EXPERIMENTAL ANALYSIS THE DEFLECTION OF TALL BUILDING CORES – STIFFENED BY LINTEL BEAMS - USING PLEXIGLAS MODEL

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Summary: *This paper presents the procedure for the experimental determination of the horizontal deflection of a point on the model made of Plexiglas due to horizontal force effects. The model`s geometry is proportional to the geometry of the numerical examples which 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 - stiffened by lintel beams at each floor level - 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 applicability and reliability and 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,

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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]).

In the case of tall buildings, the influence of transverse loading caused by winds or seismic activity can be significant. This load is most often supported by a reinforced concrete core, which houses the elevator shaft or the staircase of the building. Due to the small thickness of the core walls compared to the dimensions of the cross section, which, again, are small compared to the height of the building, according to the Vlasov theory, the core can be treated as a thin-walled, open cross section cantilever beam. Floors act as transverse stiffeners providing the necessary cross section rigidity of the core. The core foundation is usually stiff enough, so full restraint can be assumed.

If the shear centre of the core cross section is located asymmetrically in respect to the base of the building, or if the transverse loading is eccentric, the core is, apart from bending, exposed to torsion, as well. In the case of taller buildings the torsion influences are greater, so it is necessary to provide appropriate torsional rigidity to the core. Lintel beams connecting the core walls at each floor level also contribute to torsional rigidity. The influence of these elements on the total torsional rigidity of the core can be significant.

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 testing results will be compared with the results obtained by the FEM 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 ([6], [7] and [8]). Figure 1 illustrates the outline and geometric data of the model.

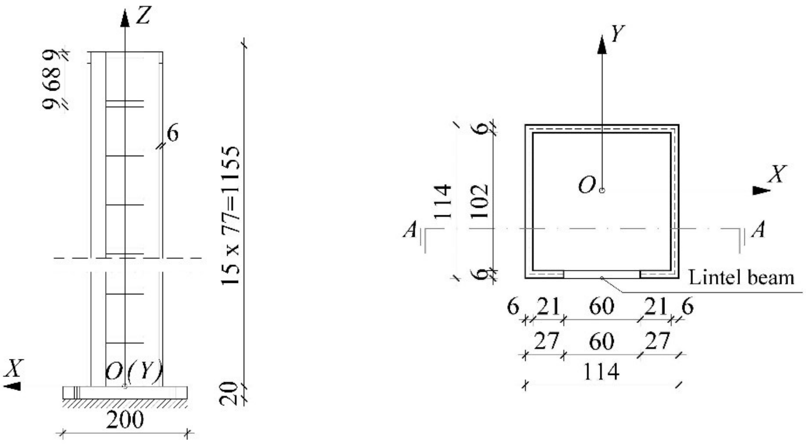

Figure 1. Cross section A-A and base plot of the experimental model

It is made of Plexiglas (PLEXIGLAS XT) sheets with a thickness of 6mm and 10mm. 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. A wooden mould and special glue ACRIFIX®109 was used to shape the model. Figure 2 illustrates details of the model manufacturing.

Figure 2. Details of the mould

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
Height of lintel beams	457	9	1:50.778
Length of lintel beams	3048	60	1:50.800
Cross section dimensions of the core	5791/5791	114/114	1:50.798
Width of the opening	3048	60	1:50.800
Height of a storey	3810	77	1:49.481
Total height of the building	57150	1155	1:49.481

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. 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 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).

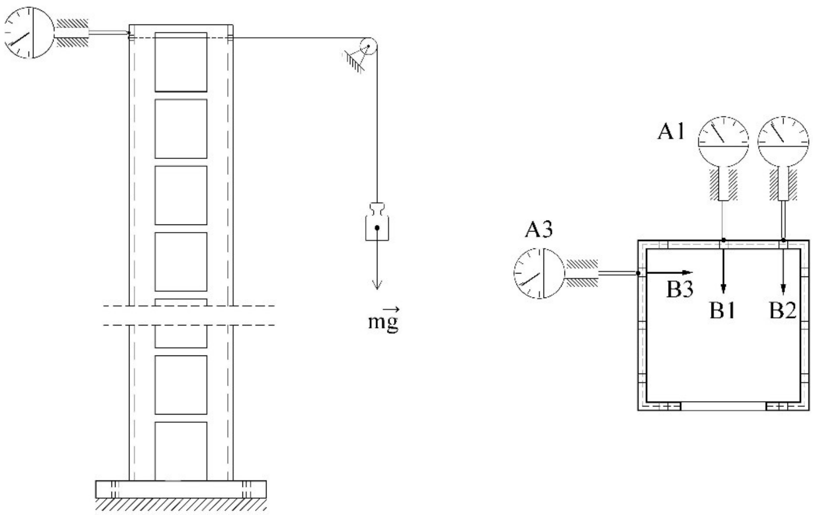

Figure 3. Position of comparators and the direction of loadings

Horizontal moving *Δu* was measured by the 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 only to bending (load in B1), as well as to a combination of bending and torsion (load in B2 and B3).

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*=1550g. Further analysis of the model occurred only in this so-called flexible zone.

Figure 4. The experimental model and measuring device

4. FEM ANALYSIS

The experimental model with analysis including FEM application was shaped with 2355 nodes, 2160 Four-node Quadrilateral Shell elements and 120 Frame Elements of Rectangular shape. 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=3000·10^{3}N/mm^2. The shear modulus was taken over from the Evonik manufacturer website and equals G=1095·10^{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 FEM 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.

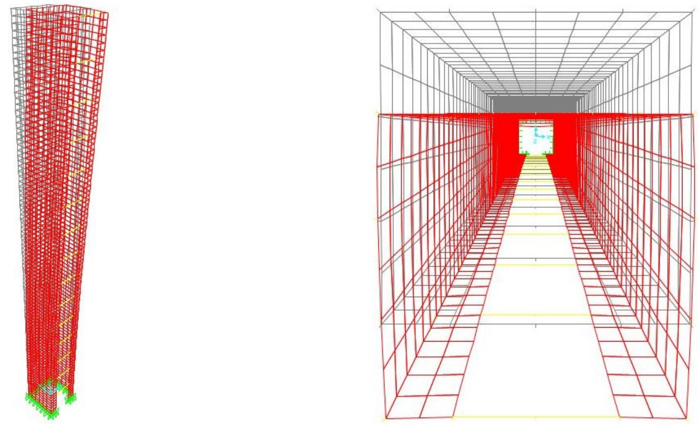

Figure 5. Deformed shape of the model with the load in B1

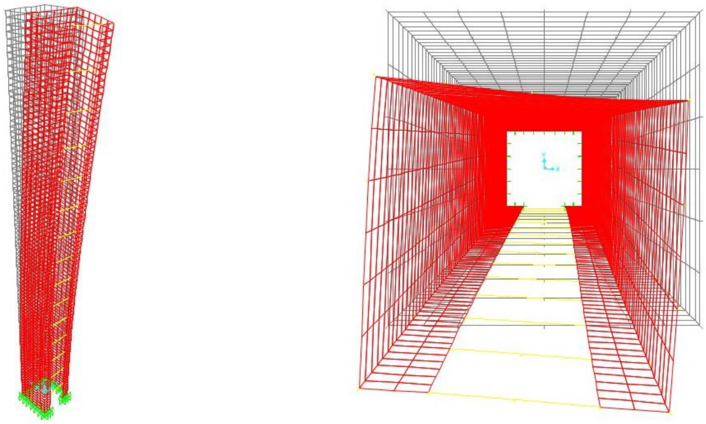

Figure 6. Deformed shape of the model with the load in B2

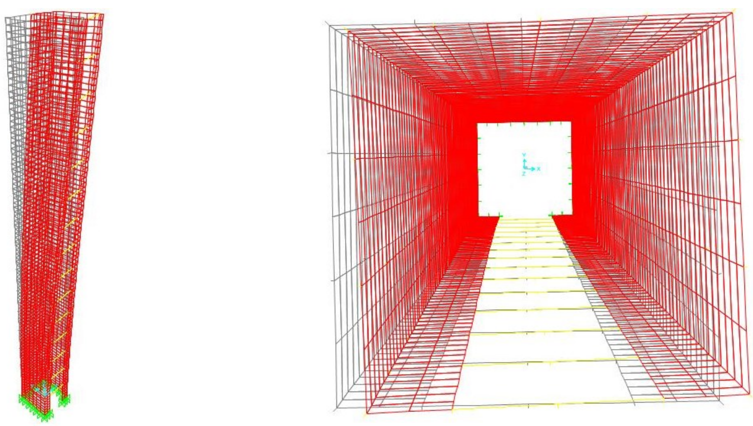

Figure 7. Deformed shape of the model with the load in B3

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 FEM 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=250÷1250g with steps Δm=250g.

The values of the horizontal deflection of the model points show significant agreement between calculation results obtained by the FEM 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 FEM 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.

Table 2. Analysis of the experimental model results

Measured point / loading	Weight mass [g]	Experiment [*microns*]	SAP2000 [*microns*]	Difference [%]
A1 / B1	250	122	119	2.74
	500	245	238	3.14
	750	369	357	3.45
	1000	494	476	3.85
	1250	620	595	4.18
A2 / B2	250	127	123	2.94
	500	255	247	3.38
	750	385	370	4.07
	1000	517	493	4.87
	1250	654	616	6.09
A3 / B3	250	156	149	4.62
	500	309	298	5.08
	750	479	447	7.14
	1000	644	596	8.09
	1250	818	745	9.92

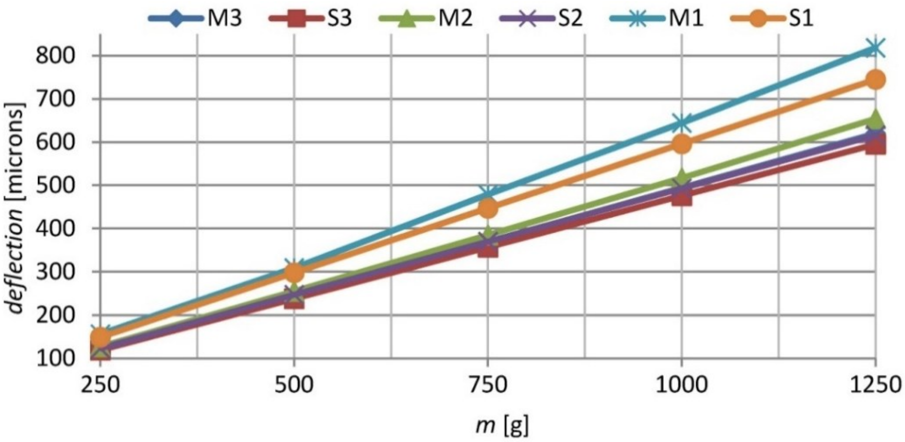

Figure 8. Change of deflection values of the model points A1, A2 and A3

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ЕКСПЕРИМЕНТАЛНА АНАЛИЗА ПОМЕРАЊА ЈЕЗГРА ВИСОКИХ ЗГРАДА - УКРУЋЕНА ПОПРЕЧНИМ ГРЕДАМА - ПОМОЋУ ПЛЕКСИГЛАС МОДЕЛА

Резиме: *У раду је приказан поступак за експериментално одређивање хоризонталног померања тачке модела израђеног од плексигласа услед дејства хоризонталне силе. Геометрија модела је сразмерна геометрији нумеричког примера који је узет у радовима многих аутора за анализу језгра високих зграда. Ово испитивање нуди могућност експерименталне анализе армирано-бетонског језгра - укрућеног попречним гредама на нивоима спратова - 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*