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GUST FACTORS FOR THE DESIGN OF BUILDINGS

WINDSTOSSFAKTOREN FÜR DIE BERECHNUNG VON HOCHBAUTEN

CARACTÉRISTIQUES DES COUPS DE VENT DANS LE CALCUL DES CHARPENTES

Professor R. H. SHERLOCK,
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Before the wind pressures acting on a structure can be determined, it is necessary to select the maximum wind velocity which is proper for the locality and for the size and exposure of the structure. This is the design velocity. It must include an allowance for gusts which are of relatively short duration but which are of sufficient extent to envelop the building and to permit the corresponding aerodynamic effects to develop.

The only continuous long-time records of wind velocity for all parts of this country are those of the United States Weather Bureau. These cannot be used without elaborate study, due to differences in conditions of exposure at the first order weather stations, changing conditions of exposure at some stations as the surrounding area was built up, and changes in the types of anemometers. The Weather Bureau records contain very little on the subject of gusts, since its reports are based upon five-minute average velocity. The fastest mile of passing wind can be read from the records, but this is of only limited usefulness since, in a gale, it corresponds to a period of about one minute during which several strong fluctuations may occur. It is therefore necessary to supplement the Weather Bureau records by studies of gustiness in records from other sources.

The observations made near Ann Arbor during the winters of 1927—1934, in connection with Engineering Research Project 505, University of Michigan, are believed to have yielded the most complete existing records from a large scale installation and from anemometers which were sufficiently sensitive for a study of wind gusts[2]. They had previously been subjected to statistical analysis in the range of preliminary study only. In this report, they have been subjected to further analysis resulting in nomograms of the relations between design velocity, five-minute average velocity, average velocity of the storm sample, and gust factors, at different heights up to 175 feet. Variations of gust factors with height are also shown for different gust durations.

Origin of wind gusts

The wind is motion of the air caused by gravity, by deflective forces due to the earth's rotation, and by centrifugal forces due to curvature of the wind path. These forces are opposed by others arising from friction and viscosity. The air never flows with a perfectly smooth and streamline motion, but always with fluctuations which, when sudden and relatively brief, are called gusts. The masses of air involved in gustiness may simultaneously and in the same area cover a wide range of sizes from very small to very large. The velocity fluctuations have vertical as well as horizontal components.

Gustiness, or atmospheric turbulence, is accompanied by so many variations of velocity, temperature, and humidity, that no completely satisfactory theory exists as to why it arises or how it proceeds[9]. Nevertheless, several of the causes are sufficiently outstanding to warrant a discussion for the purpose of obtaining a better understanding of the records presented in this report.

Gusts are caused chiefly by the growth of eddies, local pressure differences, deflection around objects, vertical thermodynamic interchange, and by combinations of these causes.

Growth of Eddies: When the air flows past a smooth solid, it is retarded by friction at the surface of contact. At low velocities, this retardation is transmitted to successive thin layers through molecular viscosity, that is, the molecular activity causes molecules to pass from one layer to another and by collision with others to transfer momentum from layer to layer. In a real fluid like air, this highly idealized laminar flow can exist in a thickness of only a few thousands of an inch, if at all, beyond which the eddy motion of turbulent flow sets in.

A surface of kinetic discontinuity can exist between adjacent air parcels of different velocity, but it is only transitory[10] and is quickly replaced by a stratum of vortices. Some of the vortices grow in size and assume dominant importance in their portion of the moving air mass while others are destroyed or amalgamated by collision with better established systems. It has been stated that „Turbulence consists essentially of an agglomeration of vortices or superimposed vortical systems“[10].

The reality of large vortices in the free atmosphere has been demonstrated beyond question by the analysis of extensive and refined records taken during winter storms near Ann Arbor[4]. Specially designed anemometers were mounted on a line of poles fifty feet high and on a tower 250 feet high, so that it was possible to obtain simultaneously a horizontal and a vertical section of the passing wind. Twelve anemometers were used and their records taken on a single strip of photographic paper in a 12-element oscillograph. From these records, diagrams were prepared which showed the structure of the wind by means of iso-velocity contours. The minimum size of horizontal vortex which could be disclosed was limited by the minimum spacing of anemometers on the tower, 25 feet, and the corresponding minimum interval for which average velocity was read from the records, one-quarter second.

An inspection of these wind diagrams[4] and a comparison with the diagrams of theoretical cases made it possible to identify many vortices, some with vertical axes, some with horizontal axes, some with the three-dimensional flow at the open ends of the vortex cylinders, and some with the three-dimensional out-flow near the mid-length of the cylinder.

The most favorable position for the development of horizontal vortices was at a height of 150 to 200 feet immediately behind the steep velocity gradient of the gust front. A number of cases were found where the vortex in this position was so well developed that the diagram bore an almost perfect resemblance to the theoretical cases. The most favorable position for the development of vortices with vertical axes was near the sides of the gust and immediately following the gust front. The configuration of the iso-velocity contours for these vortices was more irregular than in the cases of those with horizontal axes. This is no doubt due to the fact that the line of anemometers at the 50-foot elevation was so close to the ground that it involved not only the three-dimensional flow into the open ends of the vortex cylinders, but also complex turbulence generated by friction with the ground.

Numerous vortices within the rapidly moving mass of air in the gust were discovered[4] in varying degrees of perfection. There have been some attempts to ascribe trouble with such types of structures as smokestacks to the presence of cyclic forces in gusty air. These diagrams disclosed no large vortices travelling as a cyclic system in the free air. However, it would not be safe to say that large systems of this kind never occur, since there are in the diagrams a number of surfaces of kinetic discontinuity where there is evidence of the formation of cyclic systems whose component vortices were smaller than 25 feet in diameter, and were thus not completely shown by the iso-velocity contours.

The rotary motion of the vortices causes a resultant increase in velocity on one side of the vortex center and a decrease on the other. Each of these effects produces velocity gradients within the moving mass of air. They may be of importance to small structures which may be subjected to a twisting movement of short duration by this effect. However, the most intense vortices were from 50 feet to 75 feet in diameter, which means that the impact effect would take place over a period of time of one-half to three-quarter seconds. This is small for all except very small structures such as sign boards. Indefinitely smaller eddies could no doubt be discovered by using closer anemometer spacing and smaller time intervals, provided that care is used to preserve a proper relation between the spacing, time interval, wind velocity, and size of the space to be explored. However, these small vortices are of no significance in the design of ordinary small structures.

Local Pressure Differences: The wind diagrams discussed in the previous item disclose some greatly elongated configurations at the higher stations on the tower, within which high velocities persist for periods as long as one minute. The velocities within the configuration are higher than those at the stations both above and below. The only explanation for this is that a temporary channel had been established through which the air rushed to equalize unbalanced pressures between two fairly large masses of air within the larger flowing mass. Such a condition has also been shown on a smaller scale in the observations of WILHELM SCHMIDT[11]. He referred to these small channels of rapidly moving air as „jets“.

Since these jets have been observed on a small scale of less than 1 meter near the ground by SCHMIDT, and on a larger scale of 50 feet to 75 feet with one-minute duration, and at a height of 200 feet, at Ann Arbor, it is only safe to assume that the pressure differences which gave rise to them can also exist in larger sizes and at higher elevations.

Deflections: Gusts caused by deflection over and around buildings, trees, hills and other objects on the ground are observed by everyone. They are commonly looked upon as the most important source of atmospheric turbulence. Although this popular opinion is not true, gusts from this cause are important and their effect, acting through eddy viscosity, penetrates to a considerable height. The flow may also be deflected by collision with masses of more slowly moving air with consequent change of speed and direction and this may occur at any height.

Vertical Interchange: The phenomenon of vertical interchange due to thermal instability is well known[12]. When a cold air mass moves over ground which has previously been covered by a warm air mass, the lower strata are warmed so that conditions necessary for thermodynamic stability are changed. „It is of interest to note that the colder of two adjacent air masses will normally be less stable than the warmer mass. The least stable mass will usually be more turbulent than the more stable one“[12]. During the storms recorded in this investigation, the highest velocities and the most violent gusts occurred within the southwest quadrant of the low pressure area, that is, while the highly turbulent and unstable front portion of the cold mass was passing. In this zone of transition there was a condition of thermal instability which permitted occasional and sometimes violent interchanges between the higher and lower strata. Large gusts occurred near the ground because masses of air from the more rapidly moving higher strata reached the ground before loosing all of their excess forward momentum.

Gusts from this source may be of a violence which is limited only by the kinetic energy present in the higher strata. There is some height at which the effect of ground friction transmitted through eddy viscosity to higher strata is negligible, and where the air is free to respond to the pressure gradient without this retarding effect. As the air at the lowest level comes in contact with the warm ground, it rises and must be replaced by the colder fast-moving air from above. If the masses of air involved in this interchange are sufficiently large, the retardation produced upon the falling mass of air, through eddy viscosity and collision with slower moving masses, may be so small that the cold mass loses only a small part of its velocity before reaching the lower strata, and a violent gust occurs.

On the investigation at Ann Arbor, the wind diagrams[4] showed that a times the downward surges reached the 50-foot station within five seconds after they had reached the 200-foot station. The effect must have travelled downward with a vertical velocity of about 30 feet per second, about 20 miles per hour. This effect could be produced through shear between horizontal layers, or through vertical displacement of masses of air having different velocities, or through a combination of these two means. At times, these falling masses of rapidly moving air reached the 200 or 250-foot station and receded without reaching the lower stations.

Combinations: Gustiness is such a complex phenomenon that it would be hazardous to say that any one of the foregoing causes is ever dominant to the complete exclusion of some of the others. However, it is safe to say that vertical interchange due to thermal instability is the most important influence in producing large and intense gusts.

Statistical representation of gustiness

Turbulent flow is characterized by a dispersion of velocity readings within any time interval. The most generally accepted and most scientific method of seeking orderly behaviour in data which are widely dispersed and apparently without order, is to reduce them to statistical[13, 14, 15] form and proceed either graphically or analytically to examine the results for significant relationships.

The data of the present study are grouped into five-minute intervals, because this is the interval for which the longtime records are available in the United States Weather Bureau reports. No such interval can be said to be completely homogeneous, that is, free from all variable factors except velocity. This is because the observations were taken in uncontrolled natural situations where each effect had a multiplicity of causes. The chief variables in the complex situation associated with atmospheric turbulence are temperature, humidity, barometric pressure, the phase of the meteorological cycle, wind directions, topography, geographic location, and season of the year. The first five are known to have varied during the course of these observations. The data are therefore unlike those obtained from laboratory experiments in which only one causative factor is permitted to vary at one time and from which future behaviour can be predicted within the same narrow limits that are possible in the control of the variable. The behavior of the wind can be described and predicted, therefore, only in a statistical manner. It is the purpose of this analysis to discover the extent to which orderly behavior is shown within the data when they are described in terms of statistical functions.

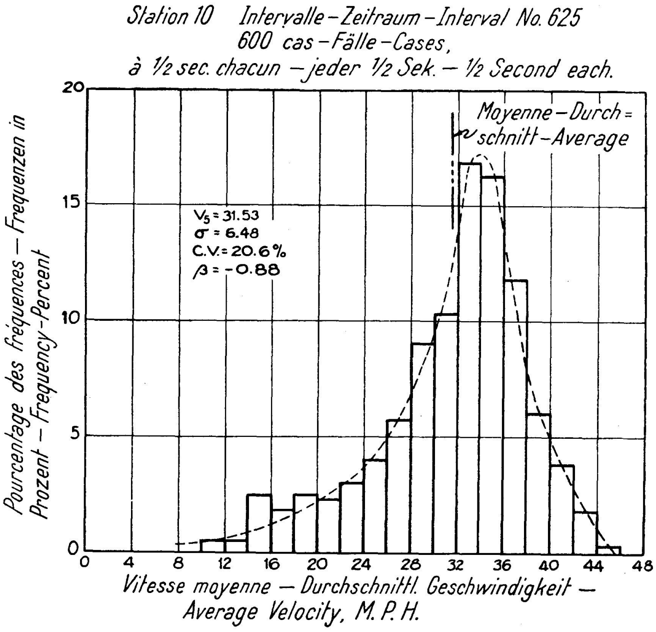

Fig. 1.

Distribution Diagram — Verteilungskurven — Diagramme de la distribution des fréquences.

The degree to which the wind velocities are dispersed within a five-minute interval is illustrated in Figure 1 where the histogram for the Interval 625, Station 10, is shown in terms of the $1/2$-second average velocities.

The velocity scale has been divided into velocity cells of two miles per hour each. It will be seen that 3.83 % of the 600 cases are within the velocity cell lying between 40 and 42 miles per hour, and that 10.33 % of the cases lie within the cell between 30 and 32 miles per hour. There is a central tendency which causes the cases to occur more frequently in the cells near the average; the frequency of occurrence diminishes in those cells farther away on either side of the average. A dash curve has been drawn to pass near the midpoint at the top of each column in the histogram. This curve suggests the curve for the Normal Law of Error except that it is not symmetrical. It might be possible that a larger sample, having many more than the 600 cases included in this set, would show a closer approximation to the Normal Law. However, additional study of the results shows this is not true for the collected data of this storm and that the statistical study must be extended beyond those methods based upon the Normal Law alone. For the benefit of readers who have not had occasion recently to make use of statistical methods, a review of the notation and general significance of the terms is given.

Statistical Functions and Standard Curves: The statistical functions which have been found most useful in presenting the characteristics of wind gusts are the average, the standard deviation, and the coefficient of skewness. The variable for which the statistical functions will be computed is the velocity, and the magnitude of the velocity during any small interval of time will frequently be referred to as the variate.

The average, in this discussion, will refer to the arithmetic mean; that is, the sum of the variates divided by the number of variates.

The standard deviation is a mathematical measure of the dispersion of the variates with respect to the average. It is equal to the square root of the sum of the squares of the deviation from the average divided by the number of variates. That is,

$$\sigma = \sqrt{\frac{(v_i - V_5)^2}{N}}$$

where σ = standard deviation
v_i = a particular value of the variate
V_5 = average velocity for an interval of 5 minutes
N = the number of variates in the group

It will be seen that the standard deviation has the dimension of the variate, in this case, that of velocity. It is frequently referred to as the root-mean square deviation.

The coefficient of skewness is the measure of tendency for the variates to group themselves more on one side of the average than on the other. It is given by the expression,

$$\beta = \frac{1}{\sigma^3} \frac{\Sigma (v_i - V_5)^3}{N}$$

It will be seen that the coefficient takes into consideration the magnitude of the deviation from the average, and, since it is an odd power of the deviation, it will have a positive or a negative value, depending upon whether the preponderance of variates lies below or above the average. It will be seen also that the coefficient is a dimensionless number since both the numerator and the denominator have the dimension of velocity cubed.

Standard variates are obtained by dividing the deviations from the average by the standard deviation. Standard variates are thus independent of the dimensions of the variates whose dispersion is being analyzed. They make it possible to set up type equations and type curves which may be useful in a statistical approach to the analysis of any group of dispersed data, regardless of the dimensional system in which they occur.

Figure 2 shows typical distribution curves using standard variates. All three of the curves follow the equation of Pearson's Type III, with coefficient of skewness equal respectively to + 0.5, 0.0, and —1.0. The Pearson types were designed to provide mathematical curves which bear a similarity to the Normal Law and which, for some types, coincide with the Normal Law at zero skewness. They offer a sufficiently wide variety to make it possible to fit almost any group of dispersed data taken at random from nature. The Pearson Type III curve was chosen for this study because, (a) it is widely used in many other statistical studies, (b) graphical studies showed that it gives a reasonably good fit to the velocity data, (c) tables are readily available for its use.

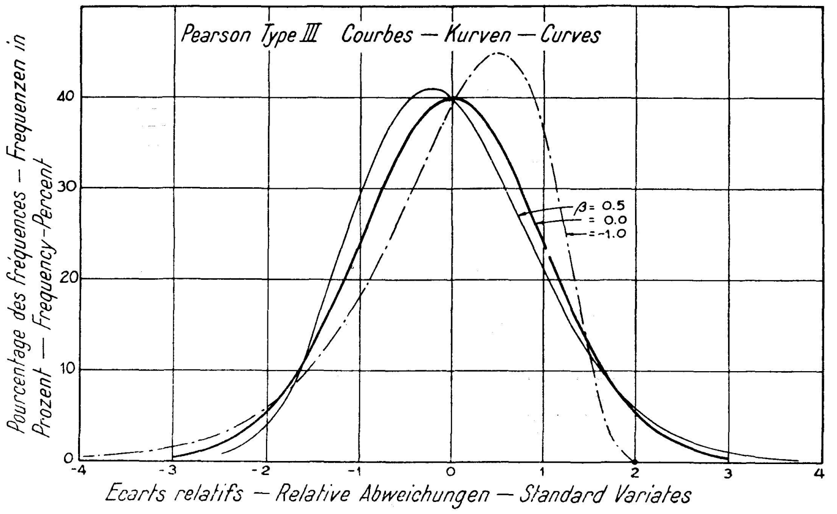

Fig. 2.
Pearson Type III Curves — Pearson Kurven Typ III — Courbes Pearson Type III

It will be seen from Figure 2 that positive skewness is accompanied by a negative intercept along the axis of the variates, and that negative skewness is accompanied by a positive intercept. This property of the curve has been found useful in identifying the physical significance of the statistical functions and statistical curves.

Storm characteristics

Reference will be made to records taken during three different storms, namely, those of March 6, 1929, April 1, 1929, and January 19, 1933. Most of the gust studies are taken from the storm of January 19, 1933, and some meteorological information is therefore included regarding it. The records from the other two are not satisfactory for gusts of less than ten seconds duration. They are, however, entirely satisfactory for other purposes, especially to give information on the difference between wide gusts and those at a point, and they are used here for such purposes.

Meteorological Data, January 19, 1933: Figure 3 shows curves for barometric pressure, wind velocity, wind direction, and temperature during the three days on which the storm was developing and receding. It will be seen that the barometer started to drop at about 9 a. m. on January 18, and reached its low point between 5 and 8 a. m. on January 19, after which it rose rather irregularly to a new high at about noon on January 20. The hourly wind velocity was relatively steady in the early morning hours of the 19th, but increased abruptly to a new steady position which continued for about four hours until 7 a. m. At this point, there was a very sudden rise in the velocity curve, followed by an irregular approach to the two peaks, one between 10 and 11 o'clock and the other between 1 and 2 o'clock, after which the velocity dropped irregularly until 6 p. m. on January 20. The wind direction was relatively steady until about three hours before the lowest barometric pressure was reached, at which time the wind shifted from ESE to SW in an interval of one hour, and farther into WSW in an interval of another hour. This wind shift occurred at almost precisely the same time as the passage of the warm front. An additional shift from West and later into WNW accompanied the passage of the cold front.

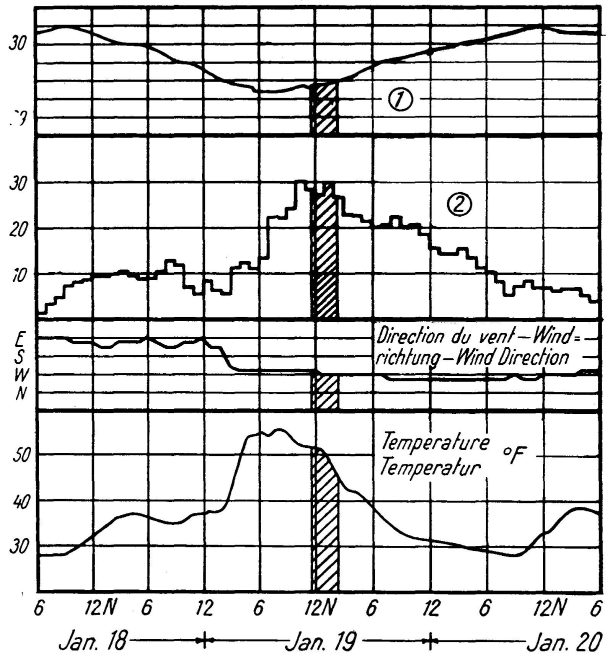

Fig. 3.

Meteorological Data, January 19, 1933 — Meteorologische Daten, 19. Januar 1933 — Données météorologiques, 19 janvier 1933.

1 Barometer Inches Mercury Sea Level 32° F — Barometer in Zoll Quecksilbersäule, Meereshöhe 32° F — Mesures barométriques en pouces au-dessus de la mer 32° F.

2 Wind Velocity, Hourly Averages M. P. H. — Windgeschwindigkeit, stündlicher Durchschnitt — Vitesse du vent, moyenne par heure.

The arrival of the warm front with its accompanying wind shift had relatively little effect in producing a greater velocity. The highest velocities occurred in the early stages of the development of the cold front. This is an important point; it has been referred to earlier in the section dealing with the origin of wind gusts.

That portion of the storm during which records were taken is indicated by cross hatching. It included at least part of the highest velocities and also the time of most rapidly falling temperature.

Distribution of V_5 Velocities: During the storms of March 6 and of April 1, 1929, records were taken on one cup anemometer and 2 dynes anemometers at the site of the experimental station. The anemometers were at a height of about 35 feet above the ground and each had a slightly different topography of the ground lying to the windward. In neither case were records taken during the entire period of the storm, but only during the most active portion of the storm and when the prevailing wind was approximately normal to the axis of the power line in connection with which the records were chiefly concerned.

Figure 4 shows the distribution of five-minute average velocities, V_5, by means of a histogram for each of the two storms. Due to the limited number of cases, neither histogram presents a completely symmetrical or even a regularly skewed appearance. It is reasonable to suppose, however, that in this situation, as in all situations dealing with natural phenomena, the regularity of the diagrams would improve with the number of cases in each sample. Pearson Type III curves were fitted to the data as shown.

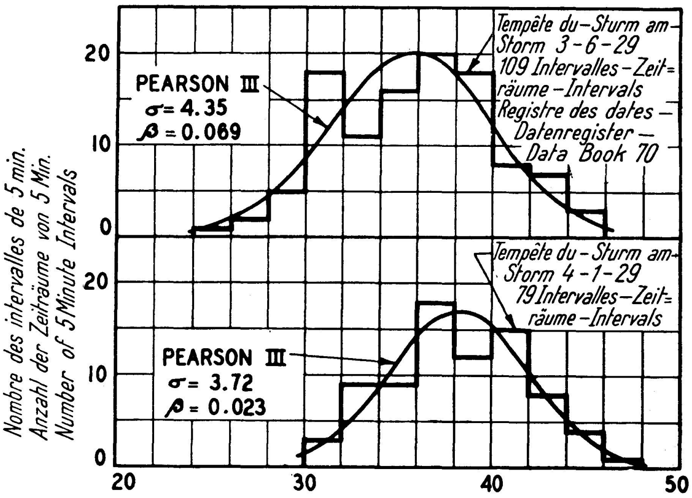

Fig. 4.

Distribution of 5-Minute Average Velocities within 2 Storms — Verteilung der mittleren Geschwindigkeiten während 5 Minuten bei zwei Stürmen — Distribution des vitesses moyennes dans l'intervalle de 5 minutes pendant deux tempêtes.

V_5 = 5 Minute Average Velocity, M. P. H. — V_5 = Durchschnittliche Geschwindigkeit innerhalb 5 Minuten — V_5 = Vitesse moyenne pendant 5 minutes.

It will be seen that the sample from the storm of March 6 showed a wider dispersion and somewhat greater skewness, as shown by σ and β respectively, than was the case with the storm of April 1. In each case, the skewness is small and the most significant function is that of dispersion. The storm of April 1 was the more intense, as indicated by the greater central tendency of its diagram, or, at least, the sample of 79 cases shows this tendency as compared to the 109 cases for March 6.

If the earlier and later portions of the storms had been included in the records, there would have been a larger number of five-minute intervals with low velocities. The dispersion would have been wider and the skewness greater. Any attempt to establish limits to the time interval occupied by a storm therefore involves some arbitrary decisions and destroys the random nature of the statistical samples. The statistical functions and curves shown in Figure 4 are therefore characteristic of the samples rather than of the storms as a whole. But this is not an undesirable situation in the study of gusts, since the question to be answered is this: „During the most intense portions of a storm, what gust factor must be applied to each five-minute average velocity to obtain the most probable maximum gust for each five-minute interval?“, or, more specifically, „What gust factor must be applied to the maximum V_5 on record in order to obtain the most probable gust velocity of a specified duration?“ We are interested in the statistical properties of the most active portion of the storm.

In each case, the storm records are taken from the most active portion of the storm and are therefore considered to be a sample whose average velocity characterizes the strength of that portion of the storm. It may be called the „storm average“, or, more appropiately, the „sample average“.

Distribution of Gust Records: For the purpose of this report, a gust is completely defined by its velocity, its duration, and its lateral extent. The gust factor is defined as the ratio of the maximum gust velocity to the five-minute average velocity.

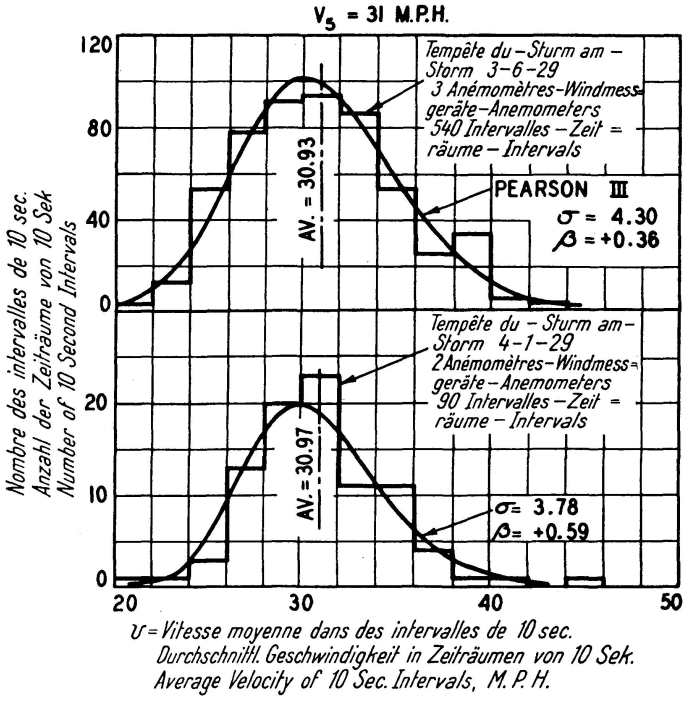

Fig. 5.

Distribution of 10-Second Velocities, $V_5 = 31$ m. p. h — Verteilung der 10 Sek.-Geschwindigkeiten, $V_5 = 31$ M/St. — Distribution des vitesses de 10 sec., $V_5 = 31$ m/h.

Gustiness was studied in the storms of March 6 and April 1, 1929, by dividing each five-minute interval into thirty ten-second intervals and taking the average velocity from the records for each of these smaller intervals. Ten seconds was chosen because this was considered to be a sufficiently long interval for the cup and dynes anemometers to give accurate average velocities. The range of velocities was divided into cells of two miles per hour each, and each cell identified by the median velocity of that cell. For example, all five-minute intervals having average velocities lying between 30 and 32 miles per hour were identified as having an average velocity of 31 miles per hour.

Figures 5, 6 and 7 show the distribution of ten-second gust velocities in the V_5 intervals having respectively 31, 37 and 45 miles per hour. The histograms are somewhat irregular, although showing a strong central tendency, and Pearson Type III curves were fitted to each histogram. The six curves are repeated in Figure 8 for purpose of comparison. In each storm, there is a wider dispersion of the gusts when V_5 is equal to 37 miles per hour than when it is equal to 31 or 45 miles per hour. This is because 37 miles per hour was in each case fairly close to the average velocity for the sample of the storm. As one chooses V_5 intervals whose average velocities are either higher or lower than the storm average, there is a greater central tendency, that is, a smaller dispersion of the gust velocities.

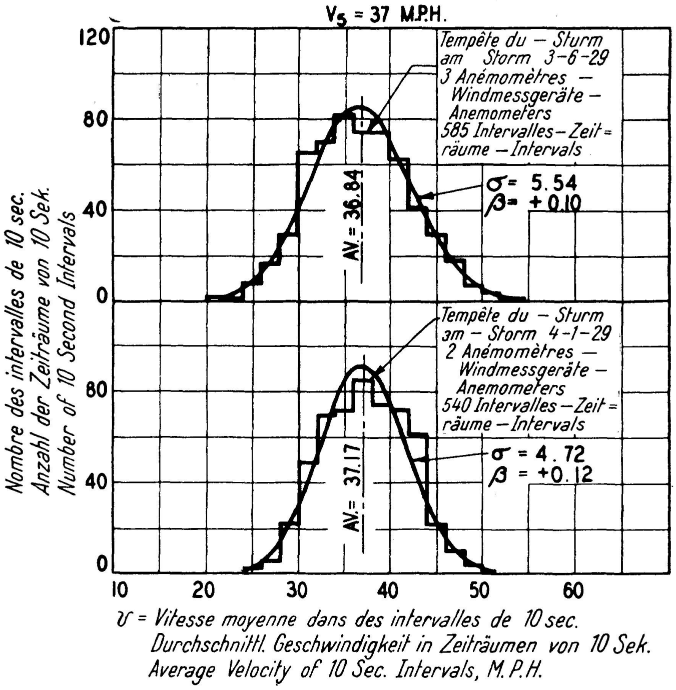

Fig. 6.

Distribution of 10-Second Velocities, $V_5 = 37$ m. p. h. — Verteilung der 10 Sek.-Geschwindigkeiten, $V_5 = 37$ M/St. — Distribution des vitesses de 10 sec., $V_5 = 37$ m/h.

Since the choice of the maximum gust must be based upon a statistical curve fitted to the actual data, rather than upon a reading from the actual data, and since the Pearson III curve with positive skewness reaches zero only at infinite velocity, there is no limit to the maximum velocity that may be read from the fitted curve. Such a limit must be set by interpreting the curve in terms of the physical conditions of the problem. For example, an actual five-minute interval contains 30 ten-second intervals, and the one having the maximum velocity will constitue $3\text{-}^1/_3$ per cent of all ten-second cases. If there are two such five-minute intervals, both exactly alike, then there will be two equal ten-second maxima, which will still constitue $3\text{-}^1/_3$ per cent of all cases. Regardless of the number of five-minute intervals, if they are all exactly alike, the sum of all maxima will be $3\text{-}^1/_3$ per cent.

If the five-minute intervals of a particular average velocity are not otherwise exactly alike, but all are equally well represented by the fitted curve, then the fitted curve may be said to represent a typical V_5 interval for that average velocity. The maximum gust velocity may be equal to but not greater than $96\text{-}^2/_3$ per cent of all ten-second cases, that is, the area under the curve to the left is equal to $96\text{-}^2/_3$ per cent of the total area under the curve, as shown in Figure 9. None of these typical five-minute intervals could contain a gust higher than this velocity unless the gust were shorter than ten seconds, that is, less than 3-$^1/_3$ per cent of all 10-second gusts. The same procedure can be followed for gusts of any other duration, as is done later under the heading „Gust Factors“ for gusts of $^1/_2$, 1, 2, 5 and 10-seconds duration.

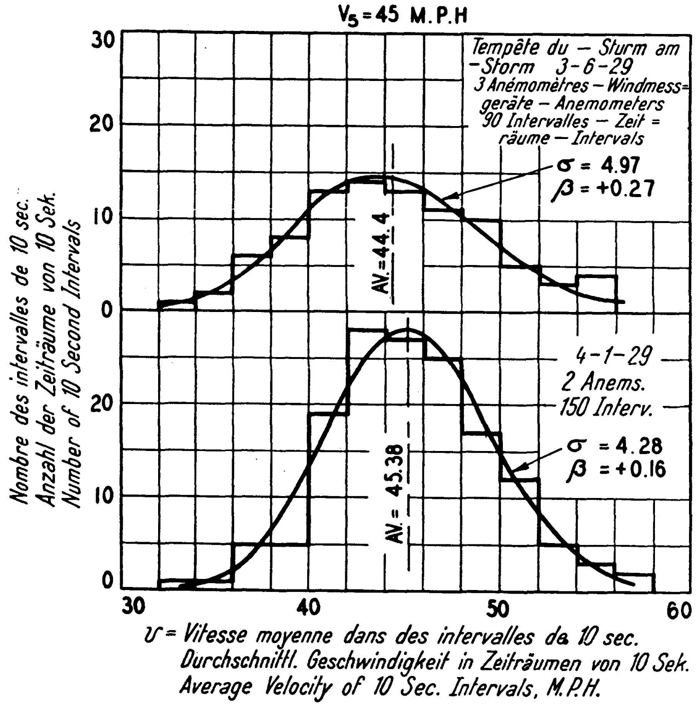

Fig. 7.
Distribution of 10-Second Velocities, $V_5 = 45$ m. p. h. — Verteilung der 10 Sek.-Geschwindigkeiten, $V_5 = 45$ M/St. — Distribution des vitesses de 10 sec., $V_5 = 45$ m/h.

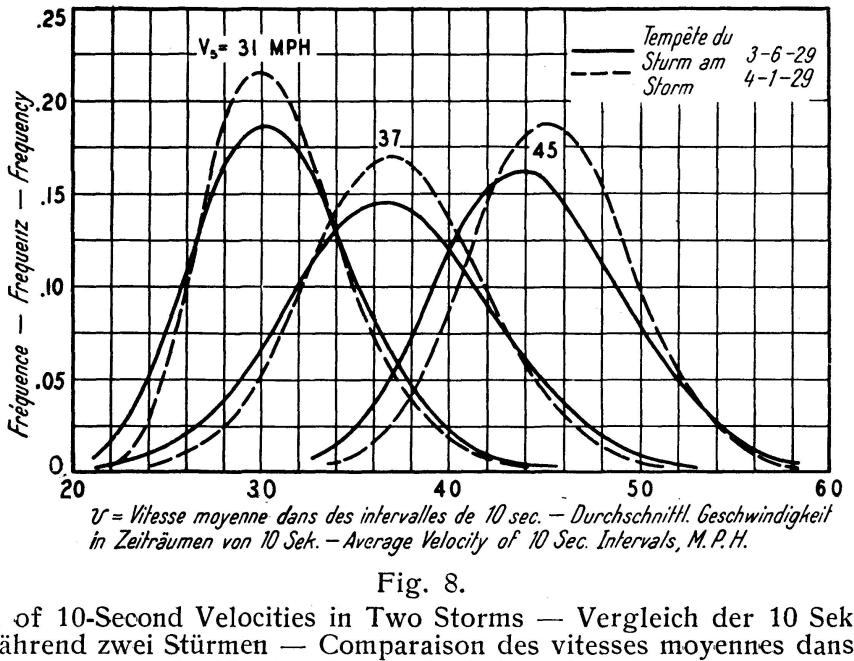

Fig. 8.
Comparison of 10-Second Velocities in Two Storms — Vergleich der 10 Sek.-Geschwindigkeiten während zwei Stürmen — Comparaison des vitesses moyennes dans l'intervalle de 10 secondes pendant deux tempêtes.

But a sample from a different storm would yield a slightly different fitted curve and a large number of storms would yield a range of velocity values for the 96-$^2/_3$ per cent point. In other words, there is a secondary distribution about the 96-$^2/_3$ per cent point established on the basis of these storms. This is also illustrated in Figure 9. Some allowance should be made for the higher velocities in the secondary distribution, and this is done in the selection of the gust factor as discussed later under that heading.

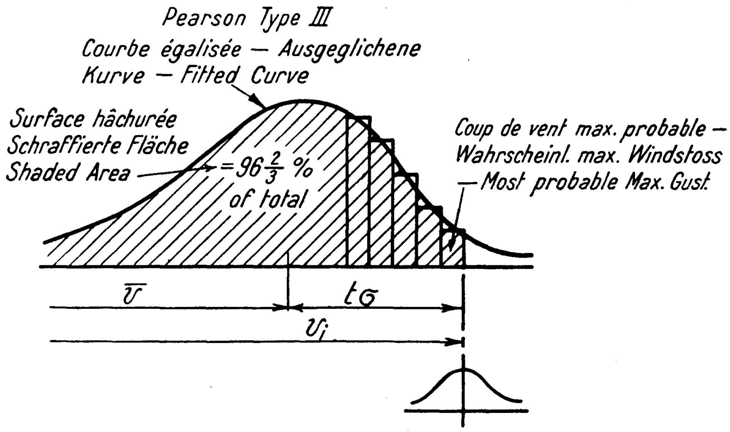

Fig. 9.
Secondary Distribution of Most Probable Gust — Sekundäre Verteilung der wahrscheinlichsten Windstöße — Distribution secondaire du coup de vent le plus probable.

Data for the computation of the ten-second gust factors from the six curves of Figure 8 are given in Table I. They illustrate the method and serve as a basis for the comparison which will later be made with gust factors for wide gusts.

The same method was used for the storm of January 19, 1933.

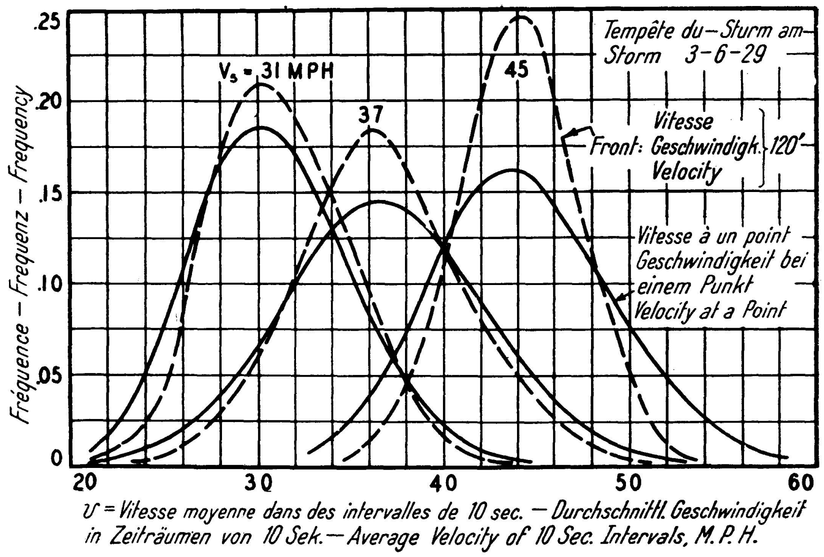

Fig. 10.
Ten-Second Gusts 120 feet Wide — 10-Sek. Windstöße bei 120′ Weite — Coup de vent de 10 secondes dans un entourage de 120′.

Table I. Gust Factors for Ten-Second Gusts.

V_5 m. p. h.	n	σ m. p. h.	β	$t=\frac{v_i-\bar{v}}{\sigma}$ Std. Var.	$t\sigma$ m. p. h.	$\bar{v}$ m. p. h.	$\bar{v}+t\sigma=v_i$ m. p. h.	G. F. $=\frac{v_i}{\bar{v}}$
Storm of March 6, 1929								
31	18	4,30	+0 36	1,96	8,43	30,93	39,36	1,27
37	20	5,54	+0,10	1,87	10,36	36,84	47,20	1,28
45	3	4,97	+0,27	1,93	9,58	44,40	53,98	1,21
Storm of April 1, 1929								
31	3	3,78	+0,59	2,06	7,78	30,97	38,75	1,25
37	18	4,72	+0,12	1,89	8,93	37,17	46,10	1,24
45	5	4,28	+0,16	1,90	8,13	45,38	53,51	1,18

V_5 = the median of the 2 m. p. h. velocity cell within which the average velocity for a 5-minute interval falls.
n = number of V_5 cases.
σ = standard deviation = $\sqrt{\frac{\Sigma(v-\bar{v})^2}{N}}$
β = Coefficient of skewness = $\frac{1}{\sigma^3}\frac{\Sigma(v-\bar{v})^3}{N}$
N = number of 10-second cases.
v = velocity of a 10-second interval.
$\bar{v}$ = average velocity.
v_i = velocity of a particular 10-second interval, in this case the interval whose velocity is equal to but not greater than 96-2/3 % of all cases.
t = standardized variate = $\frac{v-\bar{v}}{\sigma}$
$G.F.$ = Gust Factor = $\frac{v_i}{\bar{v}}=\frac{\bar{v}+t\sigma}{\bar{v}}$

Wide Gusts: The records of an anemometer give the variations of wind velocity at a point. However, buildings are affected by gusts having lateral extent. Consequently, the question arises as to the differences which would be caused by taking observations over a relatively wide front. Figure 10 shows the distribution of ten-second gusts for the storm of March 6. These are for the same location and for the same periods of time as were used in Figure 8, but, in Figure 10 the velocities were derived from the forces acting upon the conductors in a 120-foot span on an experimental power line[1], instead of being taken by an anemometer at a point.

In Figure 10 these two sets of curves have been superimposed for purposes of comparison. It will be seen that the peak of the curve in each case occurs at almost identically the same place, but that the central tendency for the wide gusts is more marked. The 120-foot span integrates the velocity variations at all points over this front, that is, it averages velocity variations across the stream as well as along the stream.

The gust factors computed as in Table I would here become:

$$GF=\frac{45,71}{37}=1,24 \text{ for } V_5=37 \text{ m.p.h.}$$

$$GF=\frac{50,12}{45}=1,11 \text{ for } V_5=45 \text{ m.p.h.}$$

These compare with 1.28 and 1.21 respectively for velocities measured at a point. In other words, measuring the gusts over a front of 120 feet gave gust factors 3.1 % and 8.2 %, respectively, less than those measured at a point. Some allowance can be made for this effect by using gusts of longer duration than seem necessary on the basis of the two dimensional flow past an anemometer.

Minimum effective gusts

It is obvious that a structure will not respond to the impact of a gust which is only a small fraction of the size of the structure. The gust must have sufficient vertical and horizontal extent, to envelop not only the structure but also those flow patterns to the windward and to the leeward which are responsible for the maximum pressures on the building. Figure 11 was traced from several photographs, which were made by Irminger and Nokkentved[7], of the flow past a model as it was drawn through water. The dash lines were made by light reflected from the particles of aluminium powder which had been sprinkled on the surface of the water. The flow of air around a building would be geometrically similar to this since these are sharp-edged buildings and there is therefore no necessity to establish scale relations through the medium of Reynolds Numbers.

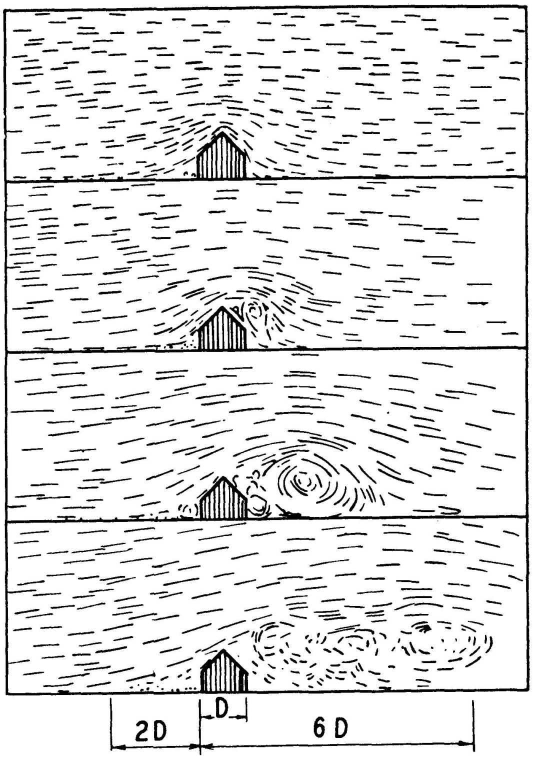

Fig. 11.

Flow Past a Model of a Building after Irminger and Nøkkentved — Strömung an einem Gebäudemodell nach Irminger und Nøkkentved — Flux du vent autour d'un modèle de bâtiment d'après Irminger et Nøkkentved.

The patterns show the development of flow from very low velocity to high steady velocity. The fluid finds its way around the sharp edges with a minimum of disturbance at low velocities, but as the velocity increases, vortices start to form at the sharp edges, with an especially large one at the ridge. This grows until it occupies the entire space behind the building.

It then breaks away and flows downstream, leaving after it a turbulent mass of air which is separated from the streamline flow above it by a vortex layer. In front of the building, a turbulent zone is likewise formed, and it likewise is separated from the streamline flow above it by a vortex layer. The entire flow pattern is such as to produce within the fluid a streamline surface which offers a minimum disturbance to the flow past the obstruction. The same streamline fluid structure was likewise shown for buildings of other proportions when tested in this same manner.

After the stream lines have been formed in the natural wind, there may be superimposed upon the average flow the additional velocities of a gust. The question arises as to the size of the gust necessary to envelop sufficient of this streamlined wind structure to transmit to all sides of the building the corresponding changes in pressure. Comparison may be made with the distance required for the changing wind structure around the wing of an airplane to fully manifest itself in the changed forces acting on the wing. This matter has been investigated by W. S. FARREN[8], who found that six or more chord lengths of the wing is the distance which the plane must travel from rest before the ultimate lifting pressures are developed. Since the wing is highly streamlined by comparison with the building, even when it is in the attitude of stalling, it may be assumed that it will develop its pressures in a relatively shorter distance than would the building. If, therefore, the small building shown in Figure 11 is assumed to be 40 feet wide, there would be required on this basis at least 240 feet of travel (6 × 40) beyond the windward face of the building before the gust would be fully effective in changing the pressures. An additional length of gust would be required for it to encompass the wind structure in front of the building. Distances of 2 × 40 plus 6 × 40 are superimposed upon the pictures of flow shown in Figure 11. They would seem to be conservative, since 320 feet does not completely cover the streamlined structure. If the gust is travelling at 75 miles per hour, that is, 110 feet per second, it should have a duration of at least three seconds to cover this distance and consequently to be fully effective in modifying the pressures on a building whose dimension is about 40 feet along the stream. A gust of three seconds duration has been adopted in this report as the minimum effective gust for small buildings of about this size and to illustrate the use of the nomographs in Figures 21 and 22.

The lateral extent of the gust must also be considered. It would need to be the length of the building, plus some reasonable fraction thereof. For a small building about 50 feet across the wind stream, an allowance of half this length at each end would give a gust front of about 100 feet. The lateral flow around the ends tends to decrease the length of the wind structure in the wake of the building, and some allowance should therefore be made by decreasing the time for the minimum effective gust. This required decrease is assumed to be at least partly balanced by the fact that the nomograph for gust factors is based upon observations at a point, whereas the previous discussion under „Wide Gusts“ shows that there is a decrease of about 11 % in the gust factor when it is based upon observations on 120 foot front instead of at a point, and with ten-second gusts instead of three-seconds.

In selecting the minimum effective gust of three seconds, it has been necessary to make several assumptions, most of which are conservative, but some of which are not. It is believed that the balance is on the conservative side. They are as follows: (1) The results obtained by IRMINGER and NOKKENTVED[7] apply acceptably well to buildings of other shapes; (2) The time-lag in the response of the pressures on an airplane wing to changing velocity, as shown by FARREN[8], applies also to buildings, and a gust eight times the length of the building is therefore of adequate length to develop the new pressures; (3) The lateral flow around the ends of the buildings decreases the length of the wake and consequently the length of the minimum effective gust, but this adverse condition is more than offset by, (a) the favorable margin in item (2), and (b) the fact that the gust factor is later chosen on the basis of observations taken by an anemometer at a point whereas, the building is affected by gusts of considerable width with the consequent decrease in the maximum observed velocities; (4) An additional margin of safety is later introduced in selecting the illustrative gust factor.

Gust factors

Specifications as to the maximum wind velocity to be used in the design of structures must necessarily refer to the long-time records of the United States Weather Bureau. These are expressed in terms of five-minute average velocity, and the maximum record at any location, after it has been corrected for height and instrumental errors, is adopted as a proper basis of reference in choosing the design value.

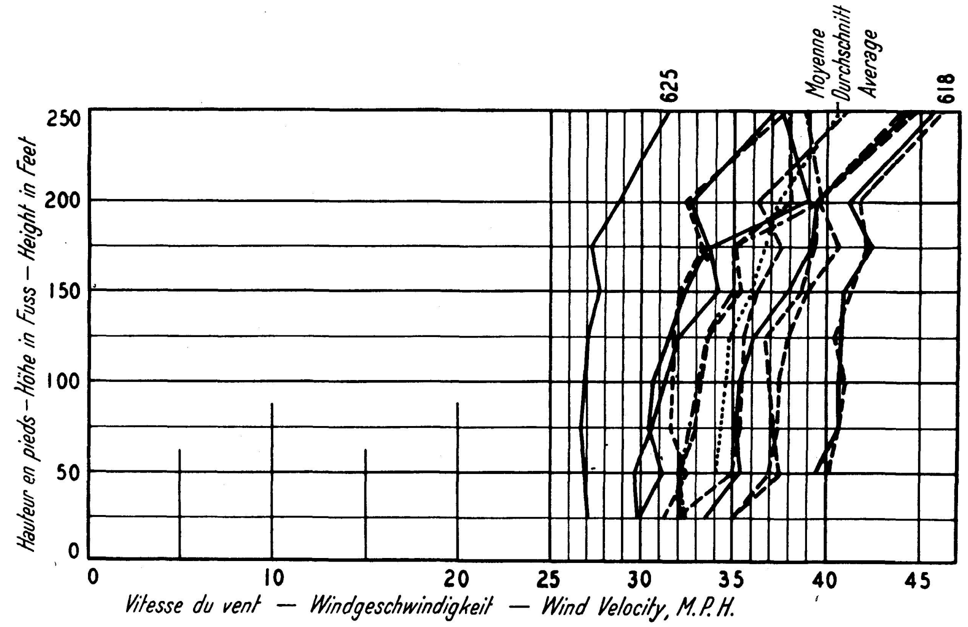

Fig. 12.

Wind Velocity vs. Height, January 19, 1933 — Windgeschwindigkeit und Höhe, 19. Januar 1933 — Vitesse du vent et altitude, 19 janvier 1933.

Within the five-minute period during which the maximum average velocity occurs, there will be fluctuations of velocity and when these are greater than the average, they are referred to as gusts. They may be of any duration up to the full five minutes, that is, 300 seconds. Three seconds has been adopted as the duration of the minimum effective gust for purposes of illustration in this report. Records from the storm of January 19, 1933 [2, 4], have been used to establish a proper and conservative gust factor, that is, the velocity of the gust divided by the five-minute average velocity.

Gust factors are studied for a duration of $^1/_2$, 1, 2, 5 and 10 seconds. Since the number of observations were not always large enough to give smooth curves, the statistical Pearson Type III curve was fitted to each five-minute interval and the maximum gust based upon the fitted curve. The manner of doing this is explained previously under the sub-heading „Distribution of Gust Records", page 216.

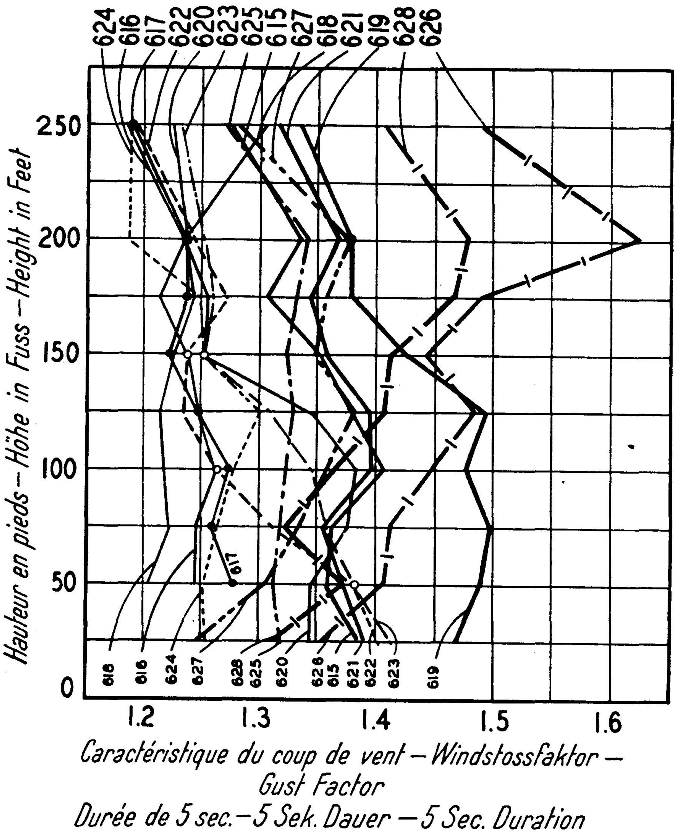

Fig. 13.

Gust Factors vs. Height, 5-Second Duration — Windstoßfaktor und Höhe, 5 Sek. Dauer — Caractéristique du coup de vent et altitude, durée 5 sec.

Figure 12 shows the average wind velocities which were obtained at the stations on the 250-foot tower for twelve of the fourteen five-minute intervals during the storm of January 19, 1933. There is quite a uniform trend in the curves except at the 200-foot level, where eight of the curves show lower velocities than the average trend and three higher. The average at this station follows the general trend.

Figure 13 shows the gust factors at each station on the tower for each of the fourteen five-minute intervals. There is a marked intermingling of the curves with very little general trend except that all but two of the curves show a decrease of gust factor with increasing height. For intervals 626 and 628, the gust factor increased up to a height of 200 feet, beyond which there is a decrease. The great majority of values for the gust factor is less than 1.4, but one value reaches 1.62, which is very large. However, the records for this storm also show, as previously noted for the ten-second gusts in the storms of March 6 and April 1, 1929, that there is a smaller gust factor for those five-minute intervals bearing the highest velocities of the storm than there is for the intervals with the average of the storm sample. The next step would therefore logically be to separate the storm records into groups according to their five-minute average velocities, so as to display this tendency.

In Figure 14, the five-minute intervals have been separated into three groups. Figure 14(a) shows that intervals 615 to 620 display the highest velocities, the average from the six intervals being 44.2 miles per hour at the 250-foot station. This means that an average wind velocity of that much was sustained for thirty minutes. Figure 14(b) shows the increment above the five-minute average velocity for the gusts of these three groups. The maximum five-second gust was determined statistically, as described on page 220, for each interval and these values averaged for the group of intervals.

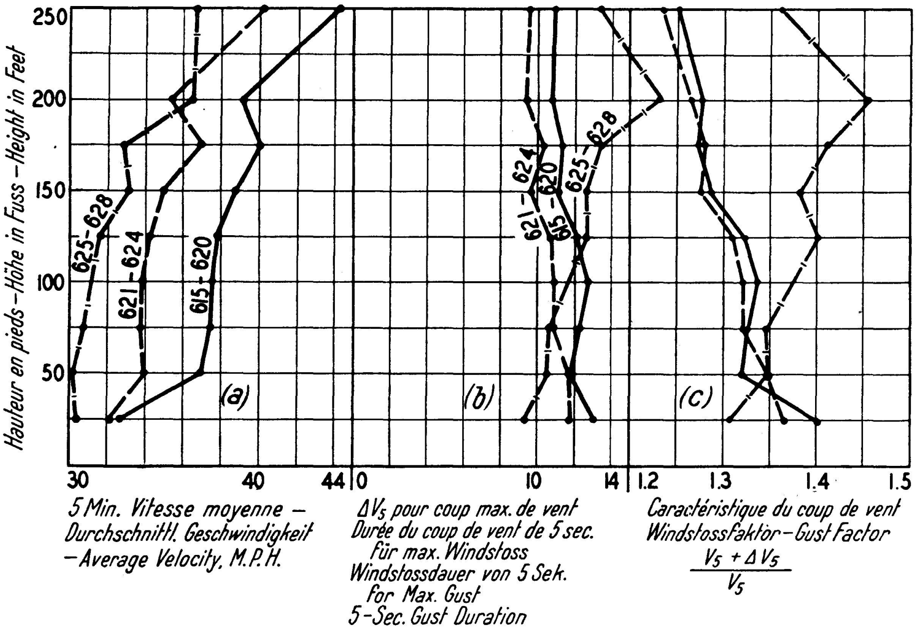

Fig. 14.

Gust Factors vs. Height, by Groups — Windstoßfaktor und Höhe, in Gruppen — Caractéristique du coup de vent et altitude, par groupes.

The very high gust factors at the upper stations of the tower appear here as large increments of velocity, but they are increments added to the group of lowest velocities. Figure 14(c) shows the gust factors for these same groups computed in the usual way for each five-minute interval and averaged for the group at each station. It will be seen that the highest gust factors accompany the lowest five-minute average velocities. Under this condition, the question must be answered, will the lower five-minute average velocities with high gust factors ever produce higher design velocity than that which is obtained by taking the highest five-minute average velocity on record and applying to it a lower gust factor?

In order to answer the preceding question the records for these fourteen five-minute intervals were plotted as shown in Figures 15 and 16. The records at the 50 and 75-foot stations were combined and a separate diagram

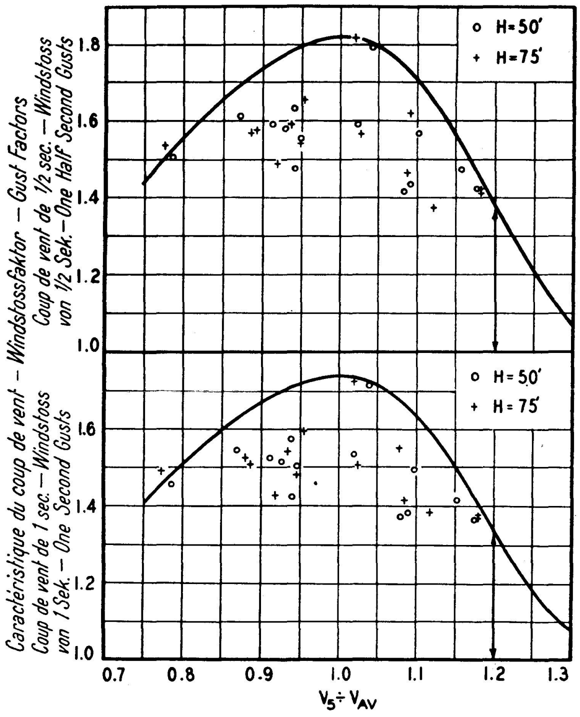

Fig. 15.

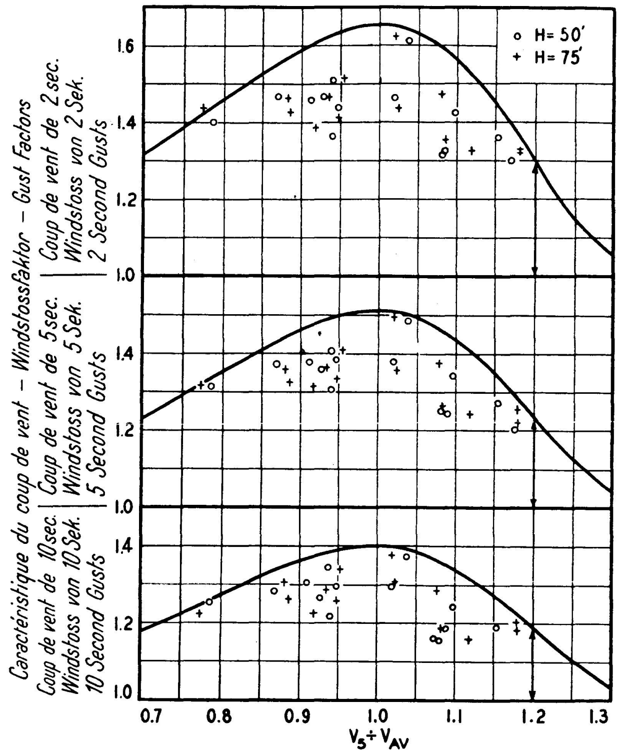

Fig. 16.

Gust Factors vs. $V_5 \div V_{ave.}$, 50' and 75' — Windstoßfaktor und $V_5 \div V_{Mittel}$, 50' und 75' — Caractéristique du coup de vent et $V_5 \div V_{moy.}$, 50' et 75'.

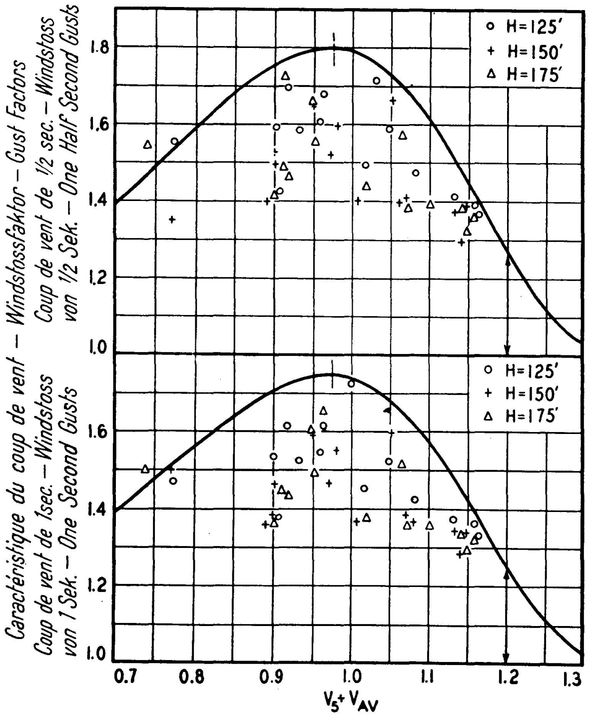

Fig. 17.

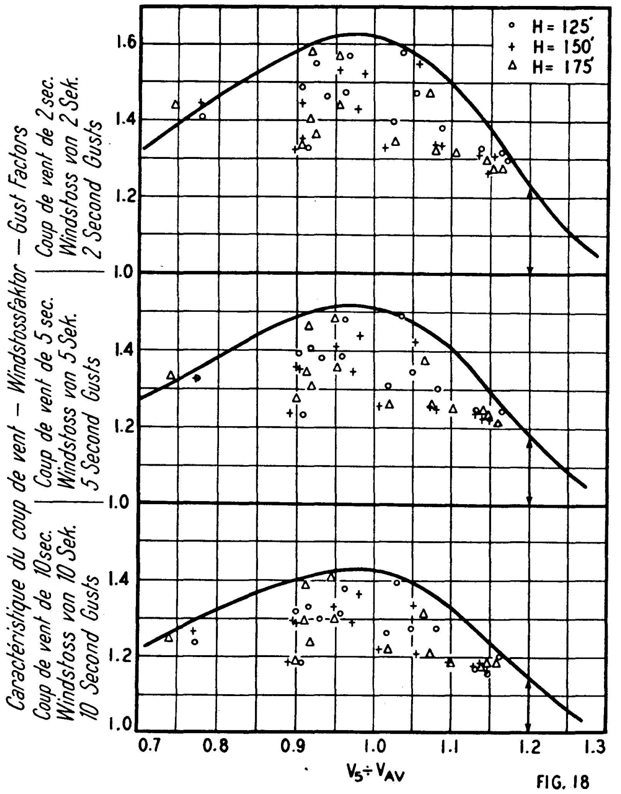

FIG. 18

Fig. 18.

Gust Factors vs. $V_5 \div V_{ave.}$, 125', 150', and 175'. — Windstoßfaktor und $V_5 \div V_{Mittel}$, 125', 150' und 175'. — Caractéristique du coup de vent et $V_5 \div V_{moy.}$, 125', 150' et 175'.

prepared for gusts of one-half second, one second, two seconds, five seconds and ten seconds duration. The fastest gust in each five-minute interval at each station was computed from the fitted curve, and the corresponding gust factor determined. The gust factors were plotted as ordinates and the velocities as abcissas. However, the velocities were expressed, not in miles per hour, but in units of the average velocity for the storm sample. This means that the five-minute average velocity for each interval and at each station was divided by the average velocity for the fourteen intervals at that station, thus giving 28 points in each division of the diagram.

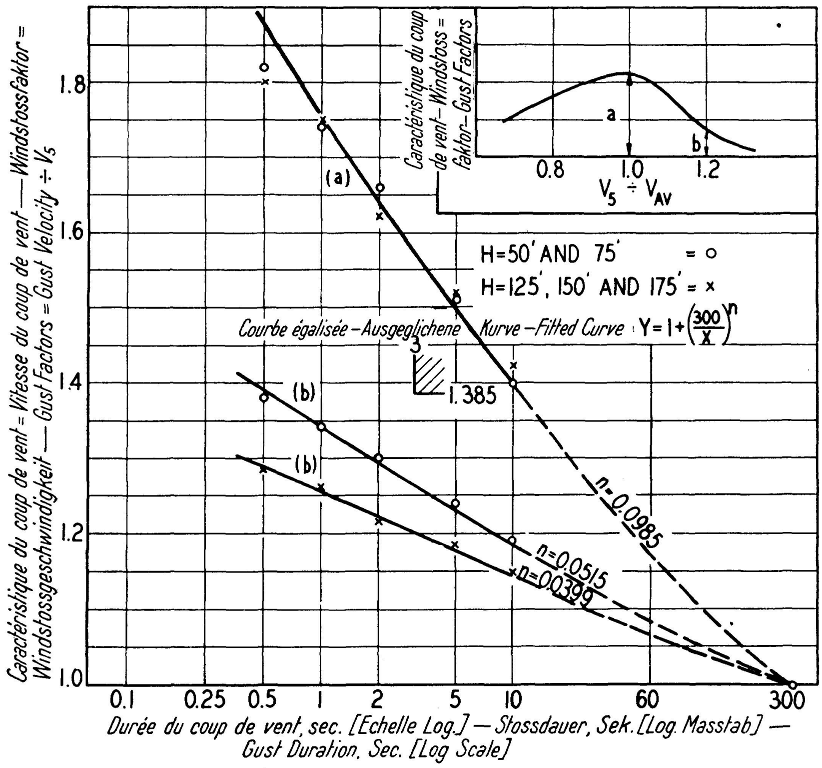

Fig. 19.
Gust Factors vs. Gust Duration — Windstoßfaktor und Windstoßdauer — Caractéristique du coup de vent et durée du coup de vent.

A curve was drawn as an envelope for the 28 points in each diagram. It was assumed that these data, like all natural phenomena, could best be represented by some variation of the laws of probability. Pearson Type III curves of different degrees of skewness were tried as an aid to the eye in fitting the envelope, and it was found that best results were obtained for a skewness of minus one. The envelopes are theoretical curves only by analogy, since the scale was established by trial. In order to compare the diagrams, it was assumed that each envelope could be characterized by two ordinates, one at the storm average and the other twenty per cent above the storm average, these values being respectively 1.0 and 1.2 for the velocity expressed in units of storm average. The values were plotted in Figure 19, using the gust factors as ordinates and the gust duration as abcissas to a logarithmic scale. These characteristic points show an orderly arrangement and the two curves give, (a) the variation of the gust factors when the five-minute average velocity is equal to the storm average, and, (b) when it is twenty per cent above the storm average. All these are for the combined data from the 50 and 75-foot heights above the ground.

Figures 17 and 18 show the same treatment of the combined data from heights of 125, 150 and 175 feet. In these Figures, there are 42 points under each envelope. Figure 19 shows, for the two height groups, that (a) the maximum gust factors, which occur approximately at the average of the storm sample, are the same for the two heights, but (b) above the storm average, there is a decrease of gust factors with increased height. Figure 20 reproduces both sets of envelopes for comparison.

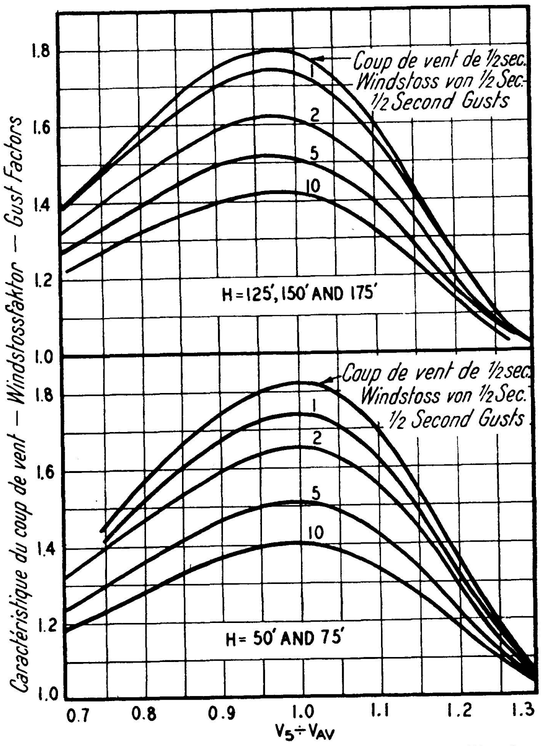

FIG. 20

Fig. 20.

Gust Factor Envelopes — Umhüllende der Windstoßfaktoren — Enveloppes des caractéristiques des coups de vent.

The results shown in Figures 15 to 19 are summarized in Figures 21 and 22, where the design velocity is plotted as ordinates and the five-minute average velocity as abcissas, each being in units of the average velocity for the storm sample. The envelopes from the previous diagrams are shown as solid curves below the value of 1.2. For all points within these diagrams, the design velocity is equal to the gust factors multiplied by the five-minute average velocity, that is,

$$\text{Design } V = (\text{G. F.})\,(V_5)$$

$$V \div V_{Ave.} = (\text{G. F.})\,(V_5 \div V_{Ave.})$$

Solid lines are also drawn to show the gust factors which at each point within the diagram give the relation between design velocity and V_5 velocity. For example, in order to read the diagram in Figure 21 one would say that a gust factor of 1.5 used with V_5 velocity of 1.2 gives a design velocity of 1.8. However, for such a relationship to be found in the normal wind of which these records are a sample, it would be necessary to use gust durations of considerably shorter periods than $^1/_2$ second and these would be effective only against very small structures such as small sign boards. The minimum effective gust adopted for illustration in this report is three seconds, for which the wind records in Figure 21 show a design

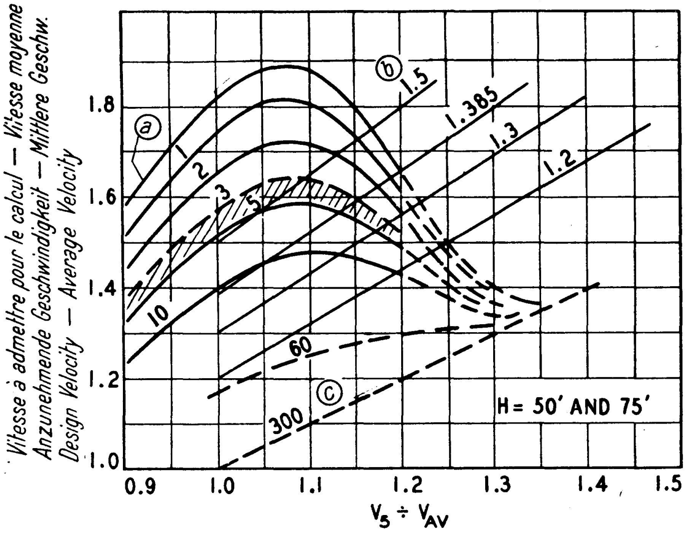

Fig. 21.

Relations Between Design Velocity, V_5, Gust Duration, and Gust Factors, $H = 50'$ and 75′ — Beziehungen zwischen anzunehmender Geschwindigkeit V_5, Stoßdauer und Stoßfaktoren, $H = 50'$ und 75′ — Relation entre les vitesses admises pour le calcul V_5, durée des coups de vent et caractéristiques des coups de vent, $H = 50'$ et 75′.

a) Gust Duration 0,5 Sec. — Windstoßdauer 0,5 Sek. — Durée du coup de vent 0,5 sec.

b) Gust Factor — Windstoßfaktor — Caractéristique du coup de vent.

c) Seconds — Sekunden — Secondes.

Previous Diagrams show that the highest gust factors occur near the average velocity of the storm sample.

This diagramm answers the question „which gives the higher design velocity, a high V_5 with a small G. F. or a low V_5 with a large G. F.?“

Design $V = V_5 \times$ G. F.

or expressed in storm units $\frac{V}{V_{av.}} = \text{G. F.} \times \frac{V_5}{V_{av.}}$

Vorhergehende Diagramme zeigen, daß die größten Windstoßfaktoren in der Nähe der mittleren Geschwindigkeit des Sturmbeispieles liegen.

Dieses Diagramm beantwortet die Frage, ob ein großes V_5 mit einem kleinen Stoßfaktor oder ein kleines V_5 mit großem Stoßfaktor die höhere anzunehmende Geschwindigkeit ergibt.

Anzunehmendes V = $V_5 \times$ Windstoßfaktor oder in Sturmeinheiten ausgedrückt:

$$\frac{V}{V_{Durchschn.}} = \text{Stoßfaktor} \times \frac{V_5}{V_{Durchschn.}}$$

Les diagrammes précédents montrent que les caractéristiques maximales des coups de vent atteignent presque la valeur moyenne de la vitesse dans l’exemple de la tempête.

Ce diagramme répond à la question, à savoir laquelle des deux hypothèses donne la plus grande vitesse servant de base au calcul.

Vitesse à admettre pour le calcul $V = V_5 \times$ caractéristiques des coups de vent ou exprimé en unités de tempête:

$$\frac{V}{V_{moy.}} = \text{Caractéristique de coup de vent} \times \frac{V_5}{V_{moy.}}$$

velocity of 1.52 when $V_5 = 1.2$. However, a gust factor of 1.385 is herewith recommended for three-second gusts and Figure 21 shows that this gives a design velocity of 1.66 when $V_5 = 1.2$. The difference between these two design velocities is available as a margin of safety to cover (a) uncertainties in the selection of the minimum effective gust of three seconds, as listed on page 222, and (b) the secondary distribution involved in the statistical computation of the maximum gust, as described under „Distribution of Gust Records" on page 220. This margin of safety is equivalent to reducing the minimum effective gust from three seconds to one-half second.

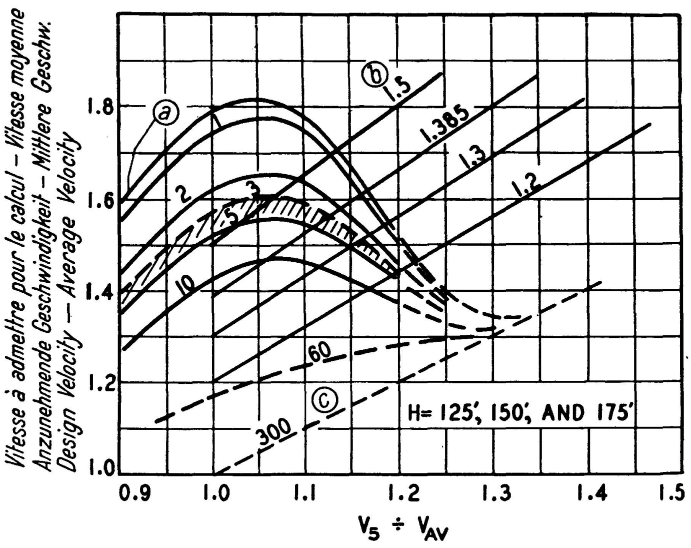

Fig. 22.

Relations Between Design Velocity, V_5, Gust Duration, and Gust Factors, $H = 125'$, 150', 175' — Beziehungen zwischen anzunehmender Geschwindigkeit V_5, Stoßdauer und Stoßfaktoren, $H = 125'$, 150' und 175' — Relation entre les vitesses admises pour le calcul V_5, durée des coups de vent et caractéristiques des coups de vent, $H = 125'$, 150' et 175'.

a) Gust Duration, Sec. — Windstoßdauer, Sek. — Durée du coup de vent, sec.
b) Gust Factor — Windstoßfaktor — Caractéristique du coup de vent.
c) Seconds — Sekunden — Secondes.

The recommended gust factor of 1.385 is discussed in the preceding paragraph in connection with a five-minute average velocity of 1.2, that is, one which is 20 per cent higher, than the average of the storm sample. No V_5 observed in this storm exceeded this value, but it is conceivable that the fastest V_5 on record at some station in the United States may have exceeded 1.2 for the sample of the storm in which it occurred. In that case, the margin of safety in the recommended gust factor would be even greater, as shown by the dash lines in Figures 21 and 22. This is entirely reasonable since the highest V_5 on record was itself a maximum gust, having 300 seconds duration, whose kinetic energy appraoched that of the source from which it was drawn at the level of the gradient velocity in the upper air.

Decrease with Height: Figure 23 shows the variation of maximum gust factors with height. The data, as previously, are combined for the 50' and 75' heights, and for the 125', 150' and 175' heights, and shown respectively at 62.5′ and 150′. Data for the 200′ and 250′ heights, not previously shown in this report, are shown at 225′. Fitted exponential curves are shown for each of six gust durations.

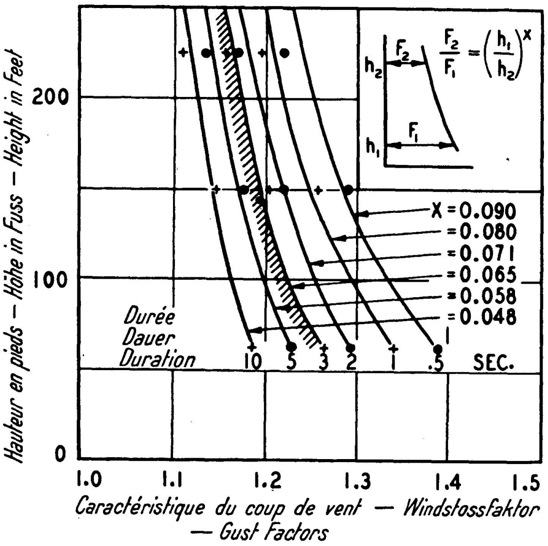

Fig. 23.

Gust Factors vs. Heights, 0.5 to 10-Second Duration — Windstoßfaktoren und Höhen, von 0,5 bis 10 Sek. Dauer — Caractéristique du coup de vent et altitude, durée 0,5 à 10 sec.

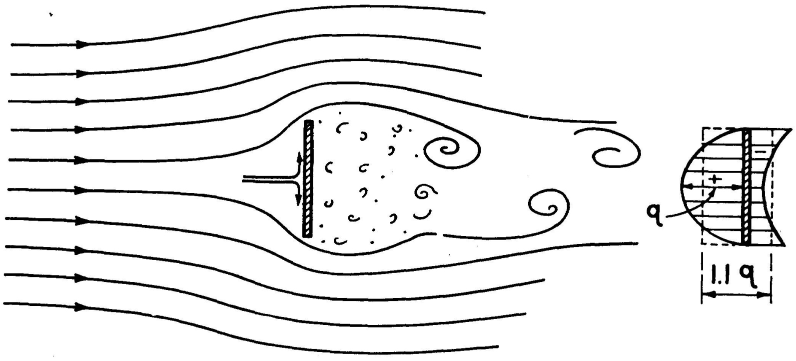

Fig. 24.

Flow and Pressure Distribution for a Square Plate — Strömung und Druckverteilung für eine quadratische Platte — Flux et distribution des pressions pour une plaque carrée.

Applications: In the discussions of „Minimum Effective Gusts“ and „Gusts Factors“ a small building was used for purposes of illustration. A minimum effective gust of three seconds was adopted together with a gust factor of 1.385. The increase of about 3.5 per cent which would be involved in stepping the data down from about 62.5′ to about 30′, as shown in Figure 23, was ignored.

The foregoing illustration will now be completed by applying the adopted gust factor to the modification of a specification for wind loading. The American Standards Association has recently released a new set of specifications [6] under the serial designation A 58.1—1945. It contains a map

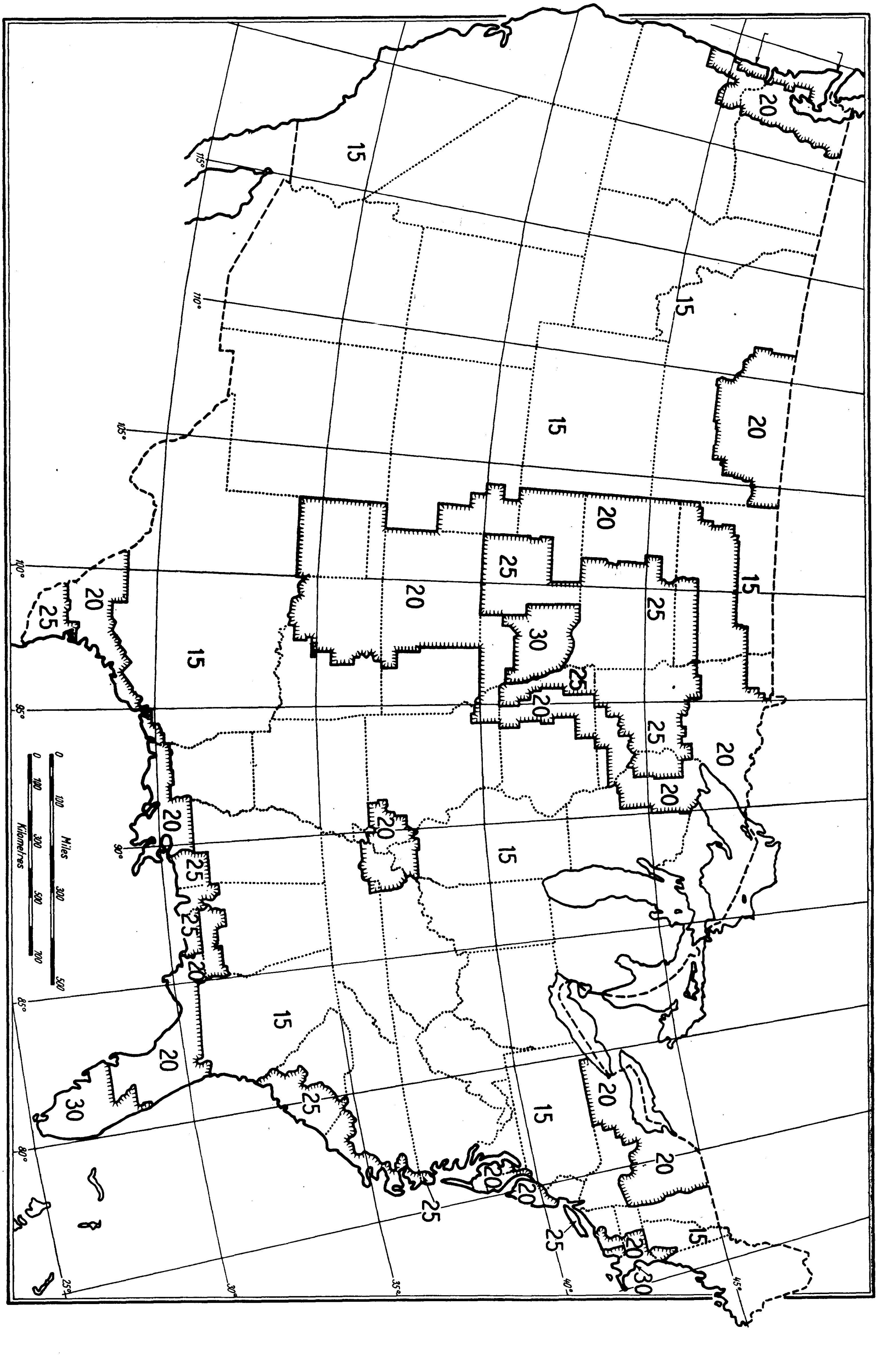
15
20
25
30
115°
110°
105°
100°
95°
90°
85°
80°
25°
30°
35°
40°
45°
Miles
0
100
300
500
Kilometres
0
100
300
500
700

Fig. 25.

of the United States (their Figure 2), showing contours of velocity pressure based upon Weather Bureau records of maximum five-minute average velocities in various parts of the country. It is assumed here that the records were corrected for the variables described in the introductory paragraphs of this report and the contours are therefore being accepted as a valid representation of the long-time weather bureau records in so far as five-minute average velocity is concerned. They are not being accepted for the size of building under consideration here, where gusts are concerned.

Each contour on the A. S. A. map is for a particular value of the velocity pressure, q, expressed in pounds per square foot.

$$q = 1/2\, \varrho V^2$$

where ϱ is the mass density and V is the wind velocity used for design purposes. When the density is that of standard atmosphere at sea level and the velocity is expressed in miles per hour, $q = .00256\, V^2$. This is not the design pressure but is the intensity of pressure which would be exerted at a point where the moving air is brought to a complete stop so as to transform all of its kinetic energy. This is said to be at the stagnation point, as shown in Figure 24. To obtain the design pressure, a coefficient must be applied to the velocity pressure to allow for the shape

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Fig. 25.

Map of the United States. Recommended Velocity Pressures due to Wind — Karte der Vereinigten Staaten. Empfohlene Staudrücke infolge Wind — Carte des Etats Unis. Pressions du vent recommandées.

Note: For the coastal counties of Washington and Northern Oregon the velocity pressure shall be taken as not less than 30 lbs./$\square'$. For exposed locations such as mountains and ocean promontories where weather bureau records show unusually high maximum five minute average velocities, or where such velocities may be expected due to local deflection of the wind, the velocity pressure shall be increased.

Recommended velocity pressures for design of low buildings. Velocity pressure q lbs./$\square' = \frac{1}{2}\, p\, V^2 = 00256\, V^2$ where $V =$ design vel. in MPH $= V_{5\,\mathrm{min.}} \times 1{,}385$ gust factor.

Design pressure w lbs./$\square' = q \times c$ where $c =$ a shape coefficient.

Bemerkung: Für die Küstengegenden des Staates Washington und des nördlichen Oregon soll der Geschwindigkeitsdruck nicht unter 30 lbs./$\square'$ angenommen werden. Für exponierte Lagen, wie Gebirge und Vorgebirge, wo die meteorologischen Stationen ungewöhnlich hohe Windgeschwindigkeiten innerhalb von 5 Minuten zeigen, oder wo solche Geschwindigkeiten erwartet werden können infolge lokaler Windänderungen, sollte der Staudruck erhöht werden.

Empfohlene Staudrücke für die Berechnung niederer Gebäude.

Staudruck q lbs./$\square' = \frac{1}{2}\, p\, V^2 = 00256\, V^2$, wo $V =$ anzunehmende Geschwindigkeit innerhalb 5 Min. $= V_{5\,\mathrm{min.}} \times 1{,}385$ Windstoßfaktor.

Winddruck w lbs./$\square' = q \times c$, wobei $c =$ Formbeiwert.

Note: Pour les contrées côtières de l'Etat de Washington et du nord de l'Orégon, la pression due à la vitesse ne doit pas être prise à moins de 30 lbs./$\square'$. Pour les endroits exposés, tels que les contrées montagneuses ou les promontoires s'enfonçant dans l'océan, où les enregistrements des stations météorologiques montrent un maximum des vitesses moyennes dans la période de 5 minutes tout à fait inaccoutumée, de même pour les contrées où l'on peut s'attendre à de telles vitesses dues à des changements locaux du vent, les pressions doivent être augmentées.

Pressions recommandées pour les calculs de constructions basses. Pression due à la vitesse q lbs./$\square' = \frac{1}{2}\, p\, V^2 = 00256\, V^2$ où $V =$ vitesse à admettre pour le calcul pendant 5 min. $= V_{5\,\mathrm{min.}} \times 1{,}385$ caractéristique du coup de vent.

Pression du vent w lbs./$\square' = q \times c$, où $c =$ coéfficient dépendant de la forme.

and proportions of the structure and the position on the surface where the pressure is being measured, as discussed in numerous other publications[5].

$$\begin{aligned} w &= C q\,. \\ &= C(1/2\,\varrho\,V^2) \end{aligned}$$

In arriving at a proper value of the design velocity, V, the A. S. A. specifications have chosen the maximum recorded five-minute average velocity, V_5, at each station, reduced to the velocity which would have occurred had the anemometer been placed at a height of 30 feet above the ground, on the assumption that the wind velocity varies as the $^1/_7$ power of the height. To this there is then applied a gust factor of 1.5 to allow for higher gust velocities which would have occurred within the five-minute period. The equation then becomes:

$$q = 1/2\,\varrho\,(V_5 \times 1{,}5)^2$$

But the gust factor being used here is 1.385 instead of 1.5 and the velocity pressure then becomes:

$$\begin{aligned} q &= 1/2\,\varrho\,(V_5 \times 1{,}385)^2 \\ &= 0{,}85\,[1/2\,\varrho\,(V_5 \times 1{,}5)^2] \end{aligned}$$

The values of the contours in the A. S. A. Figure 2 were modified accordingly and the map shown in Figure 25 was prepared to show the velocity pressures which should be used in different areas of the United States for a building of this size.

Summary

A statistical analysis of gusts, observed near Ann Arbor during three winter storms, is used to establish the probable maximum gust within a five-minute interval whose average velocity is known. The analysis deals especially with 42 000 one-half second readings of velocity from one of the storms. They were read from continuous oscillograph records obtained with specially designed anemometers. It is assumed that the statistical laws of gustiness, exhibited during these winter storms, will apply also to other storms and to other parts of the country. Nomograms were drawn showing the relations between design velocity, five-minute average velocity, average velocity of the storm sample, and gust factors, at various heights up to 175 feet, and for gust durations of 0.5, 1, 2, 3, 5 and 10 seconds. The relation between gust factors and height up to 250 feet were also shown for these same gust durations. An illustration is given for the selection of the minimum effective gust and the accompanying gust factor for a small building. This includes a map showing velocity pressures to be used for such a building in the various parts of the United States when a modern specification is modified according to this report.

Zusammenfassung

Zur Bestimmung der Wahrscheinlichkeit für das Auftreten des größten Windstoßes innerhalb fünf Minuten, in welchem Zeitraum die Durchschnittsgeschwindigkeit bekannt ist, diente die statistische Untersuchung, die in Ann Arbor während drei Winterstürmen gemacht wurde. Die Untersuchung

befaßt sich hauptsächlich mit den 42 000 Ablesungen, die alle $^1/_2$ Sekunden während einem der Stürme an ununterbrochenen Oscillograph-Registrierungen mittelst eines speziell konstruierten Windmeßgerätes gemacht wurden. Es wird vermutet, daß die statistische Gesetzmäßigkeit der Windstöße, die während dieser Winterstürme festgestellt wurden, auch für andere Stürme und Landesteile Gültigkeit haben. Die graphische Darstellung zeigt die Beziehungen zwischen der angenommenen Geschwindigkeit, der durchschnittlichen Geschwindigkeit während fünf Minuten, der durchschnittlichen Geschwindigkeit während des Sturmes und der Windstoßfaktoren bei verschiedenen Höhen bis zu 175 Fuß bei einer Dauer der Windstöße von 0.5, 1, 2, 3, 5 und 10 Sekunden. Ebenso wurde die Beziehung zwischen den Windstoßfaktoren und den Höhenverhältnissen bis zu 250 Fuß für die gleiche Windstoßdauer festgelegt. Es wurde auch der kleinste effektive Windstoß und der dazugehörige Windstoßfaktor für ein kleines Gebäude dargestellt. Eine Karte zeigt die Geschwindigkeitsdrücke, die für ein solches Gebäude in den verschiedenen Gebieten der Vereinigten Staaten berücksichtigt werden müssen, wenn neue Vorschriften gemäß diesem Bericht aufgestellt werden.

Résumé

Une analyse statistique faite à Ann Arbor lors de trois tempêtes hivernales servit de base à la détermination de la probabilité des coups de vent maximum pendant l'intervalle de 5 minutes, la vitesse moyenne du vent étant connue. Les considérations qui suivent s'occupent essentiellement des 42 000 lectures qui furent faites toutes les $^1/_2$ secondes pendant une des tempêtes au moyen des enregistrements d'un oscillographe continu et d'un appareil spécialement construit pour la mesure du vent. On formule l'hypothèse que les lois statistiques des coups de vent observées pendant ces tempêtes sont valables également pour d'autres tempêtes et d'autres contrées. Le graphique indique les relations entre la vitesse supposée, la vitesse moyenne durant 5 minutes, la vitesse moyenne pendant la tempête et les facteurs caractérisant les coups de vent à différentes altitudes jusqu'à 175 pieds pour une durée des coups de vent de 0.5, 1, 2, 3, 5 et 10 sec. De même il fut établi une relation entre les caractéristiques des coups de vent et les différentes altitudes jusqu'à 250 pieds, ceci pour la même durée du coup de vent. Le graphique contient également le plus petit coup de vent effectif et les caractéristiques correspondantes pour une petite construction. Un plan indique les pressions dues aux vitesses, pressions qui doivent être prises en considération pour une telle construction dans les différentes contrées des Etats Unis, chaque fois que des normes sont établies sur la base de ce rapport.

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