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STUDY ON THE RIGIDITY OF A PRECAST CONCRETE FRAME WITH AND WITHOUT RIGIDIZATION WITH CORRUGATED SHEETS

BY

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Abstract. The perimeter enclosures of single-storey buildings are in most cases build from corrugated metal sheets. For metal structures there are a lot of studies that have led to the creation of design guides that take into account the concurrence between the corrugated sheet and the metal structure. In the case of reinforced concrete buildings, the problem is still insufficiently thorough. There are no methods nor calculation models to help the design engineer determine the sheet contribution to the lateral stiffness of the frame. The additional stiffness added by the corrugated sheets it is often overlooked in the global design process. In order to better understand the interaction between the corrugated sheets and the reinforced concrete frame, we have carried out an experiment on a real prefabricated reinforced concrete frame structure made at a 1:3 scale. The steps followed to run the experimental test are described in the ACI T1.01 standard.

Keywords: corrugated sheets; frame stiffness; concrete frame.

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1. Overview of the Experimental Program

The main objective of the experimental test was to obtain the structural response of a real prefabricated reinforced concrete frame structure, that is laterally stiffened on two sides with corrugated sheets.

There is a significant steel quantity derived from the corrugated sheets used to build the perimeter enclosures and roof of single-storey buildings that is often omitted in the static and dynamic design calculations.

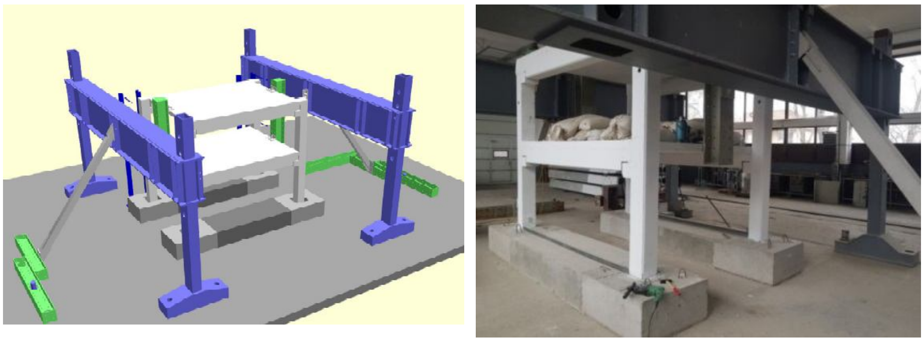

Fig. 1 – Side view Experimental Frame.

Nowadays there are no design guides in determining the contribution of the corrugated sheet from the enclosures to the lateral stiffness for reinforced concrete frames. The corrugated sheets in the perimeter enclosures can add strength and ductility capacity to the building that is not included in the current design process.

The experimental test described in this article was conducted in the Laboratory of the Faculty of Civil Engineering in Cluj-Napoca. A real two-level prefabricated reinforced concrete frame was built at a 1: 3 scale opening.

In order to build the Model Frame, whose structural response we want to obtain, a Prototype Frame was first chosen. The Prototype Frame is a frame with a 6 × 9 m bay. The section of the columns is 60 × 60 cm and the prefabricated beam has a section of 60 × 66 cm. Adding the monolithic concrete floor the beam section is 60 × 90 cm (Table 1). In elevation the frame has two levels ($H_{level}1$ = 4.00 m, $H_{level}2$ = 3.75 m).

The Model Frame is designed following a common solution in current design in seismic areas. The structure has precast concrete foundations that are joined by a counterbalance beam, which was designed with sufficient stiffness to prevent possible detachment or surface sliding.

The precast columns are fixed in the foundations. The prefabricated beams are supported by columns through a corbel. The upper part of the prefabricated beams has connectors for connection to the monolithic floor. Connectors include longitudinal concrete steel bars for the negative moment. They are attached to columns by catalog pieces embedded in the columns. The floors are made of monolith reinforced concrete (Fig. 2).

Table 1
Geometry of Structural Elements and Structure - Prototype & Model

Structural Element	Prototype Element	Model Element
Column, [cm]	60 × 60	20 × 20
Beam (prefabricated) , [cm]	60 × 66	20 × 22
Beam (final) , [cm]	60 × 90	20 × 30
Floor, [cm]	24	8
Height Level 1, [m]	4.00	1.33
Height Level 2, [m]	3.75	1.25
Bay, [m]	6.00 × 9.00	2.00 × 3.00

The frame was built inside the Laboratory in December 2013. The first experimental test, without side-stiffeners with corrugated sheets took place in April 2014 and the objective was to observe the behavior of the frame nodes (Fig. 1). Afterwards, in April 2019, for the experiment described in this article, the frame was laterally stiffened with corrugated sheets on both sides (Fig. 3) and subjected in this way to a second experimental test, following the same steps as in the first case, described in ACI T1.01 standard.

Fig. 2 – First test on Experimental Frame: Non stiffened 2014.

Fig. 3 – Second test on Experimental Frame: Side stiffened 2019.

The experimental test seeks to determine the structural response of a prefabricated two-side stiffened frame with corrugated sheets. The experimental test was conducted according to the American Standard ACI T1.1-01 "Acceptance Criteria for Moment Frames Based on Structural Testing" (Figs. 4 and 5). The results complies with the test methodology recommended by it in the absence of a Romanian or European procedure that provides guidance on how to test frame structures that do not comply exactly with the requirements of the seismic design rules and codes in force.

The response of both tested structures was carried out by applying a quasi-seismic side cyclic load. The 11 loading steps of the structure are those set in the test method mentioned above. Each load step aims to achieve an imposed displacement at the top of the structure. This is also the ideology of the modern design codes that imposes drift restrictions at top of the building. The target drifts are expressed as 0.20%, 0.25%, 0.35%, 0.50%, 0.75%, 1.00%, 1.40%, 1.75%, 2.20%, 2.75% and 3.50%. For each required displacement, three loading/unloading cycles were performed. Figs. 2 and 5 shows the sequence of displacements of the two tests.

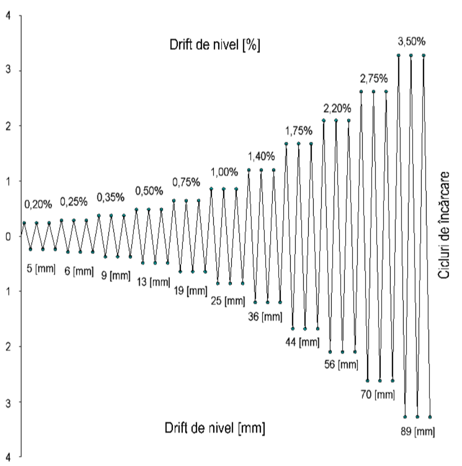

Fig. 4 – First test on Experimental Frame: All loading cycles performed.

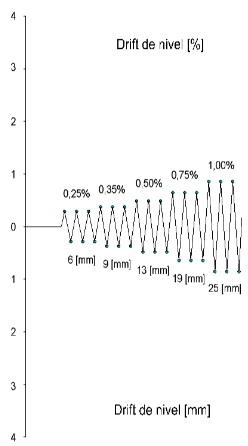

Fig. 5 – Second test on Experimental Frame: All loading cycles performed.

For the first test on the Model Frame in 2014, all loading steps were performed. In the case of the second test on the Model Frame in 2019, that was lateral stiffened with corrugated sheets, the loading steps could only be followed until the 25 mm displacement had been reached. As a result of these large displacements, the sheet became inactive because it formed excessive creases and ovalizations at the points of attachment to the concrete structure frame.

Once the corrugated sheet was detached from the frame because of the lack of fasteners grip, it could no longer take over the tensions transmitted by the concrete structure and the subsequent steps would be useless to follow. After the failing of the corrugated sheet, the experimental testing was considered complete (Fig. 8).

2. Results of the Experimental Tests

Fig. 6 – Side view A: classical reading.

Fig. 7 – Side view B: digital image correlation.

The Model Frame was laterally stiffened with two-sided metal sheet. In this way the torsion of the frame during loading was prevented. In addition, we had the ability to monitor both faces through two different acquisition methods. On one side the classic method of micro compact clocks and tensiometers was used (Fig. 6) and on the other side, we were able to acquire the information needed with the digital video recording method that uses image comparison between different images with specialized software (Fig. 7).

Starting with the first loading step, it was noticed how the corrugated sheet started to stress. It was observed that immediately after the loading was applied, the sheet took over the tensions in the frame. The tensions were spread throughout the entire surface. Table displacements were recorded by micro comparative clocks, but they were also observed visually.

As the experimental test progressed, the corrugated sheet folds became more distorted, and there was noticeable effort at the fastening points. In the fastening area, the sheet was ovalized, and by the increasing in the load, the sheet detached from the grip due to the widening of the hole. After the corrugated sheet was elongated in the fastening points, the table did not offer much more capacity to the frame. It was observed that after the corrugated sheet was altered in the fastening points, it became an area where the table couldn't take tensions any more. The corrugated sheet constantly balanced the tension by distributing it to other fasteners. The perimeter fasteners started to fail one by one. The reason for failing was in most cases that the fastener surface was not enough to ensure a proper fixing on the corrugated sheet because of the ovalized phenomenon. A few fasteners failed by tearing.

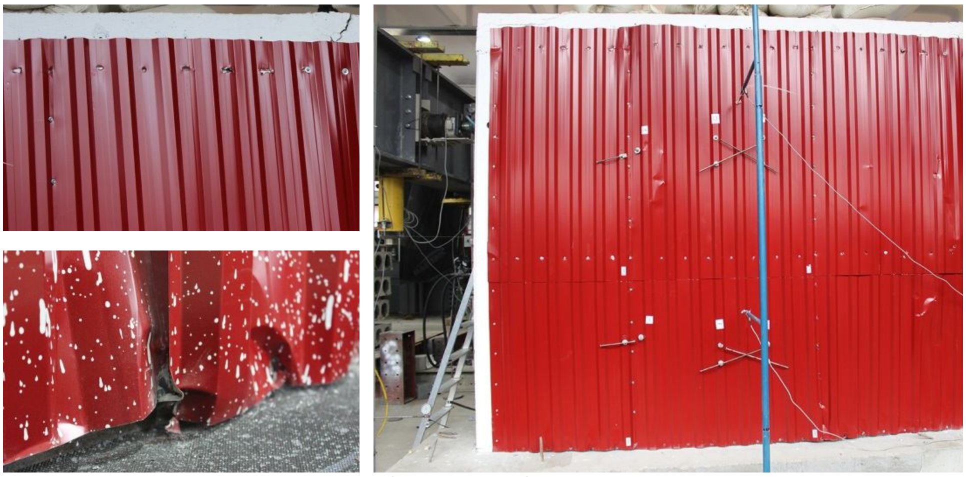

Fig.8 – Distortion of the board after the experimental test.

3. Conclusions

According to the test methodology followed (ACI T1.1-01) the test specimen must have a similar response on both loading directions. Also, the experimental test to be relevant, the ratio between the model and prototype should not be less that 1:3. The 3.5% story drift is the maximum allowed at the top of the building. The Model Frame fulfilled all the above mentioned requirements.

In this article is presented a real precast concret frame structure that was subjected to quasi-seismic side cyclic loading in two different experimental tests. In the first experimental test the frame was tested withoud any lateral brace system. In the second experimental test the frame was side stiffened with corrugated sheets. The experiments were conducted using the same testing methodology so that the results can be compared. The aim of the article is to see how much rigidity the corrugated sheet adds to the frame. Based on the hysteretic curves, the rigidity of the frame can be calculated. In Fig. 9 and Fig

10 is displayed the results of the graph of the rigidity of the frames in both experimental test. In the first experimental test the rigidity of the frame in one direction "+" is 8.42 kN/mm (Fig. 9) and for the second experimental test the rigidity of the frame in the same direction is 12.19 kN/mm (Fig. 10). There is a 44.73% increase in rigidity. The rigidity of the frame in the opposite direction "–" is 8.85 kN/mm and for the second experimental test the rigidity of the frame in the same direction is 10.84 kN/mm. There is a 22.48% increase in rigidity. In the direction of the first loading, at the fastening points, the corrugated sheet starts to elongate. After the elongation is created, the sheet capacity is diminuend and in the opposite direction the rigidity of the frame will always be smaller.

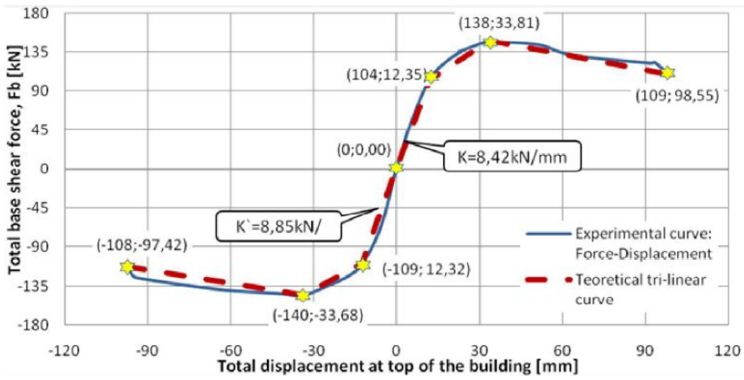

Fig. 9 – Ductility and rigidity on both directions („+" and „–")
First test on Experimental Frame: Non stiffened 2014.

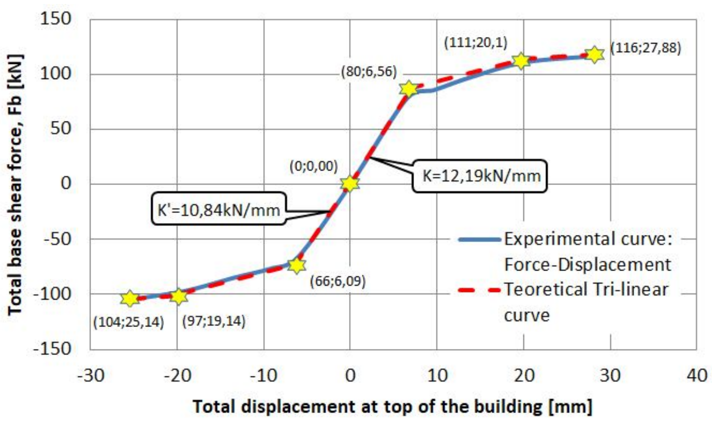

Fig. 10 – Ductility and rigidity on both directions („+" and „–")
Second test on Experimental Frame: Side stiffened 2019.

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STUDIUL RIGIDITĂȚII UNUI CADRU SPAȚIAL PREFABRICAT CU ŞI FĂRĂ RIGIDIZARE CU TABLĂ CUTATĂ

(Rezumat)

Închiderile perimetrale ale halelor se realizează de cele mai multe ori cu tablă cutată. În cazul structurilor metalice, există numeroase studii în domeniu care au condus la creare de normative şi ghiduri de proiectare ce iau în calcul conlucrarea dintre tabla cutată şi structura de metal. În cazul halelor din beton armat însă, problema este încă insuficient aprofundată. Lipsesc metode şi modele de calcul care să ajute inginerul proiectant să determine aportul tablei cutate la rigiditatea laterală a cadrelor. De multe ori se neglijează în calcule această rigiditate suplimentară care poate aduce un surplus de rezistență şi rigiditate. Pentru a înțelege mai bine interacțiunea dintre tabla cutată şi cadrul de beton armat, am desfăşurat o încercare experimentală pe o structură reală în cadre spațiale din beton armat prefabricat executată la scara 1:3. Pentru derularea experimentului am folosit metoda de testare descrisă în standardul ACI T1.01. Cadrul testat a mai fost supus anterior unei încercări experimentale urmând aceiaşi paşi, însă fără a fi rigidizat lateral cu tablă cutată. Prin compararea rezultatelor celor două încercări experimentale distincte s-a dorit obținerea răspunsului structural şi a surplusului de rigiditate adus de tabla cutată.