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Technics Focus
Wind Does Not Break Window Glass

Dr. H. Scott Norville of the Glass Research and Testing Lab and consultant **Paul E. Beers** discuss limitations of current design methods.

An important new standard, ASTM E 1300 *Practice for Determining the Minimum Thickness of Annealed Glass Required to Resist a Specified Load*, will soon become the model for window glass design in the United States as well as in some other countries. It can be used to size window glass thickness and to design window glass constructions subjected to wind loadings and uniform loadings of long duration. While ASTM E 1300 represents a marked improvement over the current design recommendations in model building codes, it does not address many problems of window glass design or breakage.

The document itself states: "Many other factors need to be considered in glass type and thickness selection. These factors include, but are not limited to: thermal stresses, the effects of wind-borne debris, excessive deflections, behavior of glass fragments after breakage, seismic effects, heat flow, edge bite, noise abatement, etc. In addition, considerations set forth in federal, state, and local building codes along with criteria presented in safety glazing standards may control the ultimate glass type and thickness selection." Although window glass thickness is traditionally designed according to its ability to resist wind loads, window glass failures most often result from causes other than wind. In this article, the methodology used by ASTM E 1300 for architectural window glass design will be examined, and the many factors it does not address, including the primary causes of glass breakage and post-breakage performance, will be explored.

Designing Window Glass Using ASTM E 1300

Required Definitions. The design of a window glass lite or a window glass construction using ASTM E 1300 consists of selecting an appropriate glass type and glass thickness to resist an equivalent design loading. Designers must understand certain definitions before they can use ASTM E 1300. The ASTM definitions cover glass type, loads, glass thickness, thickness designations, and glass lite geometry.

ASTM E 1300 defines five window glass types for which it can be used. These are annealed (AN) monolithic glass, heat strengthened (HS) monolithic glass, fully tempered (FT) monolithic glass, laminated (LG) glass, and insulating glass (IG) units. The design procedure in ASTM E 1300 is used only for lateral loads. "Lateral" is defined in the standard as the direction perpendicular to the glass surface. A "load" is defined as a uniformly distributed lateral pressure. Four specific terms are defined as loads in ASTM E 1300, the design load, the equivalent design load, the non-factored load, and the allowable load.

The *design load* consists of all loads that act on the glass including self-weight, wind load, snow load, and any other loads. The design load is to be used only in the calculation of lateral deflections. The *equivalent design load* is the magnitude of a constant load of 60-second duration which represents the cumulative effects of the components of all loads that act on the glass. The design load must be converted to an equivalent design load. The methodology to accomplish the conversion is not addressed by ASTM E 1300; it relies on the "specifying authority" to provide this information.

The charts depicted in ASTM E 1300 provide *non-factored loads* for window glass lites of specific nominal dimensions. The values from the charts are multiplied by an appropriate type factor to determine the *allowable load* for a specific glass type. The type factor accounts for the differing strengths of the various glass types as well as load duration. The allowable load is the 60-second equivalent load associated with a probability of failure of 8 lites per 1000 (or 0.008) at the first occurrence of the load. Because the type factor for annealed glass is 1.0, the non-factored load charts represent 60-second duration allowable loads for AN glass.

The "equivalent design load" is a nebulous term to most architects and engineers who design window glass. It incorporates the duration of the lateral loads that are expected to act on the glass, the time variations of magnitudes of these lateral loads, and, indirectly, the time dependence of glass strength. According to ASTM E 1300, the specifying authority is the only one who can provide information to calculate the equivalent design load. Unfortunately, beyond defining the specifying authority as "those responsible for interpreting local, state, and federal building codes," the authority's identity is unknown. The definition of "specifying authority" relieves ASTM E 1300 from providing any guidance as to how appropriate equivalent design loads for window glass should be determined.

Non-Factored Load Charts. ASTM E 1300 represents the strength of AN monolithic glass lites with continuous support on all four sides using non-factored load charts. These charts differ radically from window glass strength charts presented in model building codes. The ASTM E 1300 non-factored load charts are an improvement in that they better represent the strength of A[illegible]low glass that has been in service for several y[illegible].

To illustrate the use o[illegible]on-factored load charts, we will consider the [illegible]le that is illustrated in the chart for ¼" no[illegible]hickness (1a). To determine the non-factore[illegible] for a rectangular glass lite with nominal di[illegible]s of 60" x 80" x ¼", enter the ¼" non-fact[illegible]ad chart by drawing a vertical line from th[illegible]zontal axis (long dimension) at 80 and draw[illegible]zontal line from the vertical axis (short dim[illegible] at 60. These two lines intersect between the [illegible]on-factored load lines for 25 psf and 30 psf. [illegible]olating along the radial line from the lower [illegible]ner of the chart that passes through the in[illegible]on point of the horizontal and vertical lines[illegible]on-factored load for this lite is then "read" f[illegible]e chart as being approximately 27 psf.

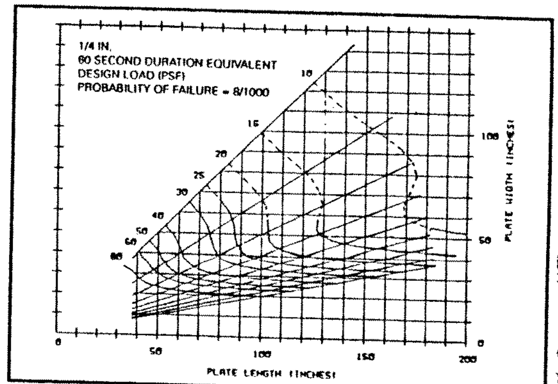
Type Factors and Glass Lit[illegible]h. The strengths of the different glass types [illegible]d in the definitions above are represente[illegible]pe factors. Two basic sets of type factors are [illegible]ned in ASTM E 1300: type factors for 60-sec[illegible]ration loads and type factors for long duratio[illegible]s. For 60-second duration loads, the type fac[illegible] AN monolithic glass is 1.0, the type factor fo[illegible]onolithic glass is 2.0, and the type factor for [illegible]nolithic glass is 4.0. For other glass types su[illegible] G and IG units, there are more type factors [illegible] are additional type factors for long duratio[illegible] that result in a reduction of the allowable lo[illegible] particular glass lite or construction. This re[illegible]n considers the fact that glass strength dimi[illegible]s load duration is increased.

Returning to the simpl[illegible]nple discussed above, the 60-second duratio[illegible]gth of a monolithic AN glass lite having re[illegible]r dimensions of 60" x 80" x ¼" to resist a uni[illegible]ad of 60-second duration is:

Non-factored Load x AN T[illegible]tor =
27 psf x 1.0 = 27 psf

In other words, the streng[illegible] monolithic AN lite under a 60-second durat[illegible]d is simply the value found from the non-fa[illegible]oad chart. The strength of a monolithic HS [illegible]aving the same dimensions to resist a 60-seco[illegible]tion load is:

Non-factored Load x HS T[illegible]tor =
27 psf x 2.0 = 54 psf



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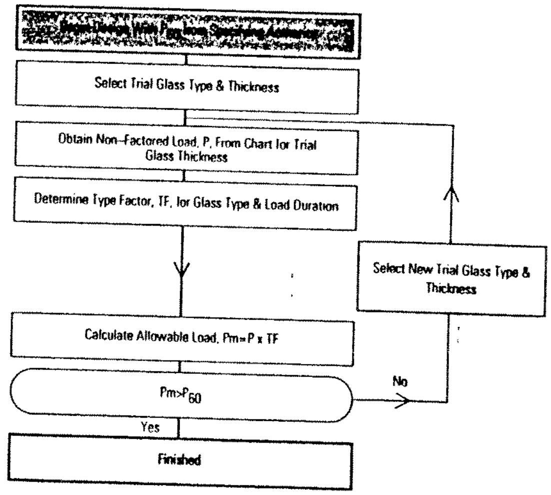
1a NON-FACTORED LOAD CHART FROM ASTM E 1300 FOR MONOLITHIC GLASS HAVING A NOMINAL THICKNESS OF 1/4"



1b FLOW CHART OF WINDOW GLASS DESIGN PROCEDURE USING ASTM E 1300

The strength of a monolithic FT lite having the same dimensions to resist a 60-second duration load is:

Non-factored Load x FT Type Factor =
27 psf x 4.0 = 108 psf

The strengths of glass lites obtained using this procedure represent uniform loads of constant magnitude that act continuously for 60 seconds. Furthermore, if the allowable load did occur on a window glass lite, it would not necessarily fail. The probability of failure at the first occurrence of the allowable load would be 0.008.

Design Procedure. The window glass designer using ASTM E 1300 simply has to select an appropriate glass type and thickness to resist the equivalent design load, as provided [illegible] pecifying authority. To accomplish the selecti[illegible] designer must follow the procedure show[illegible]e flow chart (1b). There is no requiremen[illegible] design procedure for the designer to check [illegible] deflection, which is an important consideratio[illegible]ptional procedure is included in ASTM E 1[illegible]at enables the window glass designer to co[illegible] lateral deflections under the design load. AS[illegible]300 offers no guidance as to acceptable lat[illegible]flections. It, along with most other window [illegible]sign recommendations, makes lateral defle[illegible]considerations the responsibility of the desig[illegible]

Limitations in ASTM E [illegible]here are some limitations concerning the t[illegible] window glass that can be designed using A[illegible] 1300. One of the major ones is that ASTM [illegible]0 offers no procedure to design window gl[illegible] is supported only along two opposite sides. [illegible]r limitation arises from the absence of a pr[illegible] to design unsymmetrical LG and IG units [illegible]metrical lites were recommended as a mean[illegible]trolling visual distortion in IG units in P[illegible] 1991, pp. 43–45]. ASTM E 1300 allows only [illegible]f LG and IG units for which both plies or lit[illegible]ass are of the same glass type and the same [illegible]l thickness. While these limitations might be [illegible]sed in future modifications to ASTM E 130[illegible]vill most likely not be incorporated into the [illegible]ning edition. For such guidance, designers [illegible] refer to *A Guide to the Structural Peformance* [illegible]*itecural Glass with Saflex Plastic Interlayer.*

Finally, the most restri[illegible]nitation in lack of guidance given by ASTM [illegible] concerns conversion of design loads to equ[illegible] design loads. The "exact" conversion is di[illegible]o accomplish. It depends upon a knowle[illegible] the load-induced tensile stresses across the [illegible] of the glass lite as well as the glass type. If th[illegible]ner wishes to convert a load with time-varyin[illegible]itude to an equivalent design load, an integ[illegible]echnique must be used (see "Failure Pre[illegible] for Thermally Tempered Window Glass [illegible]n Recommended Reading, below). Wind l[illegible]cuments such as *Guide to the Use of Wind Lo*[illegible]*sions of ASCE 7-88* give wind pressures associ[illegible]h 3-second to 10-second gusts. If the desig[illegible]s these pressures without converting them [illegible]econd equivalent design loads, his designs, i[illegible] cases, will result in glass thicknesses greate[illegible] required to resist the wind loads. This will [illegible]se the labor and material costs for the glazing system and supporting structural members.

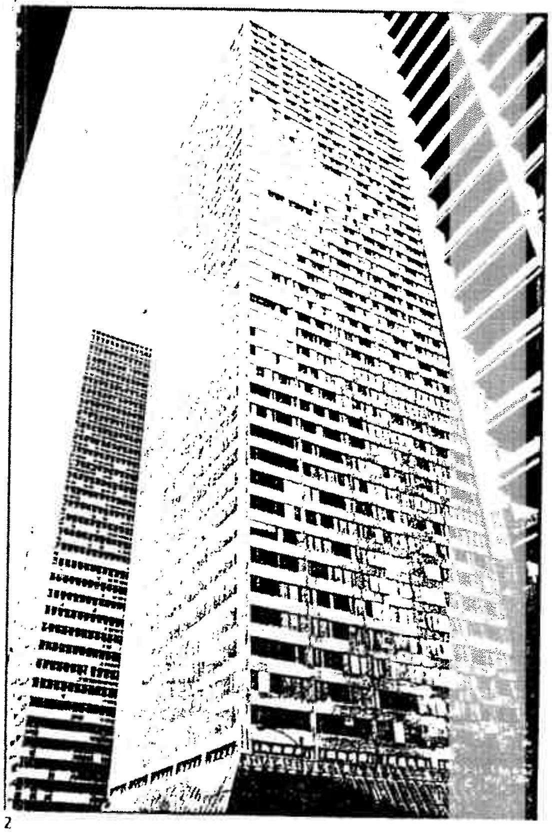
Why Window Glass Fails

Despite the focus on wind loading in the determination of glass thickness, damage surveys conducted following recent disasters have revealed that wind pressure does not cause glass breakage. Factors such as wind-borne debris, excessive building motion, and blast pressures have been documented as the cause of widespread glass breakage. The designers of window glass at the affected projects did not anticipate these factors. A major consequence of the glass breakage was a breach in the building envelope that resulted in damage to property and personal injury.

A substantial amount of glass breakage occurred in a relatively small area in downtown Houston, Texas, during Hurricane Alicia. In photographs taken after the hurricane, the density of broken window glass lites can be readily observed from the density of the plywood replacement panels (2). It is highest at a level near the elevation of the roof line of an adjacent building. The breakage density decreases with changes in elevation from rooflines of adjacent buildings. This suggests strongly, if not conclusively, that the window glass broke as the result of wind-borne debris, such as roof gravel, carried by the wind from the adjacent building. Close-up photos of broken windows (3) reveal from the fracture origin and pattern that the breakage was caused by impact rather than by the wind. Certainly wind was a factor in that it carried the debris, but it was not the ultimate cause of breakage.

Window glass broken during explosions results from uniform pressure loadings of high magnitude and short duration (4, 5). In explosions, wind has nothing to do with glass breakage. Glass breakage is also common in areas subjected to earthquakes. Breakage occurred almost at the onset of shaking in a department store near Union Square in San Francisco during the Loma Prieta earthquake of October 17, 1989 (6). Again, wind had nothing to do with the breakage. Other buildings affected by the earthquake show evidence of racking movements that could have resulted in – but fortunately did not – glass breakage (7).

Spontaneous glass breakage often occurs at projects glazed with fully tempered glass (8). Nickle sulfide contamination, a leading cause of spontaneous breakage of tempered glass, apparently cannot be



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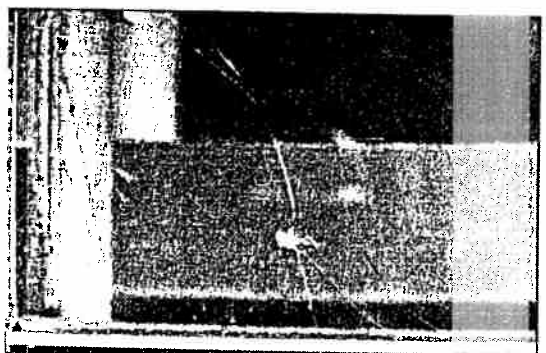

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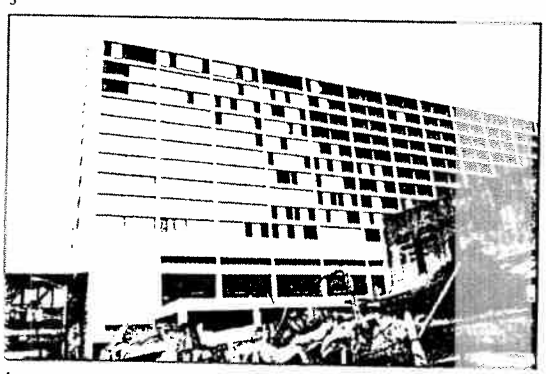

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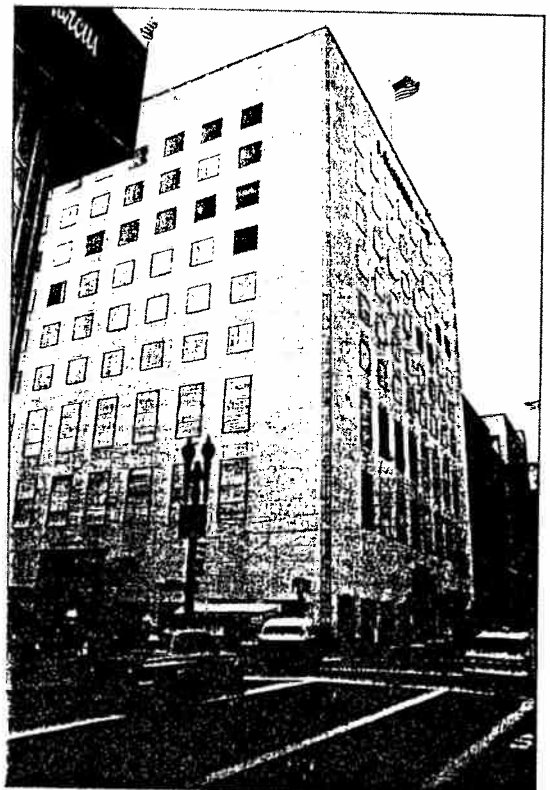

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2 This downtown Houston building suffered extensive glass breakage during Hurricane Alicia. The breakage distribution and density evident from the temporary plywood replacement panels suggests that most breakage was caused by gravel roof ballast and other wind-borne debris blown off the roof of the adjacent building – not by the wind alone.

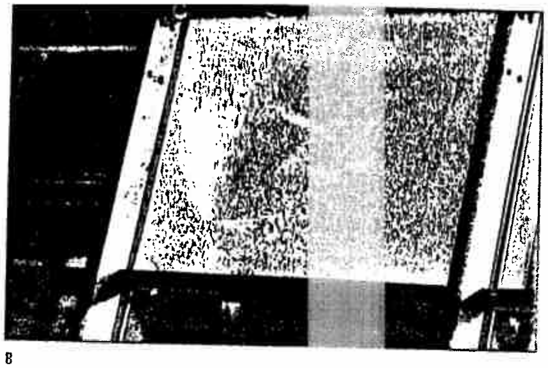
3 Study of the fracture pattern and the fracture origin of this glass from another building in downtown Houston indicates that the window was broken by impact rather than by wind.

4 This building in downtown Fort Worth suffered glass breakage following a gas explosion. The building was very close to the point where the explosion occurred. Structural damage to this building, other than glass breakage, was slight.

5 Another building with broken windows as a result of a refinery explosion in Norco, Louisiana. The building suffered significant structural damage in addition to glass breakage. In both this and the gas explosion example (4), wind had nothing to do with the glass breakage.

6 Glass was broken almost at the onset of shaking in this department store near Union Square in San Francisco during the Loma Prieta earthquake of October 17, 1989. Two persons were injured by falling glass from this building. Again, wind had nothing to do with the breakage.

7 Gaskets began to fall out from around dry glazed lites in a building in San Jose during the same earthquake. The gasket fallout resulted from sustained building motion during the temblor. Although the glass did not break, the loss of gaskets could have resulted in glass contact with the window frames and eventual glass fracture and fallout.



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8 *Tempered glass above a shopping mall in Florida suffered over one hundred spontaneous fractures. Fortunately the tempered glass was the outer lite of an IG unit and the inner laminated glass lite prevented shards from falling inside the shopping mall.*

eliminated completely by glass manufacturers and this problem has caused sufficient concern that one manufacturer has adopted a policy restricting the use of tempered glass for most architectural glazing applications.

All these cases show that window glass breaks as the result of varying causes, most of which have no relationship to wind loads. Architects or engineers cannot possibly be expected to account for all possible events that might break windows they are designing. One of the designer's main goals, though, should be to produce designs that minimize damage and injury in the event of window glass breakage.

Post Breakage Behavior

When a monolithic window glass lite breaks, wind and water can get into a building and can result in property damage and personal injury. If high winds or blast pressures are present when the glass breaks, shards may be propelled from the glass frame at high speeds.

The window glass designer must provide for the fact that, whether an explosion, wind-blown debris, or an earthquake is the cause, window glass breaks. A properly designed window should remain in the frame after breakage with a minimal number of glass shards falling from the window. A broken window should maintain the integrity of the building façade until the glass can be replaced. While unsightly when broken, the windows remain safe. If windows are designed with this criterion in mind, building damage and injuries associated with glass breakage will be greatly reduced. Such designs can be accomplished through the use of laminated glass, and some types of insulating glass.

Conclusion

Although ASTM E 1300 represents a significant improvement in window glass design methodology, it provides no guidance to the engineer or architect in determining appropriate design loads. ASTM E 1300 does not address directly many significant causes of window glass breakage, nor does it provide designers with the information necessary to allow them to protect buildings from damage and people from injuries if window glass breaks.

Windows can be designed to maintain the integrity of the building façade during a disaster. While glass breakage cannot be prevented, keeping glass shards within the window frame after breakage minimizes hazards to people and property and results in a much safer building. While ASTM E 1300 presents an excellent procedure for designing window glass to resist wind loads, it does not address the factors that really break glass.

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Recommended Reading

"An Alternative Method to the Design of Annealed Monolithic Window Glass Lites," P.M. Bove and H.S. Norville, *Journal of Structural Engineering*, ASCE, in review (available from the Glass Research and Testing Laboratory, Texas Tech University, Lubbock (806) 742-3476).

"Architectural Glass: Strengths, Selection, Sizes," J. Minor, P/A, April 1990, pp. 47–49.

ASTM E 1300-89 *Practice for Determining the Minimum Thickness of Annealed Glass Required to Resist a Specified Load*, ASTM, Philadelphia (215) 299-5585, 11 pp.

"Development of a New Glass Thickness Selection Procedure," W.L. Beason and H.S. Norville, *Journal of Wind Engineering and Industrial Aerodynamics* (Elsevier Science Publishers, New York), vol. 36, October 1990, pp. 1135–1144.

"Failure Prediction for Thermally Tempered Window Glass Lites," H.S. Norville, P.M. Bove, and D. Sheridan, Glass Research and Testing Laboratory, Texas Tech University, Lubbock (806) 742-3476), 1991, 103 pp.

Guide to Use of Wind Load Provisions of ASCE 7-88, #852, American Society of Civil Engineers, New York (212) 705-7538, 99 pp.

A Guide to the Structural Performance of Laminated Architectural Glass with Saflex Plastic Interlayer, #8043, Monsanto Company, St. Louis (800) 325-4330, 1988, 40 pp.; includes 5 1/4" DOS PC program.