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WIND SPEEDS FOR DESIGN OF TEMPORARY STRUCTURES

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Introduction

Wind speeds for the design of permanent structures are traditionally specified as a "return period," or more properly *mean recurrence interval*, which is the same as, or greater than, the assumed life of the structure. No such tradition or guidelines exist, however, for application to temporary structures, i.e. those having a life or *exposure period* much less than 50 years. Using a simplified notion of reliability, the probability of failure due to wind is determined as a function of several parameters including the wind speed probability distribution, factor of safety, mean recurrence interval of the design wind speed, and the exposure period. The objective is a procedure for specifying the design recurrence interval for a temporary structure such that the probability of failure is the same as in traditional design of permanent structures.

Simplified Reliability as Related to Wind Loads

Let Q_f be a "failure" load where failure is defined in any desired manner: first yield, permanent set, unserviceability, collapse, etc. Under conventional working stress design (WSD) the structure would be supplied with working resistance where F is defined as the "factor of safety." This value is determined by the material code of practice and the type and complexity of the structure. It is difficult to define precisely, but for most civil engineering structures it ranges from about 1.3 to 2.

Formal reliability analysis treats both the load and resistance as random variables and deals with the probability that load exceeds resistance. The above is all that will be said in this paper concerning the resistance side of this equation. We will show that its significance is diminished by more important issues on the load side. Moreover, it is not our intent to study formal reliability, but rather to examine the effect of uncertainties in wind load when coupled with traditional WSD.

On the load side, assume that the load/velocity relation is $Q = \alpha U^{\beta}$. Then $U_d = (Q_d/\alpha)^{1/\beta}$ is the design wind speed, and $U_f = (Q_f/\alpha)^{1/\beta}$ is the failure wind speed. We desire to find the "probability of failure," i.e. $P(U > U_f)$, when U_d is specified by traditional methods.

A permanent structure is presumed to have an exposure period $T_p = 50$ years and is designed for wind of mean recurrence interval $T_{dp} = 50$ or 100 years. In well behaved climates away from a hurricane coast, the extreme annual wind speed has been observed to obey the extreme value type I probability distribution, so

$$U_d = U_0 + a\{-\ln[-\ln(1 - P_{1d})]\} \tag{1}$$

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where U_0 and a are parameters fit to data, $P_{1d} = 1/T_d$ is the probability that the "design" wind speed U_d is exceeded in any single year, and T_d is the mean recurrence interval. The wind speed causing failure can then be written as

$$U_f = F^{1/\beta} U_d \tag{2}$$

The probability this speed is exceeded in any one year is the inverse of (1):

$$P_{1f} = 1 - \exp\left\{-\exp\left[-\frac{1}{a}(U_f - U_0\right]\right\} \tag{3}$$

The probability of failure during an assumed lifetime T of the structure is

$$P_f = 1 - (1 - P_{1f})^T \tag{4}$$

Combining the above equations, introducing the approximation $1 - \varepsilon \approx e^{-\varepsilon}$, leads to

$$P_{fp} = \frac{T_p}{T_{dp}^{F^{1/\beta}}} e^{(U_0/a)(1-F^{1/\beta})} \tag{5}$$

The subscript p has been introduced to P_f, T, and T_d to indicate application to a permanent structure. This result is graphed in Figure 1. Note that the selection of 50 vs. 100 years as the design recurrence interval has a small effect on reliability, compared to the factor of safety or the parameters of the probability distribution.

Reliability of Temporary Structures

The above procedure is not limited to long-term permanent structures. For a temporary structure of exposure period T_t and design wind speed of recurrence interval T_{dt}, Eq. (5) becomes

$$P_{ft} = \frac{T_t}{T_{dt}^{F^{1/\beta}}} e^{(U_0/a)(1-F^{1/\beta})} \tag{6}$$

Setting Eq. (6) equal to Eq. (5) gives the required recurrence interval such that the probability of failure of the temporary structure, exposed for period T_t, is the same as if it were conventionally designed as a permanent structure of exposure T_p:

$$T_{dt} = \left(\frac{T_t}{T_p}\right)^{F^{-1/\beta}} \times T_{dp} \tag{7}$$

This result is shown in Fig. 2, for the common parameters $T_p = T_{dp} = 50$, $\beta = 2$, and several values of F.

There are several noteworthy aspects of this result:

- The wind speed specification does not depend on the extreme-value parameters U_0 or a. Of course, after finding T_{dt} these parameters must be evaluated in order to obtain the wind speed U_{dt} using Eq. (1). But specifying the speed in terms of recurrence interval is more concise, is universally applicable to all well behaved climates, and yields considerable intuitive insight.
- If $F = 1$, an n-year structure could be designed for an n-year wind with constant probability of failure. However, P_f would be unacceptably large unless $T_t >> 100$.
- Reasonable P_f requires $F > 1$. This causes T_{dt} to be increasingly larger than T_t as the exposure period decreases. Thus while a 50-year structure can safely be designed for a 50-

year wind using the factor of safety inherent in conventional WSD practice, a 5-year (say) structure cannot be designed for a 5-year wind using the same practice. In both cases the probability that the design load Q_d is exceeded is the same, but the *amount* by which it is liable to be exceeded is greater for the temporary structure. Thus, the probability that the failure load is exceeded is greater for the temporary structure. For adequate safety, either F must be increased, perhaps entailing complex modification of WSD procedures, or T_{dt} must be increased as shown in Fig. 2.

- Alternative values of T_p, T_{dp}, and β are easily accommodated.

For short-term recurrence intervals, say $T_d < 10$ years, the relation implicit in Eq. (1) is imprecise; use instead $1 - P_{1dt} \approx \exp(-1/T_{dt})$. With this convention, Eqs. (1), (5), and (6) are not restricted in values of T. However, exposure periods of less than one year should be interpreted with caution, since the stationarity of the extreme wind random process may break down. For example, if a climate tends to experience largest winds during one season, then a structure with $T_t = 0.25$ (3 months) may be equivalent to one year, depending on the season of exposure.

Practical Design Example

A building is to be constructed in Pittsburgh. The designer would normally treat it as a 50-year structure and design it for a 50-year wind, using WSD. He feels that $F = 2$ is consistent with his notion of "failure." The structure's response to wind is quasi-static, so that $\beta = 2$. The structure is expected to exist for $T_t = 2$ years. From Fig. 2, the required design wind speed has mean recurrence interval $T_{dt} = 5$ years. The designer does not have access to raw wind data and is satisfied instead to use the ASCE standard 7-88. From Table C7 in that publication he obtains the following:

for $P_1 = 0.04$ ($T_d = 25$ years), $U_{dp} = U_{25} = 61$ mph
for $P_1 = 0.01$ ($T_d = 100$ years), $U_{dp} = U_{100} = 68$ mph

Substituting these data into Eq. (1) and solving for the two unknowns gives $a = 5.05$, $U_0 = 44.7$. Then in Eq. (1),

$$\begin{aligned} U_{dt} &= U_0 + a\{-\ln[-\ln(e^{-1/T_{dt}})]\} \\ &= 44.74 - 5.05\ln(1/5) \\ &= 53 \text{ mph} \end{aligned}$$

From Fig. 1, with $U_0/a = 8.9$, the probability of failure is 0.5 percent.

Conclusion

An interpretation of structural reliability has been introduced which treats the random variable of resistance as constant, in the sense of being restricted to traditional WSD procedures, in order to focus on the variability in loads. The wind climate characteristics—or our ability to accurately determine them—have as great an effect on reliability as does the variation of certain WSD parameters, such as factor of safety and the recurrence interval of the design wind, over commonly encountered ranges.

A procedure has been suggested to specify the design wind speed appropriate for structures of short exposure period. The resulting reliability is the same as would be obtained from traditional design of a permanent structure.

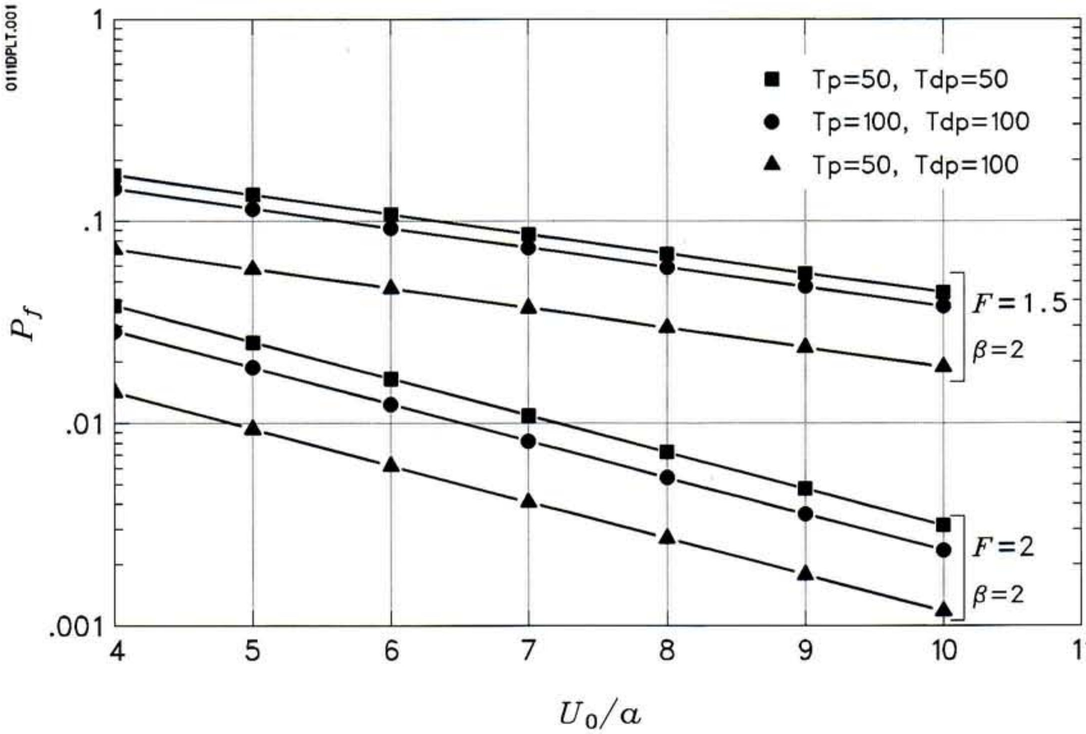

Figure 1. Probability of failure of structures under conventional WSD procedures as function of extreme wind speed probability distribution, wind speed recurrence interval and exposure period assumed for permanent structures, and factor of safety.

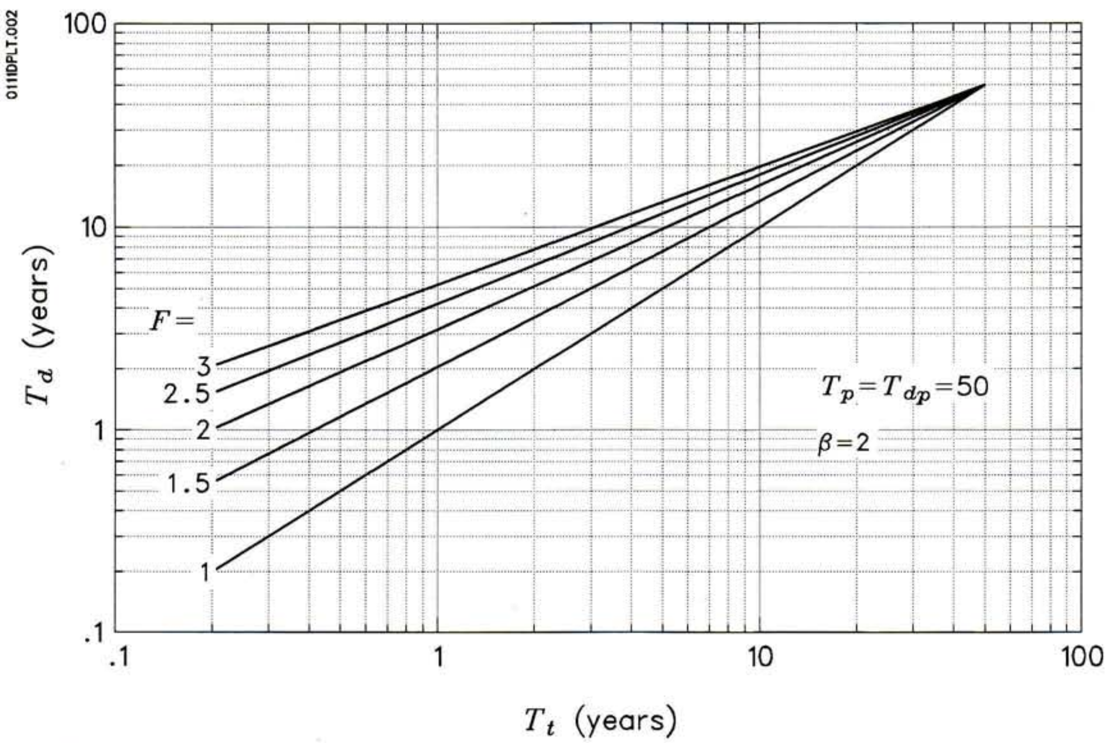

Figure 2. Recurrence interval of wind speed proposed for design of temporary structures. Probability of failure is same as in Fig. 1.