Gust Factor and Analysis Time of Gust*

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1. Introduction

Recent studies on structural theory or structural failures in the past have revealed that very short duration wind forces might be effective for destruction of buildings or other constructions. Therefore the maximum value of a few second mean wind speed is often taken for the design wind speed of the construction; for instance, E.L. Deacon (1955) has used 2 sec mean wind speed for design of a radio mast. Wind of such short duration, or short analysis time, belongs rather to the category of "gust" in meteorological sense. Since we have little knowledge about storm gust of such short analysis time, the maximum gust speed is often conventionally estimated from longer period mean wind speed (e.g. 5 or 10 min) appeared in climatological data, on the assumption that the maximum gust speed is simply proportional to the maximum mean wind speed. Its proportional constant is called a "gust factor" in engineering. This gust factor, whether it is called so or not, has been studied or evaluated in many occasions. But most of the authors have remained untouched or unsolved the important fact that this factor is dependent upon the analysis time of gust or the time interval during which the gust speed is measured. Several papers were recently published on the dependency of gust factor upon the analysis time, but their treatments are no more than qualitative ones. In the present paper, this dependency is discussed somewhat in detail, and an empirical formula is proposed.

2. Gust factor and analysis time

The results of measurement of short analysis time wind speed in the storm are available from the following two sources. The first is R. H. Sherlock's investigation (1952), which was made by the use of specially designed pressure plate anemometers surmounted on an observation tower in the open grassland in Ann Arbor, Michigan, U.S.A.. The anemometers were mounted at the heights of 16.4 m (50 ft) and 24.0 m (75 ft). The minimum analysis time in this observation is 1/4 sec. The results shown in his paper include 27 cases, each of which extends over 5 min, and 5 min mean wind speed averaged over 27 cases is 19 m/sec. Gust factors for various analysis time of 0.5 to 10 sec for each case can be read from the figures in his paper. The second source of data is the investigation by Deacon (1955), who used Sheppard type cup anemometers surmounted on a radio mast at the heights of 12.2 m (40 ft), 64.0 m (210 ft) and 153.0 m (503 ft) in the open grassland in Sale, Victoria, Australia. Wind speeds are evaluated at the time interval of 2 sec, and their time change curves of two cases, whose average values of 5 min mean wind speeds at the heights of 12.2 m, 64.0 m

Table 1. Gust factor, G and analysis time of gust s .

Ann Arbor (Sherlock, 1952)

s (sec)	0.5	1.0	2.0	5.0	10.0	P
G	1.55	1.48	1.42	1.33	1.25	0.069

Sale (Deacon, 1955)

s (sec)		2.0	4.0	8.0	16.0	32.0	P
G	40 ft	1.52	1.49	1.42	1.31	1.21	0.090
	210 ft	1.23	1.21	1.19	1.16	1.12	0.045
	503 ft	1.16	1.16	1.13	1.11	1.09	0.033

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and 153.0 m are 18, 23 and 28 m/sec respectively, are shown in his paper.

The mean values of gust factors for various analysis time are computed from the data mentioned above, and the results are shown in Table 1. Here, the gust factor for s sec gust, G_s is defined as follows:

$$G_s = V_{s\max}/V_{\text{mean}} \quad (1)$$

where V_{mean} is enough long period (D sec) mean wind speed (300 sec in these cases), V_s is wind speed evaluated for short subdivision (s sec) of D or wind speed whose analysis time is s sec, and $V_{s\max}$ is the maximum value of V_s or s sec peak gust. Table 1 shows that the gust factor decreases with increasing of the analysis time of gust. As for Ann Arbor data, the gust factor for 0.5 sec gust is 1.55 and that for 1.0 sec gust is 1.48, and their ratio ($G_1/G_{0.5}$) is 0.955, while the ratio G_2/G_1 is 1.42/1.48=0.955, and so on. This suggests that the values of G 's may be represented in geometrical series. Fig. 1 shows the relation between G_s and s plotted

Fig. 1 Variation of gust factor G with analysis time of gust s .

in logarithmic scales. From this figure, it is found out that the distribution of the points is well represented by a straight line, which confirms the above suggestion. Moreover, a regression line can be drawn without any difficulty to pass the point $G=1.00$ at $s=D$ (300 sec). We can also see the same relations in Sale data. Therefore we can adopt the following empirical formula to describe the relationship between gust factor G_s and analysis time of gust s :

$$G_s = (s/D)^{-p} \quad (2)$$

where p is a constant which is determined from the observational data. This new constant p is a more universal representative of gustiness than a gust factor. Once the value of p is given we can calculate the gust factor for any analysis time required. The value of p for each set of data is shown in the right end of each column in Table 1.

3. Variation of p with height

The values of p 's for Sale data decrease with increasing of height, as shown in Fig. 2. In this figure each axis is in the logarithmic scale. The value of p for Ann Arbor

Fig. 2 Variation of p with height z .

data is plotted with a cross at the height of 20.2 m which is the average value of two observation heights. This cross coincides with the regression line for Sale data, which means that the conditions of these observations are closely similar. It is reasonable that in strong wind the thermal stratification will become neutral and its effect on wind structure may be negligible. Therefore these data can be regarded to be a representative of the structure of strong wind over the open grassland, which may be taken for the standard of various ground conditions.

The variation of p with height for Sale data can be represented by the formula:

$$p = p_0 (z/z_0)^{-0.41} \quad (3)$$

where p_0 is the value of p at the standard height z_0 and in this case $p_0=0.97$ at $z_0=10$ m.

4. Further example

Recently storm observation by a quick response pressure type anemometer with a spherical sensor was made at Kagoshima Meteorological Observatory (1955). In this case, even though some difficulties can be ap-

Fig. 3 Variation of gust factor G with analysis time s observed by the spherical anemometer (Kagoshima 1955).

pointed on the dynamical character of the sensor, wind speed is analyzed for 1/2 sec intervals. Gust factors for various analysis time are computed from the time change curve of wind speed shown in the report, and the results are given in Fig. 3. The total observation time D is 600 sec and mean wind speed is 30 m/sec. This figure shows that the empirical formula (2) holds good also in this case. The value of p for this case is 0.10. This observation was made at the top of the wind tower but its height is not clear in the report. If we assume its height to be 10 m as in usual observatory, the value of $p=0.10$ is not so far different from the example

shown in the fore section.

In the report it is said that the maximum wind speed recorded on the trace of Dines anemometer in the same time interval was 46.5 m/sec. And the gust factor for this value is 1.55, which corresponds to the gust factor for 9 sec gust in Fig. 3. It is suggested that short period fluctuations are dynamically smoothed out and the maximum wind speed recorded on the trace of Dines anemometer corresponds approximately to the peak gust of 10 sec or so.

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突風率と風速評価時間との関係について

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非常に短い時間間隔の平均の風速は気象学上の興味の対象であるのみならず、建造物などに対する風の影響を見る場合にも問題となる。このような風速の最大値、すなわち普通瞬間最大風速と呼ばれるものと適当に長い時間、例えば 5 分または 10 分間の平均風速との比は突風率と呼ばれ、建造物などの設計風速の算出等に用いられている。この突風率 (G_s) は瞬間風速の評価時間 (s sec) のとり方によつて異なつた値をとるが、両者の間の量的な関係については従来ほとんど研究されていなかった。著者は Sherlock および Deacon の観測資料に基づいて、この関係を調べた結果、それが $G = (s/D)^{-p}$ という経験式によつて良く示されることを見いだした。ここで D は平均風速の評価時間である。また p は新しく導入された指数で、平らな草地の地面上 10 m の高度では 0.1 程度の値を示し、高さとともに減少している。