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Personnel Guardrails for the Prevention of Occupational Accidents

S. G. Fattal, L. E. Cattaneo
G. E. Turner, S. N. Robinson

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Institute for Applied Technology
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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*
Edward O. Vetter, *Under Secretary*
Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

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PERSONNEL GUARDRAILS FOR THE PREVENTION OF OCCUPATIONAL ACCIDENTS

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Existing information is compiled which would assist in determining structural and non-structural safety requirements for guardrails used for the protection of employees against occupational hazards. Critical aspects of guardrail safety are identifed through exploratory studies consisting of field surveys of prototypical installations, reviews of existing standards and industrial accident records, and compilation of relevant anthropometric data. These exploratory studies will be utilized to design an experimental program which will consist of structural tests to determine design loads and non-structural tests to determine geometric requirements for guardrail safety.

Key Words: Anthropometric measurements; guardrails; industrial accidents; non-structural safety; occupational hazards; performance standard; personnel railings; personnel safety; structural safety.

1. Introduction - Objectives and Scope

This report documents the first phase of research studies conducted at the National Bureau of Standards (NBS) in response to a request by the Occupational Safety and Health Administration (OSHA) for technical assistance in developing performance standards and design guidelines for guardrails which will be used to protect employees against occupational hazards. Under the Occupational Safety and Health Act of 1970, OSHA exercises a mandate over employee safety regulations including prescriptive requirements for all guardrails that are installed in areas where employees conduct work-related activities. The general lack of technical literature to support the existing OSHA guardrail regulations, and, for that matter, guardrail provisions of other mandatory or voluntary standards, has been one of the principal motivating factors behind the research program. The two principal objectives of the project were the development of basic technical information through research and the utilization of this information to prepare performance-oriented recommendations for the design, construction and evaluation of guardrail systems which come under the jurisdiction of OSHA.

The scope of this project was established by mutual agreement between OSHA and NBS participants. It was agreed that NBS research should apply to temporary and permanent guardrails used for the protection of employees against occupational hazards, and therefore, should only consider factors associated with guardrail use by adult personnel during the conduct of their assigned tasks. It was further stipulated that NBS research should exclude consideration of guardrail loading situations arising through flagrant abuse or through the impact of power-driven vehicles or other heavy mobile objects propelled by people. In addition, it was agreed that NBS research need not be concerned with investigations of whether or where the installation of guardrails will be required.

The types of guardrail installations given high research priority by OSHA included the following, listed in the order of decreasing priority: (1) elevated walkways (2) erected and swinging scaffolds, (3) balconies and mezzanines, (4) hot-dip galvanizing operations, (5) roofing operations, (6) cast-in-place concrete construction, (7) petro-chemical towers, (8) mobile equipment, (9) elevated work or storage areas, and (10) marine dry docks. It was understood that as many of these installations as possible should be examined within the specified project resources without diluting the credibility of the end product. NBS researchers examined eight of these installations, the excluded ones were chemical towers and mobile equipment.

At the beginning of this project it was reasoned that if the principal factors contributing to the safe functioning of guardrails could be identified in some systematic fashion, the task of developing an effective approach to meet the specified project objectives would be simplified. Accordingly, one of the earlier tasks was to devise a conceptual model which considers both human and environmental factors and their interactions with respect to safety and to proceed to study guardrails within the framework of this model. (See Section 5).

Using the guidelines of the safety model, a two-phase approach compatible with the stated project objectives was formulated. The first phase was exploratory in nature and was necessitated by almost a total lack of rational basis behind existing guardrail design provisions. It was aimed towards such studies as the prevailing modes of guardrail use in service, the adequacy of present design and construction practices, factors influencing human-guardrail interaction, and the principal agents of potential hazards. Specifically, the scope of the first phase included the following disciplinary studies which are documented in this report for the benefit of researchers and analysts concerned with guardrail safety.

(1) A literature search of available technical information and a study of the provisions of existing guardrail design standards (Section 2).

(2) A compilation of existing statistical data on the anthropometric and kinematic characteristics of the human body relevant to guardrail analysis (Section 3).

(3) A field survey of prototypical guardrail installations (the eight types mentioned above), to become familiar with current practices and, if possible, to identify safe and unsafe employee activities and environmental characteristics (Section 4).

(4) An analysis of employee accident records compiled by various agencies to determine the frequency and nature of those accidents which appear to be guardrail-related (Sections 5 and 6).

In phase two, the results presented herein will be used in the preparation and subsequent conduct of an experimental-analytical program. It is expected that these exploratory studies will prove valuable in designing experiments to measure the static and dynamic loads induced on guardrails during simulated accident situations, and in developing a data base from which the essential safety features of guardrails can be established. On the basis of information acquired from the above, performance-oriented recommendations and a guide for the design and evaluation of guardrails will be prepared.

The implementation of this project was carried out through the cooperative efforts of NBS research investigators from the structural, architectural and psychological disciplines. For convenience in recovering the original sources and data, a reference list for each of the four tasks identified above is appended to the end of the appropriate section.*

*Citations of references are indicated by numbers in brackets.

2. Review of Existing Standards and Technical Literature

This section presents a summary of existing guardrail provisions of some of the major codes and standards that are widely used througout the United States and Canada. For ease of reference, these provisions are presented in tabular form (table 2.1) consisting of entries of prescribed horizontal and vertical design loads, required height of guardrail, and notes related to these entries. The first entry gives the code references and the pertinent sections from which the listed data have been excerpted. The references from which table 2.1 has been prepared and the sequence in which they have been listed, (which is arbitrary) are as follows:

(1) Uniform Building Code [2.10]

(2) The BOCA Basic Building Code [2.11]

(3) Building Code of the City of New York [2.12]

(4) Southern Standard Building Code [2.13]

(5) The National Building Code [2.14]

(6) National Building Code of Canada [2.5]

(7) Canadian Construction Safety Code [2.16]

(8) Occupational Safety and Health Standard, Part 1910 [2.2]

(9) Construction Safety and Health Regulations, Part 1926 [2.1]

An examination of the information compiled in table 2.1 reveals a general lack of consistency and uniformity between load and height requirements. Some base their load requirements on the number of occupants while others specify loads according to guardrail location. In cases where two or three different loadings are specified, it is not always clear whether these loads are intended to be applied simultaneously or individually in design. Quite often, certain critical decisions are left to the designers with such terms as "substantial guardrails shall be provided. . ." or "openings should restrict climbing." The requirements of some of the codes are much more stringent than others. Certain codes and regulations give standard member sizes and dimensions. Sometimes there are ambiguities with regard to whether the specified loads are factored or unfactored (ultimate strength design vs working stress design).

The wide diversity of guardrail practices as evidenced by the foregoing study is principally attributed to the paucity of technical information needed to develop a rational and unified engineering approach to guardrail analysis and design. Specifically, it points out the need for experimental research to establish criteria for guardrail loads induced by human subjects either accidentally or through normal usage, and for guardrail geometry to inhibit accidental falls resulting from geometric inadequacies such as insufficient height and/or width, or excessively large openings.

In an attempt to utilize available technical knowledge and at the same time avoid the possibility of research duplication, a computerized research of published literature on the general subject of guardrails was carried out using the Engineering Index and the Government Reports Index (NTIS). This search identified more than 100 publications on experimental and analytical research investigations of highway guardrails and other vehicular crash barriers; however, no document related directly to personnel guardrails could be located. Subsequently, a selected number of these publications were acquired and examined for technical content for possible application to the analysis of personnel guardrails. However, some of these documents proved to be of little utility because they dealt with investigations of the response of guardrails under vehicular impact, which is fundamentally different from that produced by the human body. A number of other publications dealt with the evaluation of automotive safety devices through tests using human subjects and anthropomorphic dummies. Some of these publications, [2.3, 2.4, 2.22] provide information on the energy absorption characteristics of the simulated human body. A number of other publications compiled anthropometric and engineering data on the human body [2.5-2.9, 2.23-2.28].

Table 2.1 Summary of Guardrail Provisions of Existing Building Codes and Safety Standards

Ref. Sect.	Horiz. Load	Vert. Load	Height in	Notes
1) UBC/1716			42	Guardrails & stair railings Interm. rail req'd. Max. opening = 9 in.
/3305(i)			30-34	Stair handrails
/Table 23-C	50 plf 20 plf	--		Occupancy > 50 Occupancy < 50
2) BOCA/417.5.5			23-36	Railings - public assembly
/615.2			30-33	Handrails on ramps
/616.5.1	200 lb any pt. & dirc.		30-34	Handrails - stairways
/616.5.2			42	Guards - floors, mezzs., landings Balusters: 6 in max. spa. Interm. rails: 10 in max. spa. Other: mesh, grill, walls
/709.4	50 plf or 200 lb any pt. & dir.	20 plf		Railings - other than public assembly 50 plf & 20 plf not concurrent
	50 plf	100 plf		Railings - publ. assembly 50 plf & 100 plf concurrent
/870.5	Engineering Design			Guardrails - Fl. & wall openings Toeboard req'd.
3) NYC/503.4			42	Guard: rails, fence or parapet
			120	Guards - roof recreation
/503.8			36	Railings - skylight
/604			30-34	Handrails - stairs
/604.13			32	Handrails - fire escapes
			36	Guards - landings Max. opening = 5 in.
/709.5			42	Guards & parapets - roof vehicular parking areas
			8	Guards - vehicle wheels
/710.6			42	Guards & railings - perimeter of interior flr. openings.
/MDL Sec. 62			42	Guard railings & parapets: wire (mult. dwell.)
/902.3	40 plf	50 plf	42	Railings - non-publ. assembly; H & V simultaneous
	50 plf	100 plf	42	Railings - public assembly
	20 plf or 200 lb any pt. & dir.	20 plf	42	Railings - 1 & 2-family dwellings
	40 plf	50 plf		Rails: intermediate & bottom; H & V simult. (not for post and anchor design).
	20 psf	--		Solid panels of railings
	300 plf or 2500 lb (the >)	-- --		Vehicular, applied at 20-in ht.
/1903.2			42	Guardrails & solid enclosures - perim. of excavations
/1907.9			36-42	Guardrails (standard) - construction toprail: 2 x 4 midrail: 1 x 4 posts: 2 x 4 at 8 ft. altern: 1 1/4-in Std pipe; 2 x 2 x 1/4 angles

Table 2.1 (cont.)

Ref. Sect.	Horiz. Load	Vert. Load	Height in	Notes
4) Southern/512.9			26-36	Railings - public assembly
/1108			36-42	Guardrails - exterior balconies Max. opening = 8 in Max. opening at floor = 2 in
/1115.5	20 plf 50 plf	-- --		Railings - stairways Railings - balconies
5) National/318.4			26-36	Railings - public assembly
/604.8			30-34	Handrails - stairs
/902.4 /1201.2	50 plf	--	36	Railings - stairs & balconies Guardrails + 6-in toeboard - construction.
/1207.			48	Railings + 6-in toeboard - construction flr. openings.
6) Canadian /3.3.1.12			42	Guard railings - balconies, roofs, mezzanines; Max. opening = 4 in.
/3.3.2.10			26-36	Guards - public assembly
			42	Guards: bleachers; (msd. abv. ft. rest); Max. opening = 12 in.
			36	Guards: bleachers; (msd. abv. seat board); Max opening = 12 in.
		--	33	Guards: front bleachers; (msd. abv. ft. rest); Max. opening = 12 in.
/3.4.8.5			32-36	Handrails - stairs
			42	Barriers - stairway windows.
/3.4.8.6			36	Guards - stairways, ramps, passageways; Max. open. = 6 in.
			42	Guards - around landings; Max opening = 6 in.
/4.1.10.1	40 plf plus 200 lb conc.			Rails - exterior balc. of individ. residences.
	100 plf	--		Railings - exits and stairs
	150 plf	--		Railings - public assembly
	250 plf	--		Guards - grandstands & stadia including ramps.
	2500 lb or 300 plf	--		Guards: vehicular applied at 21-in ht.; 2500 lb over widths of vehic. space.
	125 lb	--		Guards - industr. catwalks (e.g.) where not crowded.
	20 psf	--		Solid panels
/4.1.10.1	--	100 plf		Guards - acting separately from req'd horiz. lds.
/9.8.7.4			32-36	Handrails - houses & small buildings.
/9.8.8.3			42	Guards - small buildings & houses except:
 /9.8.8.4			36 42	Stairguards; Landings; except:
/9.8.8.5			32	Stairguards - dwelling units
/9.8.8.6			42	Guards - garage floor openings + 6-in high board
/9.8.8.7				Max. opening. = 4 in
/9.8.8.8				Openings size should restrict climbing.

Table 2.1 (cont.)

Ref. Sect.	Horiz. Load	Vert. Load	Height in	Notes
7) Canadian Construction Safety /3.5.22			42	Guardrails + toeboards - shaft openings
/3.11.5			36-42	Guardrails: 5-in min. ht. toeboard w/ 2 x 4 on 2 x 4 at 8-ft. spacing; midrail 3-in wide on inside of posts or Taut 1/2-in wire cable with 2-in wide vert. separators at 8 ft spacing
			48	or Snow fencing: 4-ft vert. wood strips (1 1/2 in wide x 3/8 in thick at 3 1/2-in spac.) tied with specif. taut strands.
8) OSHA (Occupational Safety) /1910.23			42	Railings: 2 x 4 top and mid; on 2 x 4 at 6-ft spac.; or 2 perp. 1 x 4's top on 2 x 4 at 8 ft spac. (2 x 4 mid) or 1 1/2-in pipe top and mid on posts at 8-ft spac.
/1910.23				or 2 x 2 x 3/8 angles top and mid. on posts at 8-ft. spac.
	200 lb any pt. & dir. 200 lb any pt. & dir. except up		30-34	Handrails: 2-in diam. wood; 1 1/2-in pipe mounted at 8-ft spac.
/1910.28			36-42	Guardrails - scaffold: 2 x 4 top; 1 x 4 mid; supported at 10 ft. (or equiv.) (1 x 6 mid. for single pt. suspens.)
9) OSHA (Constr. Safety) /1926.500	200 lb any pt. & dir. except up.		42	"Standard railing: 2 x 4 top; 1 x 6 mid; 2 x 4 posts at 8-ft spac. or 1 1/2-pipe top, mid, posts or 2 x 2 x 3/8 top, mid, posts or Equivalent
			30-34	Stair railing (plus standard rail req.)
10) HUD-MPS/402-8			42	Railings - balc. & roof decks Max. opening = 5 in.
/601-7	50 plf	100 plf		Railings: Not clear if H & V concurrent. Anchors: should not fail under twice specified loads.

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3. Anthropometric Data

3.1 Introduction

The objective of this section is to compile general anthropometric data on human subjects for application in the formulation of design requirements for guardrails. For instance, the kinematic aspects of the human body could be utilized to estimate the nature and intensity of human-induced loads on guardrails. Body measurements might be relevant in specifying certain geometric aspects of guardrails such as the maximum size of openings to prevent passage of people into hazardous areas. Anthropometric studies could also assist in establishing relevant hypotheses requiring experimental verification such as the relationship between the height of the guardrail and the centroidal height of the human subject to the inhibit accidental falls.

The anthropometric information presented herein consists of four categories of data broken down according to sex and percentile levels. The first category compiles various height measurements where the subject is in a standing or sitting posture. The second category consists of dimensions and weights of the human body and the heights of convenient reference points on the body for locating other measurements such as the whole-body centroid. The third category specifies the displacement bounds of the body centroid when the subject assumes various postures with and without a 20-lb (89-N) backpack. The fourth category of data provides information on the maximum intensitites of forces human subjects are capable of exerting on the guardrail. Measurements reported herein are categorized for the 97.5, 50, and 2.5 percentile levels. Percentiles are values representing the percentage of people at or below a certain measurement. They can delineate an upper or lower bound for a specific characteristic. With regard to body height, for example, the 98th percentile designates the height at which 98 percent of the sample are shorter and 2 percent of the sample are taller.

The 50th percentile in a group of measures is called the median. It is the score that divides the ranked measures such that one half of the measures are larger than the median, and the other half are smaller. Similarly, the 97.5 percentile can represent the larger body measurements and the 2.5 percentile can refer to the smaller body measurements. Although the median value for either male or female, does not exactly represent the arithmetic average or mean, it is a close enough approximation for the purposes of this report. The average adult is the arithmetical mean between the median male and median female. All data are for U. S. adults.

The anthropometric data presented herein have been excerpted primarily from three different publications [3.1, 3.2, 3.3]. In addition, four other sources were consulted for general background information [3.4 through 3.7].

3.2 Anthropometrics Relatable to Guardrail Height

Criteria upon which proper guardrail height may be determined focus on the necessity of guardrails to be easily seen and to be capable of keeping an individual from a hazardous area. The following heights may influence the determination of proper guardrail heights:

(1) Standing height: distance from floor to vertex of head, measured from either front or back when subject is standing erect with heels together.

(2) Eye height: distance from floor to inner corner of eye when subject is standing erect with heels together.

(3) Shoulder height: distance from floor to uppermost point on the lateral edge of shoulder when subject is standing erect with heels together.

(4) Elbow height: distance from floor to the depression at elbow formed where bones of the upperarm and forearem meet, when subject is in standing erect with heels together.

(5) Crotch height: distance from floor to crotch when subject is standing erect with heels together.

(6) Seat height: distance from floor to horizontal seat reference plane measured when subject is in sitting posture.

(7) Kneecap height: distance from floor to top of kneecap when subject is standing erect with heels togehter.

Figure 3.1 gives a schematic illustration of the heights defined above and table 3.1 compiles their magnitudes for the 97.5, 50 and 2.5 percentile U. S. male and female adults. These data were prepared from various recent civilian and military samples [3.1].

Guardrails could serve as a visual as well as physical barrier for most situations. In cases where visual barriers are of primary importance, guardrail heights could be related to eye height. In instances where a guardrail need not serve as a visual barrier but as a physical barrier and where there is little threat of individuals climbing the rail, a top rail height just above the body centroid might prove to be sufficient. Guardrails of elbow height are easy to lean on and could serve as work counters. Guardrails of lower heights would not present a barrier too high to cross, but could still adequately isolate individuals by defining hazardous areas.

3.3 Anthropometrics Relatable to Guardrail Height and Strength

The centroid of a body may be visualized as the point at which the resultant of the distributed gravitational body forces acts. Other factors being equal, the stability of an object is dependent on the location of its centroids above the ground. Stability generally decreases as the height of the centroid relative to the ground increases and vice versa. Consequently, it may be conjectured that a person coming in contact with a guard-rail either by leaning on it or inadvertently walking into it might be less likely to go over it if the top of the rail is close to his centroid. In this case, the anthropometric value relevant to guardrail height would be the centroidal height of the human subject.

Certain guardrail strength requirements, may be established on the basis of static loads transmitted by human subjects in any one of a variety of stationary body postures such as leaning or sitting, as well as dynamic loads generated by the impact of moving human subjects. Anthropometric data relevant to estimating such body forces would be quantitative information on the weights of the body and individual body segments. In addition, anthropometric data on shoulder and hip width, for instance, can help in establishing lengths or areas over which body forces may be distributed.

The following anthropometric measurements excerpted from ref. [3.1] are sketched in Figure 3.2 and compiled in table 3.2 for the 97.5, 50 and 2.5 percentile U. S. male and female adult.

(1) Whole-body centroidal height: distance from floor to the centroid of the body when the subject is standing erect with heels together.

(2) Ischium height: distance from floor to the top of the lowermost of the three sections of the hip bone when the subject is standing erect with his heels together. The ischium is used as a reference point for location of other points in the body such as the centroid.

(3) Shoulder width: maximum horizontal distance across the shoulder muscles when subject is in erect sitting posture with upper arms touching his sides.

(4) Standing hip width: maximum horizontal distance across the hips when subject is in erect standing posture with heels together.

(5) Sitting hip width: maximum horizontal distance across the hips when subject is in erect sitting posture.

(6) Body weight: total body weight of the subject without clothing.

It should be pointed out that data on the centroidal height of the U. S. adult female is not available. However, Swearingen [3.2] notes that in spite of the wide variety of

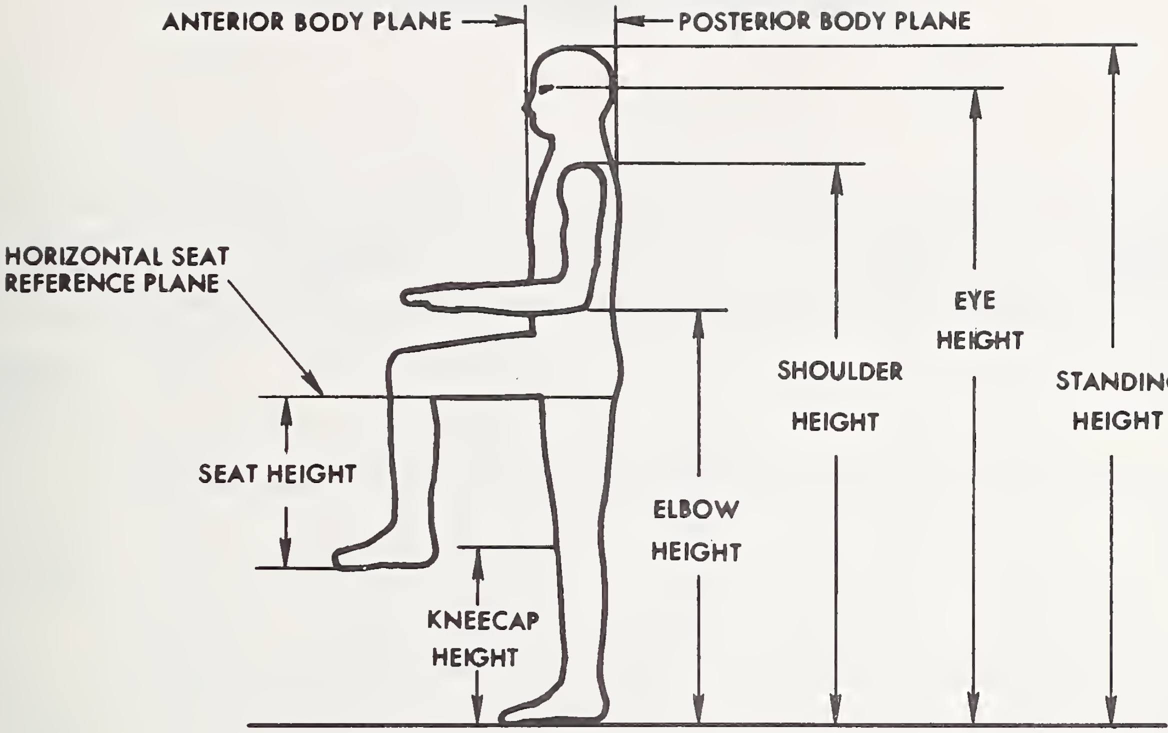

Figure 3.1 Body measurements related to guardrail height (cf. table 3.1).

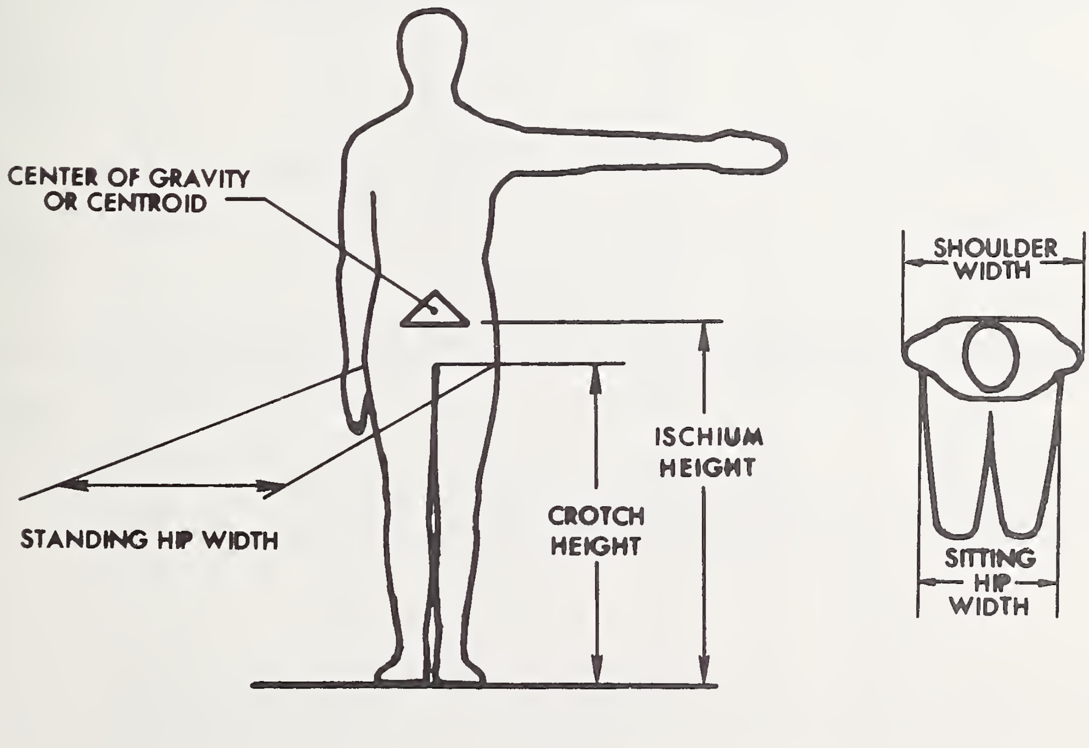

Figure 3.2 Body measurements related to guardrail height (cf. table 3.2).

Table 3.1 Height measurements from the floor level with human subjects in standing or sitting posture.

Type of Measurement	Percentile Level %	Male inches	Male (cm)	Female inches	Female (cm)	Average Adult inches	Average Adult (cm)
Standing Height	97.5	74.0	(188.0)	68.5	(174.0)		
	50	68.8	(174.8)	63.6	(161.5)	66.2	(168.1)
	2.5	63.6	(161.5)	58.7	(149.1)		
Eye Height	97.5	69.3	(176)	64.1	(162.8)		
	50	64.4	(163.6)	59.6	(151.4)	62.0	(157.5)
	2.5	59.6	(151.4)	54.7	(138.9)		
Shoulder Height	97.5	61.4	(156.0)	56.2	(142.7)		
	50	56.6	(143.8)	51.9	(131.8)	54.2	(137.7)
	2.5	51.9	(131.8)	47.8	(121.4)		
Elbow Height	97.5	45.3	(115.1)	41.8	(106.2)		
	50	42.0	(106.7)	38.6	(98.0)	40.3	(102.4)
	2.5	38.6	(98.0)	35.2	(89.4)		
Crotch Height	97.5	35.3	(89.7)	36.2	(91.9)		
	50	32.5	(82.6)	33.3	(84.6)	32.9	(83.6)
	2.5	29.6	(75.2)	30.4	(77.2)		
Seat Height	97.5	18.5	(47.0)	16.9	(42.9)		
	50	17.0	(43.2)	15.6	(39.6)	16.[illegible]	(41.4)
	2.5	15.6	(39.6)	14.3	(36.3)		
Kneecap Height	97.5	21.4	(54.4)	19.6	(49.8)		
	50	19.7	(50.0)	18.0	(45.7)	18.9	(47.8)
	2.5	18.0	(45.7)	16.5	(41.9)		

Table 3.2 Measurement of heights, widths and weight of human subject in standing or sitting posture.

Type of Measurement	Percentile Level %	Male inches	Male (cm)	Female inches	Female (cm)	Average Adult inches	Average Adult (cm)
Whole Body Centroid Height	97.5	41.2	(104.6)				
	50	37.9	(96.3)				
	2.5	34.6	(87.9)				
Ischium Height	97.5	39.5	(100.3)	36.2	(91.9)		
	50	36.4	(92.5)	33.3	(84.6)	34.9	(88.6)
	2.5	33.3	(84.6)	30.4	(77.2)		
Shoulder Width	97.5	19.4	(49.3)	17.7	(45.0)		
	50	17.7	(45.0)	16.0	(40.6)	16.9	(42.9)
	2.5	16.0	(40.6)	14.4	(36.6)		
Standing Hip Width	97.5	14.9	(37.8)	16.7	(42.4)		
	50	13.1	(33.3)	13.8	(35.1)	13.5	(34.3)
	2.5	11.7	(29.7)	11.5	(29.2)		
Sitting Hip Width	97.5	15.8	(40.1)	17.7	(45.0)		
	50	13.9	(35.3)	14.6	(37.1)	14.3	(36.3)
	2.5	12.4	(31.5)	12.3	(31.2)		
Body* Weight	97.5	192	(854)	157	(699)		
	50	172	(765)	145	(645)	159	(708)
	2.5	151	(672)	133	(592)		

*lb or (N)

body sizes and mass distributions there is surprisingly little variation in the location of the whole body centroid of U. S. men for any given posture when measured from a reference point on the pelvis (i.e.: ischium), with the centroid of at least 90 percent of the adult male population falling within a sphere of 2 in (5.08 cm) in diameter. Based on the premise that this will more or less be true in the case of U. S. females, the differences between the centroidal and ischium heights of the U. S. males may be added to the ischium heights of the corresponding percentile levels of female population to arrive at generally conservative (high side) but sufficiently accurate estimates of the centroidal heights of U. S. females. This procedure together with the appropriate data in table 3.2 yields centroidal heights of 37.9 in (96.3 cm), 34.8 in (88.4 cm) and 31.7 in (80.5 cm) for the 97.5, 50 and 2.5 percentile female population, respectively.

3.4 Location of Centroid for Selected Body Postures

The heights, weights, and widths of body components are of limited value in calculating static force vectors if the direction of those vectors cannot be determined. The whole-body centroid can serve as a reference point for these static force vectors. Since the centroid varies with the positions of the body and its extremities, it is necessary to identify the various locations of the whole-body centroid with respect to those body postures that approximate guardrail use. Swearingen has measured centroid variation relative to body position in subjects chosen to represent a wide range of body sizes and weights [3.2]. Data which appear to be of relevance to guardrail use and design are excerpted from this reference and presented in tables 3.3 through 3.6. A further discussion is presented in reference 3.2.

3.5 Peak Forces Exerted by People on Guardrails

If an individual has proper auxiliary support and can push against a guardrail thereby causing it to collapse, then a possible anthropometric criterion of maximum guardrail strength might be the maximum strength of an individual. Strength in this sense refers to the muscular capacity to exert force under static conditions. Kroemer [3.3] has measured the strength of 45 male college students. Subjects pushed against a force plate as shown in Figure 3.3. For those infrequent instances where this loading condition is felt to govern guardrail design, reference 3.3 should be consulted to obtain the required load magnitudes.

3.6 Analysis of the Anthropometric Data

The intent of the anthropometric survey was to incorporate within the body of this report a condensed and expedient source of information to assist in the evaluation of the possible effect of human body characteristics on guardrail design rather than provide an exhaustive study on the subject. Although human body characteristics alter with time, the rate of change is so slow as to be insignificant, design-wise over relatively long periods.

Table 3.3 Displacement of body c.g. by anterior movements.

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. Body standing straight	(4, 5 7/8)	± 7/8"
B. Head forward	(4 3/8, 5 3/8)	± 7/8"
C. Both arms extended forward	(5 1/4, 7)	± 3/4"
D. Head and trunk forward	(5 1/2, 4)	± 1 1/2"
E. Both legs straight forward	(9, 11)	± 1 1/4"
F. All body parts in maximum anterior position	(12, 10 3/4)	± 1 1/2"

Table 3.4 Displacement of body c.g. by posterior movements.

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. Standing, body straight	(5 1/4, 6)	± 1 1/8"
B. Head back	(5 1/2, 5 3/4)	± 1"
C. Arms back	(5 3/4, 6 1/4)	± 1"
D. Head & trunk back	(7 1/4, 5 1/8)	± 1 1/4"
E. Legs back	(6 7/8, 7 7/8)	± 1"
F. All body parts in maximum posterior position	(9 5/8, 6 1/8)	± 1 1/8"

Table 3.5 Displacement of body c.g. by lateral movements.

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. Standing, body straight	(0, 5 7/8)	± 7/8"
B. Head flexed to side	(1/2, 5 3/4)	± 3/4"
C. One arm extended laterally	(1/2, 6 3/8)	± 5/8"
D. One arm extended across chest	(3/8, 6 1/4)	± 3/4"
E. Head and trunk in lateral flexion	(1 3/4, 5 1/4)	± 3/4"
F. One leg abducted	(1 1/2, 6 3/4)	± 3/4"
G. Maximum lateral movement of both legs	(1 7/8, 6 5/8)	± 3/4"
H. All body parts moved laterally	(4 3/8, 7 1/4)	± 1 3/8"

Table 3.6 Displacement of c.g. by 20-lb back pack in sitting and standing positions (c.g. of pack 18 5/8 in above ischium, 6 in back).

Body Position	Location of Av. C. G.	Horizontal & Vertical Range For Subjects
A. Sitting without pack	(8 7/8, 9 5/8)	± 1 1/8"
B. Sitting with pack	(7 1/2, 10 1/2)	± 1 3/8"
C. Standing without pack	(5, 5 7/8)	± 7/8"
D. Standing with pack	(3 3/4, 7 1/4)	± 7/8"

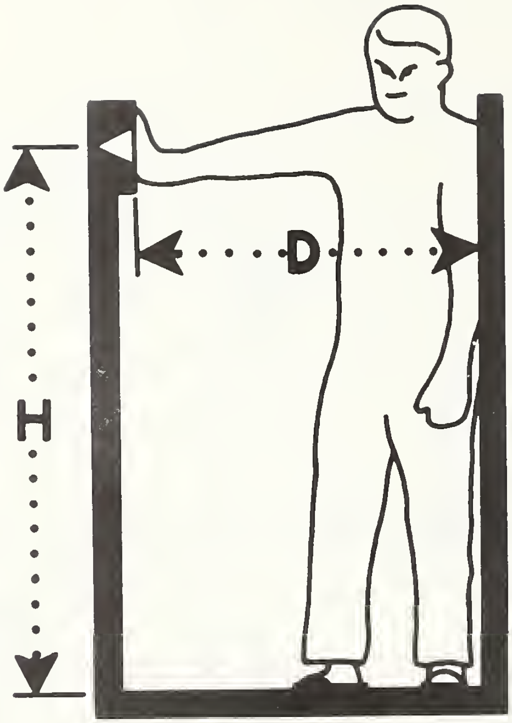

Figure 3.3 Laterally braced push with the preferred hand. Force plate adjusted to a height (H) of 100 % of each subject's acromial height, and to a distance (D) of 80% of his lateral thumb-tip reach.

Percentiles can be used in design to delineate the bounds for a particular characteristic measurement. The design of equipment or structures normally accommodates 95 percent of the sample population by specifying an upperbound, a lower bound or both. In the latter case, the data can be utilized directly to include 95 percent of a group having a particular body characteristic falling within the 2.5th and 97.5th percentile values shown. In guardrail design, however, the value of interest is more likely to be a maximum or a minimum. For instance, if the guardrail height were to safely accommodate 95 percent of the population (i.e., inhibit people from accidentally falling over it), then the measurement of interest would be the centroidal height of the 95th percentile subject. Similarly, to impede the accidental passage through the guardrail, the size of openings would probably have to relate to the head, shoulder or chest dimension of the 5th percentile subject.

The statistical data compiled in tables 3.1 and 3.2 exclude measurements for the 5th and 95th percentile subject required in guardrail analysis. Intermediate percentiles of body characteristics may be retrieved by making use of the fact that anthropometric measurements generally tend to adhere to the normal probability law. Figures 3.4 and 3.5 were developed from the measurements listed in tables 3.1 and 3.2. The ordinates in these charts represent the magnitudes of the given measurements and the abscissa represents the percentage of population whose corresponding measurements are less than the specified values. The scale of the abscissa is such that the plot of a normally distributed function would appear as a straight line. Note that in most instances the points representing the 97.5th, 50th and 2.5th percentile levels of a particular measurement are collinear. This indicates that the distribution is symmetric but not necessarily normal. Connecting these points with a straight line for the purpose of interpolation indicates that a normal distribution is being assumed to describe the variable in question.

Figures 3.4 and 3.5 provide an expedient means of extracting the 5th and 95th percentile body characteristics of both male and female subjects. The percentile characteristics of a mixed sample may be estimated with a reasonable degree of accuracy by averaging the corresponding measurements of the male and female subjects. With regard to the interpretation of body weights, however, a word of caution is in order. Curves A in figure 3.4 give the <u>average</u> body weights of male and female subjects corresponding to respective standing height percentiles specified by curves A in figure 3.5. The average weight of a man having the 95th percentile height, (see curve A of figure 3.4), for instance, is less than that of a man having the 95th percentile weight.

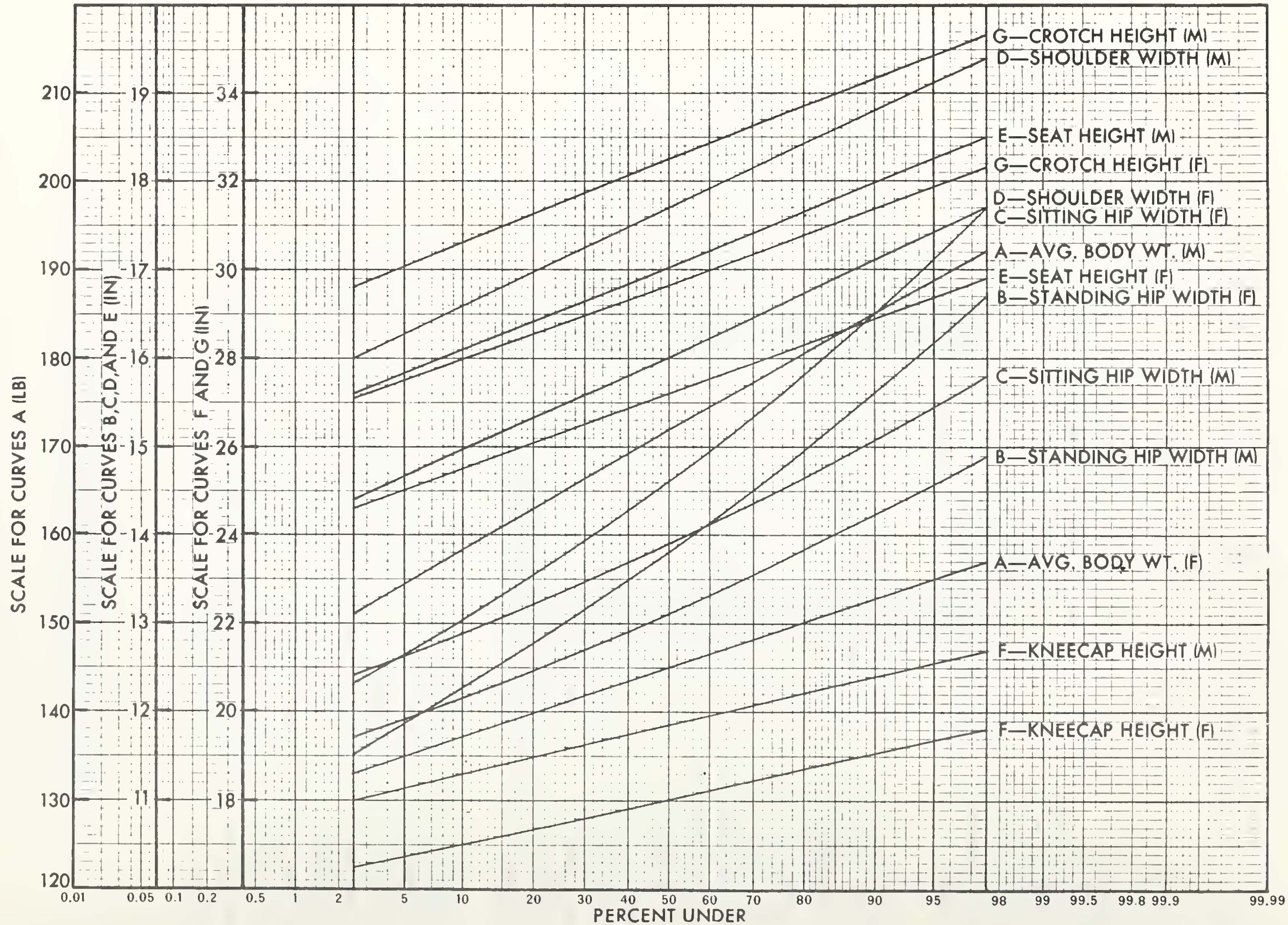

Figure 3.4 Body measurements of U.S. adult male and female subjects according to percentile levels.

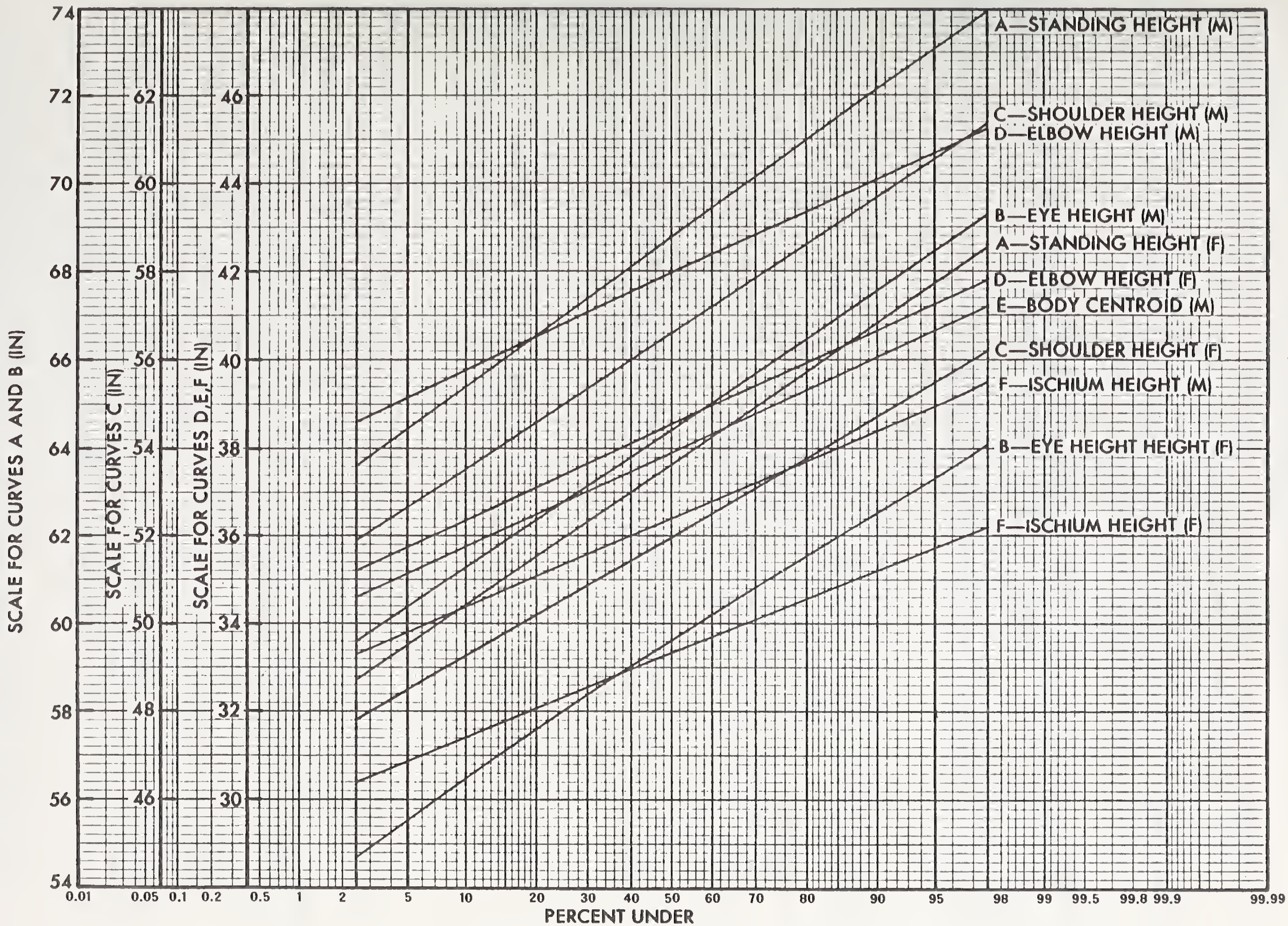

Figure 3.5 Body measurements of U.S. adult male and female subjects according to percentile levels.

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4. Field Survey of Guardrail Installations

4.1 General

This section presents a general overview of the types and locations of guardrails in the work environment based on information acquired through a field survey.

The objective of the site visits was to gain familiarity with current practices of prototypical guardrail installations and their use. Field examination of the various guardrail types helped identify safe as well as unsafe situations due to inadequacies in design and construction, exposure to corrosive agents and other detrimental environmental conditions, and, in some instances, the inadequacy of the physical environment to permit the installation of appropriate safety barriers.

Prior to the field survey, ten different types of guardrail installations in public and industrial settings were identified by OSHA to be of primary concern. These installations are listed in the approximate order of decreasing priority as follows:

(1) Elevated walkways
(2) Scaffolds and staging platforms
(3) Balconies and mezzanines
(4) Hot-dip galvanizing operations
(5) Roofing operations
(6) Cast-in-place concrete construction
(7) Petro-chemical towers
(8) Mobile equipment
(9) Elevated work and storage areas
(10) Marine dry docks

Eight of these installations were included within the scope of the field survey. The excluded ones were petro-chemical towers and mobile equipment. In addition, in a series of "by chance" encounters, other miscellaneous types of guardrail installations were observed to be used for the purpose of restricting human movement in a variety of extremely hazardous to slightly hazardous areas. In all but one of the locations visited during this survey the purpose of the guardrail was to prevent falls from a higher elevation to a lower elevation. The one location which differed was a hot-dip galvanizing plant where the "guardrail" was used to prevent movement or falls into the hot-dip kettle containing molten zinc at a level above the working surface. Because the barrier has considerable width in addition to height, both of these geometric features contribute to the prevention of workers from accidentally coming into contact with the zinc.

Visits occurred during working hours on week days. A member of the staff of the facility being visited served as a guide for the team of NBS observers. Observations during each visit were recorded on a checklist supplemented by photographs. The majority of the visits to both public and private organizations were prearranged.

The checklist was categorized to include observations not only of guardrails, but also other aspects of their environment. This method provided an ordered and overall view of accident safety and a basis for developing the second phase tasks of the project. The sources of the data were: (1) comments supplied by the guide, (2) impressions of the NBS observers, and (3) dimensional measurements and material descriptions of the guardrails. The information gathered consisted of: (1) the general location and function of the guardrail within the installation, (2) types of employee activities near the guardrail, (3) environmental characteristics of the area in the immediate vicinity of the guardrail as well as the general topography of the background, and (4) a physical description of the guardrail.

4.2 Elevated Walkways

4.2.1 Shopping Center, First Site

The first guardrail installation examined was located on the second level of an enclosed shopping center. The area was an elevated walkway which provided access to a variety of retail stores. The guardrail functioned as a barrier resticting movement or accidental falls into a series of large wells opening to the ground level (figure 4.1).

Several types of employee activities were observed in the vicinity of the guardrail. Human traffic to and from various locations typically occurred during the hours that the center was open. Surveillance and monitoring of the ground floor by security employees occurred intermittently during which time the guardrail was used for casual leaning and watching events at the lower level. Maintenance activities near the guardrail involved cleaning of carpets, benches and ashtrays and emptying waste receptacles.

The guardrail was well defined relative to the background and highly visible from all points of entry into the region aided by uniform electric and natural lighting through skylight openings in the roof. The surfaces adjacent to the guardrail were carpeted floors with rubber tile in areas around benches.

The top rail was made of aluminum tubing material and was located 41.75 in (106 cm) above the tread. The steel posts of tubular section were spaced at 5 ft (152.4 cm) on centers and the tubular steel toeboard was approximately 2 in (5.08 cm) high. There were no intermediate rails but rather 0.5-in (1.27cm) round steel balusters placed 5 in (12.7 cm) on centers. As indicated in figure 4.1, several of these bannisters were bent out of shape creating a potentially hazardous situation for accidental passage of children through guardrail openings. However, consideration of such a concern is not within the scope of these studies which are addressed to the guardrail needs of adult personnel.

4.2.2 Shopping Center, Second Site

The second guardrail installation examined was located at the edge of an elevated walkway at the exterior of the same shopping center (figure 4.2). The walkway was used for delivery of merchandise to the stores and removal of trash. The guardrail served as a barrier to prevent falls into a sodded area one story below.

Three types of employee activities were observed occurring on the walkway: (1) routine use of the walkway to gain access to either the stores or the parking area, (2) pulling or pushing hand trucks filled with merchandise, and (3) carrying boxes, packages, and other miscellaneous discarded objects.

No extreme environmental characteristics were observed. The temperature and lighting were natural, the sound level was produced by light vehicular traffic. The walkway was 5.9 ft (1.8 m) wide and consisted of a cast concrete slab supported by steel framing cantilevered from the building.

The guardrail was a solid wall made of 8-in nominal concrete masonry units (7.5 in or 19 cm in actual thickness) and precast concrete capping. The top of the guardrail was 43 in (109.2 cm) above the tread surface.

4.3 Scaffolds and Staging Platforms

4.3.1 Library Structure

The guardrails examined at this site were located around scaffolds erected on two sides of a seven-story library building (figure 4.3). The scaffold was being used for the purpose of applying masonry facing to this building. The function of these temporary construction guardrails was to prevent accidental falls to a concrete plaza one to seven stories below.

Work-related employee activities near the guardrail involved bending, stooping, crouching and standing to perform the masonry work necessary in the marble-facing operation. Other activities such as walking towards exit points and delivery of materials to locations along the scaffold occurred periodically.

Visibility of the guardrails was generally good. The flooring of the scaffolds consisted of aluminum planks. The two adverse environmental conditions observed were the presence of materials and equipment stored along walking and working surfaces and the occurrence of intermittent wind gusts particularly at the higher elevations.

The top and intermediate rails were aluminum angles or pipe sections located at a height of 39 in (99.1 cm) and 21 in (53.3 cm) from the tread surface, respectively.

Figure 4.1 Guardrail location within enclosed shopping center.

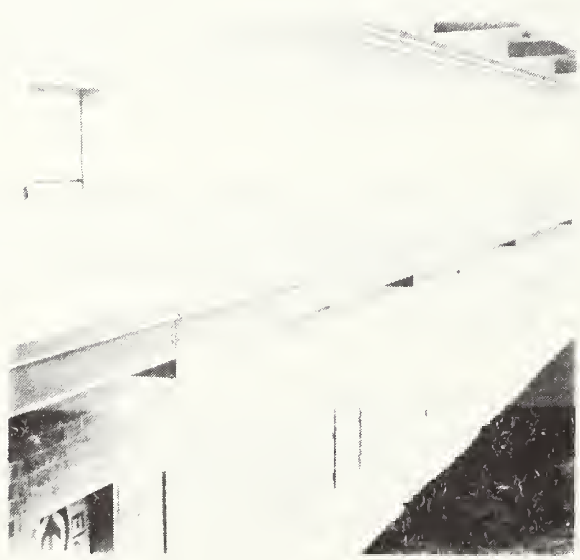
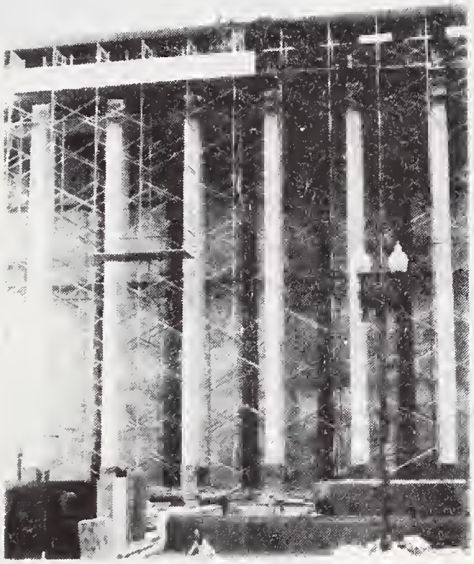


Figure 4.2 Guardrail location outside shopping center.



(a)

(b)

Figure 4.3 Temporary guardrails used during construction of a multi-story library building.

Toeboards were frequently absent. When used, they were made of 1-in by 4-in (2.54-cm by 10.16-cm), nominal, wood board. Guardrail elements were connected by bolts or miscellaneous clamping devices.

4.3.2 Pharmaceutical Supply Co.

At this location, the guardrail was attached to a suspended scaffold being used in the application of fascia materials to the building (figure 4.4). The intended function of the guardrail was to prevent inadvertent falls to the ground three stories below.

The employee task near the guardrail was the application of bolts to the concrete facade. The activity involved bending and standing. The workmen were wearing safety belts with rope lanyards attached to the wood top rail which was being used to serve as a lifeline as well as a safety barrier.

The work was being performed on the exterior of the building and there were no unusual characterisitcs observed with respect to lighting or temperature. The floor of the scaffold was made of aluminum planks. A potentially hazardous characteristic observed was the presence of power tools and extension cord attachments on the floor of the scaffold.

The top rail was a 2-in by 6-in (5.08-cm by 15.24-cm), nominal wood board, about 42 in (106.7 cm) above the tread. Although this rail was intended to serve as a lifeline as well as a barrier, it appeared to be structurally quite inadequate to support the impact load of a falling human subject transmitted through the lanyard. The wood toeboard was 1 in by 4 in (2.54 cm by 10.16 cm), nominal. There were no intermediate rails. Suspended from the roof by a counterweight device mounted on wheels (figure 4.4 b), the scaffold could be moved easily along the building perimeter. Roofers were working at the same time as the men on the scaffold and the perimeter guarding system for the roofers was either removed or being laid down to allow the mobile scaffold support system to move along the building edge. This was the first observation of a conflict between a safety requirement for one trade and the construction method of another.

4.3.3 Miscellaneous Suspended Scaffolds

Two sites of suspended scaffolds were examined while passing buildings where construction activity was occurring (figure 4.5). For one instance, the scaffold was being used by bricklayers (figures 4.5 a). It was constructed entirely of wood. The guardrail consisted of plywood boards attached to vertical wood posts joined by horizontal members at the top. The second scaffold was located at the site of a building being remodelled (figure 4.5 b). It appeared to have a metal plank floor and no guardrails at the ends or at the side nearest the building. At the far side, the wood guardrail consisted of top and intermediate rails and a toeboard, all supported by two end posts estimated to be at least 20 ft (6.1 m) apart. This spacing was judged to be excessive in relation to the apparent size of the

(a)

(b)

Figure 4.4 Temporary guardrails on scaffolds or staging platforms used during construction of pharmaceutical building.

(a)

(b)

Figure 4.5 Examples of temporary guardrails on suspended scaffolds used in construction, maintenance or renovation of buildings.

top rail to prevent a structural failure in the event of an accidental fall of the employee against the guardrail.

4.4 Balconies and Mezzanines

4.4.1 Hotel Structure, First Site

The first guardrail installation examined was located at the edges of the balconies of the guest rooms of a hotel. The guardrail served as a barrier to prevent falls from heights of one to six stories above grade (figure 4.6).

Cleaning the sliding glass doors and windows from the balcony was the principal employee activity identified at this site.

The temperature and lighting were natural. The balcony slab was cast-in-place concrete. The walls were either glass panels or brick veneer. The balcony was about 31 in (78.74 cm) wide.

All guardrail components appeared to be made of aluminum. The top rail was a 2-in wide by 4-in deep (5.08-cm by 10.16-cm) rectangular tube, the top of which was 42 in (106.7 cm) above the tread. There were no toeboards or intermediate rails but rather, 0.75-in (1.9-cm) square tubular balusters 6 in (15.2 cm) on centers between the top rail and a 1-in. (2.54-cm) square tubular bottom rail 6.5 in above the tread. The posts were 2-in (5.08 cm) square tubular sections at 52-in (132 cm) intervals. Each post was fitted into the sleeve of a base plate and attached to it by two screws driven from opposite sides. The rail components were connected by welds and screws. The square base plate was attached to the concrete slab with four anchor bolts and nuts which were not galvanized. As a result, evidence of severe corrosion was observed at several locations. In addition, many of the nuts had become loose or completely detached.

4.4.2 Hotel Structure, Second Site

The second guardrail installation examined was located within the lobby of the same building. The lobby served as an access to various hotel service areas and as a sitting lounge. On each side of an open stairway, a guardrail served as a barrier to prevent falls to the ground level one story below (figure 4.7).

The employee activities occurring near the guardrail were routine walks from one location to another and cleaning operations of floors.

The light level was high because of a nearby window wall. In additon, the window wall produced a significant amount of reflected glare in the location adjacent to the guardrail.

(a)

(b)

Figure 4.6 Permanent guardrail installations on balconies of multi-story hotel structure.

(a)

(b)

Figure 4.7 Permanent guardrails used in lobby of hotel structure.

The guardrails were quite similar in materials, layout and sectional configuration to those installed at the balconies (section 4.4.1) except the top rail was a 2-in wide by 4-in deep (5.08-cm by 10.16-cm) finished wood board. Since these guardrails were located indoors, no evidence of corrosion at the anchorages was anticipated and none was observed.

4.5 Hot-Dip Galvanizing Operations

4.5.1 Galvanizing Plant, First Site

The first location examined was a galvanizing kettle containing molten zinc equipped with an overhead conveyor system (figure 4.8). In this case the walls of the kettle above the work surface served as a barrier (guardrail) to keep the employees from accidentally coming in contact with the zinc. The top shelf of the wall served as a support for hand tools used by the employees working at the kettle.

Routine work-related employee movements included walking, standing next to and leaning over the barrier to skim the zinc surface with a wooden paddle and tapping the galvanized objects with long implements as they were retreived from the kettle.

The lighting around the work area was generally much dimmer than in a typical office. The concrete floor surfaces adjacent to the kettle were generally cluttered with debris.

The top of the wall barrier was 31 in (78.7 cm) above a 7-in high by 34-in wide (17.8-cm by 86.4-cm) platform (tread surface) located on the working side of the kettle. The width of the wall was 28 in (71.1 cm) at the top. This surface was made of welded steel plates. A typical sectional configuration of the barrier is shown in Figure 4.8 b.

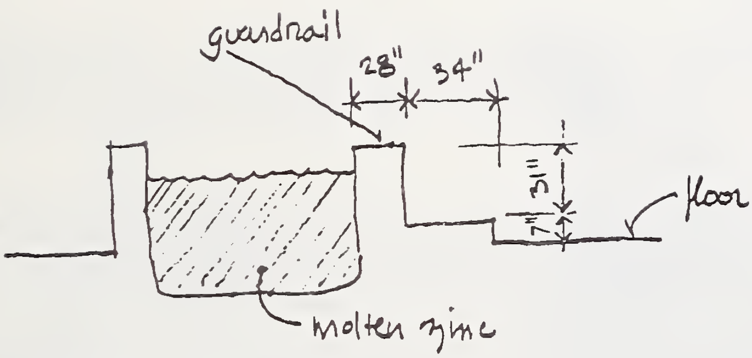
4.5.2 Galvanizing Plant, Second Site

The galvanizing kettle examined at this location was similar to the first one except the kettle walls were shallower and there were no raised work platforms (figure 4.9). As before, both the height and width of the kettle walls served as barriers to restrict employees from coming in contact with the molten zinc. The top of the wall was used as a shelf for various tools and as a means to gain leverage in maneuvering the galvanized objects with metal implements.

In addition to the work activities observed at the first site, the employees were engaged in manipulating and aligning a large suspended appliance. This involved pulling cords, pushing and tapping the appliance with hand implements, and jacking it with long rods using the shelf of the wall as pivot.

The environmental charactertistics were similar to those observed earlier. The accumulation of substantial debris on the floor adjacent to the exit side of the kettle

(a)



(b)

Figure 4.8 First example of wall barrier around molten zinc kettle used in galvanizing operations.

(the foreground area shown in Figure 4.9 b) caused a reduction in the wall height at that location and consequently in its effectiveness to function as a safety barrier.

The sectional configuration of the wall barrier was rectangular as shown in figure 4.9(c), the height and width being 26 in (66cm) and 24 in (60.1 cm), respectively. The walls consisted of an assembly of welded steel plates.

4.5.3 Galvanizing Plant, Third Site

At this location the galvanizing was carried out by using manually controlled chain and pulley equipment (figure 4.10) as opposed to the use of conveyor systems observed at the first two locations (figures 4.8 and 4.9). As before, the walls of the kettle functioned as barriers to prevent accidental body exposure to molten zinc and as support for the hand tools used by the employees working at the kettle.

Besides the activities noted earlier, this operation required manipulation of the chain-pulley assembly to lower or raise the objects being galvanized. The kettle was equipped with a ledge which provided a bearing surface for the foot to facilitate pulling the object out of the vat. However, the ledge reduced the effective height of the barrier and encouraged hazardous postures, for the purpose of gaining reach advantage, such as shown in Figure 4.10 c.

Visibility and other environmental factors were similar to those observed at the other two locations. The concrete tread surfaces near the kettle were likewise littered with various objects and debris.

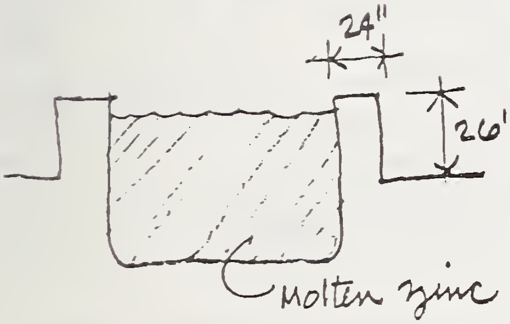
The barrier was 25 in (63.5 cm) high on all four sides and had an 11-in high by 10-in wide (27.9-cm by 25.4-cm) ledge or projecting shelf on the working side, thereby reducing the effective height of the barrier above it to 15 in (38.1 cm). The 31-in (78.7-cm) width of the barrier was in excess of those at the other two locations. The surfaces were made from welded steel plates. The line drawing in figure 4.1 (d) shows the cross sectional configurations of the kettle.

4.6 Roofing Operations (Retail Merchandise Distribution Center)

The purpose of this visit was to examine the perimeter-guarding installations used during a large built-up roofing operation on a warehouse having approximately 46 acres of (18.63 ha) storage area. The roof was approximately 30 ft (9.1 m) above grade and the roofing operations were at various stages of completion (figure 4.11 and 4.12). The guardrails at this site were symbolic rather than physical barriers, placed at a distance from the edge of the roof to alert workers of the potential hazards of the region beyond the demarcation line. These rails were not in compliance with the existing perimeter

(a)

(b)



(c)

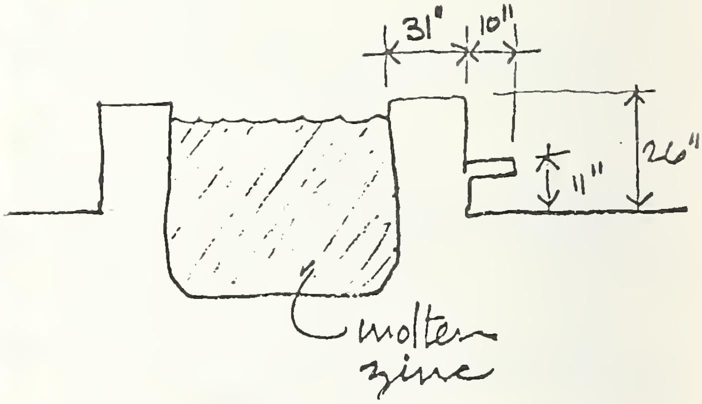
(d)

Figure 4.9 Second example of wall barrier around molten zinc kettle used in galvanizing operations.

(a)

(b)

(c)



(d)

Figure 4.10 Third example of wall barrier around molten zinc kettle used in galvanizing operations.

guarding regulations of OSHA. However, because of an absence of construction provisions, prior to the roofing operations, for the attachment of compliant guardrail systems, the roofing contractor had been given a variance by OSHA to use the portable symbolic guardrails shown, subject to specific restrictions governing the movement of workers within defined hazard zones at the periphery of the roof.

The primary activities for installing the roofing were pushing and pulling machines while applying layers of felt or tar, bending to place installation, or standing and shovelling gravel. At one time or another, the application of each layer required the employees to get close to the edges. Operations and application of roofing to the edge required the joint effort of 2 to 3 workers whose movements included standing, walking leaning and crouching.

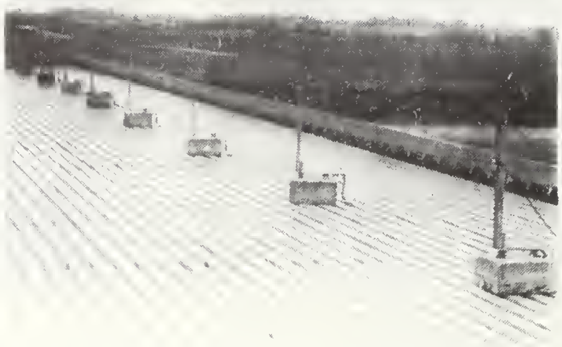
Extension of the facade beyond the top of the roof provided about a 12-in (30.5-cm) high ledge at its periphery. This served the (unintended) function of a toeboard and provided some measure of safety for employees when conducting their work tasks in a crouched posture. The roofing consisted of a corrugated steel deck on open web steel joists, and layers of rigid insulation boards, tar-coated roofing felts and gravel. At times the 1/4-in (0.6-cm) wire rope warning rails were not readily discernible against the background terrain (figure 4.11 a) and in some instances the light brown gravel surface merged with the clay-colored terrain 30 ft (9.1 m) below making it difficult to visually discriminate the drop beyond the roof edge. The presence of equipment and various materials on the walking surfaces near the edges required a certain level of alertness on the part of the observers to avoid tripping. Also very hazardous, was the slippery corrugated metal deck surface when wet.

The symbolic guardrail consisted of two 1/4-in (0.64-cm) wire ropes clamped to steel posts attached to 40-lb (178-N) cast concrete blocks at the base. Trials were being made to increase the lateral stability of the posts through adhesion of stick clips with the tar surface (figure 4.12 b). Without such adhesion, a 6 lb. (26.7N) horizontal force applied to the top of the post would cause it to overturn.

4.7 Cast-In-Place Concrete Construction

Two types of guardrails which were used in cast-in-place concrete construction work were examined while passing sites where construction was occurring. At the first site, the guardrail was being used to prevent falls from a walkway work platform adjacent to the concrete forms around the buildings (figure 4.13 a). The walkway appeared to be used by carpenters during the preparation of the wood formwork, by workers placing the steel reinforcement inside of the forms, and by workers casting and curing the concrete.

The guardrails were assembled in a manner to permit quick dismantling and reassembly for use in construction of additional floors of the building. They consisted of 2-in



(a)

(b)

Figure 4.11 Symbolic guardrails used in built-up roofing operations.

(a)

(b)

Figure 4.12 Additional exhibits of built-up roofing operations.

by 4-in (5.08-cm by 10.16-cm), nominal, wood, top and intermediate rails and vertical supports spaced approximately 8 ft (2.44 m) on centers. The rails were fitted into the slots of plywood gusset plates nailed to the posts. The platform guardrail assembly was supported by equally-spaced 4-in (10.16-cm) square, nominal, wood beams wedged between the exterior concrete floor beam and 4-in (10.16-cm) square, nominal, spliced wood shoring posts below, and by diagonal members fastened to the same shoring posts. No guardrail toeboards were observed at this site.

At the second site visited (figure 4.13 b and c), the concrete had already been cast and the forms removed. The guardrails were placed at the edge of the concrete slabs to prevent accidental falls of workers engaged in concrete curing and finishing operations. The guardrails consisted of modular steel pipe framing units joined together by a wood top rail. The assembly was seated on the concrete slab but not attached to it.

4.8 Elevated Work or Storage Areas

4.8.1 Library Building, First Site

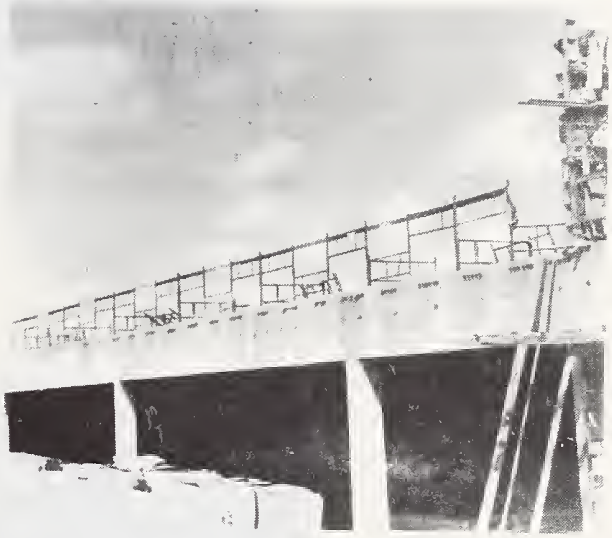
The guardrails examined at this site were located in construction work areas around large central openings inside the building (figure 4.14) to prevent accidental falls of workers from 12-ft to 72-ft (3.66-m to 21.95-m) high elevations.

The only employee activity observed was the routine movement of walking past the guardrails. Other construction-related activities are likely to occur near the rails where the interior finishes are applied and permanent guardrails are installed at the same location before the building is put in service.

The lighting around the guardrail area was generally dim. As a result, the cable rails and sometimes the wood rails as well, tended to merge with the background and were not always readily visible. Another hazardous situation was the presence of miscellaneous construction materials and debris on the concrete floor adjacent to the rails.

There were two types of guardrails installed around the opening. One was constructed of wood (figure 14.a) with a 42-in (106.7-cm) high top rail and 24-in (61-cm) high intermediate rail. The spacing of the vertical posts varied from 5 ft to 7 ft (1.5 m to 2.1 m) on centers and the toeboard height varied from 4 in to 10 in (10.16 cm to 25.4 cm). The wood members were typically 2 in by 4 in (5.08 cm by 10.16 cm), nominal, and were fastened together with nails. The second type (figure 14.b) used 1/2-in (1.27-cm) wire rope top and intermediate rails, 43 in (109.2 cm) and 22 in (558 cm) from the tread, respectively. The vertical wood supports were spaced between 5 ft to 7 ft (1.5 to 2.1 m) on centers. The wood toeboard was 6 in (15.2 cm) high. The wire ropes were looped around and tied to concrete columns located along the periphery of the openings. They were kept taut by means of turnbuckles.

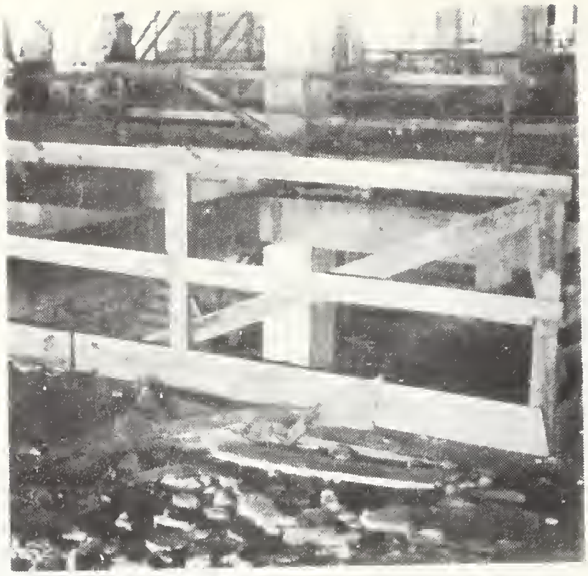
(a)



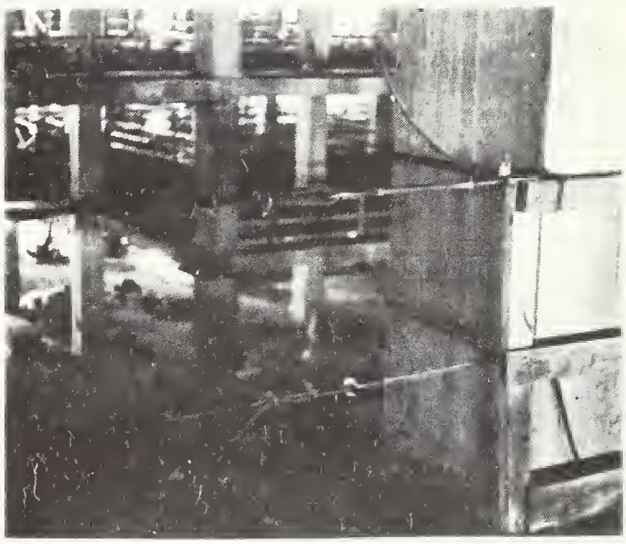
(b)

(c)

Figure 4.13 Miscellaneous types of temporary guardrails used in cast-in-place concrete building construction.



(a)



(b)

Figure 4.14 Temporary guardrails installed around openings during construction of multi-story buildings.

4.8.2 Library Building, Second Site

The second location observed was a materials storage area adjacent to a large opening in the exterior wall of the building (figure 4.15). The location served as a storage area for bricks and as an access point to the exterior scaffolding. The guardrail was symbolic and served the purpose of alerting workers to the opening approximately 10 ft (3 m) away.

The only employee activity observed was the routine movement of walking past the guardrail. It was assumed that the use of hand and motorized vehicles for carrying brick occurred near the rail.

The concrete floor surface adjacent to the rail was littered with wood remnants and other miscellaneous debris.

The guardrail consisted of two wire ropes loosely attached to two of the building columns approximately 30 ft (1.4 m) apart. The top rail was 35 in (89 cm) high and the intermediate rail was 14 in (35.6 cm) high. There were no toeboards.

4.8.3 Post Office Building

The guardrails examined were located in the mail sorting and routing areas of a large post offfice. They were installed around platforms used for the maintenance of conveyor belts and other machinery (figure 4.16). The platforms were approximately 12 ft (3.66 m) high and the rails served as barriers to prevent falls (figure 4.16).

While no employee activities were observed during the visit, the guide noted that cleaning, repair and maintenance work of motors and other pieces of equipment were the primary type activities on the work platforms.

The lighting on the platforms was adequate to distinguish between small objects. The working surface was made of steel grating.

The top rail on the first type of platform was 41 in (104.1 cm) high with a 20-in (50.8-cm) high rail and a 3-in (7.62-cm) high toeboard. Vertical supports were located at 5.25-ft (1.6-m) intervals. The top rail, intermediate rail, and toeboard were made of steel angles connected with bolts, and welds. On the second type of platform, the top rail was 41 in (104.1 cm) high, the intermediate rail was 21 in (53.3 cm) high, and the toeboard was 3 in (7.62 cm) high. Vertical supports were spaced at approximately 3 ft (91.4 cm) on centers. The rails were steel pipe sections and the toeboard was a steel angle. All connections were welded joints. On the third type of platform the top rail was 36 in (91.4 m) high, intermediate rail was 18 in (45.7 cm) high, and the toeboard was 4 in. (10.16 cm) high. Vertical supports were spaced at approximately 5.75 ft (1.75 m) on centers. The rails were steel pipe sections and the toeboard was a steel angle. All connections were welded joints.

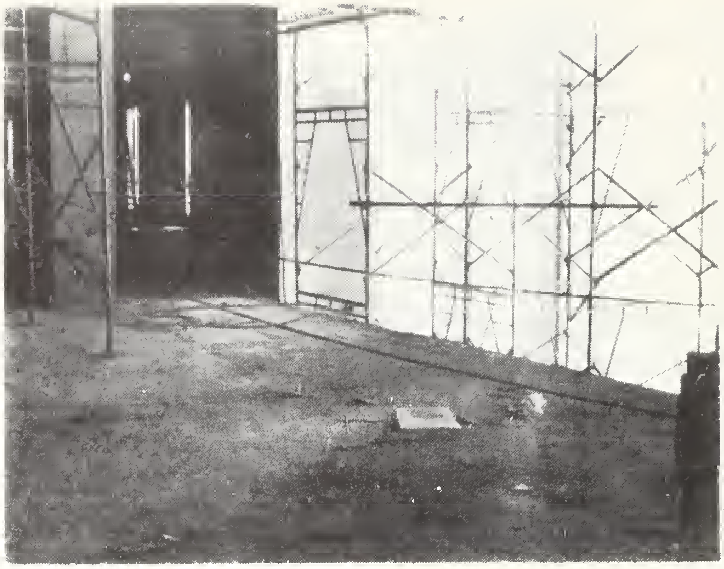


Figure 4.15 Temporary guardrails around storage area used during construction of multi-story building.

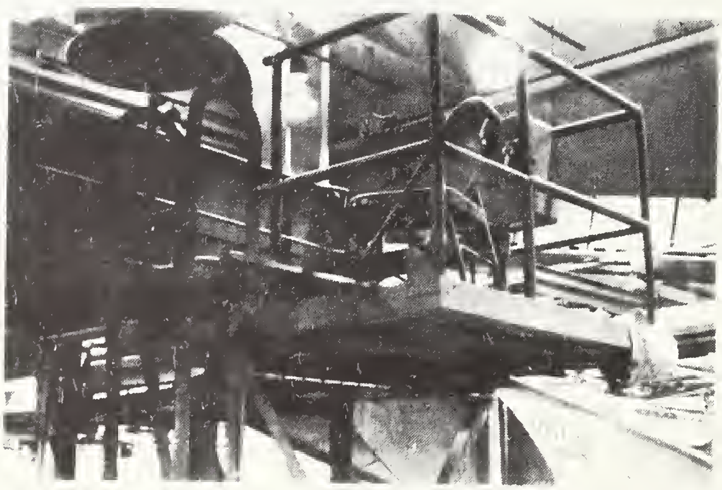


Figure 4.16 Guardrails installed around platform used for maintenance of machinery.

4.9 Marine Dry Docks

4.9.1 Ship Yard, First Site

The guardrails examined at this site were located around a dry dock for the maintenance and repair of ships (figure 4.17). Judging from a posted sign warning people not to lean against them, these guardrails were intended to be symbolic rather than physical barriers to prevent falls to a concrete surface approximately 50 ft (15.2 m) below.

The warning signs were not always effective in discouraging employees from leaning against the guardrail to observe activities in the dry dock area (figure 4.17 b). There were no other activities observed except employees walking past the guardrail.

The guardrail was visible at all locations visited. There was evidence of corrosion which is probably aggrevated by the proximity of a large body of water as well as by rain and humidity. Another potentially hazardous condition experienced was the occurrence of high wind gusts in the general vicinity of the guardrail.

The guardrail consisted of cast steel posts spaced at 7.25 ft (2.2 m) on centers, a set of 2 or 3 steel chain rails passing through slots in the posts and occasionally, a 7-in (17. 8-cm) high concrete curb or metal toeboard (figure 4.17). Despite the warning sign, at first glance the guardrail could convey the false (and dangerous) impression of being structurally sturdier than it actually is. This is partly due to the fact that the chains are installed with a built-in slack and are not constrained from sliding through the slots. Consequently, a force applied to the rail will cause it to sag excessively by taking up the slack from the adjacent spans as in figure 4.17(b). It also appeared that some of the post anchorages would not be capable of transmitting lateral forces to the foundation because of either loose fittings, or insufficient edge distance.

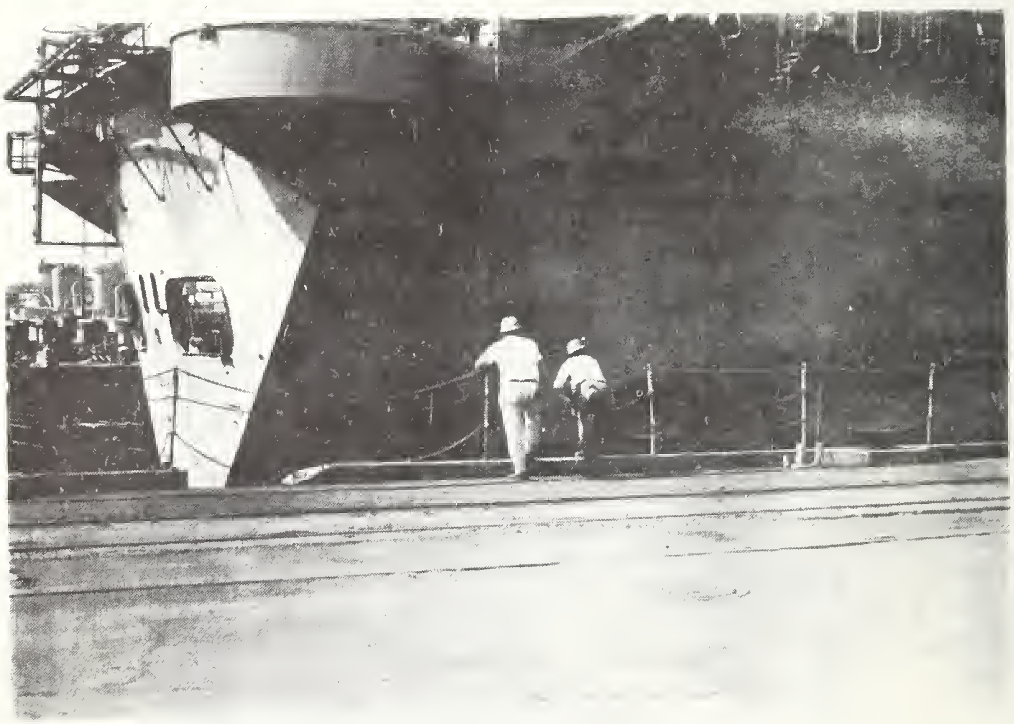
4.9.2 Ship Yard, Second Site

At this site the guardrail was located around a marine railway catwalk (figure 4.18). The marine railway is used for the maintenance and repair of submarines. The guardrail functioned as a barrier to prevent falls into water or onto a wood deck or concrete surface approximately 50 ft (15.2 m) below.

While no employee activities were observed during the visit, the guide noted that the catwalk was used only as a walkway.

The surface around the guardrail was a wood plank floor. The catwalk was 42 in (106.7 cm) wide. The characteristics considered potentially hazardous were excessive projections of the anchoring devices into the walkway and the occassional gusts of wind.

(a)

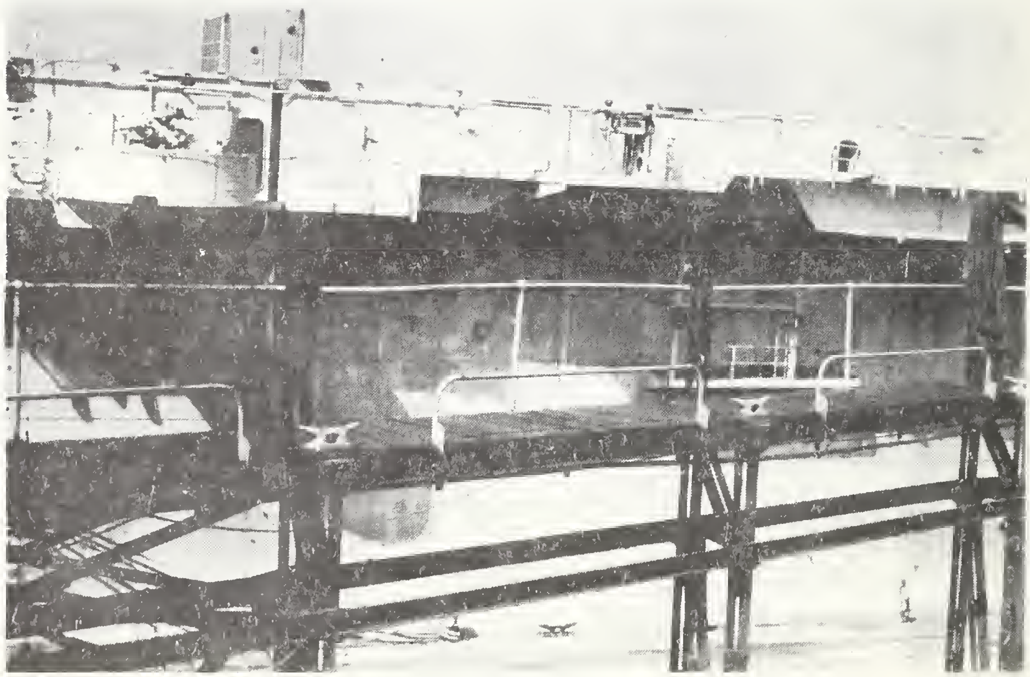


(b)

Figure 4.17 Permanent symbolic guardrails installed at marine dry dock facility.

There were different guardrails on each side of the walkway. On the outside (the side away from the ship being worked on), the top rail was 37.5 in (95.2 cm) high with vertical supports at 5 ft (1.5 m) on centers (figure 4.18 a). There was no intermediate rail or toeboard. The top rail and vertical supports were made of steel pipe connected by bolts and welded joints. On the side adjacent to the ship, the guardrail was a series of sections of steel pipe 17.5 in (44.4 cm) high by approximately 6 ft (1.83 m) long (figure 4.18 b). The sections were spaced approximately 4 ft (1.22 m) apart. Connections were made by bolts and welded joints. The size and design of the rail appeared to provide little protection from falls.

(a)



(b)

Figure 4.18 Permanent guardrails on elevated catwalks.

5. A Conceptual Model of Safety

5.1 Introduction

Safety research attempts to identify methods by which accidents and their consequences can be eliminated or mitigated to insure an acceptably low level of risk of injury or death. Since guardrails are intended to prevent people from entering or falling into hazardous areas, they may be treated as units within a broader framework of a safety system consisting of human and environmental factors. This framework can then serve as a qualitative guide in the preparation of safety requirements for guardrails.

A number of conceptual models have been developed which attempt to identify causes of accidents [5.2, 5.3]. Although most of these descriptions have assisted in further exploration and understanding of accidents and the accident development process, their practical usefulness in designing safe environments or determining safe behavior are limited. This is largely due to the fact that accident research, in general, attempts to identify the causes of accidents post hoc, based on accident data which is seldom adequate. On the other hand, safety research is focused on the prevention and control of accidents through the specification of the requirements for safe environments and procedures. Another deficiency of accident research models is that they emphasize either human causes of accidents or environmental causes of accidents. Safety is a result of complex interactions between both sets of variables, however, and can best be developed and maintained through a simultaneous treatment of both.

The safety model presented in this section attempts to systematize a decision-making process that has heretofore been subjective and often incomplete. Since it is based on fundamental notions of safety originally formulated by Gibson [5.1], a brief introduction to Gibson's ideas is presented first. This is followed by a detailed description of the safety model.

5.2 Gibson's Margin of Safety Concept

Gibson proposes that a margin of safety exists between an individual and an accident. By behaving recklessly an individual overextends his margin of safety and increases the likelihood of an accident; conversely, he may behave very cautiously and decrease the likelihood of an accident. Safe behavior is that which falls within an individual's margin of safety.

According to Gibson, individuals overextend their margin of safety in two ways. The first is by misperceiving danger in the environment (i.e., perceptual failures), the second is by reacting inappropriately to a perceived danger (i.e., behavioral failures). In short, "an individual may suffer harm from a failure to perceive or a failure to act." Perceptual and behavioral failures are often due to the absence of the environmental characteristics which indicate danger (as in a dark surrounding), or due to unreliable environmental characteristics (such as seats that look sturdy but are not). Perception may fail even when environmental characteristics are present and reliable. This may occur because of (a) defects in the sensory apparatus; (b) immaturity of the sensory apparatus; (c) temporary incapacity from drugs or illness; (d) untrained discrimination; (e) inattention. Behavior may likewise fail even though the environment provides cues to safety performance. This may occur because of defective, inadequate untrained, or temporary incapacities of behavior. As with perceptual failures the solutions to these performance failures most often involve training and education.

5.3 A Conceptual Framework of Safety

The conceptual safety model displayed in figure 5.1 extends Gibson's fundamental notions of safety by taking into account additional human and environmental factors and their interrelationships. First, accidents occur in social as well as physical environments. Safety is often a function of interpersonal activities or cultural attitudes. Safe individual behavior may do little to prevent an accident if others are behaving carelessly. Similarly, in many settings safety is a matter of management policy or the social norms of a community.

Second, safe physical environments as well as social environments can be considered in more detail. In addition to failures in the most immediate (proximal) environment, accidents may be caused by failures in the distal environment. The extent of fire damage to a building, for example, is often related to the inaccessability of firefighting equipment or units. To be complete in specifying safety requirements then, any conceptualization must include characteristics of distal as well as proximal environments.

Third, Gibson's approach appears to account only for perceptual and behavioral failures as it does not specifically address individual characteristics and abilities. Accidents, however, are often caused by structures or equipment whose design does not incorporate the body measurements (anthropometric) of their users, or by the lack of physical or mental ability of an individual to perform the proper activity, as in the case of the elderly.

Fourth, by focusing on the prevention of accidents, Gibson considers only part of the total accident sequence. A more complete analysis might apply Gibson's principles not only to the human (behaviors, abilities, and anthropometrics) and environmental (social and physical, proximal and distal) factors preceeding an accident, but also to those factors which contribute to the continuation of the accident and factors which prevent or impair recovery from an accident. By including such factors, safety practitioners can identify the safety requirements for the control of and recovery from accidents, as well as for accident prevention.

Finally, by suggesting that the margin of safety concept is focused on behavior, Gibson precludes many of the factors that originate in the environment. Not only do individuals cause accidents by perceptual failures, behavioral failures, etc., but environments cause accidents by failing to provide proper or adequate information which supports behavior.

The model shown in figure 5.1 incorporates the foregoing factors and provides a schematic illustration of the interactive process. As indicated in the figure, human factors that contribute to accidents may be related to an individual's physical characteristics, abilities, or activities. Physical characteristics include body measurements (anthropometric data) and body structure (mechanical properties); abilities include physical and mental abilities; and activities include perceptual and motor behaviors. Environmental characteristics can originate from either the social or the physical environment. Physical environmental factors are found in either the proximal or distal environments. In particular, guardrails can be considered as physical factors located in the proximal environment, as shown by the shaded elements in figure 5.1.

Table 5.1 summarizes the analysis step of the safety model. In this step, each human and environmental factor is analyzed to identify how they may contribute to an accident. Human factors may contribute to accidents by being defective, inadequate, temporarily incapacitated, or untrained (or underdeveloped). Environmental factors can contribute to accidents by being absent or unreliable. In addition, the safety model reveals that human factors may conflict with environmental factors to cause accidents, as when an elderly individual attempts to climb a set of stairs that are dimly lit or do not have a handrail. In other instances, anthropometric characteristics may conflict with proximal environmental characteristics, as when guardrails with toprails set below the human body centroid height make it physically easier for an individual to fall over them. Also, individual activities may be in conflict with proximal environmental characteristics as in the case of welders working on skyscrapers. The model, then, provides a framework for the qualitative statement of safety requirements. Table 5.2 illustrates how this may be achieved. For example, besides training, developing, educating or selecting abilities, the safety practitioner might accommodate or incorporate the physical characteristics or activities of the user into the design of the environment.

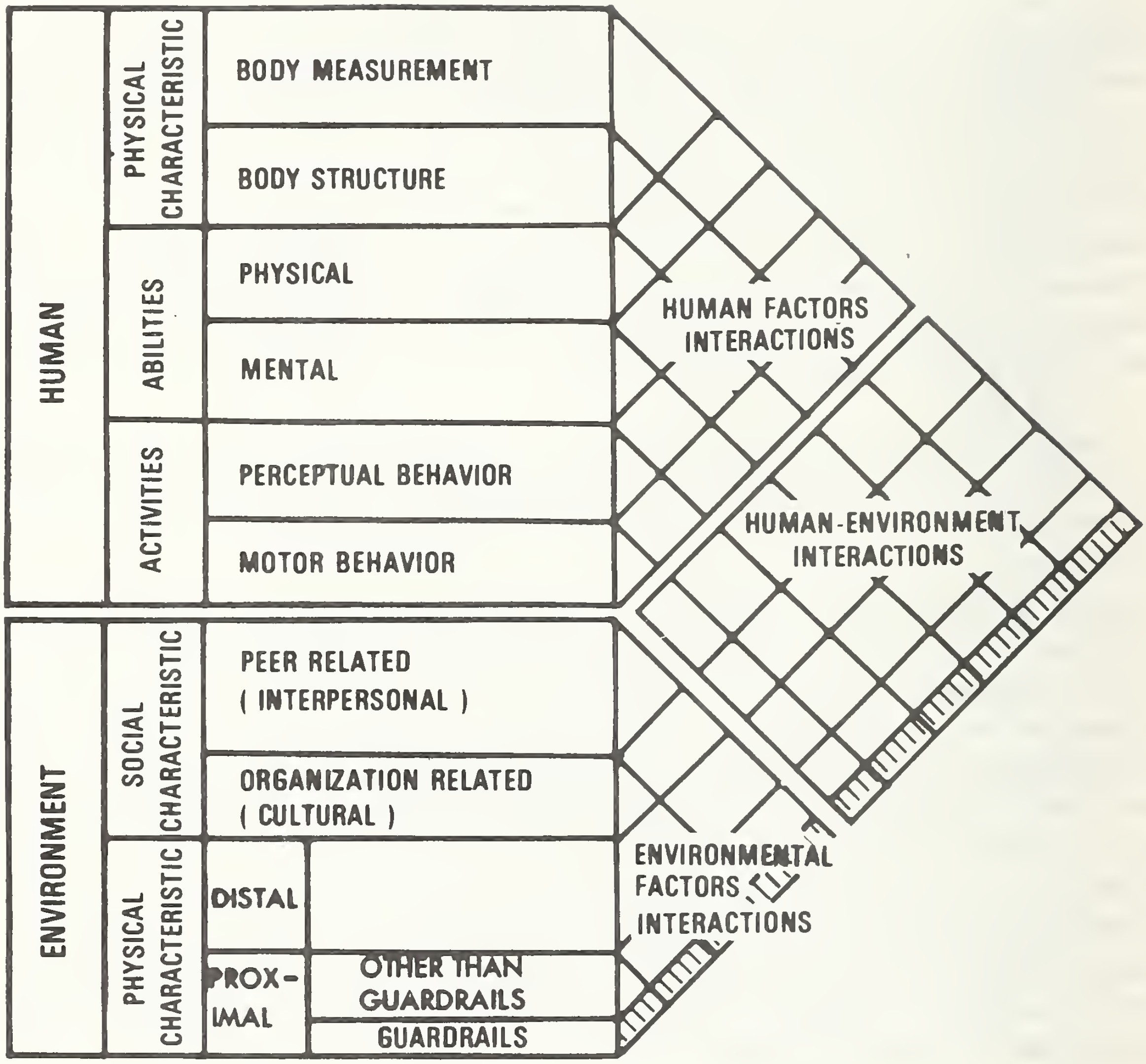


Figure 5.1 The conceptual model of safety.

Table 5.1 Application of the conceptual safety model to safety analysis.

<table>
<tr><td rowspan="3"></td><td colspan="6">HUMAN FACTORS</td><td colspan="4">ENVIRONMENTAL FACTORS</td></tr>
<tr><td colspan="2">PHYSICAL CHARACTERISTICS</td><td colspan="2">ABILITIES</td><td colspan="2">ACTIVITIES</td><td colspan="2">SOCIAL CHARACTERISTICS</td><td colspan="2">PHYSICAL CHARACTERISTICS</td></tr>
<tr><td>BODY MEASURE-MENT</td><td>BODY STRUCTURE</td><td>PHYSICAL</td><td>MENTAL</td><td>PERCEPTUAL</td><td>MOTOR</td><td>PEER OR INTER-PERSONAL</td><td>CULTURAL OR SOCIAL</td><td>PROXIMAL</td><td>DISTAL</td></tr>
<tr><td>TYPES OF FACTORS</td><td colspan="10"></td></tr>
<tr><td>CONDITIONS OF FACTORS</td><td colspan="6">1. DEFECTIVE
2. INADEQUATE
3. TEMPORARILY INCAPACITATED
4. UNTRAINED (UNDERDEVELOPED)</td><td colspan="4">1. ABSENT
2. UNRELIABLE</td></tr>
</table>

Table 5.2 **Performance requirements derived from the safety model.**

	HUMAN FACTORS						ENVIRONMENTAL FACTORS			
TYPES OF FACTORS	PHYSICAL CHARACTERISTICS		ABILITIES		ACTIVITIES		SOCIAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS	
	BODY MEASUREMENT	BODY STRUCTURE	PHYSICAL	MENTAL	PERCEPTUAL	MOTOR	PEER OR INTERPERSONAL	CULTURAL OR SOCIAL	PROXIMAL	DISTAL
REQUIREMENTS OF FACTORS	1. SELECT 2. ACCOMMODATE 3. INCORPORATE 4. TRAIN 5. DEVELOP 6. EDUCATE						1. PROVIDE 2. MAKE RELIABLE 3. EMPHASIZE			

References

5.1 Gibson, James J., The Contribution of Experimental Psychology to the Formulation of the Problem of Safety, a Brief for Basic Research, Behaviorial Approaches to Accident Research, Association for the Aid of Crippled Children, New York, New York, 1961.

5.2 Johnson, W. G., Sequences in Accident Causation, Journal of Safety Research, National Safety Council, Chicago, Illinois, June 1973.

5.3 Surry, Jean, Industrial Accident Research, A Human Engineering Appraisal, Labor Safety Council, Ontario Ministry of Labour, Toronto, Ontario, 1974.

6. An Analysis of Guardrail Accidents

6.1 Introduction

Industrial accident reports are analyzed within a conceptual framework which considers guardrails as units within a safety system (section 5). Included is information on the location of guardrail accidents, the work tasks and activities of the employee at the time of the guardrail accident, the injuries resulting from the guardrail accident, and the sequence of events that led to the guardrail accident. A clear understanding of effective as well as ineffective guardrail performance is important. The analysis of guardrail accidents reported herein attempts to identify activities associated with guardrail misuse or failure.

This section consists of three main sub-sections. The first describes the approach used in the analysis of guardrail accidents in industrial settings based on the conceptual safety model. The second presents an analysis of industrial accident investigations collected from a major source of accident reports: the National Safety Council (NSC). The third section presents a statistical analysis of causes of industrial accidents collected from two sources of industrial accident statistics: the New York Department of Labor and the United States Bureau of Labor Statistics.

6.2 Systems Approach to Guardrail Safety

The interaction between guardrail factors and guardrail user (employee) factors that contribute to guardrail accidents are shown in table 6.1. Each employee/guardrail interaction creates one of four work situations (i.e., accident, incompetence, victimization or emergency) each of which varies in the degree of safety present. Incompetence situations arise from an employee exhibiting unsafe behavior near a safe guardrail, such as sitting or standing on the top rail. An employee working near the edge of an unguarded, elevated surface represents a victimization situation. Accident situations occur "for no apparent reason," that is, when an employee is apparently exhibiting safe behavior near a safe guardrail. Emergency situations occur when an employee is acting carelessly near an unsafe guardrail.

Each work situation suggests guidelines which may rectify the unsafe conditions. These are shown in table 6.2 Incompetence situations suggest the specification of human performance guidelines to promote safe conditions. Victimization situations suggest the specification of design and construction guidelines to promote safe conditions. Emergency situations suggest the adherence to design and construction guidelines previously specified by the incompetent and vicimization situations. Accident situations suggest the specification of new or improved design, construction or user performance criteria. In addition, each unsafe situation suggests the need to implement prevention, control, and recovery

Table 6.1 Employee/guardrail interactions and the four levels of safety situations that they create.

HUMAN/ENVIRONMENT INTERACTIONS FOR GUARDRAILS		GUARDRAIL FACTORS	
		Safe guardrail factors	Unsafe guardrail factors
EMPLOYEE ACTIVITIES	Safe employee activities	ACCIDENT SITUATIONS	VICTIMIZATION SITUATIONS
	Unsafe employee activities	INCOMPETENCE SITUATIONS	EMERGENCY SITUATIONS

Table 6.2 Safety guidelines and safety countermeasures suggested by work situations.

WORK SITUATION	SAFETY GUIDELINES	SAFETY COUNTERMEASURES
ACCIDENT SITUATION	New design guidelines New construction guidelines New human performance guidelines	Prevention countermeasures Control countermeasures Recovery countermeasures
INCOMPETENCE SITUATION	Human performance guidelines	
VICTIMIZATION SITUATION	Design guidelines Counstruction guidelines	
EMERGENCY SITUATION	Adherence to: Design guidelines Construction guidelines Human performance guidelines	

countermeasures. Prevention countermeasures decrease the probability of occurrence of unsafe situations. Control countermeasures either control the unsafe condition or mitigate the severity of the consequences. Recovery countermeasures alleviate the nature, extent, or severity of personal injury or property damage. Table 6.2 indicates that prevention, control and recovery countermeasures all may interact with design, construction, and user performance guidelines.

6.3 Analysis of Guardrail Accident Reports

The National Safety Council (NSC) volunteered 5,467 reports on accidents of various types for analysis. These data were originally collected in 1974 by the NSC for the American Society for Testing and Materials (ASTM) during a project which was focused on identifying areas of need for occupational safety and health standards [6.1, 6.2]. Since the companies were assured that they would remain anonymous, no names will be reported in this review.

The sample represents 80 establishments employing a total of about 40,000 workers in the following eight, industries: automotive, steel, mining, building materials, construction, meat packing and leather, retail, and chemical.

The NSC revision of the OSHA Form 101 titled "Supplementary Record of Occupational Injuries and Illnesses," was used in the project. It combines the standard narrative reporting along with a precoded feature helpful in computer analysis. The narrative statements proved to be most useful in identifying major types of guardrail accidents, and these were analyzed following documented procedures [6.3, 6.4].

The analysis of the accident reports revealed six major types of guardrail-related accidents, (1) guardrail failure, (2) guardrail misuse, (3) guardrail as cause of injury (guardrail absent), (4) walking surface accident (guardrail absent), (5) platform accident (guardrail absent), (6) fall from high elevation. A composite of each accident type is described below. Included in each description is information as to where the accident occurred (Location), the task that the employee was performing at the time of the accident (Task), the activity that the task necessitated (Activity), the injury that resulted from the accident (Injury), and a brief description of the sequence of events of the accident (Sequence of events). Following the third and sixth accident types, guidelines and countermeasures are suggested that might rectify the unsafe situations.

6.3.1 Accident Type #1, Guardrail Failure

Location: Within a specified work area.

Task: Performing specific work tasks.

Activity: Walking, bending, reaching, pulling, pushing, etc.

Injury: Broken bones and concussions.

Sequence of events: Many times objects would fall from one elevation and injure an employee working below. Other times, an employee would trip on debris or a rough or slippery floor surface, fall toward a guarded edge, and over a low guardrail.

User-environment interaction: A common demoninator of these accidents is that they could have been controlled or prevented through safe guardrail design or construction practice. With respect to the above examples, toeboards would prevent objects from sliding under guardrails and higher guardrails would prevent individuals from falling over them. Similarly, individuals would be prevented from falling through guardrail openings if the space between the rails was minimized. Since the employees appear to exhibit safe behavior in these instances, the accidents may be mostly attributed to unsafe guardrail factors and as such would fall under "victimization" work situations (table 6.1). It was noted, however, that with respect to other accident types, these accidents seemed to occur somewhat less frequently.

6.3.2 Accident Type #2, Guardrail Misuse

Location: On the job, in the plant or work area.

Task: Operating equipment or handling materials.

Activity: Reaching, climbing, or jumping.

Injury: Sprained ankle, leg, arm or back.

Sequence of events: Employee misuses guardrail to climb upon, or over, and often to circumvent a more time consuming or difficult action. As a result, the guardrail fails to protect the employee from a hazardous area or dangerous fall.

User-environment interaction: This type of accident represents an "Incompetence" situation in which the user of the guardrail does not exhibit safe behavior (see table 6.1). The only difference between this type and Accident Type #1 is that the guardrail structure does not fail under misuse, although, they both involve static forces applied by the employee.

6.3.3 Accident Type #3, Guardrails as Causes of Injury

Location: On the job, in the plant or work area.

Task: Operating or servicing equipment.

Activity: Walking from one location to another in a work area while performing task.

Injury: Bruise or fracture of leg, arm, or hand.

Sequence of events: Employee often falls upon or impacts against the guardrail. The cause of the fall is often not related to the guardrail; however, the guardrail is usually the cause of the injury. In some cases, proper placement of the guardrail could have averted the accident.

User-environment interaction: Since guardrail factors are safe and the employee usually exhibits safe behavior, this accident type is categorized as an "accident" situation (table 6.1).

6.3.4 Suggested Guidelines and Countermeasures for Unsafe Situations in Which Guardrails Were Present but Were Either Misused or Caused Injury

Accident types #2 and #3 could have been mitigated had the employees not misused the guardrails and if the guardrails were designed properly. Improved design, construction and behavioral guidelines, though, could better control the accident situation and to some extent even the incompetence situation. First, guardrails may be designed and constructed to withstand a limited amount of misuse. Studies by Kromer (see Section 3.5) identified maximum forces that an individual can exert against a guardrail-type barrier. These accident data provide some support for using push-force information in designing and constructing guardrails that are strong enough to withstand forces exerted by employees using them as supports. A second set of guidelines might focus on dynamic forces that falling people could transmit to guardrails. Furthermore, many accident situations indicate that guardrails which are more noticeable than others are less likely to cause injury. These accident data suggest countermeasures that would make guardrails more noticeable and less likely to be bumped into or fallen upon. Such measures might involve new construction materials as well as height or placement guidelines. Finally, type #1 accident situations could be controlled and/or prevented by guardrail designs which complement employee activities.

6.3.5 Accident Type #4, Guardrail Absent: Walking Surface

Location: In the plant but not on the job. Often in a public area or hallway.

Task: Employee is usually not performing a work task at the time of the accident.

Activity: Walking or standing.

Injury: Bruise or strained back or leg. Lacerations of the hand, leg or arm are also common.

Sequence of events: Employee slips or trips and falls on walking surface while walking from point A to point B on company property. Common accident agents are slippery floors, holes or cracks in the sidewalk, protruding equipment or stock. In many instances the victim does not fall but strains himself while restoring his balance. Other times, the employee hits his head on overhanging equipment or cuts his hand or leg on protruding stock or machinery.

User-environment interaction: This type of accident can be categorized as a "victimization" situation since the employee is exhibiting safe behavior in the environment but an unsafe guardrail factor (unguarded area) causes the accident (table 6.1).

6.3.6 Accident Type #5, Guardrail Absent: Fall from an elevation

Location: On the job, in the plant or work area.

Task: Maintenance and materials handling.

Activity: Walking, standing, climbing, or reaching.

Injury: Back and head injuries.

Sequence of events: Employee is often working around an unguarded area, loses his balance and falls from one elevation to another. He is often performing a maintenance task of some kind in which he subjects himself to some degree of risk.

User-environment interaction: Due to the absence of guardrails, the environment must be considered unsafe in most cases. As long as the employee is not engaged in reckless behavior the unsafe situation can be considered one of "victimization."

6.3.7 Accident Type #6, Guardrails Absent: Platforms

Location: On the job, in the plant or work area.

Task: A variety of job tasks ranging from operating equipment and hand tools, to clerical work in an office or stock area.

Activity: These accidents predominantly occur while the employee is stepping down, stepping off or stepping onto a raised platform of some sort.

Injury: Twisted ankles or knees.

Sequence of events: Employee twists his/her ankle while stepping off an unguarded platform.

User-environment interaction: Inasmuch as a guardrail, properly placed, might have prevented the individual from leaving or entering th platform at the hazardous area (an area on which a twist is more likely than not,, this situation is categorized as "victimization." Obviously, this does not apply to cases in which the platform was merely a stool or a bench. This categorization does apply to low platforms where guardrails would designate safe areas to enter or exit.

6.3.8 Suggested Guidelines and Countermeasures From Unsafe Situations in Which Guardrails Were Absent and Employees Were Injured as a Result of Falls on Walking Surfaces, From Platforms, or From One Elevation to Another

All the accident types relevant to the guardrail-related falls reported above represent "victimization" situations in which the lack of guardrails led to an injury. This implies that the presence of guardrails might have prevented the fall or at least controlled it well enough to minimize injury. Guidelines for the proper placement of guardrails might prevent death resulting from a fall into an open pit as well as a twisted ankle resulting from a fall off a low platform. These data emphasize that the placement and function, as well as the design and construction of guardrails, are components in a complex building safety system in which guardrails contribute to the prevention and control of accidents.

6.4 Statistical Analysis of Guardrail Accidents

6.4.1 New York Department of Labor Data

The predominance of guardrail-related falls revealed in the accident analysis suggested that an assessment of fall-related accidents in industry might identify those industries most affected by the lack of guardrails or inadequate guardrails. The New York report, "Characteristics and costs of work injuries in New York State, 1966-70" was obtained from the New York State Department of Labor and was analyzed with respect to work-surface accidents [6.5] involving scaffolds and stagings, platforms and ramps, and roofs, since the previous accident analysis suggested that these might be guardrail-related settings. Data from the thirteen industries with the highest percentages of injuries from guardrail-related, work-surface falls to a different elevation are summarized in table 6.3. Also shown for each industry are the total number of injuries, total number of injuries due to unsafe work-surface, the total number of injuries involving falls to a different elevation, and the amount of compensation for injuries involving falls to a different elevation (Rows 7-10).

It is of importance to note in table 6.3 that at least 13 of the industries in New York State had injury rates of 48% or greater for injuries involving falls to a different elevation due to unsafe work-surfaces and that the total compensation for just fall injuries in these industries was over 50.8 million dollars.

Table 6.3

A Summary of Information from New York State Workman's Compensation Claims for 13 Industries

INJURIES / INDUSTRY	Painting & Decorating	Roofing & Sheet Metal Work	Carpentry & Wood Flooring	Special Trade Contractors	General Building Contractors	Structural Steel Erection	Electrical Contracting	Masonry & Stone Work	Plumbing, Heating and Air Conditioning	Concrete Work Retail trade: Building Materials	Retail Trade: Building Materials	Msc. Repair Services	Heavy Construction (Non-Highway)
% of all injuries due to unsafe work-surfaces	48	33	31	32	30	33	31	30	24	28	18	15	17
% of work-surface injuries due to scaffolds & staging platforms & ramps, & roofs.	26	43	29	35	30	20	12	41	12	22	15	8	16
% of work-surface injuries due to scaffolds & staging, platforms & ramps, & roofs involving falls to a different elevation.	96	88	91	87	90	86	84	88	84	90	82	79	85
% of all injuries involving falls to a different elevation.	38	27	22	23	20	22	20	19	14	16	15	1	12
% of falls to a different elevation due to unsafe work-surfaces	78	76	68	66	60	59	57	57	54	49	48	48	48
% of falls to a different elevation due to scaffolds & staging, platforms & ramps, & roofs	31	46	38	43	40	26	16	57	18	35	16	11	20
# all injuries # work-surface injuries # of falls to a different elevation	5,722 1,204 866	2,520 827 673	2,661 832 585	2,040 660 475	16,970 5,051 3,385	2,127 1,438 460	2,758 898 891	3,016 898 569	7,008 1,686 1,098	3,007 847 480	1,955 343 288	2,749 408 232	4,797 837 585
Amount of Compensation for fall injuries $K	5,722.9	3,818	2,257	2,240	17,118.5	3,460.7	2,788.5	2,630	3,075.5	2,947	1,003	561.7	3,202.5

In these industries injuries due to unsafe work-surfaces ranged from 15% to 48% and injuries involving falls to a different elevation ranged from 1% to 38% of the total. A significant portion of work-surface injuries (8%-43%) were due to scaffolds and stagings, platforms, and ramps, or roofs (i.e., guardrail-related). Of these guardrail-related, work-surface injuries, 79%-96% involved falls to a different elevation. Although a good portion, 4%-21%, of the guardrail-related, work-surface injuries did not involve falls to a different elevation, these data suggest that proper placement and construction of guardrails on scaffolds and stagings might have prevented or controlled many of those injuries that did. Similarly 48%-78% of injuries involving falls to a different elevation were due to unsafe work-surfaces and of these 11%-57% were due to scaffolds and stagings, platforms and ramps, or roofs. Since many injuries (at least 43%) involved falls to a different elevation that were not due to scaffolds and stagings, platforms and ramps, or roofs, there remains a sizeable number of accidents from falls that might have been prevented or controlled through the proper placement of guardrails.

To summarize these results, about 25% of work-surface accidents seem to be guardrail-related with 87% of these involving falls to a different level. About 60% of the injuries involving falls to a different level are due to unsafe work-surfaces and at least 30% of these seem to be guardrail-related. One conclusion that is suggested by these data is that most guardrail-related accidents involve inadequate protection from falls to a different elevation, and thus, guardrails might most effectively prevent and control accidents through proper placement, design and construction.

6.4.2 Bureau of Labor Statistics Data

The analysis of industrial accidents suggested that placement and function of guardrails were of critical importance to their effectiveness in preventing and controlling falls in industrial settings. A statistical analysis of industrial accidents was conducted to find evidence to further support or reject this implication. Data were obtained from sixteen independent reports on work injuries and accident causes gathered by the Bureau of Labor Statistics for different intervals during 1941-1966 [6.6 to 6.21]. Industries represented are listed below:

Water-Supply Utilities
School Lunchrooms
Fabrication of Structural Steel and Architectural Metalwork
Concrete Brick and Block
Hotel
Hospital
Longshore
Shipyard
Textile Dyeing and Finishing
Clay Construction Products

Plumbing Operations

Carpentry Operations

Paperboard Containers

Warehousing Operations

Boilershop Products

Data from selected industries regarding work injuries due to inadequate guarding and/or lack of guardrails are summarized in tables 6.4 thru 6.6. Work injury frequencies were converted to percentages of all work injuries to allow across-industry comparisons. Weighted mean percentages were calculated from frequencies and percentages as general indicators of trends. Conclusions as to the relative importance of one major category (column) to another should be made with caution since no tests of significant differences have been performed. There is little reason to believe, however, that when large differences are evident, they do not represent "real" differences in trends and can therefore serve as general, though rough, indicators. Weighted mean percentages of the data suggest that injuries due to improperly guarded agencies occur with moderate frequency in relation to those injuries due to other hazardous conditions. Also, the category "inadequate guarding" may include machine mechanism guards as well as guardrails and should be interpreted in that light. Finally, industries that were "selected" for each table, were selected solely on the basis of availability of data.

Table 6.4 This table shows work injuries due to lack of guardrails and inadequate guarding (includes machine-mechanism guards) by type of accidents for selected industries. Although a variety of accident types are indicated with respect to inadequate guarding, only falls are consistently important with respect to lack of guardrails. Also indicated is a preponderance of falls to a different level.

Table 6.5 This table identifies various activities recorded previous to accidents due to inadequate guarding and lack of guardrails. Consistent weighted mean percentages indicate manual handling, walking and using hand tools as most common. The high average for operating power equipment under "inadequate guarding" is inconsistent with the low average under "lack of guardrails" and is therefore probably due to inadequate machine guards as opposed to a lack of guardrails.

Table 6.6 This table specifies the causes of guardrail-related accidents. Inconsistencies in magnitude and direction of weighted mean percentages suggest that most accidents due to the lack of guardrails involve machines or work surfaces.

The accident analysis of Bureau of Labor Statistics data suggests that when guardrails are absent work injuries occur from falls to a different level onto work surfaces or machinery while the employee is walking. Falls through or over guardrails (guardrail failures) are not indicated as a significant cause of work injuries due to inadequate

Table 6.4

Work injuries due to the lack of guardrails and inadequate guarding by type of accident for selected industries. (ref. 6.6 - 6.21)

INDUSTRY	TOTAL # (%)	STRIKING AGAINST # (%)	STRUCK BY Total # (%)	STRUCK BY Falling Objects #	STRUCK BY Thrown Objects #	FALLS Total # (%)	FALLS To a different level #	FALLS On the same level #	CAUGHT IN, ON, OR BETWEEN #(%)	TEMPERA-TURE EXTREMES #(%)	ABSORP-TION # (%)	OTHER # (%)
Lack of guardrails												
Carpentry	382	--	10	10	--	365	347	18	--	--	--	7
operations	(4)	—	(3)			(96)			--	--	--	(1)
Clay construction	65	1	2	2	--	52	46	6	4	1	--	6
products	(1.1)	(2)	(3)			(80)			(6)	(0)	--	(9)
Concrete brick &	10	--	--	--	--	10	10	--	--	--	--	0
block	(1)	--	--			(100)			--	--	--	(0)
Weighted mean %	(3.52)	(2)	(3)			(94.15)			(6)	(0)	--	(4.7)
Inadequate Guarding												
Carpentry	1350	480	340	19	56	485	464	21	21	--	7	17
operations	(14.9)	(35.5)	(25)			(36)			(1.5)	--	(1)	(1)
Clay construction	388	43	96	47	25	64	55	9	142	16	9	18
products	(6.8)	(11)	(25)			(16)			(37)	(4)	(2)	(5)
Concrete brick &	119	7	21	5	16	12	10	2	64	2	4	9
block	(10)	(6)	(18)			(10)			(54)	(2)	(3)	(7)
Plumbing	162	3	38	32	2	70	67	3	36	6	--	9
operations	(5.9)	(3)	(23)			(43)			(22)	(4)	--	(5)
Structural steel &	214	16	129	70	11	26	24	2	29	--	--	14
metalwork	(14.8)	(7)	(60)			(12)			(14)	--	--	(7)
Paperboard	356	50	22	9	6	25	23	2	251	5	--	3
containers	(24.4)	(14)	(6)			(7)			(70)	(2)	--	(1)
Water-supply	196	2	98	78	9	41	32	9	34	15	--	6
utilities	(11.4)	(1)	(50)			(21)			(17)	(8)	--	(3)
Boilershop	294	39	119	68	29	37	32	5	80	14	--	5
products	(14.6)	(13)	(40)			(13)			(28)	(5)	--	(1)
Hotels	129	90	6	--	--	7	7	--	6	17	--	3
	(33)	(69)	(5)			(5)			(5)	(13)	--	(3)
School lunchrooms	140	93	35	--	--	6	5	1	6	--	--	0
	(7.8)	(67)	(25)			(4)			(4)	--	--	--
Weighted mean percentages	(13.38)	(38.06)	(33.83)			(30.4)			(45.41)	(6.84)	(1.85)	(4.14)

Table 6.5

Work injuries due to the lack of guardrails or inadequate guarding by activity for selected industries. (ref. 6.6 - 6.21)

Industry	Total # (%)	Materials Handling # (%)	Using Handtools # (%)	Operating Power Equipment #(%)	Walking # (%)	Standing # (%)	Climbing # (%)	Stepping # (%)	Running # (%)	Other # (%)
Lack of Guardrails										
Concrete brick & block	10 (.8)	7 (70)	1 (10)	--	--	--	--	--	--	2 (20)
Water-supply utilities	55 (3.2)	8 (14.5)	19 (34.5)	2 (4)	20 (36)	2 (4)	4 (7)	--	--	
Carpentry operations	382 (4.2)	39 (10)	35 (9)	4 (1)	30 (8)	--	2 (1)	5 (1)	4 (1)	263 (69)
Structural steel & metalwork	24 (1.7)	2 (8)	3 (12)	1 (5)	11 (46)	--	--	--	--	7 (29)
Hospitals	438 (1.4)	385 (87)	43 (10)	--	--	--	--	--	--	10 (3)
WEIGHTED MEAN PERCENTAGES	(2.68)	(78.2)	(14.32)	(2.14)	(24)	(4)	(5)	(5)	(5)	(65.32)
Inadequate guarding										
Concrete brick & block	119 (10)	17 (14)	23 (19)	52 (44)	--	--	--	--	--	27 (23)
Water-supply utilities	196 (11.4)	45 (23)	91 (46)	16 (8)	23 (12)	15 (8)	5 (2.5)	--	--	1 (.5)
Carpentry operations	1350 (14.9)	51 (4)	56 (4)	807 (60)	35 (2.5)	--	22 (1.5)	8 (.5)	8 (.5)	363 (27)
Structural steel & metalwork	214 (14.8)	12 (6)	33 (15)	118 (55)	--	--	--	--	--	51 (24)
Boilershop products	294 (14.6)	44 (15)	59 (20)	125 (42.5)	25 (8.5)	--	--	--	--	41 (13)
Hotels	129 (3.3)	2 (1)	14 (11)	87 (67)	3 (3)	--	--	--	--	23 (18)
Hospitals	766 (2.5)	533 (70)	49 (6)	--	--	--	--	--	--	184 (24)
Plumbing operations	79 (3.9)	19 (24)	16 (20.5)	--	20 (25.5)	--	--	--	--	24 (30)
School lunchrooms	140 (7.8)	10 (7)	15 (11)	103 (73.5)	--	--	--	--	--	12 (8.5)
WEIGHTED MEAN PERCENTAGES	(10.57)	(54.63)	(20.96)	(58.13)	(10.33)	(8)	(1.69)	(.5)	(.5)	(24.56)

Table 6.6

Work injuries due to the lack of guardrails and inadequate guarding by agency of accidents for selected industries. (ref. 6.6 - 6.21)

INDUSTRY	Total Cases # (%)	Stock & Materials # (%)	Handtools # (%)	Machines # (%)	Work Assemblies # (%)	Working Surfaces # (%)	Vehicles # (%)	Other # (%)
LACK OF GUARDRAILS								
Structural	24	--	--	1	--	12	6	5
steel & metal	(1.7)	(--)	(--)	(1)	(--)	(50)	(25)	(21)
Carpentry	382	--	--	--	--	333	--	49
operations	(4.2)	(--)	(--)	(--)	(--)	(87)	(--)	(13)
Concrete	10	--	--	1	--	4	5	0
brick & block	(0.8)	(--)	(--)	(10)	(--)	(40)	(50)	(0)
Paperboard	29	--	--	4	--	17	1	7
containers	(2.0)	(--)	(--)	(14)	(--)	(59)	(3)	(24)
Clay construc-	65	--	--	3	1	31	--	30
tion products	(1.1)	(--)	(--)	(5)	(2)	(48)	(--)	(46)
Water-supply	27	--	4	7	--	--	2	14
utilities	(1.5)	(--)	(15)	(26)	(--)	(--)	(7)	(52)
Warehousing	59	13	--	1	4	19	11	11
operations	(4.4)	(22)	(--)	(2)	(6)	(32)	(19)	(19)
Hospitals	438	--	--	397	--	3	3	35
	(1.4)	(--)	(--)	(91)	(--)	(.5)	(.5)	(8)
WEIGHTED MEAN PERCENTAGES	(2.6)	(22)	(15)	(87.89)	(5.2)	(78)	(14.37)	(23.32)
INADEQUATE GUARDING								
Structural	214	27	16	60	11	13	13	74
steel & metal	(14.8)	(13)	(7)	(28)	(5)	(6)	(6)	(35)
Concrete brick	119	--	6	62	15	4	26	6
& block	(10)	(--)	(5)	(52)	(13)	(3)	(22)	(5)
Carpentry	1350	--	379	446	--	333	--	192
operations	(14.9)	(--)	(28)	(33)	(--)	(25)	(--)	(14)
Paperboard	356	--	--	296	--	18	10	32
containers	(24.4)	(--)	(--)	(83)	(--)	(5)	(3)	(9)
Clay construc-	388	21	19	148	32	38	47	83
tion products	(6.8)	(6)	(5)	(38)	(8)	(10)	(12)	(21)
Water-supply	196	--	20	14	--	82	13	67
utilities	(11.4)	(--)	(10)	(7)	(--)	(42)	(7)	(34)
Warehousing	165	13	8	32	15	29	36	32
	(12.4)	(8)	(5)	(19)	(9)	(17)	(22)	(20)
Hospitals	766	--	--	512	--	3	49	202
	(2.5)	(--)	(--)	(67)	(--)	(1)	(6)	(26)
Boilershop	294	2	41	110	2	15	2	122
products	(14.6)	(1.5)	(14)	(37)	(1.5)	(5)	(1.5)	(41)
Plumbing	162	--	3	--	--	43	--	116
operations	(6.0)	(--)	(1)	(--)	(--)	(27)	(--)	(72)
Shipyards	106	--	--	5	--	70	1	30
	(16.2)	(--)	(--)	(5)	(--)	(66)	(1)	(28)
Textile dyeing	711	166	10	419	--	29	1	86
& finishing	(9.6)	(23)	(1)	(59)	(--)	(5)	(0)	(12)
Hotels	129	--	--	91	--	7	--	31
	(3.3)	(--)	(--)	(70)	(--)	(6)	(--)	(24)
School	140	--	--	127	--	5	--	8
lunchrooms	(7.8)	(--)	(--)	(90)	(--)	(4)	(--)	(6)
WEIGHTED MEAN PERCENTAGES	(11.25)	(19.22)	(23.26)	(56.6)	(8.95)	(27.41)	(12.25)	(29.16)

guarding. This would imply that placement of guardrails is at least just as significant a factor in preventing or controlling accidents as guardrail design.

6.5 Conclusions

The results of the accident analysis suggest that guardrail accidents could be better prevented and controlled by the proper placement of guardrails, by making guardrails more noticeable, and by determining guardrail design criteria with respect to how guardrails are used and who uses them. Many of the accidents resulting from structural inadequacies of guardrails can be prevented by determining guardrail strength criteria with respect to guardrail use. Similarly, accidents resulting from non-structural inadequacies could be prevented through proper height, size of openings and placement of guardrails and by environmental cues to alert an employee to the presence of a hazardous area sooner and thereby decrease the severity of the guardrail accident.

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7. Summary

This report presents results of the phase one study at the National Bureau of Standards consisting of existing information compiled in order to assist in determining structural and non-structural safety requirements for personnel guardrails. The literature search and study of existing guardrail design provisions revealed a general lack of consistency between load, height and strength requirements, and a paucity of quantitative test data and analysis procedures upon which such requirements could be based. The anthropometric data indicate those body measurements which might be significant to human-guardrail interaction. This is of value not only in determining non-structural requirements such as minimum guardrail openings, toeboard heights, etc., but also in establishing the range of guardrail sizes over which load testing should be planned for the phase two effort to follow. The field survey provided a valuable perspective by showing the broad range of usage of guardrails in service, while the analysis of guardrail-related accidents revealed that the placement of the guardrail may be as significant a factor in accident prevention as the actual design of the guardrail.

It is apparent from this study that a lack of knowledge of realistic service loads is a major obstacle to the ability to develop rational guardrail design criteria. In addition, a quantitative description of the relations between certain anthropometric data and guardrail measurements remains obscure. Accordingly, the phase two effort will consist of an experimental-analytical program which will seek to measure, among other things, static and dynamic loads on guardrails resulting from simulated accident situations. On the basis of the above information, phase two will conclude with a performance-oriented guide and criteria for the design and evaluation of personnel guardrails.

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Existing information is compiled which would assist in determining structural and non-structural safety requirements for guardrails used for the protection of employees against occupational hazards. Critical aspects of guardrail safety are identified through exploratory studies consisting of field surveys of prototypical installations, reviews of existing standards and industrial accident records, and compilation of relevant anthropometric data. These exploratory studies will be utilized to design an experimental program which will consist of structural tests to determine design loads and non-structural tests to determine geometric requirements for guardrail safety.

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