VISUAL DISTORTIONS IN HEAT TREATED GLASS AND SEALED INSULATING GLASS

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ABSTRACT

The viewing angle and the distance of the viewer from the glass, as well as the distance of the viewed objects to the glass, are critical in quantifying the perceived visible distortion.

keywords: distortion, heat treated, toughened, tempered, heat strengthened, laminated,

1. INTRODUCTION

While distorted images seem to be variable, subjective and difficult to quantify, they can be separated into their component parts and analyzed quantitatively. Distortions in glass are seen in transmission, in reflection, or in both modes, not as small deviations from flatness of the glass itself but by their effect on transmitted and reflected images. Distortions are caused by variations in glass thickness, flatness and parallelism. These separate causes will be examined in this paper. One often neglected aspect is the importance of the viewing geometry. Finally it must be remembered that, out of economic necessity, glass for architectural uses is of ‘glazing’ quality and not ‘optical’ quality, and that under certain viewing conditions some distortion will inevitably be seen. In an attempt to control distortions some architectural building specifications have been written which demand “..the glass shall be free of distortion..”. While this specification will always be impossible to satisfy absolutely, it has been found that with a basic understanding of the principles of distortion, the correct choice of glass and installation details and the judicious use of full size mock-ups, it can be possible to supply and install a product which will please all parties involved.

2. DETAIL

Float glass, made by floating molten glass on liquid tin, is in theory extremely flat and parallel, but as Sir Anthony Pilkington pointed out, even float glass is not perfectly flat; it does follow the curvature of the earth! In actual production, with hundreds of tonnes of glass flowing over molten tin every day, there are some other deviations from optical flatness caused by both the manufacturing process and the later fabrication techniques.

This paper examines the resulting two separate and distinct types of distortion: those seen in transmission and those seen only in reflection.

The first and most important cause of distortion in reflected images is through lack of flatness, even though the two glass surfaces may be parallel. This can be caused during the annealing process when the glass ribbon cools more rapidly at the edges than in the center. A slight buckling is sometimes seen in the ribbon, especially when it is thinner than the equilibrium 6 mm thickness. The buckle usually disappears completely when the ribbon edges are trimmed off.

A worse lack of flatness occurs when the glass is heat treated. On horizontal furnaces, if the glass is too hot and soft, it tries to sag between the rollers. Also the leading and trailing edges of a plate can curl up as they enter or leave a new furnace or quench section (see figure 1). Conversely if the glass is not hot enough breakage will occur in the heat treating process. Consequently furnace operators must find the optimum equipment operating temperatures to balance these two conflicting requirements. As well as the roller wave mentioned above, there can be an overall bow or dish to the plate as result of heat treatment. These distortion effects can occur more readily these days as the new

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high performance glass tints and glass with low emissivity coatings will each require their own individual furnace settings. All the above deviations from flatness can be physically measured with straight edges and gap gauges. It is easier to visually estimate the degree of distortion in the reflected image of a grid or zebra board, but harder to quantify it.

Figure 1. Exaggerated roller wave (not to scale)

The greatest thickness variation is seen with thin tempered (toughened) laminated glass. Here the soft pvb flows to fill the non-parallel gap between the two plies giving rise to a series of low power positive and negative lenses which will cause major transmitted distortions under adverse viewing conditions (see figure 2).

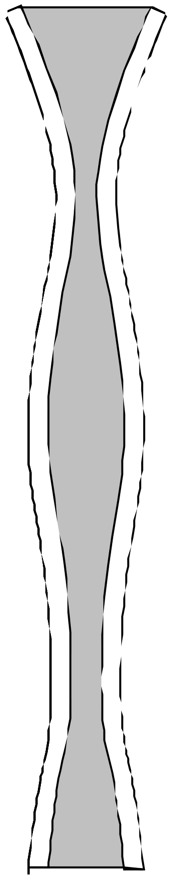

Figure 2. Laminated tempered glass (exaggerated horizontal scale).

Thickness variations across the float ribbon are small and seldom cause problems. An exception is with glass thicker than 6 mm when the thickness can occasionally vary close to the edge (see figure 3). This variation is very easy to measure.

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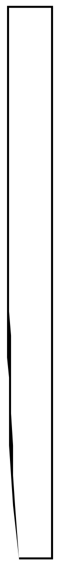

Figure 3. Section through heavy glass showing an exaggerated thickness change near one edge of the float ribbon. (Not to scale).

Finally the distortion in sealed insulating glass (IG) units must be quantified. The glass in a sealed unit can easily deflect 1.5 mm or more as the atmospheric temperature and pressure change with weather variations. The glass in very small units (about 300 mm square) with thicker glass (4 or 5 mm, or greater) will not bend much. Similarly very large units, about 2 m square, will deflect with such a large radius of curvature that visible distortion effects are again reduced.

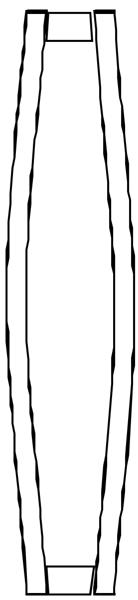

Figure 4. Section through a sealed insulating glass unit with high internal air space pressure. (exaggerated horizontal scale).

Installation details can easily add to perceived distortions. Out-of-plane frames, where two edges of an opening are not parallel to each other, will easily twist a large light of glass and show a twist in the reflected image. This is often seen at building corners where a single column of windows is at 45 degrees to the adjacent walls. Edge distortions are also seen with non-uniform glazing pressures caused by temporary glazing clips or interior and exterior glazing stops which do not align with each other and the load carrying section of the IG spacer.

The factor that is often missed is the viewing geometry. Most people are aware that as the viewing incidence angle increases from 0 degrees (straight, normal to the glass) towards 90 degrees (grazing angle), any visible reflected or transmitted distortion will be magnified. The effect is somewhat limited by the simultaneous reduction of the projected area with increasing incidence angle, and so the glass area seen makes up less of the total view.

More important is the effect of distance.

		PERCEIVED	DISTORTION
DISTANCE FROM GLASS TO OBJECT		DISTANCE GLASS TO	FROM VIEWER
		Short	Long
	Short	**Good**	**Good**
	Long	**Good**	**Bad**

Table 1. Qualitative table of perceived distortion values as a function of distance for all glass types.

Light travels in straight lines. A very small deviation in surface flatness causes a large deviation over long distances. It is for this reason that sheet glass mirrors work so well in bathrooms; both distances (glass to viewer and glass to viewed object) are short and so no matter how distorted the glass, the reflected image is invariably acceptable.

Simple spherical distortion occurs approximately in an IG unit with one reflective glass light and with high or low air space pressure. The reflections, and their distortions from the concave side will be magnified and those in the convex side reduced, compared to those from flat glass.

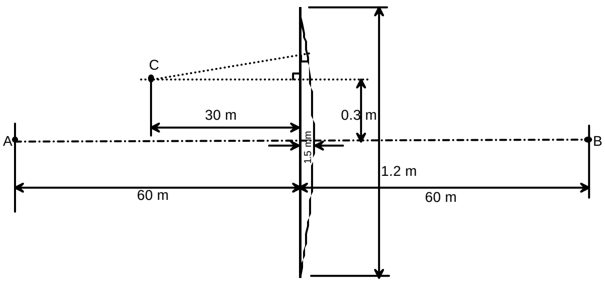

Figure 5. Plan view (not to scale) of a viewer at position A, B or C looking at the reflection of a vertical pole beside the viewer.

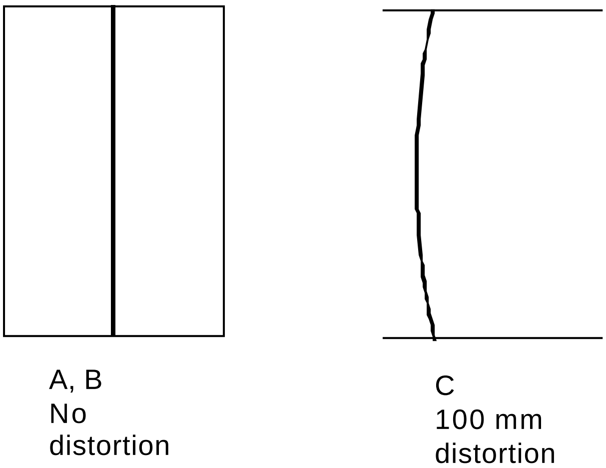

Figure 6. Images of a vertical pole seen in a 1.2 x 18 m glass from positions A, B and C of Figure 1.

As the viewer moves towards one side, to positions E, C, D and F in Figure 3 the distortion appears greater.

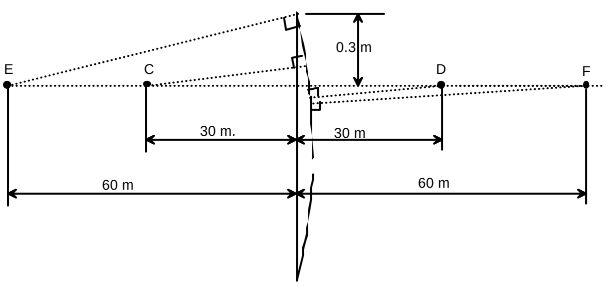

Figure 7. Plan view, as in figure 1, showing other viewing locations, E, D and F.

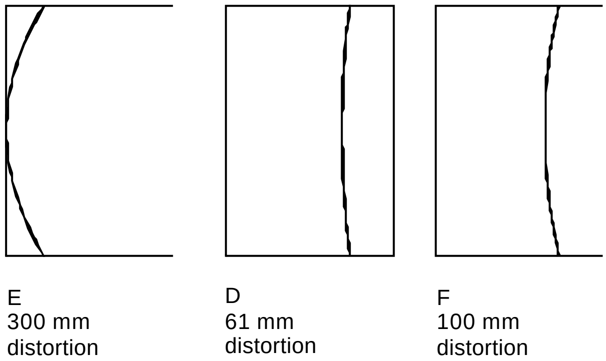

Figure 8. Differing degrees of perceived distortion in the reflected image of the same pole when viewed from positions E, D and F.

The diagrams show that when viewed along the central axis of symmetry, from positions A or B, there is no visible distortion. But moving just 0.3 m to one side results in a very different image. The distortion seen from position C on the concave side is about 65% greater than that seen from position D an equal distance from the glass on the convex side. Moving back from position C to position E (doubling the distance) on the concave side increases the apparent distortion by a factor of three. Moving the same amount on the convex side only increases the perceived distortion by a factor of about 65%.

Similar diagrams could be created for the transmitted distortion for positive and negative lenses at different distances, and for off-normal, high incidence angle, viewing of transmitted and reflected images.

3. RESULTS

The visible distortions listed above can be separately identified and understood. To control them and bring them within acceptable limits requires an understanding of their individual causes.

Specifications for a building project could simply state that distortions shall not be greater than those of agreed control samples, under equal viewing conditions, which have previously been approved. Some tempered glass fabricators have quoted maximum values for crest-to-trough roller wave, over a specified span, but this value needs to be measured separately for leading and trailing edge effects as well as for the central area of the glass. In extreme cases a glazing specification could state that the glass shall have no 'visible' distortion (specifying transmitted or reflected, or both) when viewed from a particular location with particular viewed objects at a specified distance from the glass. For such a specification it will be necessary to first establish if such glazing quality is physically possible to manufacture and economically available.

All heat treated glass will have some lack of flatness, which may or may not cause visible distortion. This lack of flatness can be somewhat reduced by using thicker glass or by using heat strengthening instead of tempering where possible.

Distortions in IG units with reflective coated glass will predominantly come from the reflective coated surface. The glass with the coating can be kept flatter during atmospheric temperature and pressure changes by making it thicker than the other light of the IG unit or by using capillary tube construction to vent the IG unit. The unbalanced thickness unit will need careful strength analysis as the wind load will now be carried almost completely by the thicker glass. The long term life operational details of a capillary tube unit need to be understood for satisfactory performance; all four spacer legs need to be full of strong desiccant and the outer end of the capillary tube must never be in a location where it can draw liquid water into the air space.

Another factor to be considered is the type of image reflected. In a city where many buildings will create rectilinear grid patterns, distortions will be very easily perceived. In fact these reflected grids can be photographed and scaled to quantify the actual glass deviation from flatness with simple geometric formulae. In rural settings where the reflected image contains trees, or clouds in the sky, it is more difficult to discern the degree of distortion in the glass when no straight lines or 90 degree angles are visible.

One situation to particularly note is where a reflective glass building is located in open flat land. Here the straight horizon can be the most noticeable reflected object. If horizontally tempered glass is installed with the peaks and valleys of the waves running horizontally, then a reflected image can give a startling pattern of alternating light and dark stripes reflected from the sky and the ground. The conventional wisdom is often quoted, left over perhaps from sheet glass days, that the waves should be glazed horizontally to avoid flickering transmitted images as one walks past the glass. In this case, where transmitted distortion is not an issue, it may be better to install the glass with the waves vertical if possible, to eliminate the strip pattern in the reflected images.

Possible solutions to distortion issues then include: controlling the heat treatment distortion to agreed limits, thicker glass, capillary tube insulating glass units, IG units with a thick reflective glass and a thinner light to take up pressure changes, heat strengthening instead of toughening, and tilting the glass slightly to reflect the sky instead of rectilinear grid patterns.

4. CONCLUSIONS

The recognition of the importance of the viewing conditions allows distorted images to be understood. In some buildings the viewing geometry is such that it is impossible to have true reflected images. In others even heat treated glass can appear flat. The best way to assess the appearance of the glass for a new building is to construct a small, but full scale, mock-up with the proposed glass. The mock-up must be located on-site in the location where the glass in the proposed building will be most visible. Then this mock-up must be viewed from the typical viewing locations for the building's users and general public. If the result is not satisfactory there are a number of reasonable alternatives which should be considered before the final glass selection is made.

REFERENCES

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