516 potential incidents were identified. These usages were then reviewed a second time to identify bonafide accidents and missteps. Only those incidents in which there was a clear misstep, loss of balance, or apparent disruption of the user's intended pattern of movement were selected. A total of 98 undisputed critical incidents were selected for the final analysis.

Matched Sample. One hypothesis of the study was that some types of behavior on stairs, or the physical characteristics of some users might have caused an incident. To test this, the personal and behavioral characteristics of the people involved in incidents on the stairs (the incident sample) were compared to the characteristics of a matching group of stair users who did not have incidents (the non-incident sample). The non-incident sample was formed by selecting the third person travelling in the same direction prior to each person who had an incident on a given flight.

This procedure ensured that the non-incident sample duplicated closely the circumstances of the incident sample in terms of the time of day, the day of the week, the stairway used, ambient environmental conditions, and the general presence of other users. It also assured that the behavior of each incident victim and his or her non-incident match would be independent of each other. The resulting groups provided a plausible basis for establishing valid relationships between specific personal or behavioral characteristics of the users and the occurrence of stair accidents, missteps, or other critical incidents.

Observer Training and Reliability. Coder training involved approximately seven hours of instruction and trial data takeoffs. Much of the training was directed toward assuring a high level of observational reliability (the reliability was rechecked periodically during the data processing phase). During this period, the observers were familiarized with the variables to be identified, the levels of each variable, videotape observation procedures and the data recording procedures. From previous research it was clear that the degree of coding precision decreased as the amount of observer judgment increased (Templer, et al., 1978). Much of the training period concentrated on improving the precision of the observers' judgmental decisions.

Coding. One hundred twenty three independent (or predictor) variables were analyzed in this study. Each was chosen for its possible influence on stair accidents. Many of these had been shown in previous studies to correlate significantly with accidents (Templer, et al., 1978; Carson, et al., 1978; Archea, et al., 1979). These variables fell into three categories:

A. Environmental conditions -- including riser height, tread depth, nosing projection, wash (the slope of the tread toward the nosing), illumination characteristics, stair width, handrail characteristics, orientation factors (such as the presence of rich views to the user's right or left), etc. All of the environmental variables were based upon precise measurements or observations made in the field.

B. User characteristics -- such as age, sex, race, body type, obvious handicaps, clothing, items carried, group ecology (such as being alone or with one or more others), etc. All of these user characteristics were coded from the videotape records obtained in the field.

C. Behavioral characteristics of the user -- including the occurrence of incidents, direction of movement, speed, route taken, degree of attention paid to others, handrail use, traffic density, gait, direction of gaze, etc. All of these behavioral characteristics were coded from the videotapes.

Statistical Analysis. Two major statistical techniques were employed: discriminant analysis and multiple regression--using the "Statistical Package for the Social Sciences" (SPSS). Where the dependent variables of interest were categorical, such as "incident versus non-incident", the discriminant analysis was employed. Multiple regression analyses were used to determine the relative impact of the independent environmental variables (e.g., handrail height, tread depth, etc.) and behavioral variables (e.g., percent of foot on the tread, direction of gaze, etc.) on metric dependent measures, such as incidence rate per flight or per tread.

DISCRIMINANT ANALYSIS

To identify the factors which discriminated between an incident occurring and no incident occurring, incidents were assigned to one group, while non-incidents were assigned to another. The issue then became: which of the many descriptors recorded for the stairs, the users, and their behavior, best discriminated between the incident and non-incident groups?

The discriminant analysis in this case was essentially a factor analysis with factor loadings on a single factor. The discriminant weightings for the variables chosen reflected the least-squares maximization of the ratio of between-group variance to within-group variance. In other words, variables were chosen and weighted to maximize the discrimination between the incident and non-incident groups.

Discriminant Analysis Results:

The discriminant analysis for the characteristics of the stair users and their behavior revealed that the factors which best distinguish the incident group from the non-incident group were:

1. The incident group tended to be those whose movement was impeded by others, and those who were older.
2. The non-incident group tended to be those who were wearing glasses, and those who were very large or heavy.

The standardized equation generated for this analysis was:

y=.87(B6B)-.62(B9A)-.46(B10B)+.43(C16B)

where B6B represents the subject's age, B9A their weight rating, B10B their use of glasses, and C16B the rating for impeded movement caused by others.

A discriminant analysis was also performed for the characteristics of the stair treads involved in the incidents compared with stair treads on which no incidents occurred. The analysis revealed that the factors which most distinguish the incident treads from the non-incident treads were:

1. The incident treads tended to be those with larger nosing projections, and those with a greater number of rated orientation changes from the previous treads.
2 The non-incident treads tended to be associated with the presence of views ahead of the subject.

The standardized equation generated for this analysis was:

y=.34(A6)-.73(A31A)+.42(A60)

where A6 represented the nosing projection, A31A the presence of views ahead of the subject, and A60 the number of rated orientation changes from the previous tread.

MULTIPLE REGRESSION

The regression analyses generated equations which represented the relative contributions of each of the independent variables in predicting variability in the dependent measures. Some of the independent measures used in the regression analyses were categorical variables, such as the tread materials or the direction of the user's gaze. Such variables were dummy coded using a binary scale (0,1).

A total of 98 incidents were recorded on 31 flights of stairs. Since there were 72 environmental conditions (A variables) it was not possible to consider all of these in a step-wise multiple regression with only 31 observations of the dependent variable (the incidence rate of each flight, or tread), so a focusing procedure was used. Simple correlations between the stair incidence rates and each of the A variables were examined and those that were statistically significant (at the .05 level or higher) were utilized as candidates in the stepwise multiple regression.

Multiple Regression Results:

Incidence Rates Per Flight. The incidence rate per flight was determined by dividing the total number of incidents recorded on each flight by the total number of people who had been recorded as users of that flight. Separate analyses were done with the data for ascent and descent combined, for ascent only, and for descent only. The independent variables used in this analysis were the means of the separate measurements made for each environmental attribute on every riser or tread within the flight.

With the data for ascent and descent combined, higher incidence rates were found on flights with a greater mean wash ($r=.407$, $df=29$, $p<.05$), higher mean effective riser height ($r=.385$, $df=29$, $p<.05$), and less mean effective tread depth ($r=-.358$, $df=29$, $p<.05$). For the 31 flights in the sample, the mean wash was 3/16", the mean effective riser height was 7-1/8", and the mean effective tread depth was 10-3/16". Based on these data for flights as-a-whole, it would appear the mean washes and mean effective riser heights that exceed 3/16" and 7-1/8", respectively, and mean effective tread depths that are less than 10-3/16" would be associated with higher than average incidence rates.

When the data for ascent were separated from those for descent, it was found that the influence of effective tread depths and effective riser heights was greatest in ascent. For ascent, the correlation between incidence rates and effective tread depth was -.430 ($df=29$, $p<.01$), while that for effective riser height was .327 ($df=29$, $p<.05$). This means that higher incidence rates in ascent were associated with effective treads that were narrower than 10-3/16" and with risers that were higher than 7-1/8" — when incidence rate per flight was used as the criterion measure.

For descent, no statistically significant correlations were found between incident rates per flight and effective riser or tread dimensions. However, higher incident rate in descent were found to be associated with greater mean nosing projections, ($r=.338$, $df=29$, $p<.05$). Since the mean nosing projection on the 31 flights in the sample was 11/16", it would appear that nosing projections that exceeded this dimension were associated with higher than average incidence rates.

Although each of the factors cited above was found to be significantly associated with incidence rates per flight, none of these contributing factors were found to be significant in a regression equation when the incidence rates in ascent and descent were considered together or separately.

Incident rates per tread. Since more than one incident was recorded for several of the treads on some of the flights, it was possible to establish a rate for each tread on which one or more incidents had occurred by dividing the number of incidents observed by the total number of users per flight. The following rates are defined:

> Incident Tread Ascent Incidence Rate (ITAIR): for those treads on which an incident occurred when the person was ascending, the ITAIR is the ratio of the number of ascending incidents on that tread to the number of observed ascending users of that tread.
>
> Incident Tread Descent Incidence Rate (ITDIR): for those treads on which an incident occurred when the person was descending, the ITDIR is the ratio of the number of descending incidents on that tread to the number of observed descending users of that tread.
>
> Incident Tread Combined Incidence Rate (ITCIR): for those treads on which an incident occurred when the person was either descending or ascending, the ITCIR is the ratio of the number of observed incidents on that tread to the number of observed users of that tread.

Table 2 shows the attributes of the treads which were significantly correlated with ITCIR. A plus sign (+) indicates that the attribute was associated with a higher incidence rate, while a minus sign (-) indicates that it was associated with a lower incidence rate. Table 2 includes the findings for the incident tread (for which the ITAIR was calculated) as well as for the three treads traversed by the user prior to reaching the incident tread.

Table 2: Tread Attributes Correlated With ITCIR

Attribute	Incident Tread	1st Prior Tread	2nd Prior Tread	3rd Prior Tread
Concrete or stone treads	-	-	-	-
Less effective tread depth	+	+		+
Open with a rich view on one side	-	-	-	-
Linoleum or tile treads	+	+	+	+
Higher effective riser height	+	+	+	+
Enclosed on both sides	+		+	
Less handrail-to-handrail width	+			
Handrail present on left side descending				+

+ : Factor Associated With Higher ITCIR
- : Factor Associated With Lower ITCIR

From Table 2 it can be seen that the steps with higher ITCIRs were characterized by having less effective tread depth (r=-.467, df=48, p<.01), higher effective riser height (r=.432, df=52, p<.01), less handrail-to-handrail width (r=-.328, df=43, p<.05), linoleum or tile treads (r=.291, df=57 p<.05), and being visually enclosed on both sides (r=-.272, df=57, p<.05). In this analysis, the mean effective tread depth was 9-15/16", the mean effective riser height was 7-3/16", and the mean handrail-to-handrail width was 44-13/16". The treads with lower ITCIRs were of concrete or stone material (r=-.526, df=57, p<.01) and had rich views open to one side (r=-.364, df=57, p<.01).

The concrete or stone materials and rich views open to one side, which were associated with treads having lower ITCIRs, were also found to be characteristic of each of the three treads prior to the incident tread. Similarly, linoleum or tile materials were also associated with the three treads prior to the incident treads with higher ITCIRs. Less effective tread depth and higher effective risers were also characteristic of the treads immediately prior to the ones having higher ITCIRs.

The multiple regression equation generated for these observations was:

$$y = -.25(A7_1)+.32(A7_3)+.95(A24C_0) - .64$$

Where y was ITCIR, $A7_1$ was the depth of the tread immediately prior to the incident tread (mean = 9-15/16"), $A7_3$ was the depth of the third tread prior to the incident tread (mean = 9-15/16"), and $A24C_0$ was the presence of stone or concrete materials on the incident tread itself.

The data for incidents occurring in descent were then separated from the data for the incidents occurring in ascent. Tables 3 and 4 show the stair attributes that were found to be significantly associated with higher or lower incidence rates in descent and ascent, respectively. Note that Tables 3 and 4 only include the incident tread (T_0) and the tread immediately prior to the incident tread (T_1). This is because the number of incidents occurring at the top or the bottom of a flight was so great, that there were not a sufficient number of treads prior to T_1 to generate an adequate number of cases to be considered in the regression analysis.

Table 3: Tread Attributes Correlated With ITDIR

Attribute	Incident Tread	1st Prior Tread	2nd Prior Tread	3rd Prior Tread
Higher effective riser height	+	+		
Concrete or stone treads	-	-		
Linoleum or tile treads	+	+		
Less tread wash	+	+		
Greater visibility of tread edges from above	+	+		
Open with a rich view on one side		-		

+ : Factor Associated With Higher ITDIR
- : Factor Associated With Lower ITDIR

Table 4: Tread Attributes Correlated With ITAIR

Attribute	Incident Tread	1st Prior Tread	2nd Prior Tread	3rd Prior Tread
Less effective tread depth	+	+		
Open with a rich view on one side	-	-		
Enclosed on both sides	+	+		
Higher effective riser height	+	+		
Concrete or stone treads	-	-		
Linoleum or tile treads		+		

+ : Factor Associated With Higher ITAIR
- : Factor Associated With Lower ITAIR

When the descent incidents were considered alone, it was found that higher effective riser heights ($r=.581$, $df=25$, $p<.01$) and the presence of linoleum or tile treads ($r=.490$, $df=30$, $p<.01$) were more strongly associated with higher ITDIRs and that the presence of concrete or stone treads ($r=-.633$, $df=30$, $p<.01$) was more strongly associated with lower ITDIRs. For these data, the mean effective riser height was 6-15/16".

By contrast when ascent was considered alone, less effective tread depth ($r=-.584$, $df=33$, $p<.01$) was more strongly associated with higher ITAIRs, while the presence of rich views open to one side ($r=.491$, $df=37$, $p<.01$) was more strongly associated with lower ITAIR. In this case the mean effective tread depth was 9-13/16".

The multiple regression equation generated for descent was:

$$y = .16(A4_1)-.83$$

where y was ITDIR, $A4_1$ was the effective height of the riser for the tread immediately prior to the incident tread (mean = 6-15/16"). The multiple regression equation generated for ascent was:

$$y = -.16(A7_0)-.18(A30C_0)+.19$$

where y was ITAIR, $A7_0$ was the effective depth of the incident tread (mean = 9-13/16") and $A30C_0$ was the absence of a rich view open to one side on the incident tread.

Other factors found to have been significantly associated with higher incidence rates in ascent (ITAIR) but not selected in the multiple regression were the presence of visual enclosures on both sides of the flight ($r=-.461$, $df=37$, $p<.01$) and higher effective riser heights ($r=.377$, $df=35$, $p<.05$). The mean effective riser heights for ascending incident treads was 7-5/16", which is 3/8" higher than that found for descent. Note that while higher effective riser heights were significantly associated with higher ITAIRs and ITDIRs, the correlation was much stronger for ITDIR.

Additional factors found to have been significantly associated with higher ITDIRs were greater visibility of the tread edges when viewed from above ($r=.440$, $df=28$, $p<.05$) and less wash on the treads ($r=-.413$, $df=24$, $p<.05$).

Overall, it was found that higher ITDIRs were associated with higher effective riser heights (especially on the tread prior to the incident tread) and the nature of the tread materials. Since measured slip-resistance was not found to have been a significant factor in this study, the higher ITDIRs associated with tile or linoleum treads and the lower ITDIRs associated with concrete or stone treads, suggest that material characteristics other than slip-resistance may have played an important role in the incidents associated with descent. Previous research (Archea, et al., 1979) suggests that appearance might be a mediating factor. However, the findings reported in the previous paragraph on the effects of the visibility of the tread edges confound this interpretation.

In ascent, the higher ITAIRs were associated primarily with less effective depth on the incident tread and on the tread immediately prior to it, to a much lesser extent with higher effective riser heights on both of these treads, and with the visual context on either side of the flight.

Since higher ITAIRs were associated with total visual enclosure on both sides of the flight and lower rates were associated with rich views open on one side, it does not appear that visual distractions of the type previously reported (Carson, et al., 1978; Templer, et al., 1978; Archea et al., 1979; Archea, 1983) could account for these findings. However, it seems plausible that the amount of caution exercised by the users might have been a mediating factor. According to this scenario, users in fully enclosed stairways may have been less cautious in their use of the stair than those whose visual attention was diverted away from the stair itself by a compelling view off to one side. The behavioral implications of this possibility will be considered in the next sub-section.

Behavioral Factors. The behavioral factors found to have been significantly associated with ITCIRs are shown in Table 5. Here all of the behaviors found to have been associated with higher or lower ITCIRs on the incident tread are presented. The four columns on the right part of Table 5 indicate the tread on which the behavior occurred.

Table 5: Behavioral Factors Correlated With ITCIRs

Action	Incident Tread	1st Prior Tread	2nd Prior Tread	3rd Prior Tread
Less of the foot on the tread	+	+	+	+
In right hand third of the flight	-	-	-	-
Looking to the right or left	+	+		+
Using the handrail to pull up		+	+	+
No hands on either rail			+	+
Foot twisted slightly to the left	-			
Watching other persons	-			
In center third of the flight		+		
Looking straight ahead			+	
Looking down				-

+ : Factor Associated With Higher ITCIR
- : Factor Associated With Lower ITCIR

With the data for ascent and descent combined, the ITCIRs were found to have been associated with the following behaviors on the incident tread: having less of their foot on the tread ($r=-.256$, $df=79$, $p<.05$), looking to their right or left ($r=.254$, $df=96$, $p<.05$), not having been in the right hand third of the flight ($r=-.233$, $df=96$, $p<.05$), not having their foot twisted to the left ($r=-.177$, $df=96$, $p<.05$), and not watching other persons ($r=-.177$, df=96, $p<.05$). Having less of the foot on each tread was consistently found to be associated with higher ITCIRs for each of the three treads prior to the incident tread as well. The same was true for not being in the right hand third of the flight; and, except for the second tread preceding the incident tread, for looking to the right or the left.

Higher ITCIRs were also found to be associated with the following behaviors which occurred in one or more of the treads preceding the one on which they occurred: using the handrail to pull up, walking in the center of the flight, having no hand on either rail, looking to the right or left, and not looking down. Of these factors, only the use of the handrail to pull up on the first through third treads prior to the incident tread and the nonuse of the handrail on the second and third prior treads appear to constitute behavioral patterns that might be related to stair accidents.

The multiple regression equation generated for ascent and descent combined was:

$$y = -.31(C9_1) + .24$$

where y was ITCIR, and $C9_1$ was the proportion of the foot placed on the tread prior to the incident tread.

When the behavioral patterns for descending subjects were separated from those for ascending subjects it was found that the subjects' behavior was much more closely associated with ITDIR than ITAIR. The behavioral factors found to be significantly associated with higher or lower ITDIR are shown in Table 6. It includes behaviors which occurred on the incident tread as well as on the three treads prior to the incident tread. Note that so few behavioral factors were significantly related to ITAIR, that no comparable table has been included for those findings.

In descent, using the handrail for guidance and balance was directly associated with higher ITDIRs ($r=.590$, df=30, $p<.01$). Having the foot twisted slightly to the left ($r=-.424$, df=30, $p<.01$), looking straight ahead ($r=-.350$, df=30, $p<.05$), and being in the right hand third of the flight ($r=-.347$, df=30, $p<.05$) were all significantly associated with lower ITDIRs on the incident tread. The ITDIR was also significantly associated with these same four behaviors occurring on the tread immediately prior to the incident tread. Using the handrail for guidance and balance and being in the right hand third of the flight on the second and third treads prior to the incident tread were also significantly associated with ITDIR.

Having less of the foot on the tread and no hands on either rail were significantly associated with higher ITDIRs for the first through third treads prior to the incident tread in descent. Looking up on the second prior tread and looking to the right or left on the third prior tread were also significantly associated with higher ITDIR.

Table 6: Behavioral Factors Correlated With ITDIR

Action	Incident Tread	1st Prior Tread	2nd Prior Tread	3rd Prior Tread
Use of handrail for guidance and balance	+	+	+	+
In right hand third of the flight	-	-	-	-
Less of the foot on the tread		+	+	+
Foot twisted slightly to the left	-	-		
Looking straight ahead	-	-		
No hands on either rail		+	+	+
Looking up			+	
Looking to the right or left				+

+ : Factor Associated With Higher ITDIR
- : Factor Associated With Lower ITDIR

The multiple regression equation generated for descent alone was:

$$y = -.78(C9_1) + .52$$

where y was ITDIR, $C9_1$ was the proportion of the foot placed on the tread prior to the incident tread. This means that having less of the foot placed on the tread prior to the incident tread was the major behavioral factor associated with the incidents recorded in this study. Further consideration of the uses of the handrails and of where the subjects were looking will be included in the discussion section.

Finally, in ascent, watching other people while on the incident tread ($r=-.300$, $df=37$, $p<.05$); not looking straight ahead on the second prior tread; and being in the right hand third of the flight, having hands on both rails, or not using the handrail for physical support on the third prior tread were all found to be significantly related with lower ITAIR. However, none of these factors appears to contribute to a consistent pattern of stair incidents and none were selected in the multiple regression analysis.

DISCUSSION

In general, four major factors were found to be associated with incidence rates in the present study. These factors were: (1) riser and tread dimensions, (2) tread materials, (3) visual surroundings, and (4) handrail use. Each of these will be discussed in turn.

Riser and tread dimensions:

High risers and narrow treads were the design features most consistently found to be associated with incidents on industrial stairs. For the combined ascent and descent data, narrow treads on the first and third treads prior to the ones on which incidents occurred were found to be significantly associated with those incidents. For the ascent data alone, narrow treads at the point at which the incident occurred were also found to be significantly associated with those incidents. For the descent data alone, higher risers on the treads prior to the ones on which the incidents occurred were found to be significantly associated with those incidents.

For ascent, it would appear that narrow treads tend to cause understepping at the point of incident, and this was the major design factor associated with stair accidents.

For descent, it would appear that overstepping the tread prior to the incident tread was the major factor associated with stair incidents. This conclusion is supported by the finding that the users had less of their foot on the tread prior to the incident tread in descent--which is the equivalent of overstepping. Since this tread was accompanied by higher risers, in descent, it would appear that much of this overstepping could be attributed to the increased forward trajectory of the descending foot as a result of having slightly further to fall from the higher tread above. The findings that having the foot twisted slightly to the left on the incident tread and on the tread prior to it were associated with lower incidence rates, suggests that those people who successfully compensated for the effects of this higher riser, had fewer incidents.

The critical dimensions associated with incidents on stairs were determined by using the means and standard deviations of the riser and tread dimensions found to be significantly correlated with incidence rates. Note that in this study all riser and tread dimensions found to be significantly associated with incidence rates were the "effective" dimensions, rather than the simple measured dimensions. This means that for riser height, the critical effective dimension was the height of the face of the riser plus the wash of the tread below. For tread depth, the critical effective dimension was the measured depth of the tread less the nosing overhang for the tread above.

Using a composite of the means per flight and per tread, higher than average incidence rates were found when the effective riser heights exceeded 7-1/8" and when the effective tread depths were less than 10-3/16". Using the standard deviations to identify dimensions more closely associated with lower incidence rates, it was found that the safest stairs would have a maximum effective riser height of 6" and a minimum effective tread depth of 11".

Although the former pair of dimensions may be appropriate for reducing the number of incidents on industrial stairs, the latter pair would be preferable for providing a genuinely safe stair. These dimensions are quite consistent with those reported by Templer (Fitch, Templer, & Corcoran, 1974; Templer, 1974).

Tread materials:

Throughout the analysis of tread-specific incidence rates: higher incidence rates per tread were consistently associated with linoleum or tile treads, while lower rates were consistently associated with concrete or stone treads. This was true for the incident tread and all three of the immediately preceding treads when the data for ascent and descent were combined. When the data for ascent and descent were treated separately, the material factor appeared to be much more critical in descent.

Since measured slip-resistance was not found to have been significantly associated with the incidents recorded in this study, it would appear that a more complex relationship might have operated with regard to tread materials. For example, it was found that higher incident rates in descent were significantly associated with having had less of the foot on the tread prior to the incident tread and with higher risers at this same location. Combining these findings with the findings on tread materials suggest that the effects of materials may have been related to overstepping, especially in descent.

According to this scenario, as the person overstepped the tread immediately prior to the incident tread, and onto the incident tread itself, they placed their foot closer than normal to the nosing, and thus brought maximum horizontal forces to bear on a minimal surface area. In this case, the rough "tooth" of concrete or stone would be in a better position to retard further forward movement toward or over the nosing, than the much smoother surface presented by tile or linoleum. Such interactions between surface materials and foot placement have been posited by others (Harper, Warlow, & Clarke, 1967; Carson, et al., 1978; Archea, et al., 1979).

The possibility that differences in the appearances of these materials may have had a mediating effect on incidence rates is also consistent with earlier findings (Carson, et al., 1978; Templer, et al., 1978; Archea, et al., 1979). However, the data from the present study do not permit the resolution of either of these alternative explanations of the effect of tread materials.

Visual Surroundings:

The discriminant analysis indicated that the incident treads tended to be those with no views straight ahead and higher numbers of orientation changes from the previous treads. However, several other findings pertaining to the availability of views to the user's right or left and to the directions in which they were actually looking, initially appear to give contradictory results. For example, in the tread-specific analysis when the data for ascent and descent were combined, lower incidence rates were found where rich views were available to the right or left, while higher rates were found when the users actually looked to their right or left. Higher rates were also found when the views to the right or left were obscured by solid walls. A similar pattern was found when the data for ascent were considered alone. In descent, lower rates per tread were found when the users were looking straight ahead, while higher rates were found when they looked away from the stairs (up or to their right or left).

Handrail use:

It was consistently found that lower incidence rates per tread were found when the user was in the right hand third of the flight, but that higher rates were found when they actually used the handrail to pull themselves up in ascent or for guidance and balance in descent. The rate was also higher when they failed to use the handrail at all in descent for the first through third treads prior to the incident tread.

Again, it would appear that the user's perception of risk and use of caution may have been a factor in handrail use. Those who needed to use the handrail to pull themselves up may initially have been more vulnerable and, thus had more incidents. This is consistent with the higher incidence rate for older subjects found in the discriminant analysis. On the other hand, those who merely used the handrail for guidance and balance may have been lulled into a sense of security that masked some of the risks involved in descending stairs. In a sense, those who stayed on the right had side of the flight were not too dependent on the handrail, but kept themselves in the best position to use it if necessary. This interpretation is largely consistent with earlier findings (Carson, et al., 1978) that, comparing residential stairways with and without handrails, proportionally more missteps occurred on residential stairs with handrails, but more serious injuries occurred on flights without handrails.

Again the data from this study do not resolve the role played by the handrail in stair accidents. However, since this issue relates more to how the stair is used, its ultimate resolution may be more of a consumer education issue than a design or maintenance problem.

CONCLUSION

In general it was found that several design factors were related to higher incidence rates on industrial stairs. These included risers in excess of 6" to 7" in effective height, treads of less than 10" to 11" in effective depth and tile or linoleum tread materials. Concrete or stone treads and the presence of visual distractions to the side of the user's path of travel were found to be associated with lower incidence rates. In the latter case, it was further suggested that, while the presence of a visual distraction may increase the degree of caution exercised by the user, those who were actually distracted were likely to experience a greater number of incidents. This issue of the interaction between the appearance of a hazard, and the user's attempts to compensate for the consequences of that hazard should be the focus of future research.

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