# Experimental investigation on the ball drop impact resistance of traditional glass windows

L. Figuli[1], C. Bedon[2], D. Papán[3], Z. Papánová[3]

[1] *University of Žilina, Faculty of Security Engineering, Univerzitná 8215/1, 01026 Žilina, Slovakia.*
*E-mail: lucia.figuli@fbi.uniza.sk*

[2] *University of Trieste, Department of Engineering and Architecture, Piazzale Europa 1, 34127 Trieste, Italy*
*E-mail: chiara.bedon@dia.units.it*

[3]*University of Žilina, Faculty of Civil Engineering, Univerzitná 8215/1, 01026 Žilina, Slovakia*
*E-mail: daniel.papan@fstav.uniza.sk*

## ABSTRACT

Given the typical features of glass fenestrations and façade systems, and their common use in buildings with several classes of use, the research on their impact resistance represents a key task for the protection of people. In this regard, the paper focuses on the experimental analysis of the impact performance and resistance of ordinary glass windows. Special care is spent for traditional systems that can be typically found in residential / commercial buildings, namely windows with timber frame as well as windows with plastic (PVC) frame. The dynamic performance of such systems is analysed experimentally, in accordance with the standard ball drop test method, and the collected outcomes are discussed to assess the fundamental dynamic mechanical characteristics of the examined fenestrations.

**KEYWORDS:** *Glass windows, impact test, impact resistance, wood frame, PVC frame*

## INTRODUCTION AND STATE-OF-THE-ART

The actual motivations for the experimental research on the dynamic response of glass systems under ball drop impact are various, and typically reflect the intrinsic vulnerability and fragility of these systems [1]. Most of the studies, however, are focused on glass for automobilistic of electronic applications, and limited efforts can be found for constructions. Tests on laminated glass panels under the hard body impact (pedestrians or driver heads) can be found in [2]. Impact experiments are reported in [3] to estimate the resistance of glass against scratches, drop impact and bumps, for the protection of displays (smartphones, tablets, etc.). Full-scale glass columns under impact are investigated in [4]. In [5, 6], experiments for the burglary resistance and protection of glass "soft targets", as well as preliminary dynamic considerations for glass windows

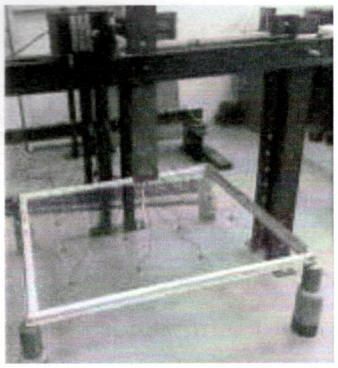
under shock, are reported.

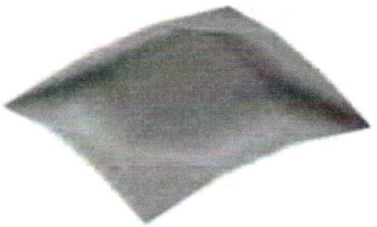
## EXPERIMENTAL INVESTIGATION

The series of dynamic experiments summarized herein was carried out at the laboratory of structural mechanics of the Faculty of Civil Engineering, University of Zilina, Slovakia (May 2019). Given two glass window systems with identical dimensions and glass composition, in particular, special care was spent on the sensitivity of their impact response to the type and features of the supporting frame. Each glass sample was in fact characterized by a total size of 1.21×1.38 m, consisting of a frame (made of timber (and reflecting the use in Czechoslovakia over 1960s) or PVC) and a monolithic glass plate. The nominal thickness of glass was 3 mm for the wooden specimen, and 4mm for the PVC frame. Regarding the size of glass, the dimensions where defined from the total size of window samples and the frames in use. Accordingly, glass surface was 1.20x1.05 m for the wooden frame and 8.10x9.70 m for the PVC window.

### Modal analysis

Modal dynamic analyses were carried out at a preliminary stage of the experimental study, so as to assess the fundamental vibration frequency and modal shape of the examined windows. A rectangular grid with 16 Deltatron accelerometers (type 4508 B 002) was installed evenly on the glass surfaces (Figure 1a). Three six channels input modules (Type 3050-B-060) were used. Each accelerometer was cable-connected to an Input Module (with two inactive positions). The measuring interfaces were connected to a PC and test records were processed via the PULSE software. The imposed excitation was realized by tapping the glass plate with various levels of impact softness, at the middle grid points of the glass surface. The measured data were then transformed into ARTeMIS and processed by FDD (Figure 1b).





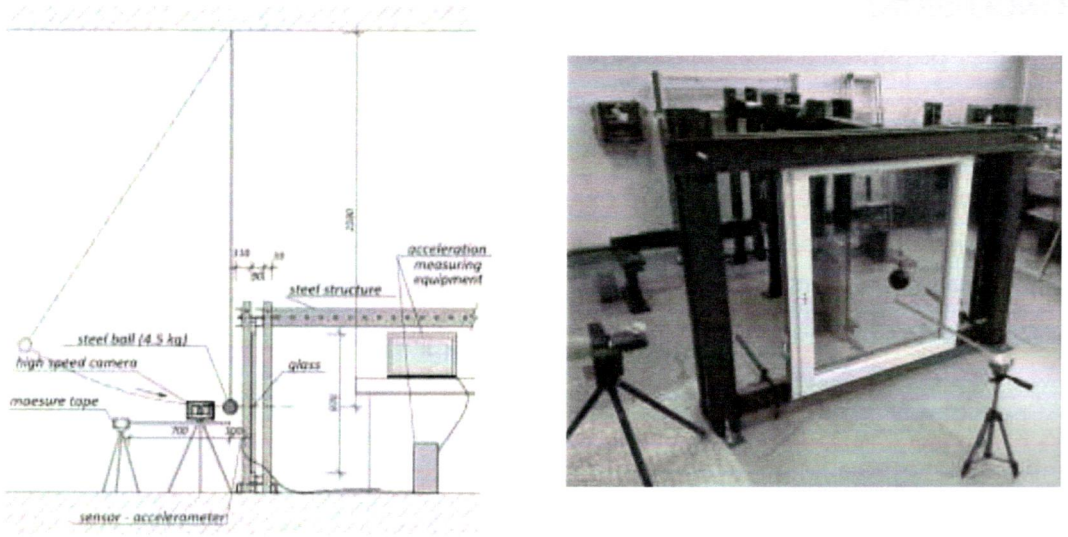
$f_{(1)^w} = 13.1\ Hz$

(a) (b)

**Figure 1**: Modal experiments. (a) Placement of sensors and (b) predicted fundamental mode of vibration.

**Dynamic impact experiments**

Later on, dynamic impact experiments were performed on the same windows. The reference test setup is shown in Figure 2. It was organized so that each steel ball could impact the window in the middle of glass, while the overall sample was attached to a rigid metal frame and. Different impact bodies (two steel balls with nominal weight of 2.644 kg and 4.571 kg) and drop height (i.e., horizontal distance between the ball and the window) were used. For each drop test, accelerations were measured by means of a set of sensors positioned in the lower part of glass (right side, at a distance of 0.2m from the edge). A high-speed camera (FASTEC TS3100SC4256 Imaging) was also used, to investigate the impact velocity based also on slow motion registrations.




(a) (b)

**Figure 2**: Impact tests. (a) Reference setup (lateral view) and (b) laboratory test.

Four experiments were carried out on two windows samples (wood / PVC), by accounting for different steel ball sizes and overall impact energies. The latter values were calculated according to Equation (1), by taking advantage of slow motion records from the high-speed camera:

$$E = \frac{1}{2} m\, v^2 \tag{1}$$

The maximum impact velocity of each test is presented in Table 1, as a function of ball size and level of impact energy, when damage of glass panel occurred.

**Tab. 1.1.** Impact resistance of windows under different ball sizes and impact velocity

| **Ball mass [kg]** | **Energy [J]** | **Impact velocity [m/s]** | **Impact horizontal distance [m]** | **Window frame** |
|---|---|---|---|---|
| **2.644** | *7.72* | *2.42* | *1.30* | *wood* |
| **2.644** | *3.36* | *1.60* | *0.90* | *wood* |
| **2.644** | *8,90* | *2.59* | *1.40* | *wood* |
| **4.571** | *19.75* | *2.94* | *0.15* | *PVC* |

## CONCLUSIONS

The paper presented a series of ball drop impact experiments, carried out to estimate the dynamic resistance of glass windows. Traditional samples with wood frame were taken into account, and compare with PVC framed systems. The fundamental vibration frequency and modal shape of the examined windows were first explored, based on modal analysis. Later on, ball drop impact tests were carried out. The study is part of an ongoing project that will include analytical and numerical analyses of the examined systems.

## REFERENCES

[1] Bedon, C., Zhang, X., Santos, F., Honfi, D., Kozłowski, M., Arrigoni, M., Figuli, D., Lange, D. (2018) Performance of structural glass facades under extreme loads – design methods, existing research, current issues and trends. Construction and Building Materials. Vol. 163, pp. 921-937

[2] Wang, X., Yang, J., Xu, H. (2018) Experimental investigation on the Impact Resistance of Laminated Glass with Various Glass Make-ups. Challenging Glass 6 – Conference on Architectural and structural Applications of Glass

[3] Xue, L., Coble, C.R., Lee, H., Yu, D., Chaparala, S. And Park, S. (2013) Dynamic analysis of the thin glass under ball drop impact with new metrics. Proceedings of the ASME 2013 International Technical Conference and Exhibition on Packing and Integration of Electronic and Photonic Microsystems InterPACK2013

[4] Bedon, C., Kalamar, R., Eliasova, M. (2017). Low velocity impact performance investigation on square hollow glass columns via full-scale experiments and Finite Element analyses. *Composite Structures*, 182, 311-325

[5] Figuli, L., Zvaková, Z., Bedon, C. (2017) Design and analysis of blast loaded windows. *Procedia Engineering*. Vol. 192, pp. 177-182

[6] Figuli, L. (2019) Analysis, design and protection of blast loaded windows. Critical infrastructure protection: best practices and innovative methods of protection. Amsterdam: IOS Press, ISBN 978-1-61499-963-8. - pp. 27-43