The salient features of the procedure are as follows:

1. Area to be covered by the window panel.
2. Support conditions (supported on two sides or four sides).
3. Aspect ratio of panel (length / width).
4. Effective wind pressure
5. Strength of glass
6. Type of glass.

A simplified procedure is described in the following sections for the determination of appropriate thickness of glass in a window panel. The salient features of the procedure are as follows:

- The maximum area of glass panel is restricted to 15 m².
- The maximum span of window is restricted to 4 m.
- Aspect ratio of the glass panel should be greater than 1.5. If it is less than 1.5, next higher available thickness should be selected.
- The factor of safety used is 2.5 considering the variability in strength of glass.
- Applicable to normal, reflective, laminated, tempered and insulating glass.
- Applicable to rectangular panels properly fixed.
- The numerical examples for computation of glass thickness for various locations and glass specifications are given in the article 3.6.

The thickness of the glass to be used in window panels is governed by the following factors:

- Type of glass.
- Strength of glass
- Aspect ratio of panel (length / width).
- Area to be covered by the window panel.
- Support conditions (supported on two sides or four sides).
- Effective wind pressure
- Strength of glass
- Type of glass.

Normally glass panes carry “out of plane” loading therefore glass panes are designed for wind load and self weight. This paper describes the method of determination of thickness of glass for different support conditions, wind pressure and aspect ratio using Draft code (Code of practice for use of Glass in buildings Part-3: Fire and Loading, DocNo.CED13(7885)WC).

### ABSTRACT

For centuries, the use of glass in building was essentially restricted to functions such as windows and glazing. Over the last decades, continuous improvements in production and refining technologies have enabled glass elements to carry more substantial superimposed loads and therefore achieve a more structural role. Glass giving beauty, aesthetics and transparency has become preferred choice of all architects and engineers. Normally glass panes carry “out of plane” loading therefore glass panes are designed for wind load and self weight. This paper describes the method of determination of thickness of glass for different support conditions, wind pressure and aspect ratio using Draft code (Code of practice for use of Glass in buildings Part-3: Fire and Loading, DocNo.CED13(7885)WC).

### KEY WORDS:
- Glass thickness
- Design wind pressure
- Boundary conditions

### 2. STANDARD NOMINAL THICKNESS (SNT)

The glass sheets may have different thickness at different locations. Table-1 shows acceptable thickness limits for different types of the glass.

**Table-1 (from AIS glass solutions)**

<table>
<thead>
<tr>
<th>Type of glass Standard</th>
<th>Nominal thickness</th>
<th>Thickness limits Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>3</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3.8</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.8</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>5.8</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>7.7</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>9.7</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>11.7</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>14.5</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>18.0</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>23.5</td>
<td>26.5</td>
</tr>
<tr>
<td>Laminated glass</td>
<td>5.38</td>
<td>4.95</td>
<td>5.81</td>
</tr>
<tr>
<td></td>
<td>6.38</td>
<td>5.95</td>
<td>6.81</td>
</tr>
<tr>
<td></td>
<td>8.38</td>
<td>7.95</td>
<td>8.81</td>
</tr>
<tr>
<td></td>
<td>10.38</td>
<td>9.95</td>
<td>10.81</td>
</tr>
<tr>
<td></td>
<td>12.38</td>
<td>11.95</td>
<td>12.81</td>
</tr>
<tr>
<td></td>
<td>16.38</td>
<td>15.75</td>
<td>17.01</td>
</tr>
</tbody>
</table>

### 3. DESIGN CONSIDERATIONS

This article deals with the design strength of the glass and the empirical relation to evaluate the minimum thickness or the maximum allowable area of the glass panel for a particular glass type for given set of design wind pressure, support condition and aspect ratio.

#### 3.1 Design Flexural Tensile Strength of Glass

The required thickness of the glass depends upon the design strength obtained after applying a factor of safety of 2.5. The minimum design thickness of normal glass for thickness 6mm is 16.7 N/mm² and for thickness > 6mm is 15.2 N/mm².

#### 3.2 Empirical Relationship

Assuming that the normal glass has design strength in accordance with article 3.1, following empirical relation between the wind pressure, area of the glass panel and the required glass thickness can be used:

\[ P \text{ net } * A = 200.0 * T^k \quad (T \leq 6 \text{ mm}) \quad \ldots \quad (1) \]

\[ P \text{ net } * A = 200.0 * T^k + 1900 \quad (T > 6 \text{ mm}) \quad \ldots \quad (2) \]

Where,
- \( P \text{ net} \) = Net design wind pressure (N/m²)
- \( A \) = area of glass panel (m²)
- \( T \) = SNT of the normal glass (mm),
- \( k \) = constant as shown in table-2.
The design of the thickness using empirical relation in accordance with article 3.2 will be valid up to a limiting aspect ratio ARmax. The value of ARmax for different SNT of glass is shown in the following table -3.

### Table-3 (from draft code)

<table>
<thead>
<tr>
<th>SNT</th>
<th>ARmax values</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>7.3</td>
</tr>
<tr>
<td>4 mm</td>
<td>6.8</td>
</tr>
<tr>
<td>5 mm</td>
<td>6.5</td>
</tr>
<tr>
<td>6 mm</td>
<td>6.3</td>
</tr>
<tr>
<td>8 mm</td>
<td>5.9</td>
</tr>
</tbody>
</table>

#### 3.3 Limiting Aspect Ratio (ARmax)

The determination of minimum glass thickness of panels of different types of glass supported on four sides as well as two opposite sides is discussed in the following sections.

#### 3.4 Determination of Minimum Glass Thickness

The thickness of panels of normal glass can be obtained using the empirical relation explained in article 3.2. This relation is valid for the glass having the minimum design strength of the material as mentioned in article 3.1 and the maximum aspect ratio limited to a value in accordance with article 3.3. However, if the aspect ratio exceeds the prescribed values under article 3.3, the design will be carried out in accordance with the article 4.2 applicable to glass supported on two opposite sides.

##### 3.4.1 Normal (Annealed) /Reflective Glass

The minimum thickness of normal/reflective glass for a particular value of net design wind pressure Pnet can be evaluated as per the procedure given in article 3.2. The thickness of the glass panel for a building with the plan of building is rectangular with the size 1.5 m supported on four sides for a 60 m high office building located in Delhi in terrain category II. The plan of building is rectangular with the size as 50 x 60 m. The permeability of building is between 5% to 20%.

##### 3.4.1.1 Normal Glass Panes

To determine the thickness of laminated / tempered / insulating glass, the thickness of the glass panel has been explained under previous articles. The wind pressure has been calculated using IS 875 (Part 3) 1987. In order to illustrate the steps, some examples are solved as follows:

#### Example - 1:

The design of tempered glass panel of size 3.0 x 1.5 m supported on four sides for a 60 m high office building located in Delhi in terrain category II. The plan of building is rectangular with the size as 50 x 60 m. The permeability of building is between 5% to 20%.

**Design:**

The step-by-step procedure to obtain the minimum thickness of the glass panel for a building with above mentioned parameters is explained below:

1. **Step1: Selection of Design Wind Pressure Pz**
   - Select value of wind pressure for Delhi, Wind Zone-IV, terrain category - II and height of window 60 m above ground. This can be taken from I.S: 875 (Part 3) and the value is 2127.25 N/m²

2. **Step2: Selection of Net pressure coefficient Cp**
   - The value of Cp for permeability in the range of

<table>
<thead>
<tr>
<th>Glass type</th>
<th>Pf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal (Annealed)</td>
<td>1.00</td>
</tr>
<tr>
<td>Laminated</td>
<td>0.80</td>
</tr>
<tr>
<td>Tempered</td>
<td>2.50</td>
</tr>
<tr>
<td>Insulating</td>
<td>1.50</td>
</tr>
<tr>
<td>Heat Strengthened</td>
<td>1.60</td>
</tr>
</tbody>
</table>

Using the modified value of Pnet as explained in this article, the thickness of other types of glass can be obtained in accordance with article 3.3.

#### 3.4.2 Glass Supported on two opposite sides

Normal and laminated glass panels supported on two opposite sides can be designed using following empirical relations:

1. **Step1: Selection of Design Wind Pressure Pz**
   - Select value of wind pressure for Delhi, Wind Zone-IV, terrain category - II and height of window 60 m above ground. This can be taken from I.S: 875 (Part 3) and the value is 2127.25 N/m²

2. **Step2: Selection of Net pressure coefficient Cp**
   - The value of Cp for permeability in the range of

<table>
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<tr>
<td>Heat Strengthened</td>
<td>1.60</td>
</tr>
</tbody>
</table>

Using the modified value of Pnet as explained in this article, the thickness of other types of glass can be obtained in accordance with article 3.3.**
5% - 20% and h/w = 60/50 = 1.2 being between ½ & 6, is 1.7 as per IS 875 (Part 3) 1987.

**Step 3: Calculation of Net wind Pressure Pnet.**

Delhi is in wind zone IV where the basic wind speed is 47 m/s. For this wind speed, I.S: 875 (Part3) gives the value of wind pressure at various heights & terrain categories. For 60 m height, terrain category II, the value of wind pressure is 2127.25 N/m².

Net Pressure Pnet = \( P_z \times C_p \)

\[ = 2127.25 \times 1.7 \]

\[ = 3616.33 \text{ N/m}^2 \]

For tempered glass, modified value,

\[ P_{net} = \frac{P_{net}}{P_f} \]

\[ = \frac{3616.33}{2.5} \]

\[ = 1446.532 \text{ N/m}^2 \]

**Step 4: Calculation of minimum thickness (supported on all sides)**

Aspect ratio = \( \frac{3.0}{1.5} \) = 2.00

Area of panel = \( 3.0 \times 1.5 \) = 4.5 m²

Using equation (1) when,

\( T = 5\text{mm}, K = 1.753 \), net pressure \( P_{net} = 746.64 \text{ N/m}^2 \)

\( T = 6\text{mm}, K = 1.765 \), net pressure \( P_{net} = 1050.15 \text{ N/m}^2 \)

Now, using equation (2) for 8mm thick glass,

\( T = 8\text{mm}, K = 1.570 \), net pressure \( P_{net} = 1585.46 \text{ N/m}^2 \)

\( >1446.532 \)

N/m²

Hence, provide 8mm thick tempered glass.

**Example: 2**

Design of a glass panel supported on two opposite sides with all other parameters same as on example 1.

Design:

Under such support conditions, the thickness of a tempered glass will be calculated using equation (5) & (6).

When \( T = 5\text{mm} \), using equation (5),

\( \text{Span b} = 0.429 \text{ m} < 1.5 \text{ m} \)

When \( T = 6\text{mm} \),

\( \text{Span b} = 0.515 \text{ m} < 1.5 \text{ m} \)

When \( T = 15\text{mm} \), using equation (6),

\( \text{Span b} = 1.1464 \text{ m} < 1.5 \text{ m} \)

When \( T = 19\text{mm} \)

\( \text{Span b} = 1.4521 \text{ m} < 1.5 \text{ m} \)

When \( T = 25\text{mm} \),

\( \text{Span b} = 1.91 \text{ m} > 1.5 \text{ m} \).

Hence, 25 mm thick tempered glass is used.

Similarly, for the same data but at different height from ground level, the net wind pressure and accordingly the glass thickness (four side supported) have been calculated which is shown in table-5.

**Table-5**

<table>
<thead>
<tr>
<th>Height of window above the ground level</th>
<th>Glass types</th>
<th>SNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height 10 m</td>
<td>Tempered</td>
<td>6 mm</td>
</tr>
<tr>
<td>Height 20 m</td>
<td>Tempered</td>
<td>8 mm</td>
</tr>
<tr>
<td>Height 45 m</td>
<td>Tempered</td>
<td>8 mm</td>
</tr>
<tr>
<td>Height 60 m</td>
<td>Tempered</td>
<td>8 mm</td>
</tr>
</tbody>
</table>

**4. CONCLUSION**

Here, method of determination of glass thickness is introduced as per recently published Indian draft code. From the above exercise, it is proved that once the glass type is selected, the required thickness of the glass panel may reduce with the reduction in the height of building as well as reduction in size of the window panel. Also, the boundary condition and wind pressure governs the design of glass for a particular case. Draft code, also gives guidelines on deflection calculation of glass against wind pressure which is not covered here, but for more accurate design of glass for structural use, the non-linear analysis should be carried out and stresses generated in glass should be checked against permissible values specified in Draft code.

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