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STRUCTURAL ENGINEERING

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Table 4-4	*Engineering News Record*, June 26, 1958, McGraw-Hill Book Company, Inc., New York, N.Y.
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(1) Human and Special Occupancy. Live load requirements for human and special occupancy are listed in Table 1-3.

(2) Warehouses. Live loads for storage warehouses are specified in Table 1-4.

b. Concentrated Loads. Unless otherwise specified, assume that concentrated loads occupy spaces 2.5 by 2.5 feet, and that they are placed to develop maximum stresses in the affected members. Design all floors to support either uniformly distributed loads or concentrated loads (whichever develops the greater stresses) as follows:

Designation	*Load*
Elevator machine room grating	300 pounds on an area of 4 square inches.
Finish light floor plate	200 pounds on an area of 1 square inch.
Floors other than those above..	2,000 pounds.
Scuttles, skylights, and accessible ceilings	200 pounds.

Use actual load if it exceeds those given above.

2. STAIR, SIDEWALK, AND DRIVEWAY LOADS.

Design stairs, sidewalks, and driveways to support uniformly distributed or concentrated loads.

a. Stair. Apply either a uniformly distributed load of 100 psf or a concentrated load of 300 pounds on center of tread, depending on anticipated usage.

b. Sidewalk. Apply either a uniformly distributed load of 250 psf or, when subject to trucking, a concentrated load of 8,000 pounds (whichever develops the greater stresses) on an area of 2.5 by 2.5 feet.

c. Driveway. Apply either a uniformly distributed load of 250 psf or the heaviest wheel load expected (minimum 12,000 pounds) in a driveway, whichever develops the greater stresses.

3. ROOF LOADS.

Because roofs are exposed to varying environmental conditions, depending on their location, they should be designed to support loads imposed by the prevailing climatic conditions.

a. Uniform Loads.

(1) Minimum Load. Design roofs to support a minimum load of 20 psf. Where snow conditions exist, design roofs to support the loads indicated in Figure 1-1 and Tables 1-5 and 1-6, using horizontal projected areas. The roof live loads shall conform to snowpack on ground weights for snowpack values of 20 through 40 psf. A roof live load of 40 psf shall be used for areas where the snowpack on the ground exceeds 40 psf. (Because of interior building heat and wind effects, it is improbable that the snow load will exceed 40 psf.)

(2) Slope Factors. The design live load shall be reduced for roofs having a slope in excess of 20 degrees in accordance with the following formula: Reduce excess over 20 psf for each degree of slope over 20 degrees by (S/40-1/2), where S is the total snow load in psf. For example, when S = 35 psf and slope = 30 degrees,

$$S_{net} = 35 - \left(\frac{35}{40} - \frac{1}{2}\right) \times (30-20) = 31.25 \text{ psf.} \quad (1\text{-}1)$$

(3) Wind Load. See as described in Section 4. Uplift forces should be stated on drawings where preengineered structural components are used.

b. Special Loads. Curved roofs, multipurpose roofs, roof trusses, and roof valleys carry loads differently from ordinary roofs and shall be designed accordingly.

(1) Curved Roofs. The formula for determining safe snow loads on arches and curved roofs is shown in Figure 1-2.

(2) Multipurpose Roofs. Roofs used for secondary purposes (such as promenades, ponding, and support of equipment) shall be designed for the loads corresponding to usage.

(3) Roof Trusses. Simultaneously with the uniform roof loads, apply a 2,000-pound concentrated load on any lower chord panel point for roof trusses over garages, hangars, and manufacturing or storage floors.

(4) Roof Valleys. Increase loads for snow accumulations in valleys. The loading intensity shall be assumed twice the normal value, varying to the normal amount of 8 feet each side of trough.

(5) Ponding. The minimum roof slope will normally preclude ponding; however, it should be considered if possible.

4. REDUCTION IN LIVE LOADS.

a. Live Loads Exceeding 100 psf. No reductions shall be applied to floor framing members. The

TABLE 1-3

Uniform Floor Live Load Requirements for Human and Special Occupancy[1]

Occupancy or use	Live load (psf)
Apartments (see Residential)	
Apparatus room	75
Armories	150
Assembly halls and other places of assembly:	
Fixed seats	60
Movable seats	100
Automatic data processing rooms	150
Bag storage	125
Bakeries; general area	100
Bakeries; storage area	200
Balconies; exterior	100
Barber shop	75
Barracks and dormitories:	
partitioned	40
nonpartitioned, including allowances for future partitions	60
corridors	100
Battery charging room	200
Boiler houses	200
Bowling alleys, pool rooms and similar recreation areas	75
Car wash rooms	75
Canteens; general area	100
Canteens; storage area	200
Catwalks; buildings	25
Catwalks; marine	50
Ceiling; accessibly furred	10
Chapels (see Theaters and chapels)	
Cobbler shop	100
Computer rooms	200
Concentrated loads:	
Elevator machine room grating (on area of 4 sq in.)	300 lb
Finish light floor plate construction (on area of 1 sq in.)	200 lb
Main corridors, large offices, and similar areas (on 2.5 ft x 2.5 ft)	2,000 lb
Scuttles, skylight ribs, and accessible ceilings	200 lb
Sidewalks (on 2.5 ft x 2.5 ft)	8,000 lb
Stair treads (on center of tread)	300 lb
Corridors:	
First floor, except as indicated	100
Other floors, except as indicated	80
Court rooms	80
Dance floors	125
Day rooms	60
Dining rooms and restaurants	100
Kitchen; general area	75
Drawing reproduction rooms (blue printing)	100
Dressing rooms (theater)	75
Drill halls	125
Drum fillings	150
Drum washing	75

Occupancy or use	Live load (psf)
Dwellings (see Residential)	
File rooms:	
Letter files	80
Card files	125
Drawing files	200
Galleys:	
Dishwashing rooms (mechanical)	300
Provision storage (not refrigerated)	200
Preparation room:	
meat	250
vegetable	100
Garages:	
Repair areas	100
Passengers cars	100
Trucks, with load, 3 to 10 tons	150
Trucks, with load, over 10 tons	200
(Check all garage floors for 150% maximum wheel load anywhere on floor.)	
Garbage storage rooms	125
Grandstands, reviewing stands, and bleachers	100
Generator rooms	200
Guard house	75
Gymnasiums; main floor and balconies	100
Hangars:	
Land planes and seaplanes	wheel loads
Hospitals:	
Wards	40
Private rooms and miscellaneous rooms	40
Corridors; main	100
Corridors; secondary	60
Operating rooms	60
Examination rooms & doctor's offices	40
Hydrotherapy	75
Radiology	75
Physical Therapy	75
Hotels (see Residential)	
Incinerators; charging floor	150
Laboratories; normal scientific equipment	100
Latrines	75
Laundries; general areas	100
Libraries:	
Reading rooms	60
Stack rooms—20 pcf or 150 max	60
Light manufacturing areas and loft buildings	125
Linen storage	125
Lobbies, vestibules, & large waiting rms	100
Locker rooms	75
Lounges, day rooms, small recreation areas	60
Mechanical equipment rooms (general)	100

TABLE 1-4 (Continued)

Uniform Live Loads for Storage Warehouses

Material	Weight per cubic foot of space (lb)	Height of pile (ft)	Weight per square foot of space (lb)	Live load (psf)
Miscellaneous: (Continued)				
Paper, writing and calendared	60	6	360	
Rope, in coils	32	6	192	
Rubber, crude	50	8	400	
Tobacco, bales	35	8	280	

design live loads on columns may be reduced 20 percent.

b. Live Loads, 100 psf or Less. The design live load on a girder or truss (carrying primary framing members), supporting 150 square feet or more, may be reduced at a rate of 0.08 percent per square foot of area supported by the member, except that no reduction shall be made for public assembly or storage areas, or where live load over areas is likely to be in place continuously for more than 90 days. A reduction shall not exceed R, as determined by equation (1-2), or 60 percent:

$$R = 100 \times \frac{D+L}{4.33L}, \quad (1\text{-}2)$$

where: R = reduction (percent),
D = dead load per suare foot of area supported by the member, and
L = design live load per square foot of area supported by the member.

Roof members may be treated as described above for uniform live load, except that in no case shall the design load be less than the actual snowpack or 12 psf, whichever is greater. This reduction does not apply to calculations for wind, seismic forces, or concentrated loads. Column and footing live loads may be reduced in accordance with values given for girders.

5. PARTIAL LOADING.

a. Uniform Distribution of Loads. In continuous framing, consideration shall be given to variations in the locations of uniform live loads in the various spans for maximum design conditions.

b. Moving Loads. All structures subject to moving or variable loads shall have each part designed with only those live loads on the structure that develop the maximum stresses in the considered part.

6. MOBILE LOADS.

a. Highway Loads. *Standard Specifications for Highway Bridges*, American Association of State Highway Officials (AASHO), (see Criteria Sources) contains standards and criteria useful in developing highway loads.

b. Railway Loads. Data for railway loads are contained in the American Railroad Engineering Association (AREA) Manual. (See Criteria Sources.)

c. Crane Runways and Supports. Crane runways and supports shall be designed to support vertical and horizontal loads delineated as follows:

(1) Vertical Loads. For wheel loads, see individual crane manufacturer's catalogs.

(2) Horizontal Loads. Lateral forces due to trolley travel shall equal 10 percent of the dead load of the trolley and 20 percent of the hook load, one-half applied at the top of each runway girder. Longitudinal forces due to crane travel shall equal 10 percent of the sum of the maximum wheel load on one runway girder.

(3) Test Loading. See NAVDOCKS DM-38 for test loading on cranes.

7. LOADS FOR SPECIAL STRUCTURES.

a. Bins and Bunkers. For loads on component parts of bins and bunkers, see *The Design of Walls, Bins, and Grain Elevators*. (See Criteria Sources.)

b. Piers, Wharves, and Waterfront Structures. Load criteria for piers, wharves, and waterfront structures are discussed in detail in *Waterfront Operational Facilities*, NAVFAC DM-25, and *Harbor and Coastal Facilities*, NAVFAC DM-26.

c. Antenna Supports and Transmission Line Structures.

(1) *Dead Loads.* Dead loads are described in Section 2.

(2) *Live Load on Stairways, Walkways, and Ladders.* Live Load criteria for stairways, walkways, and ladders are listed in Paragraph 7e, which follows.

(3) *Wind Load.* Wind load requirements are discussed in Section 4.

(4) *Ice Load.* The thickness of ice covering on guys, conductors, insulation, and framing supports shall be determined from Figure 1-3. Exceptions are areas known to have more severe icing conditions, such as coastal and waterfront areas that are subject to heavy sea spray, or high local precipitation. For ice load in these areas, consult local authorities.

(5) *Thermal Changes.* Consider changes in guy or cable sag or both due to temperature changes. See Section 6 and *Wire Rope Engineering Handbook.* (See Criteria Sources.)

(6) *Pretension Forces.* Consider pretension forces in guys and wires.

(7) *Broken Wires.* Design support structures to resist the unbalanced pull or torsion resulting from any reasonable combination of broken antenna or transmission wires. See Chapter 9 for analysis of broken guy cable.

(8) *Erection Loads.* Temporary erection loads are important in the design of antenna supports and transmission line structures.

(9) *Earthquake.* See Section 5. Consider increases in wire or guy tensions due to the vertical component of acceleration.

d. Cranes, Derricks, and Monorails. Load standards for cranes, derricks, and monorails are contained in *Weight Handling Equipment and Service Craft,* NAVDOCKS DM-38.

e. Stairways, Walkways, and Ladders. Stairways, walkways, and ladders of towers and elevated tanks shall be designed for a uniform live load of 50 pounds or a concentrated load of 350 pounds, whichever develops the greater stresses.

f. Turbine-Generator Foundations.

(1) *Vertical Loads.* For component weights of the turbine generator and distribution of these weights, refer to the manufacturer's machine outline drawings. Increase machine loads 25 percent for machines with speeds up to and including 1,800 revolutions per minute (rpm), and 50 percent for those with higher speeds. Consider additional loads (such as auxiliary equipment, pipes, and valves) supported by the foundations. Also see Chapter 9, Section B, Part 3.

(2) *Steam Condenser Load.* The condenser, or vacuum, load shall be determined from the method of mounting the condenser.

(3) *Torque Load.* See criteria on equipment supports, Chapter 9, Section 9.

(4) *Horizontal Loads on Support Framing.*

(a) *Longitudinal force.* Assume a longitudinal force of 20 to 50 percent of the machine weight applied at the shaft centerline.

(b) *Transverse force.* Assume a transverse force at each bent of 20 to 50 percent of the machine weight supported by the bent and applied at the machine centerline.

(c) *Longitudinal and transverse forces.* Longitudinal and transverse forces shall not be assumed to act simultaneously.

(5) *Horizontal Forces Within Structure.* Assume horizontal forces equal in magnitude to the vertical loads of the generator stator and turbine exhaust hood, as given on the manufacturer's machine outline drawings. Apply these forces at the top flange of the supporting girders; assume the forces to be equal and opposite.

(6) *Assumed Forces on Centerline Guides.* Refer to machine outline drawing for magnitude and points of application. Support beams for guide brackets shall have sufficient rigidity to limit the displacements relative to the main foundation to 0.005 inch under the action of the assumed forces.

(7) *Temperature Variation.* Consider forces acting within the foundation due to temperature changes.

(8) *External Piping.* Provisions shall be made to withstand loads from pipe thrusts, relief values, and the weight of piping and fittings.

8. IMPACT. Live loads shall be increased by amounts specified as follows for dynamic, vibratory, and impact effects of applied loads.

a. Supports for Elevators and Hoisting Apparatus. Provide for the following increases in moving loads for elevators and hoisting apparatus:

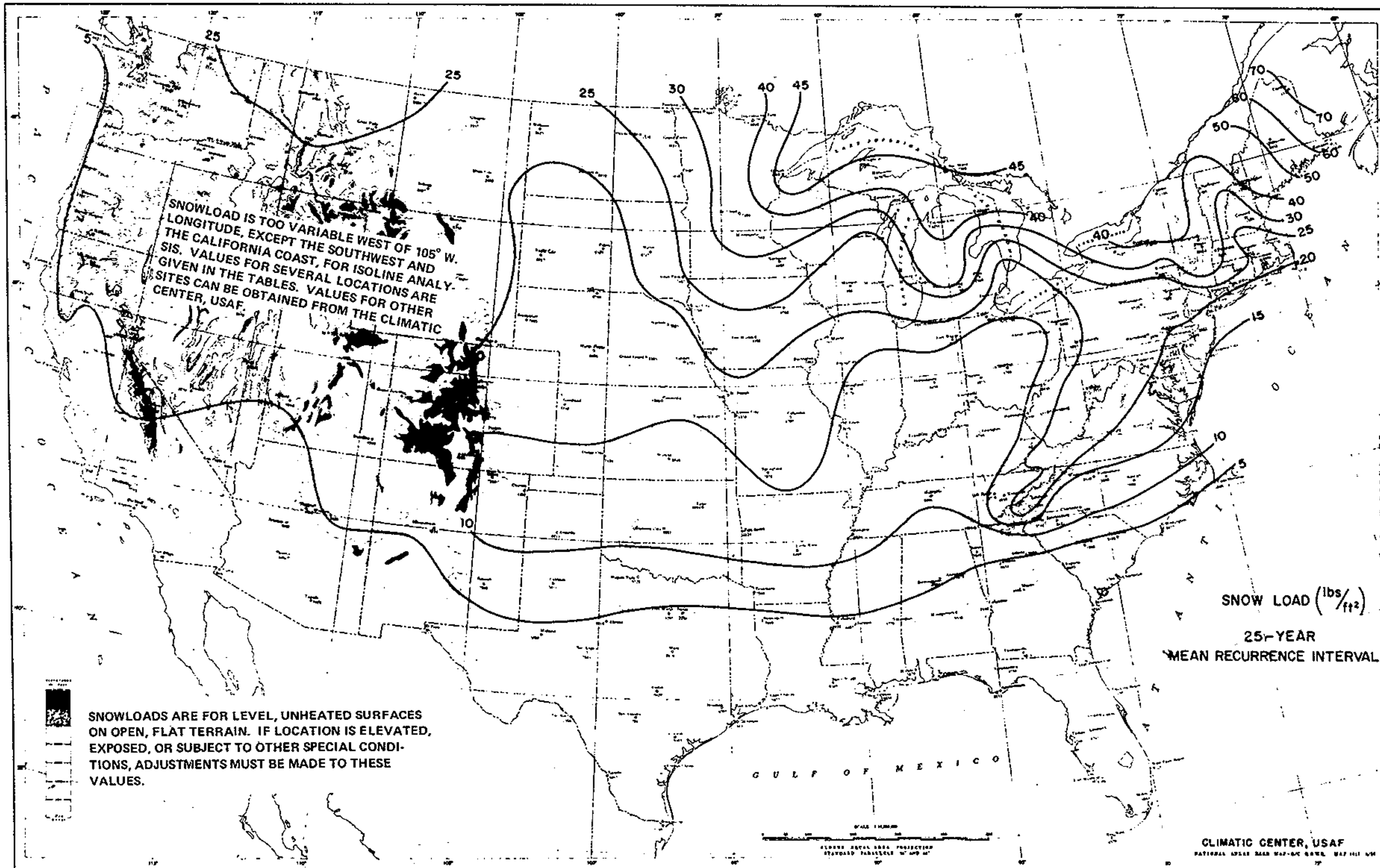


FIGURE 1-1
Snow Loadings in Contiguous States

TABLE 1-5

Wind, Snow, and Frost Data for Contiguous States

Location	Wind, peak gust velocity		Seasonal snowpack (psf)	Frost penetration (inches)
	(knots)	(mph)		
ALABAMA:				
Brookley AFB, Mobile	105	121	5	6
Maxwell AFB, Montgomery	79	91	5	9
Mobile	105	121	5	6
Montgomery	79	91	5	6
ARIZONA:				
Davis Monthan AFB Tucson	66	76	5	5
Luke AFB, Phoenix	79	91	5	7
Williams AFB, Phoenix	68	78	5	7
Phoenix	70	81	7	7
ARKANSAS:				
Little Rock AFB Little Rock	78	90	15	12
CALIFORNIA:				
Castle AFB, Merced	53	61	5	5
Hamilton AFB, San Francisco	73	84	5	5
March AFB, Riverside	51	59	5	5
Mather AFB, Sacramento	88	101	5	5
Travis AFB, Fairfield	64	74	5	5
Vandenberg AFB, Lompoc	63	72	5	5
San Diego	56	64	0	0
Pasadena	63	72	0	0
Long Beach	63	72	0	0
San Francisco	74	85	5	5
Oakland	74	85	5	5
Mare Island	73	84	5	5
Sacramento	93	107	5	5
Stockton	80	92	5	5
China Lake	60	70	5	5
COLORADO:				
Lowry AFB, Denver	61	70	20	60
Denver	61	70	20	60
CONNECTICUT:				
New London	70	81	20	35
New Haven	70	81	20	35
DELAWARE:				
Dover AFB, Dover	81	93	20	20
Lewes	100	115		
FLORIDA:				
Eglin AFB, Valparaiso	110	127	5	5
Homestead AFB, Homestead	109	127	0	0
McDill AFB, Tampa	79	91	0	2
Patrick AFB, Cocoa	109	125	5	2
Jacksonville	90	104	5	2
Miami	109	125	0	0
Key West	106	122	0	0
Pensacola	110	127	5	2
Tampa	76	87	0	2
GEORGIA:				
Hunter AFB, Savannah	90	104	5	5
Robins AFB, Warner Robins	68	78	5	5
Turner AFB, Albany	72	83	5	5
Augusta	72	83	5	5
Atlanta	75	86	5	7
Savannah	90	104	5	3
Macon	74	85	5	5

TABLE 1-5 (Continued)

Wind, Snow, and Frost Data for Contiguous States

Location	Wind, peak gust velocity		Seasonal snowpack (psf)	Frost penetration (inches)
	(knots)	(mph)		
IDAHO:				
Mountain Home AFB				
Mountain Home	72	83	20	40
ILLINOIS:				
Chanute AFB, Rantoul	81	93	15	35
Scott AFB, Belleville	71	82	15	35
Chicago	72	83	20	40
INDIANA:				
Fort Wayne	77	88	15	40
Indianapolis	90	104	15	30
IOWA:				
Sioux City	89	102	20	54
KANSAS:				
Forbes AFB, Topeka	94	108	15	30
Schilling AFB, Salina	89	102	15	24
KENTUCKY:				
Lexington	79	91	10	18
Louisville	79	91	10	18
LOUISIANA:				
Barksdale AFB, Shreveport	58	67	5	5
Chennault AFB, Lake Charles	105	121	5	4
New Orleans	105	121	5	2
MAINE:				
Dow AFB, Bangor	85	98	60	75
Loring AFB, Caribou	80	92	75	75
Portland	86	99	40	65
Bangor	85	98	60	72
MARYLAND:				
Andrews AFB				
Washington, D.C.	76	87	20	25
Baltimore	78	90	20	22
Lexington Park	90	104	20	22
MASSACHUSETTS:				
L. G. Hanscom Field				
Boston	94	108	25	50
Otis AFB, Cape Cod	105	121	20	50
Westover AFB, Springfield	75	86	30	70
Boston	94	108	25	50
Springfield	75	86	30	70
MICHIGAN:				
Kinchelow AFB				
Sault Ste. Marie	84	97	45	65
Selfridge AFB, Detroit	69	79	20	50
Detroit	66	76	20	50
MINNESOTA:				
Minn-St. Paul IAP	78	90	35	75
Minneapolis	78	90	35	75
Duluth	85	98	50	75
MISSISSIPPI:				
Jackson	90	104	5	3
Meridan	90	104	5	5
Gulfport	110	127	0	5
MISSOURI:				
Kansas City	85	98	15	28
St. Louis	70	81	15	27
MONTANA:				
Malmstrom AFB, Great Falls	72	83	25	75

TABLE 1-5 (Continued)
Wind, Snow, and Frost Data for Contiguous States

Location	Wind, peak gust velocity		Seasonal snowpack (psf)	Frost penetration (inches)
	(knots)	(mph)		
NEBRASKA:				
Offutt AFB, Omaha	84	97	25	55
Omaha	84	97	25	55
Hastings	90	104	20	53
NEVADA:				
Nellis AFB, Las Vegas	78	90	5	8
Stead AFB, Reno	80	92	25	23
Fallon	80	92	25	12
Hawthorne	80	92	25	30
Reno	83	95	25	23
NEW HAMPSHIRE:				
Pease AFB, Portsmouth	91	105	30	60
Portsmouth	90	104	30	60
NEW JERSEY:				
McGuire AFB, Trenton	74	85	20	30
Atlantic City	86	99	15	20
Bayonne	73	84	20	30
NEW MEXICO:				
Cannon AFB, Clovis	68	78	10	15
Holloman AFB, Alamogordo	70	81	5	20
Walker AFB, Roswell	75	86	10	15
Albuquerque	86	99	10	17
NEW YORK:				
Griffis AFB, Rome	71	82	40	50
Plattsburg AFB, Plattsburg	79	91	35	70
Stewart AFB, Newburgh	77	88	25	45
Buffalo	79	91	30	35
Albany	69	79	30	54
New York	73	84	20	40
Syracuse	71	82	40	56
NORTH CAROLINA:				
Pope AFB, Fayetteville	64	74	10	9
Charlotte	78	90	10	8
Wilmington	115	132	5	5
Cape Hatteras	115	132	5	5
Cherry Point	100	115	5	5
Camp LeJeune	100	115	5	5
NORTH DAKOTA:				
Grand Forks AFB Grand Forks	86	99	25	85
Minot AFB, Minot	86	99	15	80
OHIO:				
Wright-Patterson AFB, Dayton	80	92	15	40
Columbus	80	92	15	40
Cincinnati	80	92	10	20
OKLAHOMA:				
Tinker AFB, Oklahoma City	80	92	10	20
OREGON:				
Portland Int. Apt.	100	115	15	6
Portland	100	115	15	6
PENNSYLVANIA:				
Olmstead AFB, Harrisburg	63	72	20	35
Harrisburg	74	85	20	30
Pittsburgh	72	83	20	38
Philadelphia	70	81	20	30

TABLE 1-5 (Continued)

Wind, Snow, and Frost Data for Contiguous States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Seasonal snowpack (psf)	Frost penetration (inches)
RHODE ISLAND:				
Providence	99	114	20	45
SOUTH CAROLINA:				
Paris Is.		120	5	6
Charleston	106	122	5	3
SOUTH DAKOTA:				
Ellsworth AFB, Rapid City	92	106	20	55
TENNESSEE:				
Sewart AFB, Smyrna	83	95	10	10
Memphis	80	92	10	10
TEXAS:				
Amarillo AFB, Amarillo	104	120	10	20
Bergstrom AFB, Austin	75	86	5	4
Biggs AFB, El Paso	80	92	5	6
Carswell AFB, Ft. Worth	74	85	5	12
Dyess AFB, Abilene	87	100	5	10
Ellington AFB, Houston	78	90	5	3
Kelley AFB, San Antonio	77	88	5	4
Kingsville NAS, Kingsville	91	105	5	4
Reese AFB, Lubbock	75	86	10	15
Sheppard AFB, Wichita Falls	74	85	10	15
Corpus Christi	100	115	5	2
El Paso	80	92	5	6
Fort Worth	69	79	5	10
Galveston	88	101	5	3
Houston	80	92	5	3
San Antonio	65	75	5	4
Amarillo	104	120	10	20
UTAH:				
Hill AFB, Ogden	83	93	30	35
Salt Lake City	77	88	25	35
VERMONT:				
Burlington	79	91	35	72
VIRGINIA:				
Langley AFB, Hampton	95	109	15	6
Newport News	92	106	15	10
Norfolk	92	106	15	10
Richmond	77	88	15	14
Yorktown	87	100	15	14
WASHINGTON:				
Fairchild AFB, Spokane	79	91	25	65
Larson AFB, Moses Lake	63	72	25	35
McChord AFB, Tacoma	72	83	20	10
Bremerton	72	83	20	9
Seattle	72	83	20	8
Spokane	79	91	20	30
Pasco	65	75	30	25
Tacoma	72	83	20	8
WEST VIRGINIA:				
Charleston	70	81	15	30
WISCONSIN:				
Truax Field, Madison	99	114	25	50
Milwaukee	97	112	25	54
Green Bay	87	100	25	54
WYOMING:				
Francis E. Warren AFB Cheyenne	86	99	20	70
WASHINGTON, D. C.	80	92	15	20

TABLE 1-6
Wind, Snow, and Frost Data for Locations Outside the United States

Location	Wind, peak gust velocity		Roof snow load (psf)	Frost penetration (inches)
	(knots)	(mph)		
AFRICA:				
Libya:				
Wheelus AB	73	84	0	0
Morocco:				
Casablanca	73	84	0	0
Port Lyautey NAS	73	84	0	0
ASIA:				
India:				
Bombay	74	85	0	0
Calcutta	92	106	0	0
Madras	75	86	0	0
New Delhi	74	85	0	0
Japan:				
Itazuke AB	80	92	10	6
Johnson AB	90	104	10	6
Misawa AB	82	94	20	18
Tachikawa AB	85	98	10	6
Tokyo	85	98	10	6
Wakkanai	100	115	55	36
Korea:				
Kimpo AB	63	72	20	30
Seoul	63	72	20	30
Uijongbu	51	59	15	36
Pakistan:				
Peshawar	71	82	10	6
Saudi Arabia:				
Bahrain Island	70	81	0	0
Dhahran AB	70	81	0	0
Taiwan:				
Tainan	104	120	0	0
Taipei	113	130	0	0
Thailand:				
Chiang Mai	68	78	0	0
Bangkok	68	78	0	0
Sattahip	74	85	0	0
Udonthani	55	63		
Turkey:				
Ankara	80	92	20	24
Karamursel	91	105	15	12
Viet Nam:				
Da Nang	104	120		
Nha Trang	82	94		
Saigon	82	94	0	0
ATLANTIC OCEAN AREA:				
Ascension Island	54	62	0	0
Azores:				
Lajes Field	102	117	0	0
Bermuda:				
Bermuda NAS	96	110	0	0
Kindley AFB	110	127	0	0
CARIBBEAN SEA:				
Bahama Islands:				
Eleuthera Island	120	138	0	0
Grand Bahama Island	120	138	0	0
Great Exuma Island	120	138	0	0

TABLE 1-6 (Continued)
Wind, Snow, and Frost Data for Locations Outside the United States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Roof snow load (psf)	Frost penetration (inches)
CARIBBEAN SEA—Continued				
Cuba:				
Guantanamo NAS	78	90	0	0
Leeward Islands:				
Antigua Island	120	138	0	0
Puerto Rico:				
Raney AFB	81	93	0	0
San Juan	101	116	0	0
Vieques Island	120	138	0	0
Trinidad Island:				
Port of Spain	48	55	0	0
Trinidad NS	48	55	0	0
CENTRAL AMERICA:				
Canal Zone:				
Albrook AFB	54	62	0	0
Balboa	54	62	0	0
Coco Solo	45	52	0	0
Colon	50	58	0	0
Cristobal	50	58	0	0
France AFB	50	58	0	0
EUROPE:				
England:				
Birmingham	72	83	15	12
London	77	88	15	12
Mildenhall AB	84	97	15	12
Plymouth	76	87	10	12
Sculthorpe AB	80	92	15	12
Southport	84	97	10	12
South Shields	80	92	15	12
Spurn Head	80	92	15	12
France:				
Nancy	70	81	15	18
Paris/Le Bourget	82	94	20	18
Rennes	89	102	15	18
Vichy	99	114	25	24
Germany:				
Bremen	69	79	25	30
Munich-Riem	79	91	40	36
Rhein-Main AB	69	79	25	30
Stuttgart AB	73	84	45	36
Greece:				
Athens	75	86	5	0
Italy:				
Aviano AB	64	74	10	18
Brindisi	89	102	5	6
Sigonella-Katania	78	90	...	...
Scotland:				
Aberdeen	73	84	15	12
Edinburgh	80	92	15	12
Edzell	73	84	15	12
Glasgow/Renfrew Airfield	84	97	15	12
Lerwick, Shetland Islands	90	104	15	18

TABLE 1-6 (Continued)

Wind, Snow, and Frost Data for Locations Outside the United States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Roof snow load (psf)	Frost penetration (inches)
EUROPE–Continued				
Londonderry	108	124	15	12
Prestwick	81	93	15	12
Stornoway	97	112	15	12
Thurso	85	98	15	12
Spain:				
Madrid	67	77	10	6
Rota	76	87	5	0
San Pablo	95	109	5	6
Zaragoza	95	109	10	6
NORTH AMERICA:				
Alaska:				
Adak, Aleutian Islands	108	124	15	24
Anchorage	84	97	35	60
Annette	82	94	20	24
Attu	155	178	35	24
Barrow	89	109	20	permafrost
Bethel	82	94	33	60
Cold Bay	96	110	20	36
Cordova	82	94	76	48
Eielson AFB	65	75	33	60
Elmendorf AFB	81	93	35	60
Fairbanks	65	75	35	60
Gambell	113	130	25	48
Juneau	80	92	42	36
King Salmon	100	115	12	60
Kodiak	101	116	17	48
Kotzebue	106	122	20	permafrost
McGrath	74	85	50	84
Middleton Island AFS	109	125	47	48
Nikolski, Umnak Island	112	129	25	36
Nome	104	120	43	permafrost
Northeast Cape AFS St. Lawrence Island	116	133	26	48
Shemya Island	155	178	34	24
St. Paul Island	91	105	24	36
Umiat	97	112	30	permafrost
Wales	91	105	50	permafrost
Yakutat	86	99	108	36
Canada:				
Argentia NAS, Newfoundland	93	107	47	36
Churchill, Manitoba	87	100	66	permafrost
Cold Lake, Alberta	65	75	41	72
Edmonton, Alberta	68	78	27	60
E. Harmon AFB, Newfoundland	91	105	86	60
Fort William, Ontario	65	75	73	60
Frobisher, N.W.T.	87	100	50	permafrost
Goose Airport, Newfoundland	72	83	100	60
Ottawa, Ontario	73	84	60	48
St. John's, Newfoundland	92	106	72	36
Toronto, Ontario	73	84	40	36
Winnipeg, Manitoba	66	76	45	60
Greenland:				
Narsarssuak AB	112	129	30	60
Simiutak AB	134	154	25	60
Sondrestrom AB	97	112	20	permafrost

TABLE 1-6 (Continued)
Wind, Snow, and Frost Data for Locations Outside the United States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Roof snow load (psf)	Frost penetration (inches)
NORTH AMERICA—Continued				
Thule AB	115	132	25	permafrost
Iceland:				
Keflavik	100	115	30	24
Thorshofn	118	136	30	36
PACIFIC OCEAN AREA:				
Australia:				
H.E.Holt, NW Cape		130	0	
Caroline Islands:				
Koror, Palau Islands	83	95	0	0
Ponape	95	109	0	0
Hawaii:				
Barber's Point	58	67	0	0
Hickam AFB	69	79	0	0
Kaneohe Bay	73	84	0	0
Wheeler AFB	55	63	0	0
Hawaiian Islands:				
Hawaii			0	0
Kahoolawe			0	0
Kavai			0	0
Lanai			0	0
Maui			0	0
Molokai			0	0
Nihau			0	0
Oahu			0	0
Johnston Island	63	72	0	0
Mariana Islands:				
Agana, Guam	135	155	0	0
Andersen AFB, Guam	135	155	0	0
Kwajalein	90	104	0	0
Saipan	130	150	0	0
Tinian	130	150	0	0
Marcus Island	130	150	0	0
Midway Island	76	87	0	0
Okinawa:				
Kadena AB	160	184	0	0
Naha AB	155	178	0	0
Philippine Islands:				
Clark AFB	76	87	0	0
Sangley Point	59	68	0	0
Subic Bay	67	77	0	0
Samoa Islands:				
Apia, Upolu Island	128	147	0	0
Tutuila, Tutuila Island	128	147	0	0
Volcano Islands:				
Iwo Jima AB	180	206	0	0
Wake Island	75	86	0	0

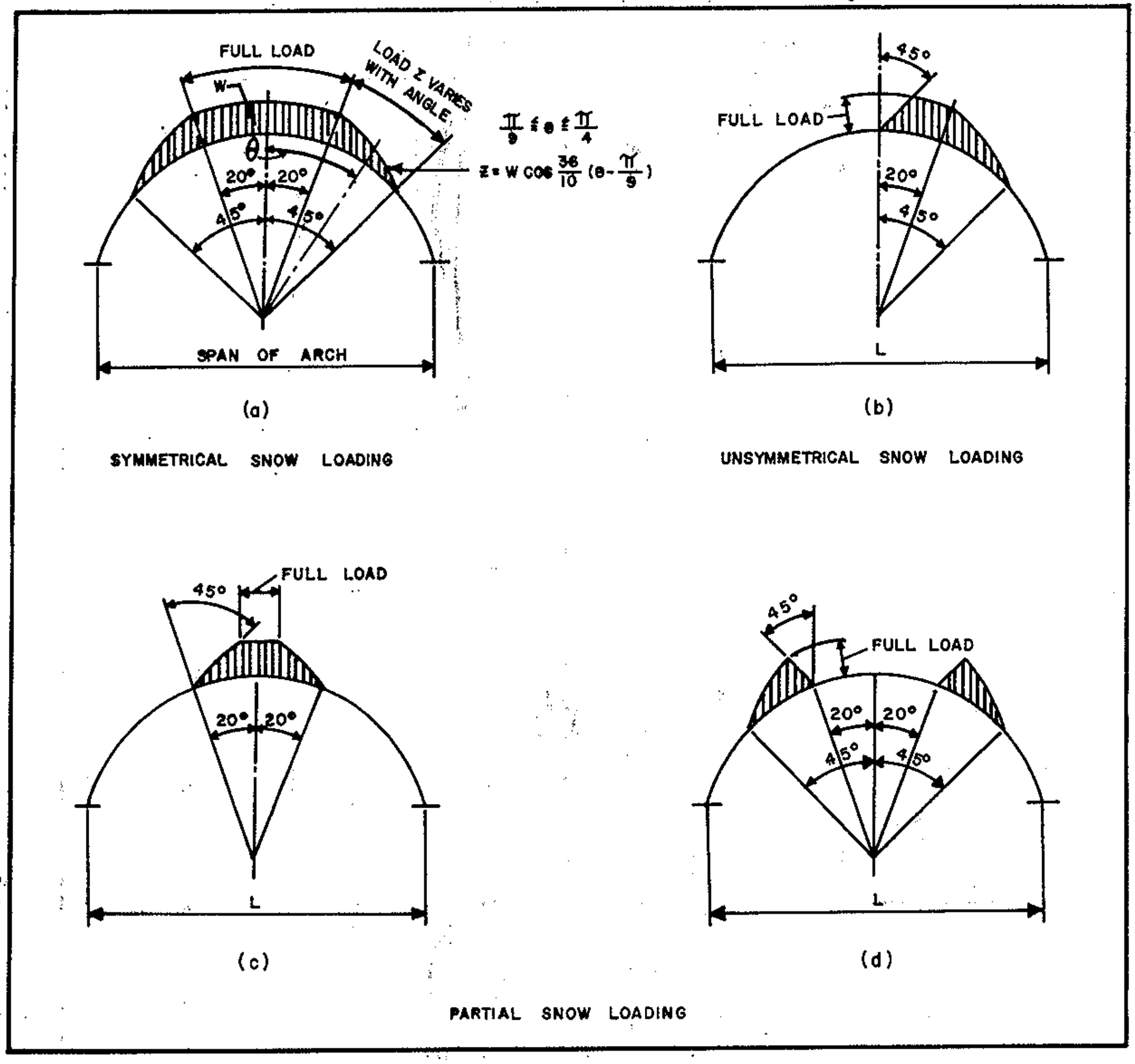


FIGURE 1-2
Snow Load on Arches

Member	*Increase (%)*
Beams	100
Columns	80
Foundations, footings, and piers	40

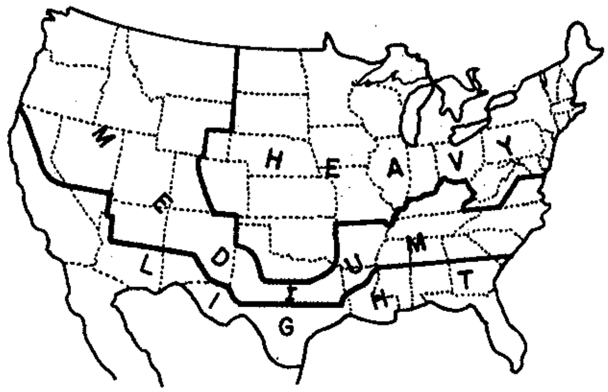
b. Machinery. For reciprocating machinery or heavy power-driven units, increase loads a minimum of 50 percent. For light shaft or motor-driven machinery, increase loads a minimum of 25 percent.

c. Crane Runways and Supports. Percentages of increase for impact on crane runways and supports are listed in Table 1-7.

d. Highway Loadings. Highway loadings are listed in the AASHO Standards.

e. Railway Loadings. Proper railway loadings are specified in the AREA Manual.

f. Escalators. Add 15 percent to total of dead plus live load.



(a) GEOGRAPHIC DISTRIBUTION

LOADING DISTRICT	RADIAL THICKNESS OF ICE (In)
HEAVY	0.50
MEDIUM	0.25
LIGHT	NONE

(b) THICKNESS OF ICE COVERING

FIGURE 1-3
Ice Load on Antenna Supports and Transmission Line Structures

TABLE 1-7
Crane Runways and Supports, Load Increases for Impact

Capacity of hook load (short tons)	Load increase expressed as percent of maximum crane reaction							
	Speeds 200 fpm or less				Speeds exceeding 200 fpm			
	Overhead traveling crane, traveling wall crane		Fixed revolving cranes	Traveling revolving cranes	Overhead traveling crane, traveling wall crane		Fixed revolving cranes	Traveling revolving cranes
	Runway girders	Columns	Towers	Docks, piers, tracks	Runway girders	Columns	Towers	Docks, piers, tracks
25 or less	15	12	15	12	18	14	18	15
26 to 50	13	10	13	10	15	10	15	12
51 to 80	10	9	10	8	12	12	12	10
81 to 120	9	7	9	6	10	8	10	8
121 to 180	8	6	8	6	9	7	9	8
Over 180	6	5	6	6	8	6	8	8

9. VIBRATIONS. Vibrations are induced in structures by reciprocating and rotating equipment, rapid application and subsequent removal of a load, or by other means. Vibrations take place in flexural, extensional, or torsional modes, or any combination of the three.

a. Resonance. Resonance will occur when the frequency of an applied dynamic load coincides with a natural frequency of the supporting structure. In this condition, vibration deflections increase progressively to dangerous proportions. Prevent resonance by insuring in design that the natural frequency of a structure and the frequency of load application do not coincide.

b. Collateral Reading. For further information on the solutions of vibratory stresses and deflections, see *Soil Mechanics, Foundations, and Earth Structures*, NAVFAC DM-7, and Chapter 9, Section 9 of this manual. Also refer to *Vibration Problems in Engineering* and *Dynamics of Framed Structures* (See Bibliography).

Section 4. WIND LOADS

1. EXTERNAL PRESSURE. Buildings or other structures shall be designed to withstand applicable external wind pressure.

a. Velocity Pressure. Velocity pressure (q) is determined by:

$$q = \frac{1}{2}\rho V^2 C_h = \text{velocity pressure (air at } 15^\circ \text{ C temperature -- sea level)}$$

$$q = \frac{1}{2} \times \frac{0.0765}{32.2} \times \left(\frac{5280}{3600}\right) V^2 \times C_h \qquad (1\text{-}3)$$

$$q = 0.00256\, V^2 C_h,$$

where

q = velocity pressure of wind (psf),
C_h = height correction factor,
V = wind velocity (mph), and
ρ = density of air.

(1) *Wind Velocity.* Peak gust wind speeds are given for the contiguous United States in Figure 1-4 and Table 1-5, and for locations outside the States in Table 1-6. Use a minimum of 80 miles per hour wind velocity for design. For locations subject to hurricanes, typhoons, or other winds in excess to 90 miles per hour, Chapter 9, Section 9 provides additional criteria and recommendations for design.

(2) *Gust Factors.* Gust factors are incorporated in the peak gust wind speeds given in Figure 1-4 and Tables 1-5 and 1-6. Use of the peak gust speed eliminates the need for estimation of the gust factor. The gust factor is variable, dependent on the general wind speed level at the particular location. The peak gust velocity indicated is assumed to be sustained for an interval of 2 to 3 seconds, and therefore will ordinarily be treated as a steady wind because the natural response period of most structures is less than 1.5 seconds. When the response period of the structure exceeds 1.5 seconds, appropriate methods of analyses for dynamic forces shall be used.

(3) *Correction Coefficient for Height.* Use curve A of Figure 1-5 or Equation 1-4 to obtain the correction coefficient for velocity pressures above 30 feet. The correction factor, C_h, below 30 feet is equal to 1.0. The correction factor above 30 feet is

$$C_h = \left(\frac{h}{30}\right)^{2/7}, \qquad (1\text{-}4)$$

for h = 100 feet

$$C_h = \left(\frac{100}{30}\right)^{2/7} = 1.41.$$

For towers 300 feet and higher refer to Chapter 9.

b. Wind Pressure. The design wind pressure for buildings and other structures shall be determined by the applicable velocity pressure q, (obtained in accordance with Equation 1-3 or Figure 1-5) multiplied by the appropriate shape (Figure 1-12), or pressure coefficients (Figures 1-6 through 1-11).

2. MAIN FRAMES, TRUSSES, AND OTHER MAIN MEMBERS. Design main frames, trusses, and other main members for the external pressure ($p = q \times C$) where C is the shape coefficient.

3. PURLINS, GIRTS, SHEATHING, SIDING, AND FASTENINGS. The maximum loading for purlins, girts, sheathing, siding, and fastenings shall be obtained from the following combinations of loads and shall be used as the design load:

(1) External pressure (p) and internal pressure of 0.6q acting outward as a bursting force.

(2) External pressure (p) and internal pressure of 0.4q acting inward as an internal suction. In the above loading combinations, the internal pressures are assumed to be uniformly distributed over the interior surface of the building.

4. BRACING. Wall and roof bracing shall be designed in accordance with the applicable provisions of Paragraphs 2 and 3 of this section and Chapter 9. Bracing shall be located so that lateral forces will be transmitted as directly as possible to the foundation. Bracing should assist the decking or roofing in diaphragm action, and should be adequate to prevent buckling of compression members, such as columns and compression chords of trusses. Specific requirements follow.

a. Structural Integrity. To insure structural integrity of the building and to provide for structural interaction between walls and roof, bracing shall be designed to transmit wall reactions (at the plane of the roof) to the foundation. In addition, buildings shall be designed as a unit; where diaphragm action exists, it shall be taken into account. Proper anchorage shall be provided between horizontal diaphragms and endwalls. The wall reactions shall be based on the pressure (p); the shape factor (c) for sidewalls and roof, as given in Figures 1-6 through 1-11; the shape factor (c) for endwalls equal to +0.9 and for roof equal to −0.7 with wind normal to the endwall; and internal pressures of 0.6q acting outward as a bursting force, or 0.4q acting inward as an internal suction. The external loadings (p) and internal loadings (+0.6 and/or −0.4q) shall be combined for maximum loading of members.

b. Column Action. For members subjected to the combination of loads listed in Section 8, beam column action of compression members shall be investigated.

5. EAVES AND CORNICES. Overhanging eaves and cornices shall be designed for an upward pressure of twice the external pressure (p).

6. BRIDGE STRUCTURES. Criteria on wind loads and their effect on bridge structures are contained in the AASHO Standards and the AREA Manual.

7. SHIPS. Considerations for wind forces on ships are outlined in *Waterfront Operational Facilities*, NAVFAC DM-25, and *Harbor and Coastal Facilities*, NAVFAC DM-26.

8. TANKS, TOWERS, STACKS AND SIMILAR STRUCTURES.

a. On-Support Structures. Modify wind pressure in accordance with the shape coefficients given in Figure 1-12.

b. Drag Sensitivity. In general, tanks, towers, and stacks are drag-sensitive structures. Consequently, in the design of such structures, the effects of wind-induced vibration shall be investigated.

c. Collateral Reading. For further information, see *Wind-Induced Vibrations in Antenna Members*, ASCE (see Bibliography).

9. EXTERIOR BEAMS AND GIRDERS. The circular cross section is more vulnerable to vortex-shedding phenomenon than other structural shapes. However, failure of standard types of structural members has been attributed to wind-induced vibrations. Little information is available on vibrations in members of I and WF shapes. However, to avoid vortex-shedding phenomenon, rectangular beams and girders should have a width-to-depth ratio of less than 0.75 or greater than 3.5.

10. CRANES AND DERRICKS. For nonoperating conditions, design cranes and derricks for external wind pressures as determined above. For criteria for operating conditions, see *Weight Handling Equipment and Service Craft*, NAVDOCKS DM-38.

11. GUY WIRES AND CABLES. Use the coefficients from the curves in Figure 1-13 to compute the total wind forces on guy wires or cables. The wind direction is assumed to be parallel to the Y direction in the sketch. An inclined plane, determined by the wind direction vector and the guy chord, contains the lift and drag forces. The drag is assumed to act in the direction of the wind, and the lift is assumed to act normal to the drag. For ease of making calculations, the lift force usually is broken into horizontal and vertical components; that is, horizontal component of lift = lift cos ρ; vertical component of lift = lift sin ρ. For additional information, see *Engineering Aerodynamics* (See Bibliography).

Section 5. EARTHQUAKE LOADS

1. CRITERIA SOURCE. Criteria and guidance for the design of buildings in seismic areas shall be in accordance with *Triservice Engineer Manual for Seismic Design for Buildings*, NAVFAC P-355. In addition to NAVFAC P-355, the requirements of paragraphs 1a and 1b, below, shall be applied to the locations indicated. The data in paragraphs 1a and 1b consist of site specific design earthquakes based on microzonation studies and will be extended as more studies are performed.

a. Collapse Resistance Criteria. See Figure 1-3a. In addition to the requirements of NAVFAC P-355, all structures shall be checked for their ability to resist collapse when subjected to a base shear corresponding to $V = S_a W$, where S_a replaces the coefficients ZKC as stated in NAVFAC P-355 and W is the weight of the structure. Distribution of forces will be as stated in NAVFAC P-355. Values of S_a are given in Figure 1-3a.

b. Critical Sturctures Design Criteria. See Figure 1-3b. It is further stipulated that the value of S_a from the Figure 1-3b, or ZKC computed in accordance with NAVFAC P-355 (whichever is larger), be used for calculating base shear for design of "critical" structures. A "critical" structure is one that must remain functional after an earthquake.

c. Parts or Components. For forces on parts or components of a structure, the value computed in accordance with NAVFAC P-355 will be used.

2. EARTHQUAKE ZONES. Earthquake zones are contained in NAVFAC P-355.

Acceleration Response Spectra
Seattle, Washington, Area

(Bangor, Bremerton, Keyport, Seattle, Whidby Island)

(In Addition to NAVFAC P-355 Requirements, Base Shear (V) = SaW)

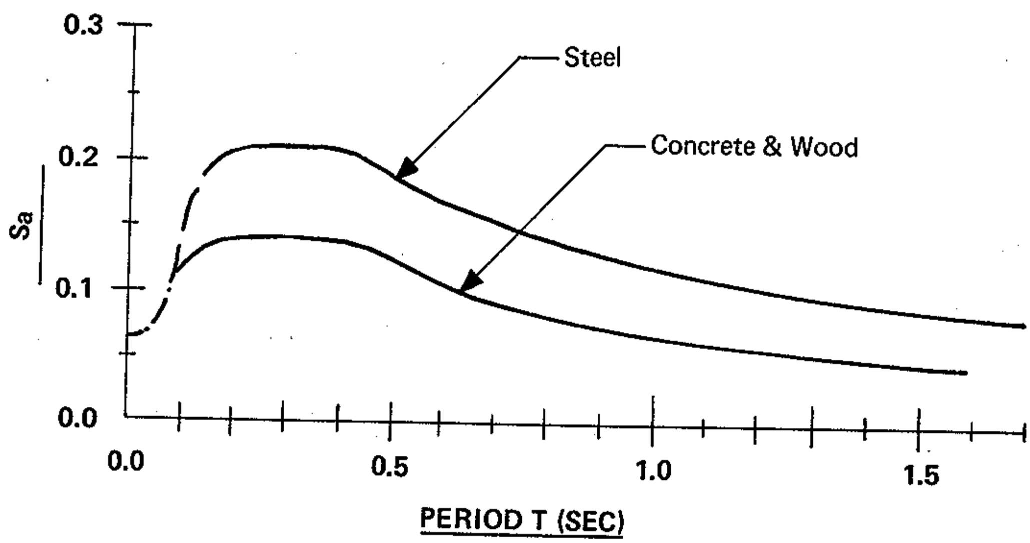


Figure 1-3a
All Structures Collapse Resistance Criteria

NOTES:

1. This criteria is for critical structures only. A critical structure is one that must remain functional after an earthquake.

2. Use yield strength for ductile materials and 1.33 x allowable for brittle materials.

3. Masonry structural systems or steel frames with masonry shear walls, use 0.9 x value for steel shown by curve.

4. For periods between 0.0 and 0.15 seconds, use:
   Sa = 0.15 for steel,
   Sa = 0.10 for other structures.

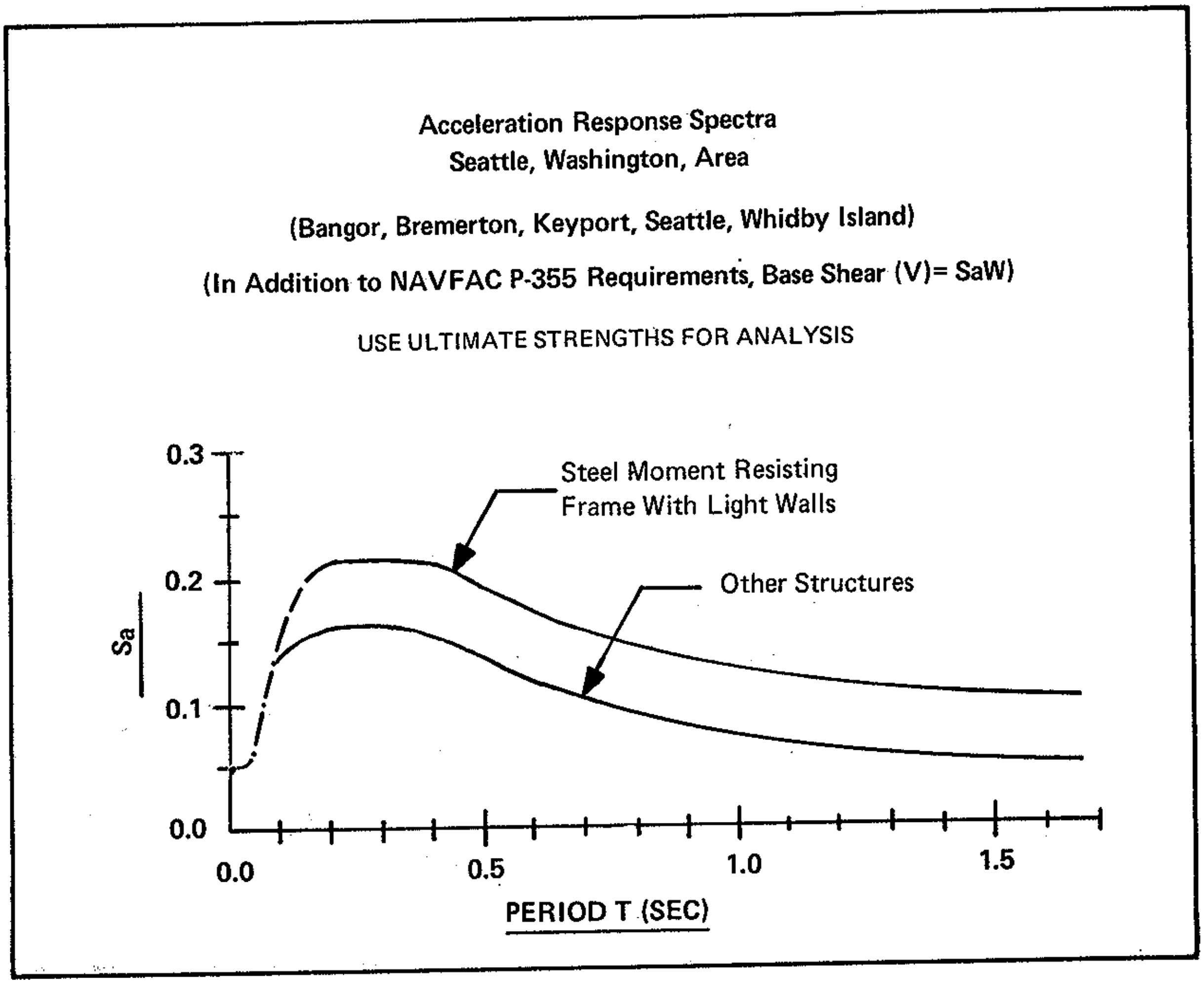


Figure 1-3b
Critical Structures Design Criteria

NOTES:

1. For periods between 0.0 and 0.15 seconds, use:
   $S_a = 0.15$ for moment resisting frames with light walls,
   $S_a = 0.11$ for other structures.

2. For steel moment resisting frames where lateral loads are carried by shear walls, use the curve for "other structures." Where there are some walls or partitions providing shear resistance, the engineer may use a value between the two curves.

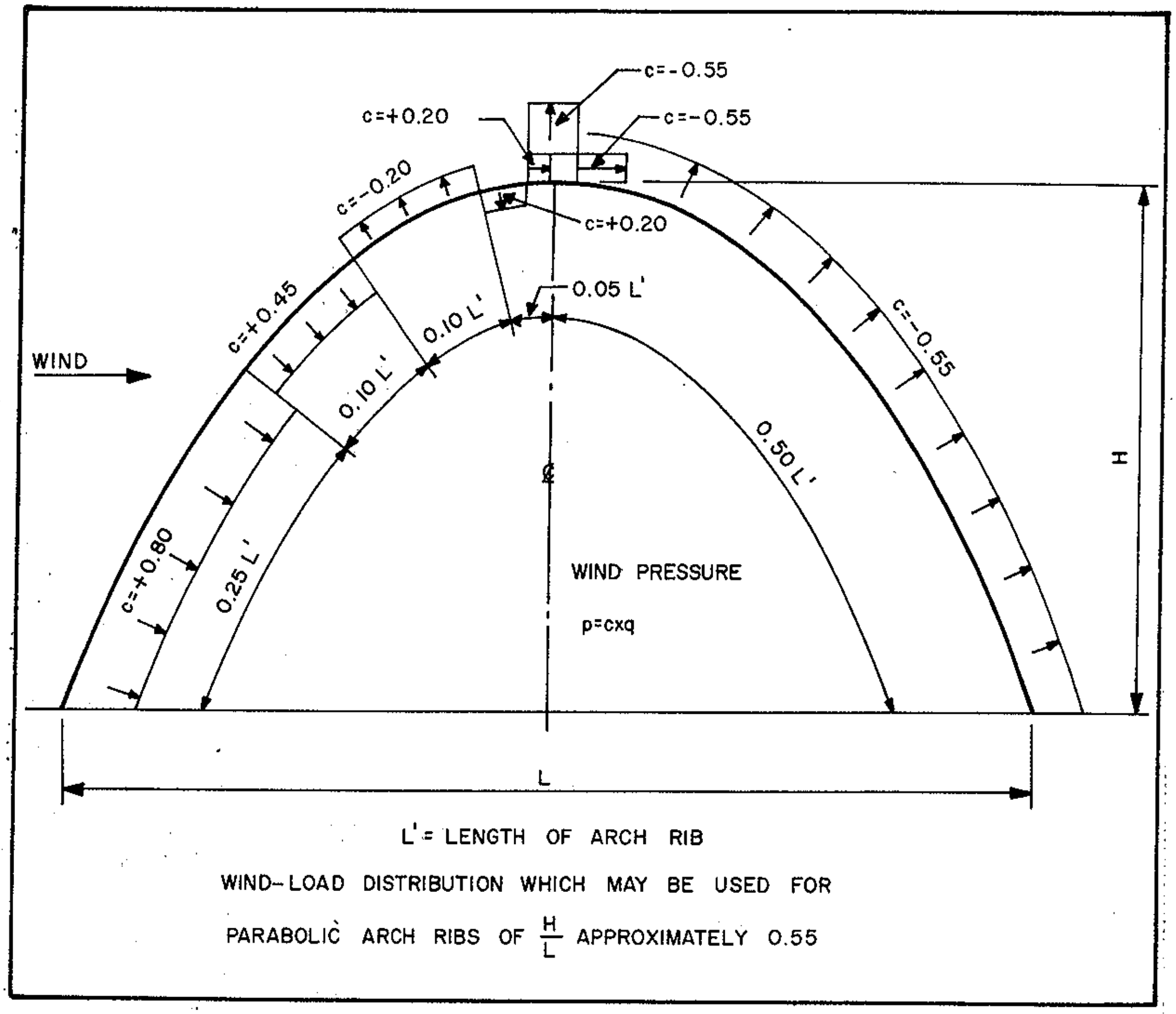
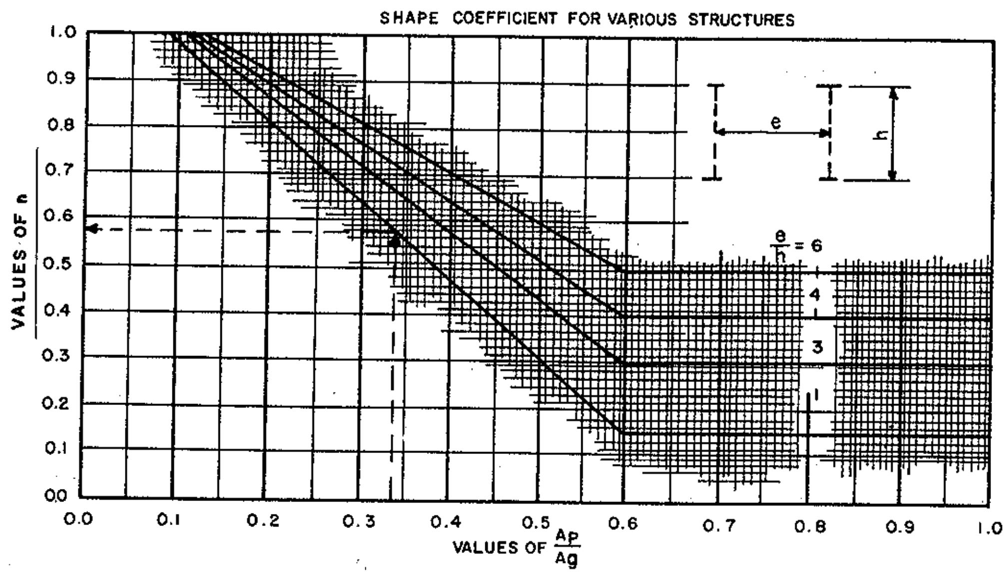


FIGURE 1-11
Wind-Pressure Coefficients for Arch With Monitor



Ap = TOTAL PROJECTED AREA OF MEMBERS ON ONE SIDE OF THE STRUCTURE.

Ag = TOTAL AREA WITHIN THE LIMITING LINES FOR ONE SIDE OF THE STRUCTURE.

P = TOTAL WIND LOAD ON THE STRUCTURE. $P = S x q x A_p$

n IN THE DIAGRAM APPLIES TO TRUSSES AND LATTICED MEMBERS EXCEPT TRIANGULAR TOWERS.

S = SHAPE COEFFICIENT

TYPE OF STRUCTURES	SHAPE COEFFICIENT ON PROJECTED AREA S
DOUBLE PARALLEL SOLID GIRDER	1.10
DOUBLE PARALLEL TRUSSES AND DOUBLE PARALLEL LATTICED MEMBERS	1.6 (1+n)
GIRDERS AND TRUSSES WITH m PARALLEL MEMBERS WHERE m IS MORE THAN 2	1.5+(m−2)0.5
SQUARE AND RECTANGULAR CHIMNEYS	1.20
CONICAL, HEMISPHERICAL AND SEMIELLIPTICAL SURFACES	0.60
SIGNBOARDS	1.20
SPHERES	0.40
TOWERS	
SQUARE CROSS SECTION, WIND ON FACE → □	1.6 (1+n)
SQUARE CROSS SECTION, WIND ON CORNER → ◇	1.92 (1+n)
TRIANGULAR CROSS SECTION, WIND ON FACE → ▷	2.26
TRIANGULAR CROSS SECTION, WIND ON CORNER → ◁	1.93

USE 2/3 OF ABOVE VALUES FOR CYLINDRICAL MEMBERS

CYLINDRICAL SURFACES

TANKS, RISERPIPES, CHIMNEYS, FLAGPOLES, ANTENNAS AND SIMILAR STRUCTURES

LENGTH/DIAMETER	1	2	3	10	20	40	∞
S	0.63	0.69	0.75	0.83	0.92	1.00	1.20

FIGURE 1-12
Shape Coefficients for Miscellaneous Structures

d. Other Bearings. Use the *Mechanical Engineers Handbook* (see Criteria Sources) for coefficients of friction. Base the forces on dead load reactions plus any applicable longtime live load reactions.

7. SHRINKAGE.

a. Stress. Arches and similar structures shall be investigated for stresses induced by shrinkage and rib shortening.

b. Coefficient of Shrinkage. For masonry structures, the minimum linear coefficient of shrinkage shall be assumed as 0.0002, and the theoretical shrinkage displacement shall be computed as the product of the linear coefficient and the length of the member.

8. FOUNDATION DISPLACEMENT AND SETTLEMENT. Criteria for foundation displacement and settlement are outlined in *Soil Mechanics, Foundations, and Earth Structures,* NAVFAC DM-7.

9. FROST DEPTH. See Figure 1-14 and Tables 1-5 and 1-6.

10. BOMB AND BLAST LOADS. For forces due to bomb impact and blast waves, see Criteria Sources indicated in Chapter 9.

Section 7. DISTRIBUTION OF LOADS

1. VERTICAL LOADS. For distribution of concentrated loads, use AASHO Standards, Section 3. Also see *Engineering Monograph No. 27,* Bureau of Reclamation (Bibliography).

2. HORIZONTAL LOADS.

a. Distribution of Horizontal Shears. Reinforced concrete slabs and other similar permanent structural elements may be assumed to act as horizontal diaphragms to transfer lateral loads to the resisting vertical elements. Distribution to the vertical elements shall be proportional to their rigidities, or distribution of rigidities, or both.

b. Symmetry of Elements. The center of rigidity of resisting vertical elements should coincide with the resultant of the lateral loads. Otherwise, provide for any resulting torsional moment or shear.

c. Overturning. The stability moment, computed for dead loads only, shall be a minimum of 1.5 times the overturning moment, unless the structure is anchored so as to resist the excess overturning moment. The weight of earth superimposed over footings may be included in computing the moment of stability due to dead loads.

d. Sliding. For factor of safety against sliding, refer to *Soil Mechanics, Foundations, and Earth Structures,* NAVFAC DM-7.

Section 8. COMBINED LOADS

1. HIGHWAY REQUIREMENTS. Standards for combined loads applicable to highway requirements are contained in the AASHO Standards.

2. RAILWAY REQUIREMENTS. Combined loads applicable to railway requirements are found in the AREA Manual. (See Criteria Sources.)

3. TOWERS. See Chapter 9.

4. OTHER STRUCTURES. Except as provided in specific design manuals, structures other than those indicated above shall be designed for the following combinations of loads with corresponding allowable stresses:

Load combinations	*Percentage of basic stress*
Dead + live + impact	100
Dead + wind	133
Dead + live + wind	133
Dead + live + impact + wind	133
Dead + live + impact + lateral + longitudinal forces	100
Dead + live + impact + earthquake	133
Dead + live + impact + temperature + friction + shrinkage	125
Other improbable and/or infrequent loading combinations or loads of short duration	133

Members may be proportioned for stresses greater than the basic unit stress, provided the sections thus established are not less than those required for load combinations with no increase in basic stress.

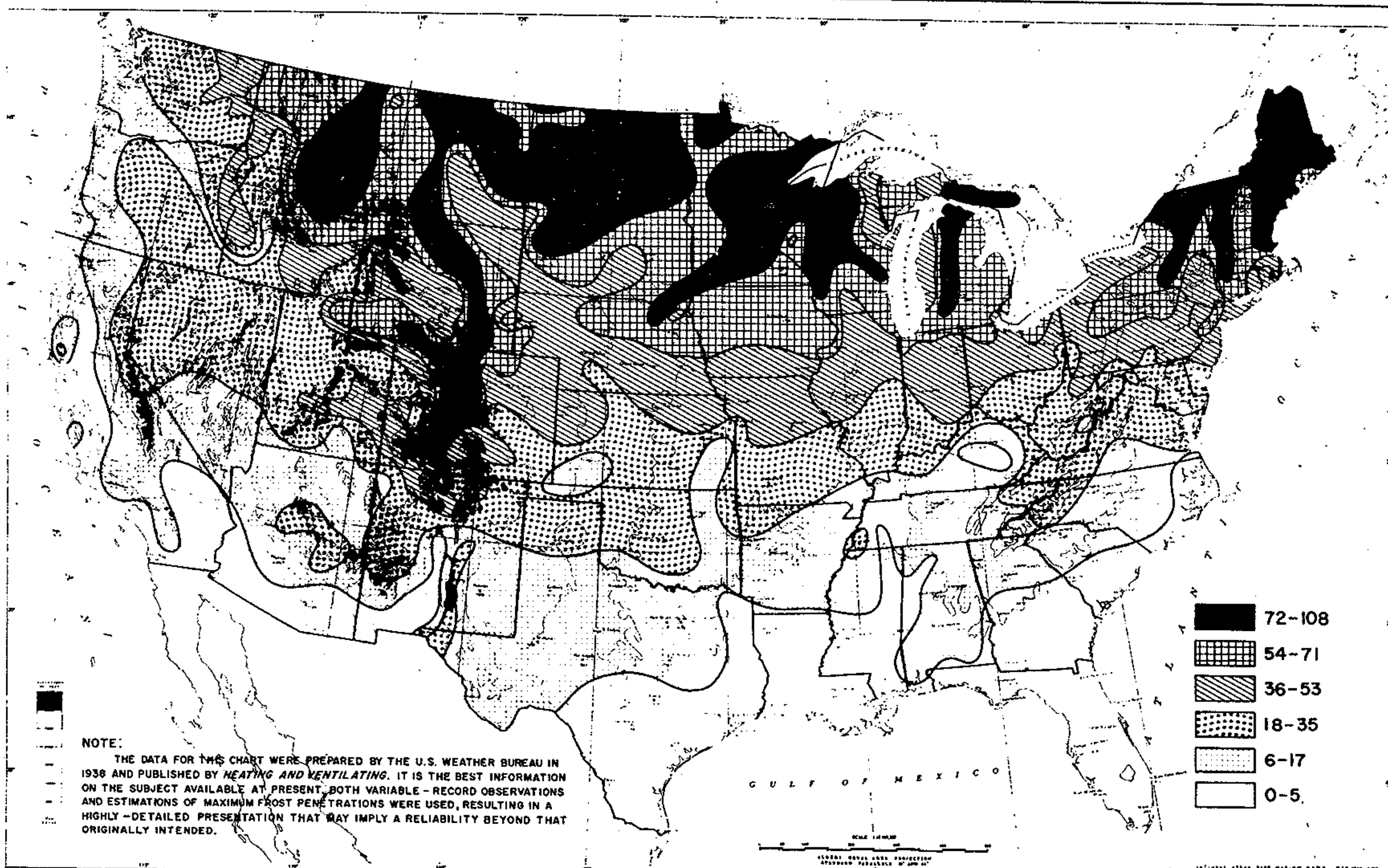


FIGURE 1-14
Maximum Depth (in Inches) of Frost Penetration for Contiguous States