INTERACTION OF WINDOW GLASS AND WIND

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Current design of window glass for wind loads is based on the use of empirical charts giving the maximum design pressure as a function of area and thickness in combination with design wind pressures derived from the Australian wind loading code. The charts are derived from experimental data of the failure pressure for loading of one minute duration of a large number of glass pane sizes, the design pressure being derived from the mean failure pressure data by dividing the latter by 2.5. This is purported to give a probability of failure of 8 to 1000 at design load based on an assumed normal distribution of strength with a coefficient of variation of 25 per cent.

The charts are empirical because they are derived from a fit of the experimental data to straight lines on a log-log plot of area versus failure pressure for different thickness and not from any considerations of the structural mechanics involved. During recent years Beason [1] has developed a model based on the structural mechanics of window glass behaviour under uniform pressure which promises to replace the empirical approach and enables a much more rational approach to window glass behaviour to be undertaken.

However, like the current charts, the Beason model in its current form [2] only gives the strength of a glass pane under uniform constant pressure for a specified duration (usually one minute) and a prescribed probability of failure.

Because the strength of glass is dependent on load duration the use of code prescribed wind loads with the glass strength information derived from either the Beason model or the empirical charts is questionable. It has been suggested that in Australia it would be correct if the strength information was corrected to 3 second duration since wind loads are based on 3 second gust velocities. But the wind pressures in the code are not 3-second duration pressures! They are estimated peak pressures from a system of fluctuating loads. In theory they have no duration.

Beason based his model on a model proposed by Brown [3] which comprised two elements, one accounting for the load duration effect and the other for the effect of surface area on failure.

The load duration effect is accounted for by a relationship based on fracture mechanics and the work of Charles [4,5] and others which if temperature and humidity effects are ignored reduces to

$$\int_0^{t_g} [\sigma(t)]^n \, dt = \text{constant}$$

where $\sigma(t)$ is the surface tensile stress as a function of time
t_f is the time to failure
n is a constant of the order of 16.

The surface area effect is based on a statistical description of a brittle failure proposed by Weibul [6] for a materials with surface flaws in which the probability of failure is given by

$$p_f = 1 - e^{-B}$$

where $$B = \int_0^A k\left(\frac{\sigma}{\sigma_0}\right)^m dA$$

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and σ is the surface tensile stress

A is the surface area

k, m, σ_0 are constants.

For biaxial stress conditions Weibul proposed an equivalent stress which is a function of the principal stresses.

The constants k and σ_0 are interdependent. If k is made equal to 0.693 then σ_0 is the median failure stress of a unit area of the materials under uniform biaxial tension.

If $\sigma(t)$ is known, as well as the constants σ_0 and m, which will be characteristics of the glass, then probabilities of failure can be evaluated and thus a rational design approach developed.

Unfortunately there are problems as the stress is not proportional to pressure due to the non-linear behaviour of thin plates such as glass under transverse loads, and to be meaningful the integration with respect to time should take place over the full life of a window pane.

Beason simplified the problem by assuming $\sigma(t)$ is constant - ie. that a constant load is applied - for a fixed time and has produced with Morgan tables which enable the statistical characteristics of failure under a uniform constant pressure of one minute duration to be evaluated if the glass characteristics k, σ_0 and m are known [2]. (Beason takes σ_0 as unity and works in terms of k and m.) He achieved this with the use of a finite difference program for analysing the stresses in thin plates developed by Vallabhan and Wang [7]. He showed how it could also be used for determining the glass strength characteristics from test data if the location of the flaw causing failure in each test is recorded together with the load-time curve to failure. Unfortunately most existing test data does not include this information but from information generally available about the loading system and assuming a linear relationship between load and stress approximate estimates of the glass characteristics can be made using the Beason model.

To date the problem of the fluctuating nature of the wind loads has been addressed by at least three different groups of researchers. In the mid 1970's Mayne and Walker [8] at the Building Research Station in the United Kingdom using recorded wind pressures from full scale measurements of wind loads on windows to determine the character of hourly fluctuations, in conjunction with an estimated distribution of mean hourly wind speeds over 50 years, and ignoring non linear effects, concluded that the use of design wind pressures derived from the British wind loading code in conjunction with glass design strengths compatible with a uniform constant pressure of approximately 3 second duration appeared 'reasonable'. Dagliesh [9] at the National Research Council of Canada also assumed a linear relationship between stress and pressure in evaluating the time integral, and concluded that failure is dominated by the worst storm and often by the peak pressure pulses within this storm. He has proposed an effective glass pressure coefficient comprising two components, one to account for the cumulative weakening of occurring during the worst storm, and the other a function of the peak pulse only. The design pressures evaluated with this coefficient would be used in conjunction with the 60 second glass strength data. In a more recent study Reed and Simiu [10] at the National Bureau of Standards in the United States have described a detailed Monte Carlo approach using step-by-step time wise integration of artifically generated pressure fluctuations, in combination with fracture mechanics, the Weibul model of brittle failure and non linear stress analysis.

All these approaches have their limitations and represent partially successful attempts at solving the problem of developing a truly rational approach to window glass design for wind loads. Factors not mentioned which further complicate the problem are the apparent deterioration in the strength of glass with age due to weathering [11], the effect of edge defects on glass strength [12], the interaction between internal pressures and external pressures during severe winds, and the estimation of the duration characteristics of severe wind storms and the wind loads generated by them.

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