THE EXPERIMENTAL DETERMINATION OF DEFLECTION ON PLEXIGLAS MODEL

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UDK: 624.042.7:519.87
DOI: 10.14415/konferencijaGFS2018.020

Summary: *This paper presents the procedure for the experimental determination of the horizontal deflection of a point due to the horizontal force effects on the model made of Plexiglas with proportionally the same geometry as the numeric example applied in works of several authors for the analysis of the tall building cores. This examination offers the experimental analysis possibility of the reinforced-concrete core on effects of the horizontal load of seismic forces and the wind. These results are compared with the results obtained by FEM showing significant agreement.*

Keywords: *experimental model, tall building core, thin-walled beam, torsion*

1. INTRODUCTION

The reliability and applicability of the new methods for the tall building cores analysis is usually tested by comparison with other, already known methods that are available in the literature and/or with FEM results. Unfortunately, there is a lack of data compared with experimental results in most of the cases, especially concerning the core with open cross-section. One approach to check reliability of the calculation method is the application of such a method on an experimental model. In order to prove the validity of his calculation method, Ambrosini , tested thin-walled beams made of aluminium, as described in the works [1] and [2]. The results of Ambrosini's calculations were compared with the results of the experiment and FEM. Wu Qian, Fang and Yan [3] made their experimental models using Plexiglas.
Regarding comparison as a method, it is preferable to select such a parameter that could equally be determined by calculation as well as by experiment. Such parameter could be, for example, the horizontal deflection on certain spots of a model. It is well-known that horizontal deflection in high buildings is particularly important data. Its maximum value that usually appears on the upper part of a building must always be determined and limited (Zalka [4] and [5]).

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This paper will consider those tall buildings in which transverse (horizontal) load of seismic activity and wind effects is held by the central reinforced concrete core. This core may also be used as the elevator shaft and/or stairways in a building.

This type of construction contains a central core, symmetric or asymmetric in comparison with one or both axes, and periphery pillars. Considering the fact that the core stiffness is much higher than in periphery pillars, the premise can be adopted that the entire horizontal load of such building is held by the reinforced concrete core.

Keeping in mind the buildings' geometry, the calculation model usually approximated by the core behaviour in tall buildings is structured of a thin-walled beam of arbitrary or open cross-section which is connected at the bottom and free at the top; i.e. a cantilever beam. The authors consider the general case where the shear centre of the core cross section is located asymmetrically in respect to the base building, or the transversal load is eccentric, the core is also exposed to the bending and torsion (Prokić [6]).

The experimental model that will be applied in order to analyse the aforementioned core is made of Plexiglas. The model`s geometry is approximately proportional to the numeric example used in numerous scientific papers. The authors took into account that the Plexiglas sheets had been manufactured only with certain thicknesses, thus it was not possible to achieve full geometric similarity between the model and the numeric example. The testing results will be compared with the results obtained by the SAP2000 application.

2. EXPERIMENTAL MODEL

The experimental model in this paper had already been analysed before, in order to check the accuracy of the numeric method for the determination of the dynamic characteristics of the tall building core ([7] and [8]). It is made of Plexiglas (PLEXIGLAS XT) sheets with a thickness of 6mm and 10mm and bonded by the special glue ACRIFIX®109. The wooden mould was used to shape the model. Figure 1 illustrates details of the model manufacturing.

Figure 1. Details of the mould

The lower part of the model was bonded with two mutually glued Plexiglas panels of 10mm thickness. It was connected with four screws M8 to a steel panel 5mm thick. The steel panel was fastened to a immobile base by 4 screws M8. Figure 2 illustrates the outline and geometric data of the model.

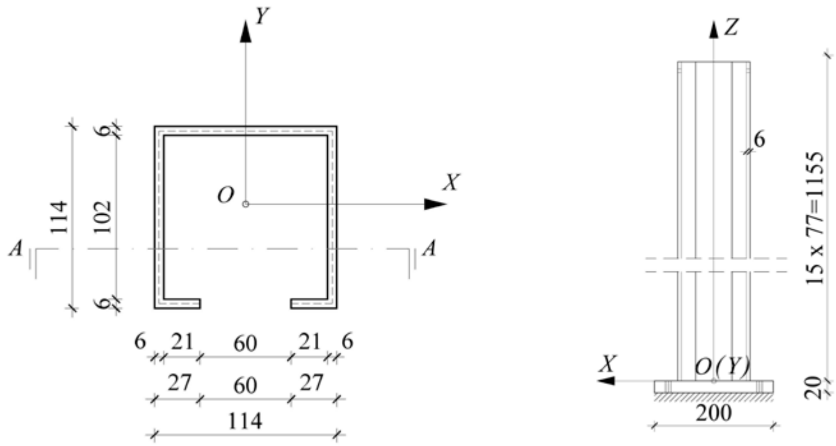

Figure 2. Base plot and cross section of the experimental model

There is a similarity between the numeric example and the Plexiglas model by element dimensions according to Table 1.

Table 1. The example elements and Plexiglas model geometric data

Geometric characteristics of elements	Example [mm]	Model [mm]	Ratio
Wall thickness of the core	305	6	1:50.833
Cross section dimensions of the core	5791/5791	114/114	1:50.798
Width of the opening	3048	60	1:50.800
Floor height	3810	77	1:49.481
Total height of the building	57150	1155	1:49.481

Mutual relations of dimension values in the model justify the intention to treat the core as a thin-walled beam with open cross section which is compacted at the bottom into the foundation panel while it is free at the top.

3. EXPERIMENTAL ANALYSIS

The purpose of the experimental analysis is to define the horizontal deflection of certain points in the experimental model due to the effects of the known horizontal force by accurate measurements. The horizontal force in the model is applied by a thin nylon string (Damyl) and roller. One end of the nylon string is fixed at the hole (with a diameter of 6 mm) that was drilled in the model. The other end of the nylon string is loaded by the known weight force (Figure 3).

Horizontal moving Δu was measured by the digital comparator with accuracy 0.001mm. In order to fit the comparator, the authors used a magnetic holder with a mechanism (Figure 4). The model and the measuring devices were installed in the steel testing frame at the **Laboratory for Structures and Materials** at the facilities of the Faculty of Civil Engineering in Subotica, Serbia [9]. The weight force that has loaded the model was defined by the mass of the scale weight *m*. The points in which the deflection was measured (A1, A2 and A3) were selected in order to overlap the node points of the model in the FEM analysis. The aim of selecting the holes (i.e. places to enter the force) was to expose the model to bending (load in B1), as well as to a combination of bending and torsion (load in B2 and B3).

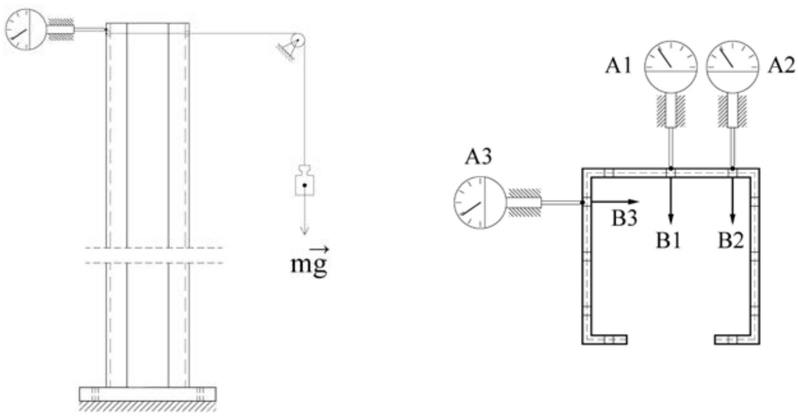

Figure 3. Position of comparators and the direction of loadings

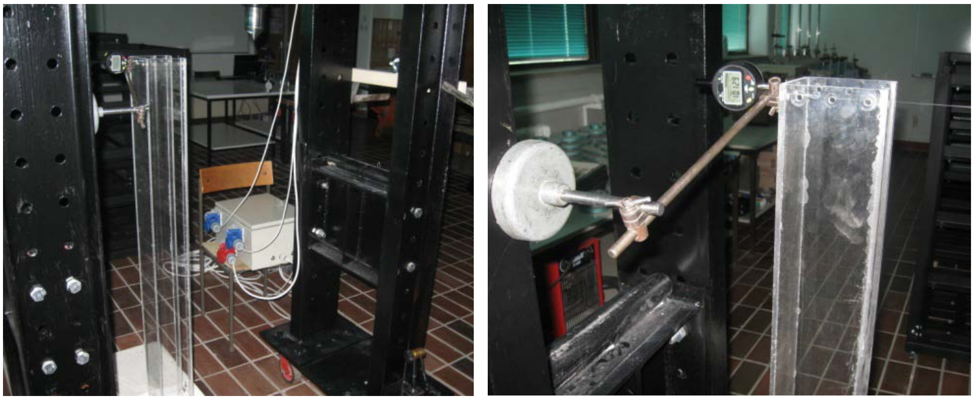

Figure 4. The experimental model and measuring device

In the course of the experimental analysis the intensity of forces was gradually increased. After each increase, a certain time period was needed to stabilize the value at the display on the comparator. It was thus seen that the greater the load intensity increase, the greater the time period necessary for stabilization. Over a certain load value the model deflection could not be stabilized any further, i.e. the plastic deformation of the Plexiglas occurred. Based on the above-mentioned, it is necessary to determine the upper limit of the load intensity up to which the model behaves flexibly. The authors conducted testing in all measurement points A1, A2 and A3 with the load B1, B2 and B3, aiming to establish the largest force value. This testing first resulted in plastic deformation in the measurement point A3, given B3 load. The force intensity was complemented with the weight force of the scale weight mass m=1150g. Further analysis of the model occurred only in this so-called flexible zone.

4. FEM ANALYSIS

The experimental model with analysis including SAP2000 application was shaped with 2250 nodes and 2160 *Four-node Quadrilateral Shell* elements. The nodes at the foundation panel level were fully restrained. The testing for the Young modulus took place at the same location, at the **Laboratory for Structures and Materials** of the Faculty of Civil Engineering in Subotica. The Young modulus was determined experimentally $E=3000\cdot10^3 N/mm^2$. The shear modulus was taken over from the *Evonik* manufacturer website and equals $G=1095\cdot10^3 N/mm^2$.
In order to ensure comparability, the calculation used the same force intensities as were used in the measurements. The deformed shape of the model obtained by the SAP2000 application is presented in the Figures 5-7. When the model was subjected to the B1 load the model was exposed to bending only. With the loads B2 and B3, in addition to bending, the model was exposed to torsion, too.

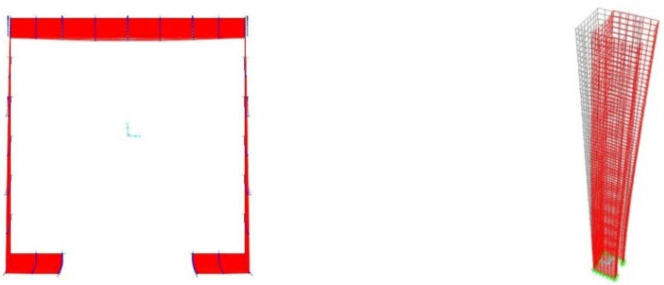

Figure 5. Deformed shape of the model with the load in B1

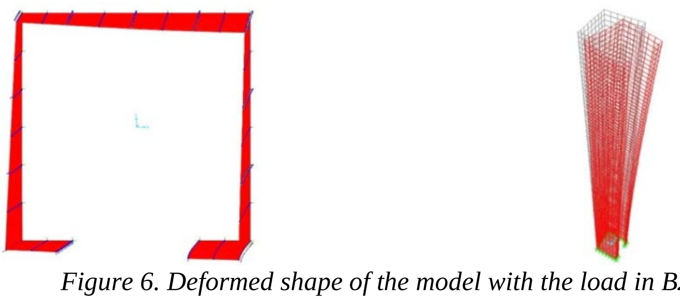

Figure 6. Deformed shape of the model with the load in B2

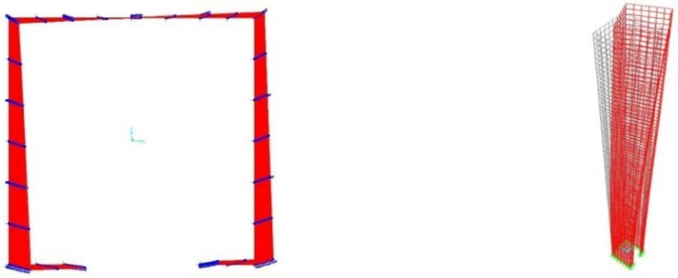

Figure 7. Deformed shape of the model with the load in B3

5. CALCULATION AND MEASUREMENT RESULTS ANALYSIS

Table 2 presents the numerical values of the horizontal deflection in the model points (A1, A2 and A3) obtained by the experiment and SAP2000 application, as well as their comparison. The weight force used to load the model is defined by the scale weight mass *m* and varies in the range: m=200÷1000g with steps Δm=200g.

Table 2. Analysis of the experimental model results

Measured point / loading	Weight mass [*g*]	Experiment [*microns*]	SAP2000 [*microns*]	Difference [%]
A1 / B1	200	101	99	2.02
	400	203	198	2.52
	600	306	297	3.03
	800	411	397	3.53
	1000	519	496	4.63
A2 / B2	200	118	115	2.61
	400	238	230	3.48
	600	359	346	3.76
	800	483	461	4.77
	1000	610	576	5.90
A3 / B3	200	216	208	3.85
	400	437	417	4.80
	600	665	625	6.40
	800	903	834	8.27
	1000	1156	1042	10.9

The values of the horizontal deflection of the model points show significant agreement between calculation results obtained by the SAP2000 application and the measurements. It was noticed that with increase of the intensity of forces, the relative difference in each measuring point increased, as well as. At the measuring point A3 this increase was more prominent than by two others. The data outlined in Table 2 is given in graphical form Figure 8. The lines obtained by the SAP2000 application are marked with *S*, while those obtained by the measurements are marked with *M*. The measurement points are labelled as Numbers 1, 2 and 3.

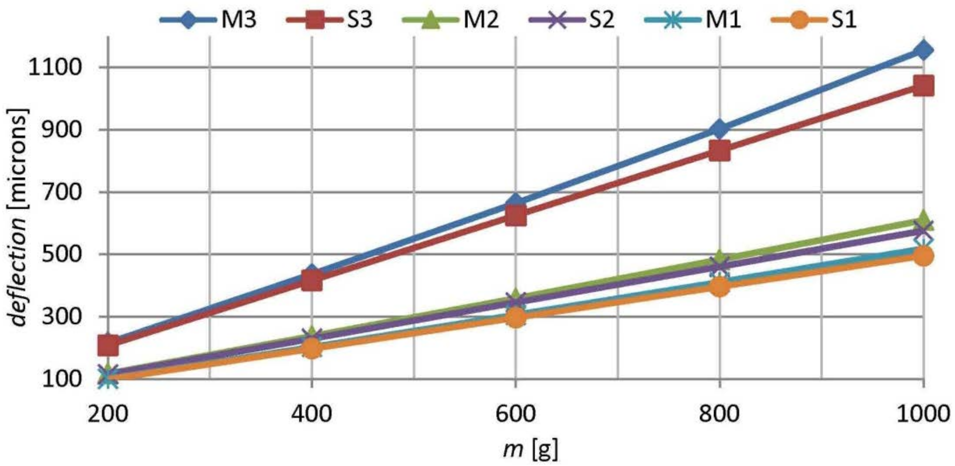

Figure 8. Change of deflection values of the model points A1, A2 and A3

6. CONCLUSION

This paper offers a description of the procedure for the horizontal deflection points of the Plexiglas model by the experiment with the horizontal force effect. The model is described and details about the experiment are provided. The authors especially focused their attention on the determination of the largest force value in which the model still behaves flexibly. Further, an analysis was conducted with the SAP2000 application and the outcomes presented. The authors state that the results of the experiment and the calculation are thoroughly consistent.

On the basis of the above-described analysis the following conclusion can be drawn:

- Tall buildings core considered in this paper can be modelled with sufficient accuracy with reduced Plexiglas models given the horizontal deflection analysis initiated by the horizontal force effect. However, special attention ought to be paid to the load intensity, which is to stay within the limits where the model behaves flexibly.
- The presented procedure enables the user to prove the reliability and applicability of the new methods for the horizontal deflection calculation for each point of thin-walled beams with open cross-section due to the horizontal force effect.

The illustrated experimental testing results argue in favour of certain possibility of the experimental model development that contains additional constructive elements able to significantly impact the horizontal deflection of the core. These are, for example, the lintel beams and floor slabs. The experimental analysis of this model described in this paper offers the possibility of determining the quantitative and qualitative influence of lintel beams and floor slabs on the horizontal deflection of the core. The results of this research lend a better insight in the behaviour of tall buildings containing the central core as the most important carrying element holding the horizontal impact. This will lead to designers achieving more reliable and economic planning in such structures.

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ЕКСПЕРИМЕНТАЛНО ОДРЕЂИВАЊЕ ПОМЕРАЊА НА ПЛЕКСИГЛАС МОДЕЛУ

Резиме: *У раду је приказан поступак за експериментално одређивање хоризонталног померања тачке услед дејства хоризонталне силе модела израђеног од плексигласа, који има сразмерно исту геометрију као и нумерички пример узет у радовима многих аутора за анализу језгра високих зграда. Ово испитивање нуди могућност експерименталне анализе армирано-бетонског језгра на утицаје хоризонталног оптерећења од сеизмичких сила и дејства ветра. Резултати су упоређени са резултатима добијеним помоћу МКЕ и показују значајно слагање.*

Кључне речи: *експериментални модел, језгро високих зграда, танкозидни носачи, торзија*