Wind Pressures in Various Areas of the United States

United States Department of Commerce

National Bureau of Standards

Building Materials and Structures Report 152

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Wind Pressures in Various Areas of the United States

Guttorm N. Brekke

Building Materials and Structures Report 152

Issued April 24, 1959

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.
Price 15 cents

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Wind Pressures in Various Areas of the United States

Guttorm N. Brekke [1]

A procedure is described for developing a wind-pressure map that shows minimum resultant wind pressures (30 feet above ground) for design purposes throughout the continental United States. This map was used in the 1955 revision of the American Standards Association's standard A58.1, *American Standard Building Code Requirements for Minimum Design Loads in Buildings and Other Structures*.[2] It is based on records of annual fastest-single-mile wind speeds at 155 U. S. Weather Bureau stations. In computing resultant wind pressures from these data, allowance was made for gusts and for building shape. Values for 15 of the stations were also adjusted for altitude or for unusual local wind conditions. A table of design wind pressures at various heights from less than 30 to more than 1,200 feet above ground is derived for use with the map. The principal sources of strong winds affecting building constructions are briefly reviewed.

1. Introduction

Experience has shown that the derivation of wind pressures used in designing structures and writing building codes is freqently misunderstood. At the same time, a need has been observed for greater emphasis on a wind-pressure map as a primary tool for determining minimum design wind pressures at any particular location within the United States.

This paper contains a step-by-step description of procedures used to develop a design wind-pressure map for the United States and to construct a table of wind pressures for different heights above ground. Major emphasis is placed on the method used to calculate wind pressures from recorded wind speeds. However, a number of other factors that affect the final value of minimum design wind pressure are also considered. These include the effect of gusts, variation of wind speed with height above ground, altitude above sea level, distance from the seacoast, topographical configuration, and the frequencies of various types of storms.

In revising the 1945 standard, *American Standard Building Code Requirements for Minimum Design Loads in Buildings and Other Structures*, A58.1, a new wind-pressure map (fig. 1) was developed. It was originally prepared by the National Bureau of Standards, with the assistance of the U. S. Weather Bureau, for use by American Standards Association Sectional Committee A58. After careful study, the new map was accepted by the Committee and now appears in the revised standard, dated 1955.

In the 1945 edition of A58.1, a table of design wind loads had a prominent place in the standard, whereas the wind-pressure map appeared in the appendix. The table gave the wind-pressure values for different heights starting with a value of 20 lb/ft^2 at 30 ft above the ground. However, it did not show the increase in wind pressure with height above ground for those areas in which the wind pressures differed from 20 lb/ft^2 at 30 ft. To remedy this situation, the wind-pressure map in the 1955 revision showing design wind loads at 30 ft above ground throughout the United States was included in the standard, together with a table showing the increase in wind pressure with height for each wind-pressure area on the map.

It should be noted that minimum wind loads recommended by existing building codes are often quite different from those given on the wind-pressure map in A58.1–1955. These differences may be due to the use of different sources of data or a different method of determining wind pressures from recorded wind speeds. The values given on the map are based on the fastest-single-mile wind speeds reported during the 39 years prior to 1952.

2. Principal Sources of Strong Winds

The discussion (sec. 5) of the determination of minimum resultant wind pressures and of the development of the map may be more readily understood if, first, the types and sources of the strong winds involved are briefly reviewed.

According to the U. S. Weather Bureau, the principal sources of strong winds are cyclonic storms, frontal regions, tropical cyclones (hurricanes), severe thunderstorms, squalls, tornadoes, and special winds. The driving force of winds depends upon the horizontal pressure gradient (closeness of isobars); the steeper the pressure gradient, the greater the tendency for strong winds.

2.1. Cyclonic Storms

Cyclonic storms, or extratropical cyclones, are the low-pressure areas in the middle latitudes, particularly those with steep horizontal-pressure gradients. These storms cover circular or nearly circular areas with an average diameter of about 1,500 miles. Unlike tropical cyclones, which affect only small areas, a cyclonic storm may cause precipitation and cloudiness over an area of 1 million or more square miles.

[1] Dr. Brekke was formerly with the National Bureau of Standards, now retired.

[2] Obtainable from the American Standards Association, 70 East 45th Street, New York 17, N. Y., for $1.50 a copy.

2.2. Frontal Regions

A frontal region is a region of transition between two air masses of different temperatures, densities, or wind speeds, in which relatively steep gradients characterize the horizontal variations of such elements. Strong, gusty winds are usually associated with frontal regions when the horizontal pressure gradient is very steep.

A frontal region may contain either a cold front or a warm front. A cold front is a line at the earth's surface along which the forward edge of relatively cool air acts like a wedge in underrunning and displacing a warmer air mass. A warm front is a line at the earth's surface along which the forward edge of an advancing current of relatively warm air is replacing a retreating colder air mass.

2.3. Tropical Cyclones (Hurricanes)

Tropical cyclones are severe storms accompanied by strong, squally winds ranging from 75 to 150 mph. Those of concern to the United States are the hurricanes which develop over the Caribbean Sea, Gulf of Mexico, or neighboring Atlantic waters, and which affect the southern, southeastern, and eastern coasts of the United States. When they move northward, their characteristics become somewhat modified. Thus, when such storms move inland they may tend to dissipate, especially if their moisture supplies are cut off as they move over a homogeneous land environment or impinge against mountains, producing heavy rain. However, when these storms move along a path that permits a continuous influx of moisture from the neighboring ocean or a lake, they may display considerable energy and do much damage from strong winds, water action, or precipitation. If conditions are such that the circulation about the storm draws in cold air as it moves into middle latitudes, it may develop into a large extratropical cyclone of great intensity.

2.4. Severe Thunderstorms and Squalls

Severe thunderstorms and squalls are often observed in conjunction with fronts, frequently with prefrontal squall lines and at other times as severe local storms. A squall is a wind of considerable intensity caused by atmospheric instability; it is characterized by gusts that rise quickly and fall gradually. A squall is sometimes accompanied by thunder, lightning, and precipitation, and is often named after the special weather phenomenon that accompanies it; e.g., rain, snow, or hail squall [1, 2].[3]

[3] Figures in brackets indicate the literature references at the end of this paper.

2.5. Tornadoes

Tornadoes are violent whirlwinds producing narrow vortices[4] with cores of low atmospheric pressure. The wind pressures and suctions in the immediate path of tornadoes are considered to be so great that construction strong enough to withstand them is not economically feasible. Therefore, in recommending design wind pressures, building codes do not take into consideration the violent forces that can be expected within the narrow path of a tornado.

It is well known that there is usually a significant difference between the pressure of the core of a tornado and the pressure of the surrounding area and that this is believed to be the cause of the so-called "explosion" of tightly closed buildings over which the vortex passes. In the U. S. Weather Bureau's publication on tornado safety rules,[5] there are recommended, among other things, certain measures believed to be helpful in relieving interior pressures that might occur at the time of a tornado passage [3, 4, 5].

2.6. Special Winds

Special winds are associated with mountainous or other topographical configurations where steep pressure gradients and strong downward accelerations occur along steep slopes. Such winds are the Santa Ana winds in southern California; the gorge winds in the Columbia River Valley of Washington and Oregon; the Wasatch Mountain winds in Utah; and the Chinook winds along the eastern slope of the Rockies in Montana, Wyoming, and Colorado [6]. No specific minimum allowable wind pressures are assigned to the regions of these winds for design purposes. However, attention is called to these regions on the wind-pressure map in order that special precautions may be taken against unshielded exposures when important wind-sensitive buildings are to be erected.

3. Definitions

For the purpose of this discussion, the following definitions are submitted:

Design wind pressure. The gust-velocity pressure times a shape factor.

Effective height. The theoretical distance above ground at which a given anemometer would register a mean wind speed equal to that which would be observed if there were no obstructions such as buildings or trees in the vicinity.

Fastest-single-mile wind speed. The wind speed in miles per hour based on the shortest recorded time interval in which the wind traveled a horizontal distance of one mile relative to the earth.

[4] By vortex is meant a column of air whirling around a core of low pressure.
[5] See U. S. Weather Bureau Tornado Safety Rules, January 1952. Means for ventilation can be installed to obviate or mitigate the destructive effects of unequal pressure (see references 3, 4, and 5).

Gust. A sudden brief increase in the speed of the wind due to turbulence set up by some surface obstacle, by eddies, or by thrusts of more rapidly moving air from the free atmosphere.

Gust factor. The ratio between the true gust speed and the fastest-single-mile speed.

Gust-velocity pressure. The velocity pressure multiplied by the square of the gust factor.

Modified shape factor. The shape factor appropriate for a given structure relative to the shape factor for rectangular buildings (1.3) which is included in the values on the map and in the table of A58.1–1955 and of this paper.

Normal sea-level conditions. Barometric pressure $(B)=29.92$ in. mercury; temperature $(t)=59°$ F; and acceleration of gravity $(g)=32.2$ ft/sec^2.

Resultant wind pressure. For the purpose of this paper, the gust-velocity pressure at a given height multiplied by the shape factor for rectangular buildings, 1.3. The value 1.3 is the resultant of the pressure and suction coefficients on the exterior walls (0.8 for the windward and −0.5 for the leeward wall); it thus represents the total force exerted per square foot of exposed surface.

Shape factor. The ratio of the actual wind pressure on a building or structure to the theoretical wind pressure or velocity pressure.

Velocity pressure. The pressure developed when air of a given velocity is brought to rest by impact (variously called dynamic pressure, impact pressure, stagnation pressure).

Wind-sensitive buildings. For the purpose of this paper, buildings for which wind loads are the major external loads.

4. Letter Symbols and Abbreviations

Letter symbols and abbreviations used in this paper are defined below:

B = barometric pressure, inches of mercury,
C_R = shape factor for rectangular buildings (see Definitions),
C_{G30} = gust factor at 30 ft above ground,
C_{GH} = gust factor at H ft above ground,
g = acceleration of gravity, ft/sec^2,
H = a specified height above ground, ft,
h = height of anemometer above ground, ft,
P_{i30} = minimum allowable resultant wind pressure at 30 ft above ground, lb/ft^2,
P_{iH} = minimum allowable resultant wind pressure at H ft above ground, lb/ft^2,
q_o = velocity pressure $=\frac{1}{2}\rho v^2$, lb/ft^2,
q_{30} = velocity pressure at 30 ft above ground, lb/ft^2,
q_{i30} = gust velocity pressure at 30 ft above ground, lb/ft^2,
ρ = density of air (mass of unit volume), slugs per ft^3 or (lb sec^2/ft^4),
t = temperature, ° F,
v = wind speed, ft/sec,
V = wind speed (fastest-single-mile speed), mph,
V_h = recorded wind speed at anemometer height h, mph,
V_{30} = wind speed at 30 ft above ground, mph,
V_{i30} = gust wind speed at 30 ft above ground, mph,
V_H = wind speed at height H, mph,
V_{iH} = gust wind speed at H ft above ground, mph.

5. Computation of Minimum Allowable Wind Pressures

To provide a basis for the wind-pressure map, minimum allowable wind-pressure values at 30-ft heights were computed for representative locations throughout the United States. The computations involved the previously mentioned conditions that affect wind pressures; however, the basic formula used was eq (1) which gives velocity pressure in lb/ft^2:

$$q_o=\frac{1}{2}\rho v^2, \tag{1}$$

where ρ is the density of air, 0.00238 lb sec^2/ft^4 (at normal sea-level conditions), and v is the wind speed expressed in feet per second. When the wind speed is given in mph, V,

$$q_o=\frac{1}{2}\times 0.00238\times\left(\frac{5{,}280}{3{,}600}\right)^2 V^2=0.00256\ V^2. \tag{2}$$

The original computations were made on the basis of normal sea-level conditions, realizing that modifications would be necessary for those stations at high elevations where the decrease in air density and temperature was sufficient to have an appreciable effect on the resulting wind pressure (see sec. 6.1). For the greater part of the country, the height above sea level is not enough to cause any significant differences.

The next step was to obtain appropriate values for V and to substitute them in eq (2) along with the other factors that would affect the minimum allowable wind pressures.

5.1. Minimum Allowable Wind Pressures at 30 Feet

Through the courtesy of Herbert C. Thom, Chief Climatologist, U. S. Weather Bureau, the latest data were obtained for the maximum recorded single-mile wind speeds at 155 well-distributed U. S. Weather Bureau stations. These data are given as monthly maximums and, in most cases, covered a period of about 39 years prior to 1952. The maximum single-mile wind speed ever recorded at a station was used to calculate the wind pressure for that station.

Information on the height of the anemometer above ground at the time the maximum wind speed occurred was also necessary, as the wind speeds had to be adjusted to the previously selected height of 30 ft. This height corresponds approximately to the 10 m (about 33 ft) which is the international standard for effective height. For 149 of the 155 stations, the local climatological summary for each station included this information. For the remaining 6 stations, at which the anemometer height was unknown, a height of 30 ft was used.

To adjust the 149 fastest-single-mile wind-speed values V_h, observed at anemometer height, h, to the wind speed at a height of 30 ft, V_{30}, the 1/7-power relationship was used:

$$V_{30}=V_h\left(\frac{30}{h}\right)^{1/7}. \tag{3}$$

Then, in order that the final resultant wind pressure represent the maximum to be expected at any time during the life of a building, it was necessary to take into account the gusts that occur during the time interval for the passage of a mile of air. To do this, the wind speed, V_{30}, was multiplied by 1.3, which is the gust factor at 30 ft (see page 6 for discussion of gust factors). Denoting the gust factor at 30 ft as C_{G30}, and the corresponding gust wind speed as V_{i30}, we have

$$V_{i30}=C_{G30}V_{30}=1.3\ V_h\left(\frac{30}{h}\right)^{1/7}$$

$$=1.3\ \ 30^{1/7}V_h\times h^{-1/7}. \tag{4}$$

This value for V_{i30} may now be substituted for V in eq (1) and the corresponding velocity pressure at 30 ft, q_{i30}, then becomes

$$q_{i30}=0.00256\ (V_{i30})^2$$

$$=0.00256\times 1.3^2\times 30^{2/7}\times (V_h)^2\times h^{-2/7}$$

$$=0.01143\ (V_h)^2\times h^{-2/7}. \tag{5}$$

On the map prepared for A58.1—1955, it was decided to present the wind pressures as minimum allowable pressures for direct use in design of ordinary rectangular buildings rather than as velocity pressures as was done in the 1945 standard. This required one additional step to take into consideration the shape factor, C_R, for rectangular buildings.

The resultant wind pressure, P_{i30}, at the 30-ft height is then given by

$$P_{i30}=C_R\times q_{i30}, \tag{6}$$

where C_R is equal to 1.3, the resultant of the pressure and suction coefficients on the exterior walls, 0.8 for the windward and −0.5 for the leeward wall. By substituting for q_{i30} as given by eq (5),

$$P_{i30}=1.3\times 0.01143\ (V_h)^2\times h^{-2/7}$$

$$=0.01486\ (V_h)^2\times h^{-2/7}. \tag{7}$$

By substituting the Weather Bureau values for the fastest-single-mile wind speed, V_h, and the height of anemometer, h, in eq (7), the minimum allowable resultant wind pressure at 30 ft is readily calculated.

It was found that the distribution of wind-pressure values was such that by rounding off these values to the nearest numbers divisible by 5, the entire country could be divided into sizable areas representing 5-lb/ft² intervals between 20 and 50 lb/ft². In plotting wind pressures near the seacoast on the map, it was necessary to take into account the gradual decrease in wind pressure with distance from the coast. In the absence of precise experimental data on this effect, the high-pressure winds along the seaboard due to hurricanes and other severe storms were reduced stepwise to the lower pressures prevailing inland. This accounts for the three or four zones along the coast, each approximately 30 miles wide (totaling 90 to 120 miles) and each representing a 5-lb/ft² decrease in wind pressure. This procedure seemed reasonable considering the following statement by W. T. Van Orman [7]:

> We know definitely from temperature studies, from balloon flights, and similar phenomena, that the direct influence of the sea breezes extends at least 30 miles inland. Furthermore, it is also reasonable that the complete damping influence of the surface friction of the land area is not fully effective until a distance of about 100 miles from the Atlantic seaboard has been reached.

5.2. Wind Pressures at Height *H*

Table 1 gives the design wind pressures at various heights above ground for each of the wind-pressure areas indicated on the map. These

Table 1. *Design wind pressures for various height zones above ground* [a]

Height zone	Wind-pressure-map areas (lb/ft²)						
	20	25	30	35	40	45	50
ft	Design wind pressures, lb/ft²						
Less than 30	15	20	25	25	30	35	40
30 to 49	20	25	30	35	40	45	50
50 to 99	25	30	40	45	50	55	60
100 to 499	30	40	45	55	60	70	75
500 to 1,199	35	45	55	60	70	80	90
1,200 and over	40	50	60	70	80	90	100

[a] This table is designed for use with the wind-pressure map (fig. 1). The wind pressure at any height is found in the body of the table under the column heading giving the minimum resultant wind pressure for any particular locality on the map.

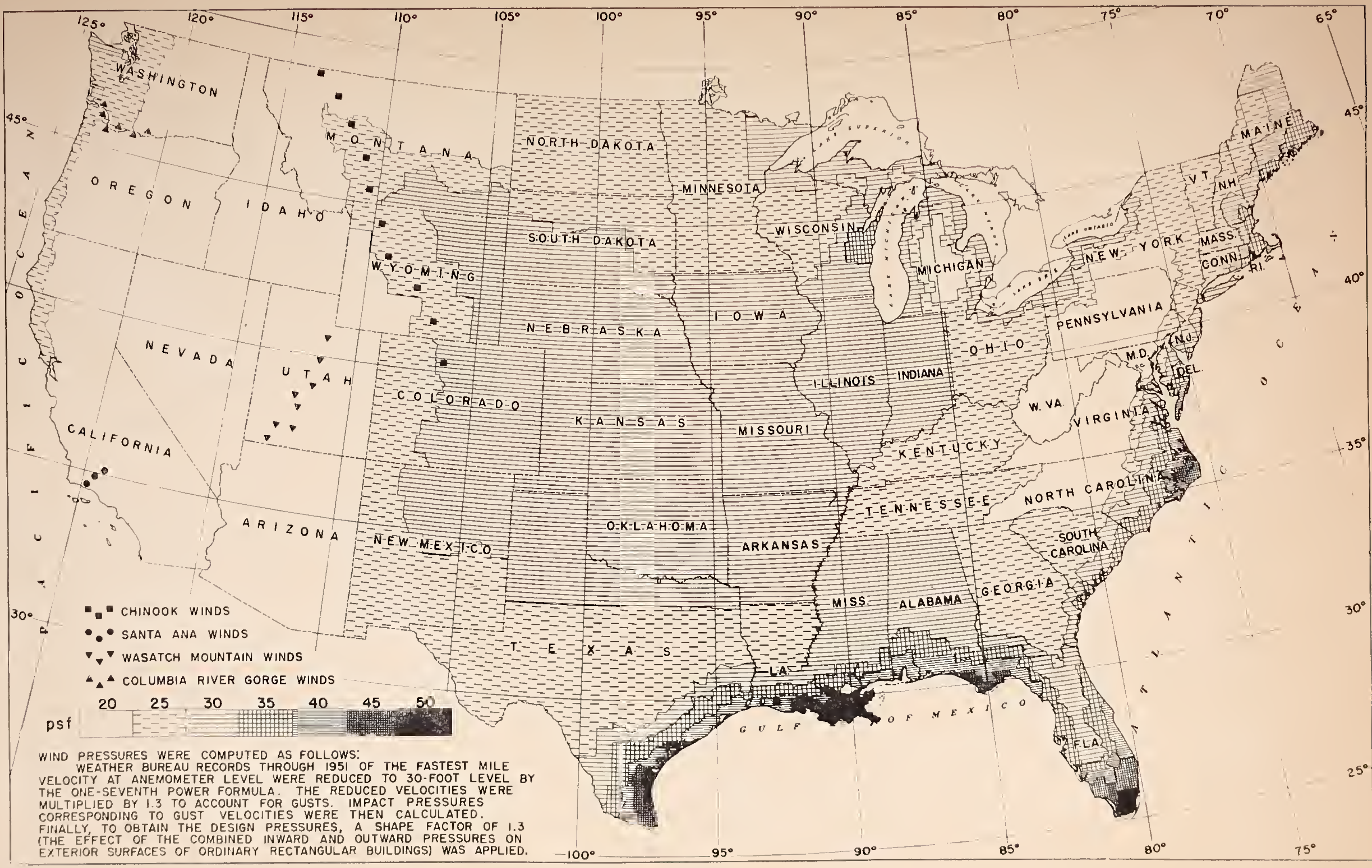

FIGURE 1. *Minimum allowable resultant wind pressures at 30 feet.*

values were obtained by using the wind speeds at 30 ft and taking into account: (a) increase in wind speed with height; and (b) decrease in the gust factor with height.

Inasmuch as both the wind speed at height H, V_H, and the wind speed at a height of 30 ft, V_{30}, are given by the 1/7-power formula, these two wind speeds are related as follows:

$$V_H = V_{30}\left(\frac{H}{30}\right)^{1/7}. \tag{8}$$

Then if the gust factor, C_{GH}, which decreases with height above ground, is taken into account as was done in eq (4), the gust wind speed, V_{iH}, at height H can be obtained. The values for the gust factor used in these computations are based on rather limited data and are those recommended by aerodynamic authorities at the National Bureau of Standards and the U. S. Weather Bureau. They are the values 1.3 at 30 ft (as was used in eq (4)), 1.14 at 500 ft, and 1.08 at 1,200 ft. Thus, the gust wind speed, V_{iH}, at height H is given by

$$V_{iH} = C_{GH}V_{30}\left(\frac{H}{30}\right)^{1/7}. \tag{9}$$

The values for C_{GH} between 30, 500, and 1,200 ft were interpolated as follows: Between 30 and 500 ft, $C_{GH}=1.3-(0.16/470)(H-30)$; and between 500 and 1,200 ft, $C_{GH}=1.14-(0.06/700)(H-500)$, where H is the specified height above ground, in feet.

By taking into account the shape factor for rectangular buildings, C_R, the resultant wind pressure, P_{iH}, at any height H is

$$\begin{aligned} P_{iH} &= C_R \times 0.00256(V_{iH})^2 \\ &= 1.3\times 0.00256(C_{GH})^2(V_{30})^2\, H^{2/7}\, 30^{2/7} \\ &= 0.00126(C_{GH})^2(V_{30})^2\, H^{2/7}. \end{aligned} \tag{10}$$

Substitution of values for H, and the corresponding values for C_{GH} as interpolated, and the value for V_{30} which was used in calculating the wind pressure at 30 ft, in eq (10) gave the wind pressures for the various heights in table 1.

6. Adjusted Wind-Pressure Values for 15 Stations

For 140 of the 155 stations, the design wind loads calculated from eq (7) were such that areas of approximately the same wind load could be fairly well defined on the map. However, for each of the remaining 15 stations, this equation gave a result that was much greater than the average of the other stations in the same area.

In each case, there appeared to be special conditions which caused the computed value for each of these 15 stations to be greater than that of the area surrounding it. These special conditions and the reasons for reducing the computed wind-pressure values are discussed in the following sections. Table 2 shows the computed values together with the wind pressure shown on the map for the surrounding area.

TABLE 2. *Adjusted minimum allowable resultant wind pressures*

Stations	Minimum allowable resultant wind pressures	
	From eq (7)	Map value
	lb/ft²	*lb/ft²*
Albuquerque, Bernalillo County, N. Mex.	40	30
Block Island, Newport County, R. I.	40	35
Cape Henry, Norfolk County, Va.	85	40
Evansville, Ind.[a]	45	30
Green Bay, Brown County, Wis.	65	35
Hatteras, Dare County, N. C.	60	45
Indianapolis, Ind.[a]	40	30
Marquette, Marquette County, Mich.	40	30
Miami, Dade County, Fla.	80	50
North Head, Pacific County, Wash.	50	30
Omaha, Nebr.[a]	50	30
Pueblo, Pueblo County, Colo.	35	30
Sheridan, Sheridan County, Wyo.	35	30
Tatoosh Island, Clallam County, Wash.	40	30
Wichita, Kans.[a]	35	30

[a] Counties are not mentioned because the area of the whole State is involved.

6.1. Variation With Altitude

Table 3 gives the variation of the coefficient of V^2 in eq (2) as ρ varies with temperature and altitude. Up to this point, this coefficient has been considered constant at 0.00256, the value for dry air at normal sea-level conditions. However, at higher altitudes this assumption is not justified. For three entries in table 2 (Albuquerque, N. Mex.; Sheridan, Wyo.; and Pueblo, Colo.), a temperature of 59° F was assumed and correction for barometric-pressure change with elevation was made.

Albuquerque, for example, has an elevation of 5,000 ft. The minimum allowable resultant wind pressure corrected for the air density at 5,000 ft would be as follows:

$$P_{i30} = \frac{0.00213}{0.00256}\times 40 = 33\ \text{lb/ft}^2.$$

6.2. Tornado-Like Winds

For Wichita, Kans., table 2 shows a reduction in minimum allowable wind pressure from 35 to 30 lb/ft². Although Wichita is 1,372 ft above sea level, its altitude is not sufficient to account for the difference of 5 lb/ft². However, the unusually high wind speeds recorded at Wichita and other parts of the Mississippi Valley basin can be attributed to an unusually high frequency of tornadoes and a high frequency of severe thunderstorms. Winds following tornadoes are similar to tornadoes in that

TABLE 3. *Values for* $\frac{1}{2} \times \rho \times (5{,}280/3{,}600)^2$ *in eq (2) as* ρ *varies with changes in temperature and elevation above sea level*

[Standard value is for 0 feet and 59° F.]

Air temperature	Elevation above sea level (feet)										
	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
° *F*											
−50	0.00325	0.00313	0.00301	0.00290	0.00280	0.00270	0.00261	0.00251	0.00242	0.00234	0.00225
−40	.00317	.00305	.00294	.00283	.00273	.00264	.00254	.00245	.00237	.00228	.00220
−30	.00310	.00298	.00287	.00277	.00267	.00257	.00248	.00240	.00231	.00223	.00215
−20	.00303	.00292	.00281	.00271	.00261	.00252	.00243	.00234	.00226	.00218	.00210
−10	.00296	.00285	.00275	.00265	.00255	.00246	.00237	.00229	.00221	.00213	.00205
0	.00289	.00279	.00268	.00259	.00249	.00241	.00232	.00224	.00216	.00208	.00201
+10	.00283	.00273	.00263	.00253	.00244	.00236	.00227	.00219	.00211	.00204	.00196
20	.00277	.00267	.00257	.00248	.00239	.00231	.00223	.00215	.00207	.00200	.00192
30	.00272	.00262	.00252	.00243	.00234	.00226	.00218	.00210	.00203	.00196	.00188
40	.00266	.00257	.00247	.00238	.00230	.00221	.00214	.00206	.00199	.00192	.00185
50	.00261	.00252	.00242	.00233	.00225	.00217	.00209	.00202	.00195	.00188	.00181
60	.00256	.00247	.00237	.00229	.00221	.00213	.00205	.00198	.00191	.00184	.00178
70	.00251	.00242	.00233	.00225	.00216	.00209	.00202	.00194	.00187	.00181	.00174
80	.00246	.00238	.00229	.00220	.00213	.00205	.00198	.00191	.00184	.00177	.00171
90	.00242	.00233	.00225	.00216	.00209	.00201	.00194	.00187	.00181	.00174	.00168
100	.00238	.00229	.00221	.00213	.00205	.00198	.00191	.00184	.00177	.00171	.00165
110	.00234	.00225	.00217	.00209	.00201	.00194	.00187	.00181	.00174	.00168	.00162

they generally strike in short, narrow paths. Thus, the probability that any particular building or structure will be hit is comparatively small, and these winds may be partially discounted. This type of reduction is not unreasonable for Wichita, Kans. The same conditions apply to Evansville, Ind.; Indianapolis, Ind.; and Omaha, Nebr.

6.3. Extreme Winds in Coastal Areas

Abnormal distortions and funneling effects attend the passage of cyclones near coastal areas. Also, when the wind passes from sea to land, even when the land is low and flat, surface friction markedly increases. The consequent retardation of the lower air causes thickening of the flow sheet, in effect simulating a small hill. This increases wind speeds in the upper air. For offshore wind, the situation is reversed and wind speeds increase at the lower levels because of falling air. Down currents may be found even at a height of 1,500 ft. Conditions such as these may be the cause of higher winds not only along the ocean coasts but also at Green Bay, Wis., and Marquette, Mich.

Exposed locations along the seaboard are occasionally hit by severe storms, squalls, or hurricanes with winds of exceptionally high speeds. Squalls develop because of differences in air temperature over land and sea. They are often accompanied by gusts and are characterized by splashes of cold air that fall from heights and disperse horizontally. Squalls and hurricanes are the probable causes of the unusually high winds recorded at Weather Bureau stations such as Block Island, R. I.; Cape Henry, Va.; Hatteras, N. C.; and Miami, Fla. Likewise, North Head, Wash., and Tatoosh Island, Wash., are in exposed locations and subject to severe cyclonic storms and a long fetch of wind over the ocean. These winds can hardly be considered typical of the adjacent areas; therefore, in each case the same wind pressures were used for these localities as for the surrounding area.

7. Wind Pressures for Certain Counties

On the wind-pressure map, the boundary lines between pressure zones are generally the State or county lines. However, the markings for some counties are not clearly distinguishable because of the small scale of the map. For this reason, the minimum allowable resultant wind pressures for certain counties along the Atlantic seaboard, as well as for two counties on the Pacific, are given below:

	lb ft²
Connecticut	
New London	30
Delaware	
Sussex	35
Kent	30
New Castle	25
Georgia	
Chatham	35
Maryland	
Worcester	40
Somerset and Wicomico	35
Caroline, Dorchester, and Saint Marys	30
Massachusetts	
Barnstable, Dukes, and Nantucket	40
Bristol, Essex, parts of Norfolk and Middlesex facing Massachusetts Bay, Plymouth, and Suffolk	35
New Jersey	
Cape May	35
Atlantic, Cumberland, Monmouth, and Ocean	30
New York	
Cayuga (part north of 43d parallel), Chautauqua, Erie, Jefferson, Kings, Monroe, Nassau, Niagara, Orleans, Oswego, Queens, Richmond, Suffolk, and Wayne	30

North Carolina	lb/ft²
Dare and Hyde	45
Beaufort, Camden, Carteret, Currituck, Pamlico, Pasquotank, Tyrrell, and Washington	40
Pennsylvania	
Crawford, Erie, and Warren	30
Rhode Island	
Bristol, Newport, and Washington	35
Kent and Providence	30
South Carolina	
Beaufort, Charleston, Georgetown, and Horry	35
Virginia	
Accomack, Northampton, and Princess Anne	40
Elizabeth City, Gloucester, Isle of Wight, James City, Lancaster, Mathews, Middlesex, Nansemond, Northumberland, Surrey, Warwick, and York	35
Washington	
Clallam and Pacific	30

8. Discussion

The maximum wind-speed value for each station was used in determining the pressures given in this paper and in the ASA standard A58.1–1955; however, during the study of wind problems by the National Bureau of Standards and the U. S. Weather Bureau, investigations were made of several methods of treating the problem statistically. The latter investigation was only of a preliminary nature because funds were not available for conducting the extensive analysis of the Weather Bureau data that would be required for computing the statistical quantities.

It is generally realized that, in time, the highest recorded wind speed for any station will be exceeded and that the frequency of this occurrence will diminish as the value of the highest wind speed increases. By treating statistically the frequency of occurrence of wind speeds and the frequency at which the maximum wind speed is exceeded, it would be possible to determine for a station a wind-speed value corresponding to a selected probability of occurrence. Some of the methods investigated in this study were those developed by E. J. Gumbel [8] and those of Fisher and Tippett [9]. Gumbel perfected a chart on which the frequency curves for the occurrence of extreme values can be shown as straight lines. The chart has been applied successfully to flood problems and to gust problems in aeronautics for gust data accumulated on flights above 1,500 ft.

The U. S. Weather Bureau, in cooperation with the American Society of Civil Engineers, has been working for years to fit recorded data into a pattern to which mathematical statistics might be applied, and has perfected a chart that also shows the frequency curve for extreme values as a straight line. The Weather Bureau chart, which is based on Fisher and Tippett's second method with additional consideration for likelihood of occurrence, is said to be applicable to conditions below 1,500 ft.

Study of wind speeds is complicated by the difference in recordings made at stations in certain cities and adjacent airports. On the average, the recordings at the airports show higher speeds than could be expected if the recorded values at the nearby cities were reduced by the seventh-root rule to the same height as the airport anemometers. Apparently the wind speeds recorded by anemometers over these cities are influenced by friction and obstacles. For example, a building may produce a vertical component of air motion which serves to raise the effective friction layer and which at the same time may cause errors in the wind-speed measurements.

Some authorities [10, 11] doubt the validity of the seventh-root rule for use with very strong winds. However, this rule has considerable backing among other authorities and is believed suitable for use until additional data indicate need for change.

Grateful acknowledgment for scientific and technical assistance is made to Louis P. Harrison of the Observations and Station Facilities Division of the U. S. Weather Bureau.

9. References

[1] H. A. Giblett et al., The structure of wind over level country (H. M. Stationery Office, London, England, 1932).
[2] Great Britain, Meteorological Office, Geophysical Memoirs No. 54, **6**, 4.
[3] National fire code for the prevention of dust explosions (National Fire Protection Association, Boston 10, Mass.).
[4] J. Hartman and J. Nagy, Effect of relief vents on reduction of pressures developed by dust explosions (U.S. Bureau of Mines, Washington 25, D.C.).
[5] Hylton R. Brown and Richard L. Hanson, Venting dual explosions, National Fire Protection Association Quart. **26**, 328–41 (1933).
[6] Weather Bureau Forecasters Forum **4**, 9 (1952).
[7] W. T. Van Orman, Preliminary meteorological survey for airship bases on the middle Atlantic seaboard, pp. 7 and 11 (for the International Zepplin Transport Corp., 52 Wall St., New York, N.Y., Feb. 21, 1931).
[8] E. J. Gumbel, Return period—reduced variate chart, School of Engineering, Manhattan College, Riverdale, N. Y.
[9] R. A. Fisher and L. H. C. Tippett, Limiting forms of the frequency distribution of the largest or smallest member of a sample, Proc. Cambridge Phil. Soc. **24**, pt. 2, 180–190 (1928).
[10] W. Kaufman, Hydromechanik, pt. 2 (Julius Springer, Berlin, 1934); O. Flaschbart, Die belastung von Bauwerken durch Winkkrafte, ch. 9.
[11] E. L. Deacon, Gust variation with heights up to 150 m, Quart. J. Roy. Meteorol. Soc. **81**, 562–573 (1955).

WASHINGTON, October 17, 1958

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