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STUDY ON THE BRACING EFFECT ADDED BY THE CORRUGATED SHEETS FOR A SINGLE-STOREY PRECAST REINFORCED CONCRETE STRUCTURE

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Abstract: *The façades of single-storey industrial buildings are made mostly of corrugated sheet panels or sandwich panels. Although the steel from this perimeter closures makes the structure stiffer, this is rarely included in the structural design analysis. In this article, a study is presented on the use of the corrugated sheets acting as a bracing system for a single-storey reinforced concrete building that is degraded after a simulated seismic action. A real structure was subjected to an alternating loading cycle with and without lateral stiffening. The experimental results show an increase of the strength of the structure by up to 22% added by the corrugated sheet panels fastened to the structure.*

Key words: *corrugated sheets, frame stiffness, concrete frame.*

1. Introduction

A large amount of the buildings designed today are single-storey precast reinforced concrete structures. In the event of a post-seismic structural damage, a possible additional consolidation solution that could be taken into consideration is represented by the corrugated sheets from which the façades are made. The corrugated sheet becomes a stiffening element for the structure that is attached, although this is rarely caught in the structural analysis. Due to the fastening parts by which it is fixed to the structure, the efforts in the structural elements are transmitted to the corrugated sheets. In this way the corrugated sheet board becomes a participant element in taking over the efforts transmitted by the structure [1].

The intent of the study presented in this article id to observe the structural response of a single-storey reinforced concrete structure that is presumed damaged by a quasi-seismic action, and later laterally consolidated with corrugated sheet panels acting as a brace system.

In order to study the rigidity, resistance and ductility brought by the corrugated sheets to these single-storey structures, an experimental test was carried out. For the experimental testing a real 3D precast reinforced concrete frame was erected in the

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Laboratory of the Faculty of Construction of the Technical University of Cluj-Napoca. Three separate tests were carried out on the same Model Frame.

2. Presentation of the Model Frame

The concrete frame undergoing the experimental test, hereinafter referred to as the Model Frame, was based on a Prototype Frame whose dimensions were reduced, based on the theory of similarity, with a transformation factor $\lambda = 3$. The chosen Prototype Frame has an opening of 6x9 m. The columns are precast reinforced concrete and they have a section of 60x60 cm. The beams are also precast reinforced concrete with the section of 60x66 cm and after the topping the section becomes 60x90 cm. The height regime is P + 1E with (H_{level1} = 4.00 m, H_{level2} = 3.75 m) [4].

The Prototype Frame has relatively large dimensions, with a footprint of 2.80x4.00 m and a total height of 2.98 m. The structure is designed based on a solution that is commonly used in seismic areas.

Geometry of structural elements and structure - Prototype & Model Table 1

Structural Element	**Prototype Frame**	**Model Frame**
Column	60x60 cm	20x20 cm
Beam (prefabricated)	60x66 cm	20x22 cm
Beam (final)	60x90 cm	20x30 cm
Floor	24cm	8 cm
Height Level 1	4.00 m	1.33 m
Height Level 2	3.75 m	1.25 m
Bay	6.00x9.00 m	2.00x3.00 m

Fig. 1. *Pocket Foundation (before and after topping was added)*

The structure is attached to the floor by precast concrete pocket foundations that are linked together by a beam designed with sufficient stiffness to be able to avoid column uplifting or surface sliding (Figure 1).

The precast columns are fixed in the precast foundations and support the precast beams through a corbel. Stirrup connectors are used to connect the precast part with the topping from the slabs. Longitudinal reinforcement bars are placed in the top corners of the stirrups with the role of taking negative bending moments. The longitudinal reinforcement is further anchored into the columns, using mechanical coupling elements and through. The slabs are executed using monolithically reinforced concrete (Figure 2).

Regarding the materials used for structural elements C40/50 was used for columns, beams and foundations and C30/37 for slabs. The steel reinforcement used was S500C, except for the ø6 stirrups where S255C was the only available choice. For the slabs the reinforcement chosen was S345C.

Fig. 2. *Beam-column connection (before and after topping was added)*

3. Overview of the Testing Procedure

The experimental test on the 3D precast concrete Model Frame presented above was conducted following the steps described in the testing procedure from the American Standard ACI T1.1-01 (ACI T1.1R-01, 2001) [6]. For the application of the lateral loading, a testing stand was created. The test stand consists of two rigid planar frames with which the experimental test can be carried out (Figure 3).

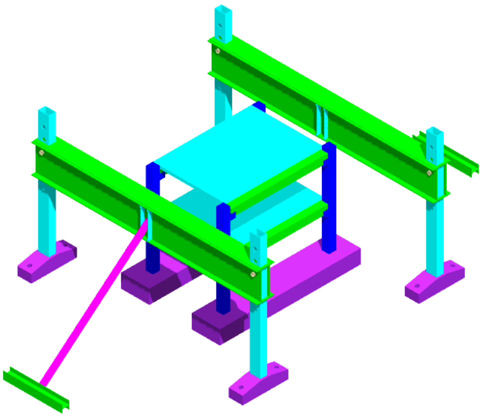

Fig. 3. *Model Frame and Testing Stand*

The P100-1/2013 [7] stipulates that the earthquake-induced action must be transmitted to the building at the floor level. In our case, for the distribution of the lateral force to the two levels of the structure, a steel profile HEA250 was used. The steel frame with HEA250 section has been mounted so that it has only contact with the floors of the experimental frame. In this way all the force transmitted in the structure was directed to the floors and from the floors to the rest of the structure. A hydraulic press was fixed on the steel profile and a force sensor for acquiring the force induced by the hydraulic press (Figure 4).

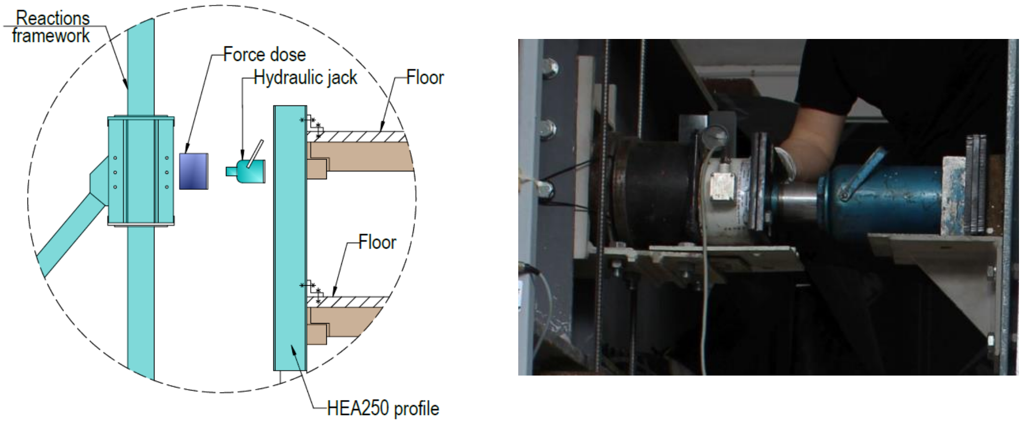

Fig. 4. *Force application and measurement*

The displacement of the structure was recorded electronically, but with different equipment for each side. While on one side a MGCplus data acquisition system connected to a personal computer was used, on the other side was used a Digital Image Correlation (DIC) acquisition system based on image comparison (Figure 5).

The two systems acquired data independently, one on each of the two sides stiffened with corrugated sheets. The software used were CatmanEasy/AP 3.0 developed by HBM Company and Vic 3D [8] from Correlated Solutions for DIC [2]. For measuring the necessary force for each imposed lateral displacement, two force pressure sensor of 1 MN capacity were installed. The drift of the structure was measured using displacement sensors (HBM WA type of 100 mm and 300 mm) and pressure sensors.

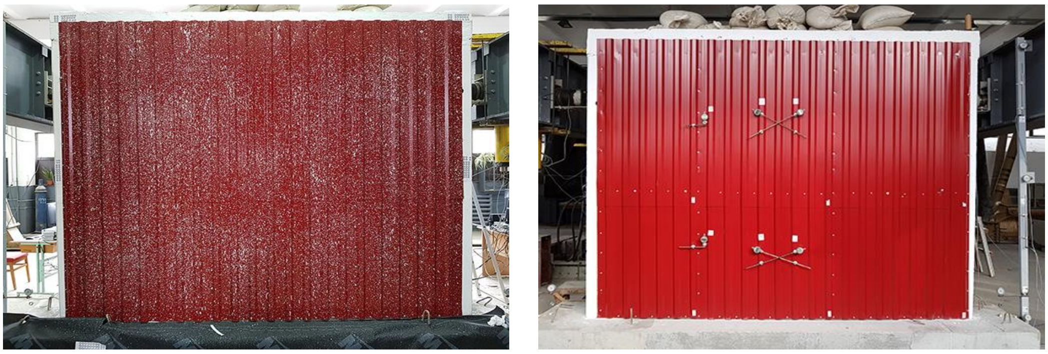

Fig. 5. *Monitoring displacements and deformations of the structure*

The ACI T1.1-01 states that a number of 11 horizontal controlled displacement cycles should be applied on the structure, corresponding to drifts of 0.20%, 0.25%, 0.35%, 0.50%, 0.75%, 1.00%, 1.40%, 1.75%, 2.20%, 2.75% and 3.50% at top of the building. Each cycle consist of 3 steps with a displacement induced from the right side to the left and alternatively another 3 steps with a displacement applied from left side to the right. Also each step had 4 sub-steps in order to be able to draw the hysteresis curves (force-displacement P vs. Δ) afterwards.

4. Presentation of the Experimental Program

In order to obtain the desired results, three experimental tests were carried out on the Model Frame. The Model Frame, as it was before starting each of the three experimental tests, is presented in the Figure 6.


Test 1
Test 2
Test 3

Fig. 6. *Test 1: Non stiffened; Test 2: Two-sided stiffened; Test 3: Removal of the corrugated sheets stiffening effect*

In the first experimental test, the frame was laterally loaded simulating a seismic action on the frame in quasi-static regime, following the steps described in the testing procedure from the American Standard ACI T1.1-01 (ACI T1.1R-01) [6]. For the first test on the Model Frame without any lateral stiffeners, all loading steps were performed (Figure 8).

After the completion of the first experimental test, the frame suffered significant degradation as expected. This situation is similar to a real-life seismic force acting on a precast frame structure. Plastic joints formed at the base of the pillars and at the ends of the beams. These led to the degradation of the base of the pillars and frame nodes (Figure 7).

Fig. 7. *Degradations of the Model Frame after first experimental test (without lateral stiffeners)*

In the second experimental test, the damaged structure was consolidated by replacing the degraded concrete with Sika MonoTop 910N. After the repairs and corrections were finished, corrugated sheet boards were attached on two sides of the Model Frame. The Model Frame was than again laterally loaded following the same steps like in the first experimental test and in this way the two can be compared.

In the case of the second test, the loading steps could only be followed until the 25 mm displacement had been reached (Figure 9). As a result of these large displacements, the sheet became inactive because it formed at the fixation points to the concrete structure frame excessive cambers and oval holes.

Once the corrugated sheet was detached from the frame because the fastener`s grip was lost during the loading, the corrugated sheet could no longer take over the stresses transmitted by the concrete structure and the subsequent steps would be useless to be further investigated.

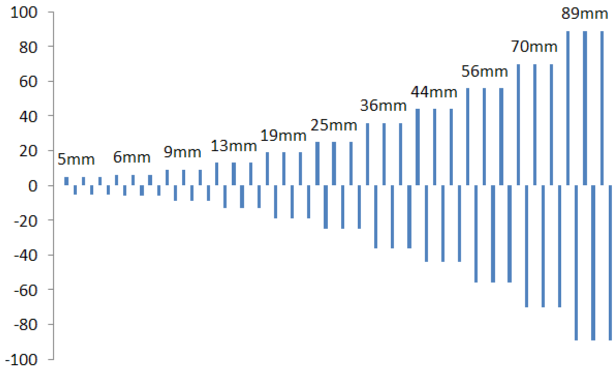

Fig. 8. *Test 1: Non stiffened - Loading steps performed*

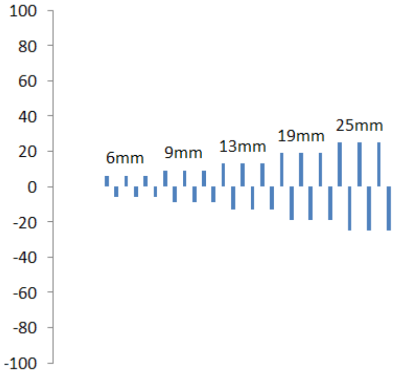

Fig. 9. *Test 2: Two-sided stiffened - Loading steps performed*

In the third part of the study, the lateral consolidation from the corrugated sheets was detached and the structure was loaded again, but this time the loading did not follow a cyclic alternation but instead was monotonic loaded from one side ("+"). For this last experimental test it was desired to observe the capacity and resistance reserves that the structure still has after the test [5].

Fig. 10. *Distortion of the corrugated sheet at the end of the experimental test*

5. Conclusions

The study presents three experimental tests performed on the same precast concrete frame. In the first experimental test the frame had no lateral brace system. In the second experimental corrugated sheet panels were fixed to the frame for stiffening effect. The third experimental test aimed to study the capacity of the frame after the corrugated sheets were detached. The study was conducted using the same testing methodology (ACI T1.1R-01) [6] to have comparable results.

Hysteretic curves were drawn for the first two experimental tests. Based on the hysteretic curves the rigidity of the frame was calculated.

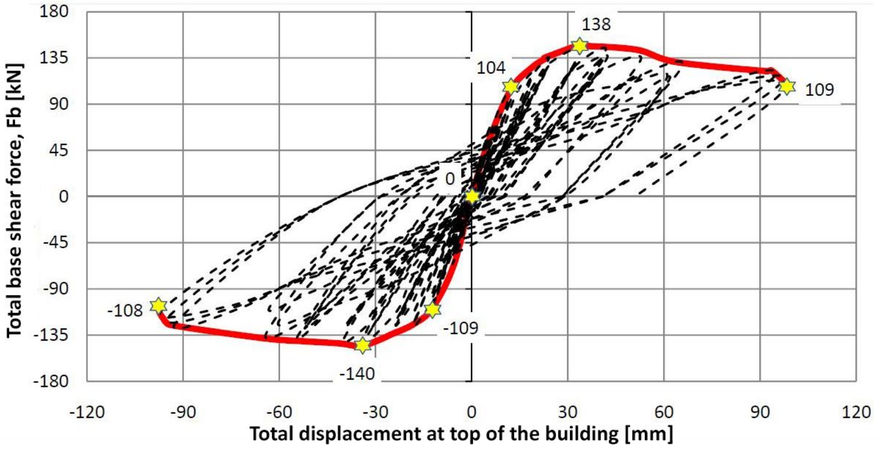

Fig. 11. *Test 1: Ductility and rigidity directions* („+” *and* „–”) [3]

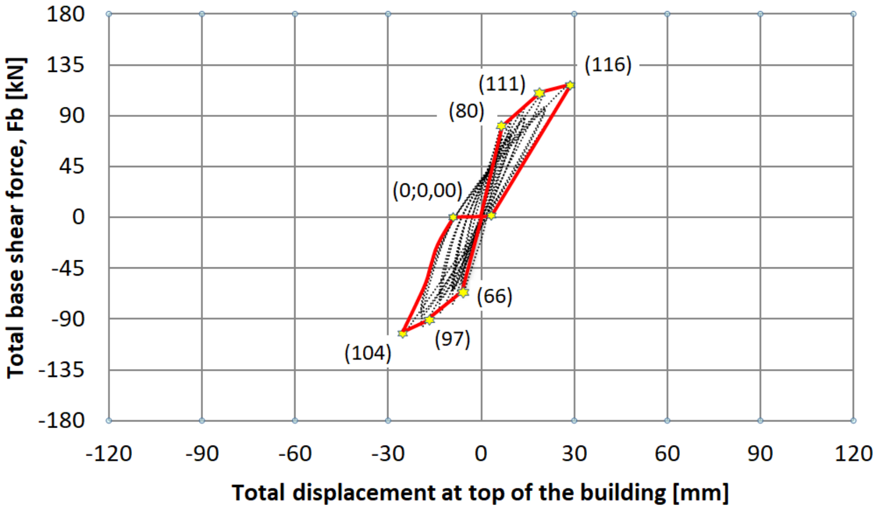

Fig. 12. *Test 2: Ductility and rigidity directions* („+” *and* „–”)

In the first experimental test the rigidity of the frame in first direction “+” is 8.42 kN/mm (Figure 11) and for the second experimental test the rigidity of the frame in the same direction is 12.19 kN/mm (Figure 12). As it can be seen the corrugated sheet panels added significant strength to the Model Frame. In the first experimental test [3] the Model Frame had a 138 kN force resistance capacity and in the second experimental test the capacity was 116 kN. The corrugated sheets added 84% capacity to the frame.

In the third experimental frame it showed that after the corrugated sheets were detached the structure was weak. In reaching a 6 mm displacement, only a 7 KN force was needed, that is 10% of the force used in the second experimental test to reach the same top displacement.

Corrugated sheets are a solution that should be consider in the post seismic consolidation of a single-storey concrete frame. If the sheets are well fastened it can add an extra capacity to the frame that should be take into account in analysis.

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