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GLASS BUILDING ELEMENTS - TECHNICAL ASPECTS OF SAFE USAGE IN THE STRUCTURE

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Abstract: Recent years have shown increased interest in the use of glass structures in the construction industry. Investors value qualities such as aesthetics and the good environmental resistance of glass. It has become commonplace to use glass not only to construct façades, but also in horizontal partitions (floors, building coverings) and in such elements as protective canopies, passageway screens or fire barriers. Such extensive use of this building material has been made possible by the development of technology for manufacturing glass with improved strength properties, in particular, toughened and laminated glass. However, glass has some disadvantages as a building material – first of all, low tensile strength, impact strength and point load compressive strength. The use of glass with improved strength properties minimises these defects to a considerable extent. Nevertheless, it sometimes happens that glass structures crack or lose their aesthetic value. This results from errors made during the design stage as well as during the construction work on the structure. Based on an “in situ” study and the literature on the subject, the article identifies risks associated with the use of glass elements, in addition to analysing their causes and possible effects. Examples of real elements in the course of their use are provided in order to illustrate the factors under analysis. Moreover, the article includes recommendations linked to the safe usage of glass in the structure when discussed against the background of assembly errors.
Keywords: building glass, security glazing, safety in civil engineering

1. INTRODUCTION

Glass as a building material has some specific properties. The visual qualities and the good environmental resistance of glass, combined with the considerable stiffness of glass panes, make glass a highly valued material by architects, builders and investors. Thanks to the development of glass technology, this building material is used not only in windows, but also in many other structural elements. Glass façades have become a standard feature of particular types of buildings, such as public utility buildings: office, retail and educational developments, etc. (Pietrzak, 2014). Glass is also widely used in elements such as: floors, building coverings, all-glass doors, partition walls (including fire barriers), protective canopies, as well as glass panels near stairways and other passageways.

However, glass has some disadvantages. Glass has a tendency to crack, especially at impact (Olmos Navarrete et al., 2017; Pathirana et al., 2017; Sundaram and Tippur, 2018). Therefore, glass elements should be used in building in a well-thought-out manner to ensure the safety of people and property during the use of buildings and premises.

The objective of the analysis presented in the article was the identification of the risks associated with the application of glass elements in the construction industry, in the context of their safe use and durability. The study outlines the causes and consequences of the most frequent errors in this respect. The analysis was based on an "in situ" study and the literature on the subject.

2. BASIC FEATURES OF BUILDING GLASS

Glass at atmospheric temperatures has the macroscopic characteristics of a solid body and a disordered atomic structure, which is similar to a liquid. It is an amorphous body which does not have a sharply defined melting point, but a certain temperature range in which it becomes ductile. Its structural behaviour is determined by the following properties (Klindt and Klein, 1997; Jaśkowska, 2009; Kozłowski, 2010):

- glass has very high compressive strength, which exceeds 500 MPa;
- visually, it is a homogeneous material, but in the micro scale it features many microcracks, mainly on the surface, which means that its tensile and flexural strength is many times lower (approx. 45 MPa) than its compressive strength; which makes glass a brittle material,
- microcracks have a tendency to expand, which means that the tensile strength of glass is much lower for long-term loads than when compared to short-term loads;
- a glass pane is almost perfectly elastic, which gives it poor impact strength and low point load compressive strength – the yield in the material is unable to cope with loads distributed over a small area, which may increase stresses in localised areas and fracture the glass pane;
- for the same reason, even a microcrack can grow over time, leading to the destruction of the glass pane – areas near the edge of the glass are particularly sensitive to cracks.

Thanks to the development of glass technology and appropriate construction of glass building elements, it is currently possible, at least partially, to eliminate these disadvantages. In this case, glass with improved strength parameters should be mentioned first – this group of products includes **toughened glass and laminated glass.** Such glass is used to manufacture various types of safety glass and security glazing, grouped into specific classes depending on its resistance to: burglary, bullet attack, explosion force, as well as its improved acoustic insulation and flame retardancy (Kozłowski 2010; Respondek, 2012).

Thermally toughened (tempered) glass (ESG) is obtained through appropriate heat treatment which introduces required initial stresses into the mass of glass, increasing the bending strength of the glass pane to over 120 MPa. Resistance to localised temperature variations – for toughened glass it is 150÷250 K, for standard glass (annealed) it is approx. 40 K. However, toughened glass has a certain disadvantage – local cracking causes the entire pane to break into small pieces. Tempered glass

fragments do not have sharp edges, but this manner of glass damage generates certain technological limitations. The processing of glass panes – cutting, hole drilling, edge grinding – must be carried out before the glass is thermally toughened, which significantly increases the production costs of products made of this type of glass.
The construction industry also uses **heat strengthened glass** (TVG) – this type of glass requires lower temperatures during its tempering process than ESG. Heat strengthened glass has lower mechanical strength than ESG and a specific method of cracking – each crack propagates towards the edge of the pane and, after destruction, large fragments are formed, which wedge together and do not fall out of the frame. This is beneficial in terms of its safety of use.
Laminated glass (VSG) is manufactured as a result of combining at least two layers of glass (tempered or annealed) using special film or resin. As already mentioned, the yield in the glass is unable to cope with loads distributed over a small area. The layers placed between the panes partially eliminate this defect. The glass is also destroyed in a different way – in the case of laminated glass, the damage to one of the panes does not immediately destroy the entire glass unit – fragments of glass, also tempered glass, remain mostly glued to the foil and remain in place (Du Bois et al, 2003; Yuan et al., 2017; Vedrtnam and Pawar, 2017; Castori and Speranzini, 2017). Laminated glass can therefore be considered as safe glass.
Insulating glass units (IGU) are commonly used in windows and glass façades. IGU consists of at least two panes of glass connected with an edge spacer, with a sealed gas-filled gap between the panes. This design not only improves thermal insulation properties but also the safety of use. Fragments of broken insulating glazing are usually supported by them being connected to the edge spacer and the window frame.

3. RISKS LINKED TO THE STRUCTURAL USE OF GLASS ELEMENTS

Based on the material collected, it was confirmed that the risks that occur during the use of glass elements in buildings (cracking, loss of aesthetic value) most often result from:

- sudden events;
- thermal loads and other climatic conditions;
- improper choice of glass support methods;
- action of water and water vapour;
- installation errors.

Practical examples illustrating these risks are provided below.

3.1. Damage to glass elements as a result of sudden events

Figure 1 shows an example of damage to a slanted insulating glass unit (single tempered glass + laminated glass underneath), which was a vestibule roofing element. The damage was caused by the impact of an icicle. As a result of the impact, the tempered glass was completely destroyed, but although the laminated glass located below cracked, it remained in the frame, and it prevented fragments of the tempered glass from falling to the ground. Therefore, it can be said that when selecting the glazing material, one should remember about how the glass cracks – single non-laminated glass panes must never be installed directly above people's heads, because that poses a threat to people’s safety. In the case of glass panes installed vertically, the vicinity of communication routes, such as pavements, corridors, staircases, etc. poses such a risk.

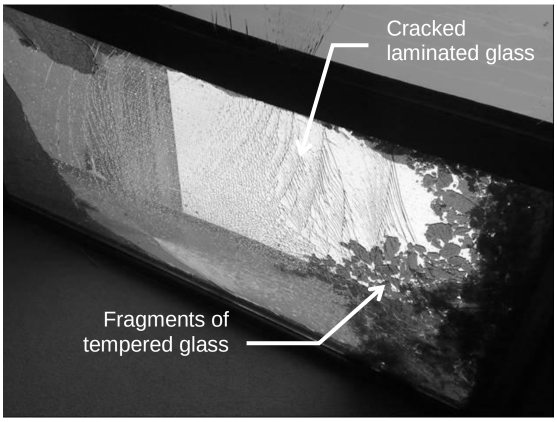

Fig. 1. Damage to a slanted insulating glass unit

3.2. Thermal loads

Thermal cracks can occur as a result of glass overheating under the influence of solar radiation (Wang et al., 2014). The use of low absorptivity glass is therefore recommended. Tempered glass should be used for glass façades with an absorption capacity of more than 50% – for example, using full-body coloured glass. At this point, one possible defect of this type of glass should be mentioned. During the manufacture of the glass in the plant, nickel sulphide inclusions may enter the glass mass. These inclusions, through the increase in their volume during the glass toughening process, may cause uncontrolled glass cracking under operating conditions. The risk of thermal cracks can be reduced thanks to the additional verification of tempered glass using the Heat Soak Test. This test consists in heating the tempered glass at a temperature of approx. 290^{o}C. This process identifies glass panes which carry defects and cracks, which allows their elimination from the supply process (Schneider et al. 2016).

Thermal cracks can also occur as a result of uneven heating of the glass, which can result from:

- at the cut-off line when part of the glass pane is exposed to sunlight and part of it is obscured;
- on the edge of the glass pane covered by the window frame;
- when a part of the glass pane is permanently covered with, for example, an advertising film sheet glued to the pane, especially when there is a large difference in the colour scheme of these elements.

Insulating glass units are also at risk of damage resulting from climatic conditions. Such units feature a sealed gas-filled gap. Under the influence of short-term changes in temperature and atmospheric pressure, a difference in pressure can form between the gas-filled gap and the surrounding environment, which subjects the unit to a particular load. In extreme cases, such loads may lead to the cracking of the glass on building façades. Multi-glazed IGUs are particularly susceptible to this hazard (Stratiy, 2017).

3.3. Choice of glass support methods

The most advantageous solution is supporting the glass pane in a frame alongside all its edges. Unsupported edges always increase the risk of breakage. The assignment of glass to a particular protection class (against burglary, bullet attack, explosion force) is based on a study of samples supported along the circumference – the lack of support at even one of the edges may reduce the product's resistance to sudden events.

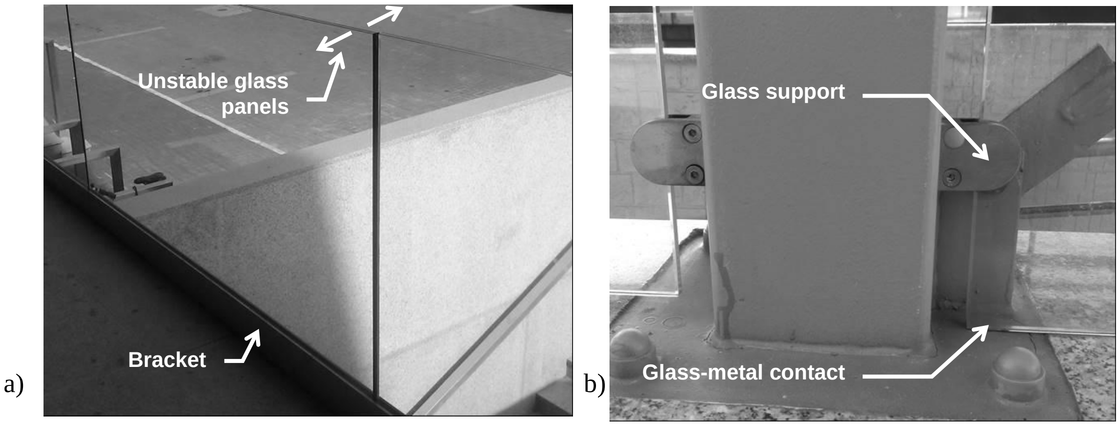

Fig. 2. Examples of incorrect methods of glass support: a) cantilever plate, b) contact point fixing

An example of an incorrect method of glass support is presented in Fig. 2a. The screen protecting a communication route is a large cantilever plate made from laminated glass. For this system to be stable, the lower edge of the laminated glass should be rigidly fixed to the bracket. This was achieved by using gaskets and wedge clamps. After a few years of use, the support lost its properties, most likely as a result of detrimental effects of the weather – even under slight pressure the plates rotate noticeably on the support, and the upper edges of the adjacent plates are shifted in relation to each other.

The point support method is also used in structures made of glass. They should be implemented by means of appropriately designed point connectors which pass through apertures made in glass (Kuliński et al., 2017; Major et al., 2017). In the case of small elements; however, it is common practice to affix laminated glass panes using contact point fixing, which may be very risky. Corrosion of gaskets or loosening of connections, for example, as a result of temperature changes, can cause the glass to shift uncontrollably. This danger applies in particular to outdoor structures. Fig. 2b is an example of a glass pane which has shifted in this way.

3.4. Action of water and water vapour

Glass shows considerable resistance to chemical substances. The main cause of corrosion of building glass is water, in particular, water remaining on the surface of the glass or water vapour condensing on the surface of the glass panes. First of all, water causes the hydrolysis of glass (adhesion of hydroxyl groups to silicon atoms) which enhances the possibility of surface micro-cracks enlargement. Secondly, water contributes to the rinsing of calcium, sodium or potassium atoms, which in turn causes the permanent matting of the glass (Jaśkowska, 2009; Luo et al., 2016; Potter et al., 2018). Flat protective canopies are particularly exposed to water retention (Fig. 3a). On the other hand, condensed water vapour remains the longest on the opaque parts of glass façades (Fig. 3b). The effect of additional insulation of this part of the façade is revealed here – the external surface of the pane has a reduced temperature, which fa Olmos Navarrete vours condensation.

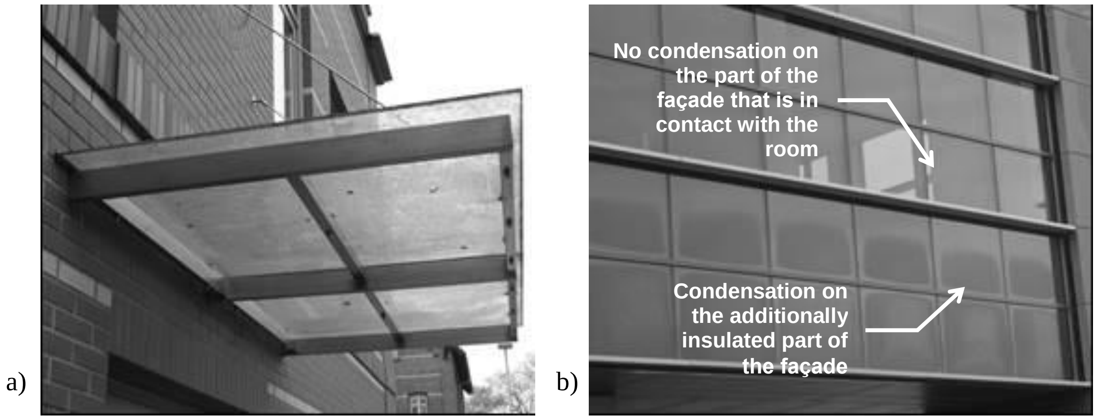

Fig. 3. Elements exposed to water and water vapour: a) protective flat canopy, b) condensation of water vapour on the glass part of the façade.

4. GUIDELINES FOR THE SAFE INSTALLATION OF GLASS ELEMENTS

Installation errors can result in various types of damage, including breakage of glass elements. The following basic installation recommendations can be formulated:

- the glass pane should be installed in a stable manner but be capable of free thermal movement,
- when using clamping elements, the clamping pressure must not be too high,
- glass panes with parameters or dimensions inconsistent with those assumed should not be installed, and if the supporting structure has geometrical deviations it should not be used,
- glass should not come into contact with hard elements, especially metal or adjacent glass elements; in such contact points there is always a danger of localised cracking, which usually increases over time;
- materials in contact with glass (spacers, gaskets, adhesives and sealants) must remain flexible during the use of the structure,
- bare or unsupported glass edges must be ground or at least made blunt; in the case of more significant structures, all edges must be machined,
- glass elements in the structure are there to fill in the empty areas, and therefore it is unacceptable to install glass walls for them to take over the loads from the building's structure.

An installation error example is shown in Fig. 4. It shows a fractured glass pane which is adjacent to a door. The crack was caused by a rigid connection between the door guard and the wall frame. In this instance, a flexible pad or a self-locking mechanism should have been used.

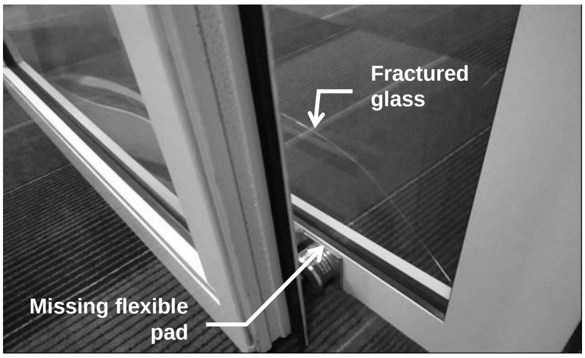

Fig. 4. Example of an installation error – the door guard is rigidly fixed to the frame of the adjacent glass wall

5. CONCLUSION

The advancement of glass technology contributes to the ever-increasing use of glass elements in construction. The currently used glass with improved strength parameters is more resistant to accidental impact, while actions such as vandalism or burglaries are more difficult to achieve if the glass used features the appropriate protection class parameters. During the use of glass elements, however, defects may occur, the examples of which are described in this article. The prerequisite for avoiding such errors is the awareness of designers and contractors of the causes and consequences of these defects. The identification of risks associated with the use of glass elements should be carried out primarily during the design and installation phase. Integrated management systems of building processes may play a vital role in the matter in question (Sobczyk et al., 2018). Inspections of glass elements in the course of their use are also crucial. They make it possible to assess the correct operation of the structure, and identify any cracked or shifted elements.

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