



Designation: E3401/E3401M – 24

# Standard Practice for Design and Performance of Laminated Glass Subject to Hydrostatic Loads<sup>1</sup>

This standard is issued under the fixed designation E3401/E3401M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice covers elements related to laminated glass when exposed to hydrostatic loads such as in the construction of swimming pools and aquariums. This practice includes laminated glass performance, and safe behavior considerations. It addresses the characteristics unique to glass and laminated glass.

1.2 This practice does not address applications constructed with monolithic glass, glass block, insulating glass units, glass tiles that are directly bonded to a non-glass structural substrate, acrylic, or other plastics.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance of this practice.

1.4 This practice is not meant to address consumer products such as portable aquariums. This practice is meant for fixed or temporary pools or aquariums at a specific location.

1.5 This practice does not address dynamic flood loads or impact loads such as wave action, floating debris, or human and animal collisions.

1.6 This practice does not address issues concerning corrosion and or surface degradation effects of glass.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recom-*

*mendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

**C1036** Specification for Flat Glass

**C1048** Specification for Heat-Strengthened and Fully Tempered Flat Glass

**C1172** Specification for Laminated Architectural Flat Glass

**E631** Terminology of Building Constructions

**E1300** Practice for Determining Load Resistance of Glass in Buildings

## 3. Terminology

3.1 *Definitions*—For definitions of general terms related to building construction used in this practice, refer to Terminology **E631**.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *duration of load, n*—the period of continuous application of a given load, or the aggregate of periods of intermittent applications of the same load.

3.2.1.1 *Discussion*—Any load duration longer than one month shall be considered a permanent load, that is, load duration of 15 years. Concentrated live loads shall have a load duration of at least ten minutes.

3.2.2 *ionomer interlayer, n*—a partially neutralized copolymer of ethylene and acrylic or methacrylic acid, used to permanently bond two or more lites of glass.

3.2.3 *laminated glass, n*—an assembly consisting of two or more lites of glass bonded by an interlayer.

3.2.4 *liquid resin interlayer, n*—liquid formulations, generally polyester-, urethane-, or acrylic-based, that react to form solid interlayers after being introduced between two lites of glass.

3.2.5 *polyurethane interlayer, n*—polymer sheeting based on isocyanates and mostly polyester or acrylic polyols, or both.

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee **E06** on Performance of Buildings and is the direct responsibility of Subcommittee **E06.52** on Glass Use in Buildings.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [www.astm.org/contact](http://www.astm.org/contact). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.6 *polyvinyl butyral (PVB) interlayer, n*—polymer sheeting prepared from polyvinyl alcohol by reaction with butyraldehyde used to permanently bond two or more lites of glass.

3.2.7 *post-breakage glass retention, n*—the ability of the broken glass to remain in place so as to reduce cutting and piercing injuries from the broken shards and to deter fall through or glass fallout.

#### 4. Significance and Use

4.1 Glass is a brittle material with different time dependent properties than other building materials used in the construction of pools. Therefore, the properties of glass are important considerations in the design and construction of glass pools and aquariums.

4.2 Post-breakage glass retention and strength shall be considered in the design of a glass pool or aquarium as a means of maintaining the integrity of the system, deterring cutting/piercing injuries, or fall-through or fallout of the glass.

4.3 The structural design shall be confirmed by calculations by a design professional in accordance with Section 6.

4.4 If testing is required (see 4.4.1 – 4.4.3) to verify post-breakage behavior of the glass, the testing shall be in accordance with Section 7.

4.4.1 For laminates with two glass plies, verification testing is required.

4.4.2 For laminates with more than two glass plies, verification testing is not required if calculations completed in accordance with 4.3 demonstrate that the glass assembly has sufficient strength to sustain the full design load with any one glass ply broken.

4.4.3 When verifying post-breakage behavior by calculation, allowable glass stress for permanent load duration in accordance with Table 1 shall be used for all load cases greater than 1 month.

4.5 The manufacturer of glass pools and aquarium systems shall provide installation directions and fabrication and installation tolerances of their systems.

#### 4.6 Structural Support System—Deflection:

4.6.1 The glass and support system shall be sufficiently stiff to limit the deflection of the supported glass under the design load to no more than  $L/240$  or 13 mm [0.5 in.] whichever is less, where  $L$  is the longest unsupported span for three or fewer side supported systems, or the longest supported length for four side supported systems.

#### 5. Load Conditions

5.1 The hydrostatic load shall be determined using Eq 1. A permanent load duration shall be used with hydrostatic loads, except when combining live loads and hydrostatic loads, then use the shorter load duration.

$$p = h\rho g \quad (1)$$

where:

$p$  = pressure, Pa [psf],

$h$  = water height, m [ft],

$\rho$  = density of the water,  $\text{kg/m}^3$  [slug/ft<sup>3</sup>], and

$g$  = gravity,  $\text{m/s}^2 = 9.81 \text{ m/s}^2$  [32.2 ft/s<sup>2</sup>].

NOTE 1—For chlorinated water, a density of  $1000 \text{ kg/m}^3$  [1.94 slug/ft<sup>3</sup>] may be used and for saltwater pools use  $1020 \text{ kg/m}^3$  [1.98 slug/ft<sup>3</sup>].

#### 5.2 Application of Loads for Horizontal Glass:

5.2.1 Horizontal glass used for the bottom of pools and aquariums shall use the water pressure calculated in accordance with Eq 1. In addition, the self-weight of the glass due to gravity shall also be included.

5.2.2 For horizontal glass intended as a human or animal walking surface and having a water level less than 0.49 m [20 in.], a minimum hydrostatic load of 4.79 kPa [100 psf] shall be considered. In addition, a concentrated live load of 1.33 kN [300 lbf] or more based on the occupant shall be applied to the glass surface over a 152 mm by 152 mm [6 in. by 6 in.] area in conjunction with the hydrostatic load. Apply the load to maximize the stress and deflection of the glass and glazing system components.

#### 5.3 Application of Loads for Vertical Glass:

5.3.1 Vertical glass used for the sides of pools and aquariums shall use the water pressure calculated in accordance with Eq 1; however, the load shall be applied gradually with the largest load at the bottom (Fig. 1).

5.3.2 Vertical glass intended for human or animal occupancy or access shall also consider a concentrated live load of 0.89 kN [200 lbf] or more based on the occupant shall be applied horizontally to the glass surface over a 152 mm by 152 mm [6 in. by 6 in.] area in conjunction with the hydrostatic load. Apply the load to maximize the stress and deflection of the glass and glazing system components.

#### 6. Calculation Procedure

6.1 Use established engineering methods, such as engineering mechanics or finite element analysis, to determine glass assembly stresses and deflections. Such methods shall account

**TABLE 1 Allowable Glass Stresses for Nominal Load Conditions**

NOTE 1—An allowable stress reduction factor may be required for some acid etched, sandblasted, or patterned glasses; consult the manufacturer.

NOTE 2—Values derived from Practice E1300, factored for load duration.

| Glass Type        | 10 min<br>MPa [psi] | 60 min<br>MPa [psi] | 1 Month<br>MPa [psi] | Permanent<br>MPa [psi] |
|-------------------|---------------------|---------------------|----------------------|------------------------|
| Annealed          | 8.9 [1300]          | 8.1 [1170]          | 5.4 [780]            | 3.9 [560]              |
| Heat-strengthened | 30.9 [4480]         | 29.2 [4240]         | 24.3 [3520]          | 20.3 [2940]            |
| Fully Tempered    | 65.3 [9470]         | 63.0 [9140]         | 55.4 [8040]          | 49.4 [7170]            |