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BEHAVIOUR OF MECHANICAL CONNECTIONS UNDER LATERAL SHEAR LOADS

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ABSTRACT

The design of joints and connections is in many cases the most important consideration in precast concrete structures. Connections control resistance and inelastic response of prefabricated wall panels. The aim of the present paper is to study the behaviour of precast panel under lateral shear loads. In this paper, two (02) types joint connections are investigated: i) horizontal joint between panels consisting of mechanical connectors completed by infilled mortar and ii) vertical connection between panels by means of mechanical connectors only.

To this end, an experimental campaign encompassing monotonic and cyclic shear load tests was conducted on typical panel solutions.

The modes of failure obtained are examined and measured results including load deflection curves, from which parameters such as ductility and dissipation energy can be obtained are presented.

***Key Words**: Precast Concrete, Panel, Joint, Connection, Testing, Cyclic, Seismic, Shear.*

INTRODUCTION

Precast Building structures using prefabricated concrete panels are an efficient, economic, and potentially aesthetic alternative to conventional building techniques and have been used successfully and extensively in Spain and other countries. The main advantage of this type of systems is related to the fact that the panels act both as vertical and horizontal load-bearing elements as well as cladding elements, reducing the overall cost of the completed structure, compared to traditional precast solutions.

The use of this type of structure in seismic areas is however limited by the local standards, although there are many precedents of their adequate performance (as shown by Paulay and Priestley (1992), Park (2003), Boivin and Paultre (2010), Henry and Ingham (2011) among others). The generation of experimental information regarding the behaviour of these structures is a valuable tool in order to increase the confidence of the technical community and responsible administrations in this type of solution.

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The most critical design issue in construction with prefabricated panels are the connections between panels. There is limited experience regarding their behaviour. In this paper, an experimental program designed to test the behaviour of several joint types of prefabricated panels subject to both static and cyclic loading with load reversal is presented.

TEST PROGRAM AND RESULTS

Description of the joint connection tested

The panels tested are connected by means of a steel plate welded to an L70x7 profile anchored to the prefabricated panel by means of a welded rebar. The weld detail is shown in Figure 1.

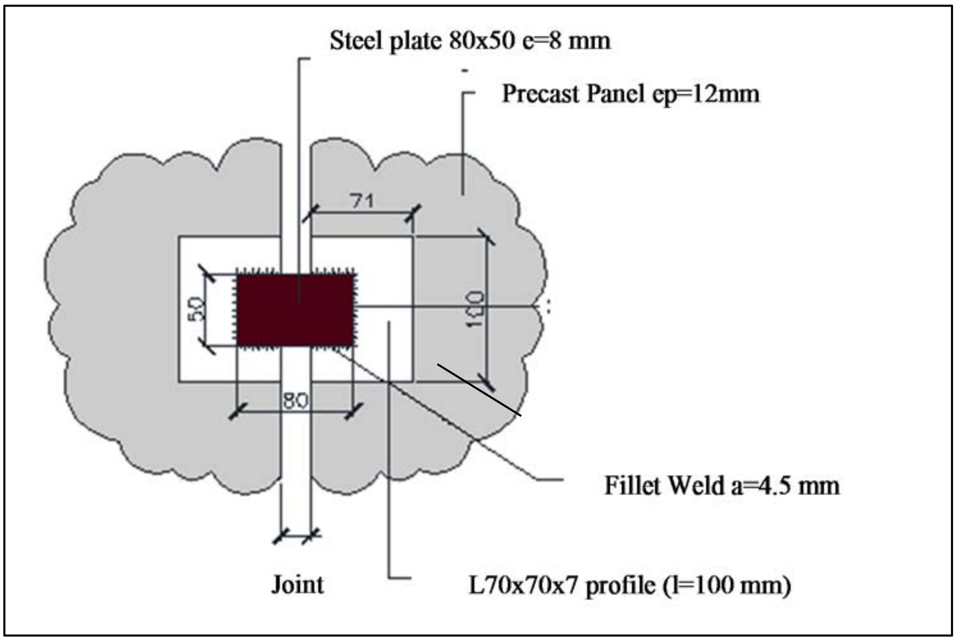

Figure 1. Definition of joint detail

Materials used in the manufacturing of the specimens

The material characteristics used for the tested specimens were the following:

- Concrete: Target strength of 30 MPa, with a maximum aggregate size of 12 mm. Compression tests using standard 300x150 mm cylinders were carried out obtaining the strength values and density values reported in Table 1.
- The panel reinforcement was class B 500S
- The strength class of the steel plates was S 275

Table 1. Measured strength and density for different batches

Batch ID	Age at testing [days]	Density [kg/m^3]	Strength [MPa]
H-7692	7	2.323	38.78
H-7692	11	2.325	40.81
H-7692	11	2.322	43.35
H-7694	7	2.304	38.78
H-7695	7	2.316	43.57

No tests were carried out for the steels because their strength was not determining for the type of failure expected (and observed), in which the connection between the L70x7 profile and the concrete was critical.

VERTICAL JOINT BETWEEN PANELS

The vertical joints between panels were tested for both static (Test identification code: E-SC-1) and cyclic reversible loading (Test identification code: D-SC-1). The test setup is represented in Figure 2 and pictured in Figure 3. As can be seen, the central panel is fixed to the two side panels by means of 4 steel plates like the one shown in Figure 1. The load is applied using the central jack while the side jacks are used to help fix the lateral supporting panels. Measurements taken included:

- Relative vertical displacement between central and side panels, measured by means of 4 LVDT devices located at the 4 corners of the central panel (for both static and dynamic tests)
- Strain in the connecting plates in the horizontal and vertical directions and along a line inclined 45º by means of strain gauges (only static tests)
- Variation of the horizontal distance between panels at the panel top and panel bottom (only static tests).
- Applied load and jack cylinder extension (for both static and dynamic tests). The load is applied in deflection control.

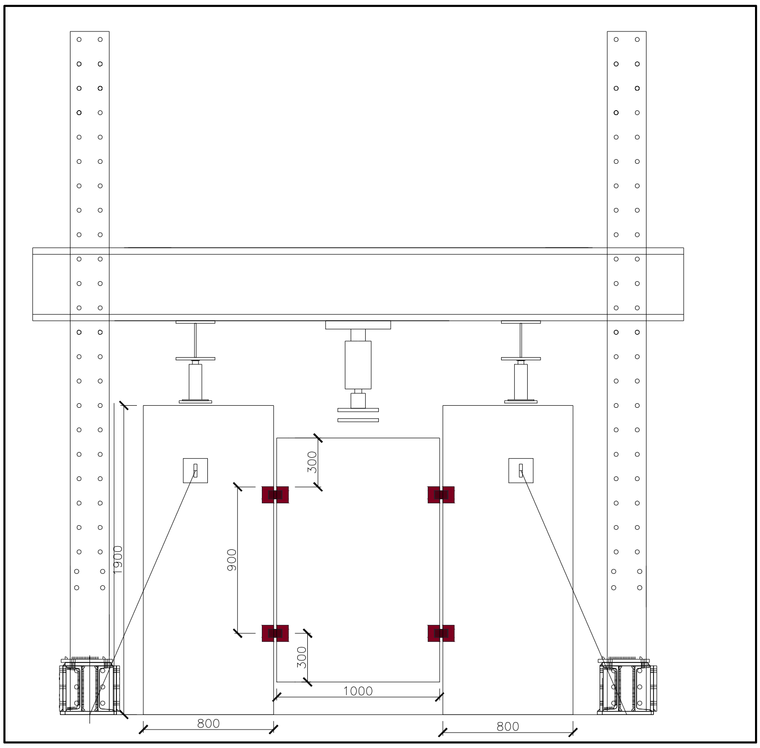

Figure 2. Test setup for testing the connection between panels

Figure 3. Picture of the test set-up

Static test

The static test of the vertical joint was carried out by applying the load history represented in Figure 4. Each load step was sustained during 5 minutes. After the third step, the load was increased by 10% in each step, reaching failure for a load of 176 kN.

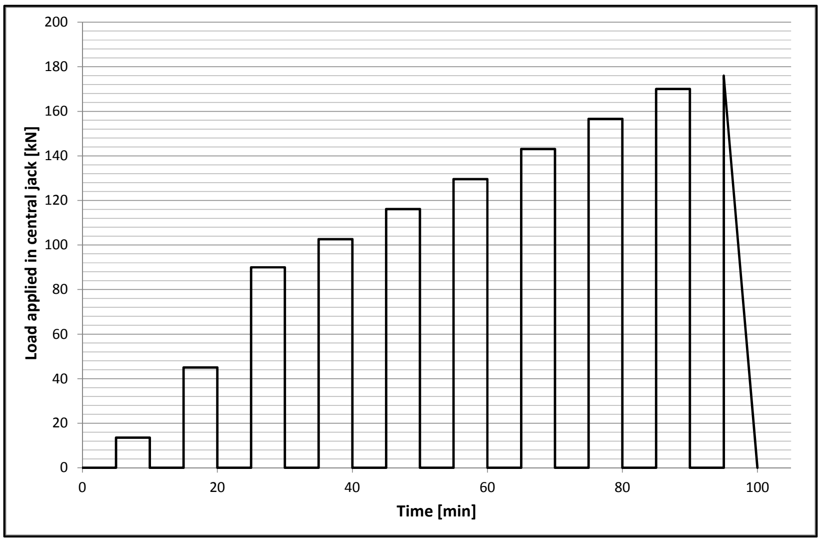

Figure 4. Load history of static load test

Failure was due to the connection between L70x7 profiles and the concrete as can be seen in Figure 5. The failure was either by crushing of concrete or by failure of the weld between the reinforcing bar anchor and the L70x7 profile.

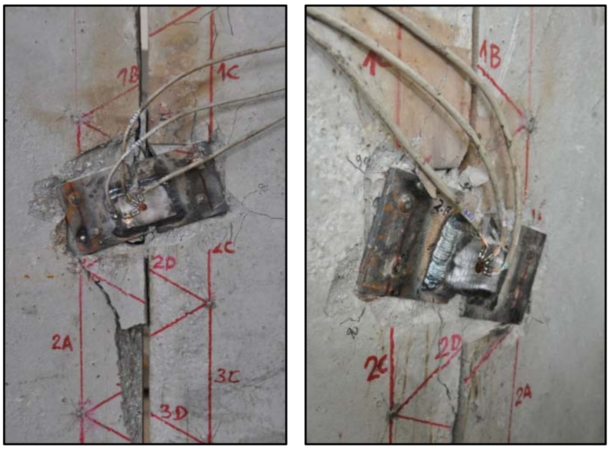

Figure 5 – Failure mode - connection between L70x70 and concrete

The load-vertical deflection diagram is shown in Figure 6. The black diamond represent the extension of the jack cylinder, which includes not only the relative displacement between panels, but also the flexural deflection of the upper reaction profile, so that the maximum relative displacement between panels before yielding behaviour (representing failure of the connection) is about 3.5 mm.

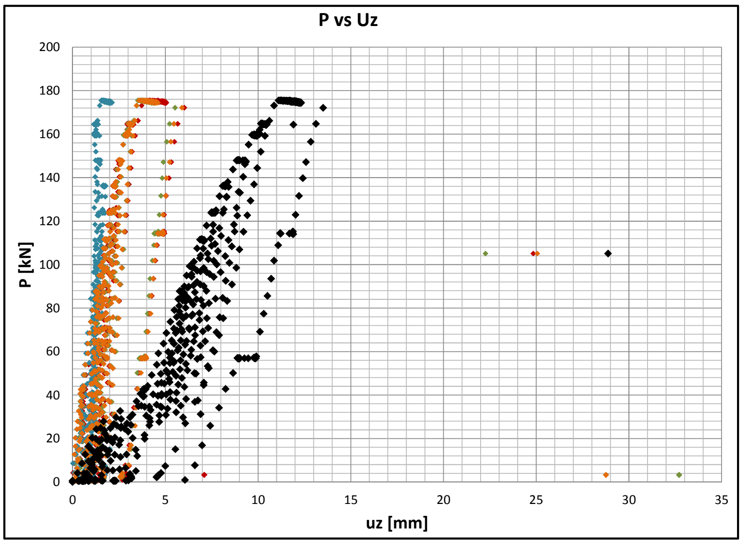

Figure 6 – Test E-SC-1 Load-vertical deflection diagram

Dynamic test

The loads applied for dynamic test were determined from the results of the static test. Load was applied with a frequency of 0.2 Hz, aiming to reach an increasing fraction of the vertical displacement measured in the static test in each step. The procedure had to be repeated up to 4 times in order to attain failure, increasing the imposed displacement in each phase, as can be seen in Table 2.

The time-displacement pattern applied in Phase 1 is shown in Figure 7 and table

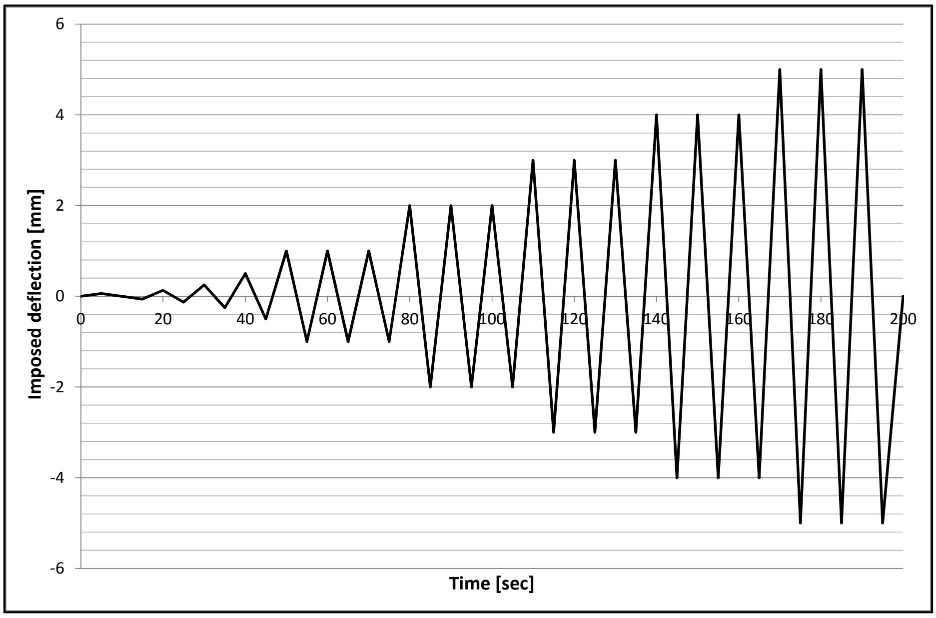

Figure 7. Imposed deflection on jack cylinder for Phase 1 of the dynamic test (D-SC-1)

Table 2. Applied displacement in each phase

			Imposed displacement amplitude [mm]			
Load level	N^{br} of cycles	Frequency [Hz]	Phase 1	Phase 2	Phase 3	Phase 4
1	1	0.2	0.06	0.38	4.00	5.00
2	1	0.2	0.13	0.50	5.00	7.00
3	1	0.2	0.25	1.00	6.00	9.00
4	1	0.2	0.38	2.00	7.00	11.00
5	3	0.2	0.50	3.00	7.50	13.00
6	3	0.2	1.00	4.00	8.00	15.00
7	3	0.2	2.00	5.50	8.50	17.00
8	3	0.2	3.00	6.00	9.00	19.00
9	3	0.2	4.00	6.50	9.50	21.00
10	3	0.2	5.00	-	10.00	-

The measured results, in terms force-displacement curves can be observed for the four phases in Figure 8. Once again, the black curve represents the displacement of the jack cylinder, which includes both the relative vertical displacement of the panel and the deflection of the upper reaction beam. The curves in different colours represent the measurement of the 4 LVDT-s and include only relative displacement between panels. It can be seen how the load carried by the panel connections diminishes in each phase, and how the displacement increases. It can also be seen that a considerable amount of energy is dissipated though the hysteretic behaviour observed.

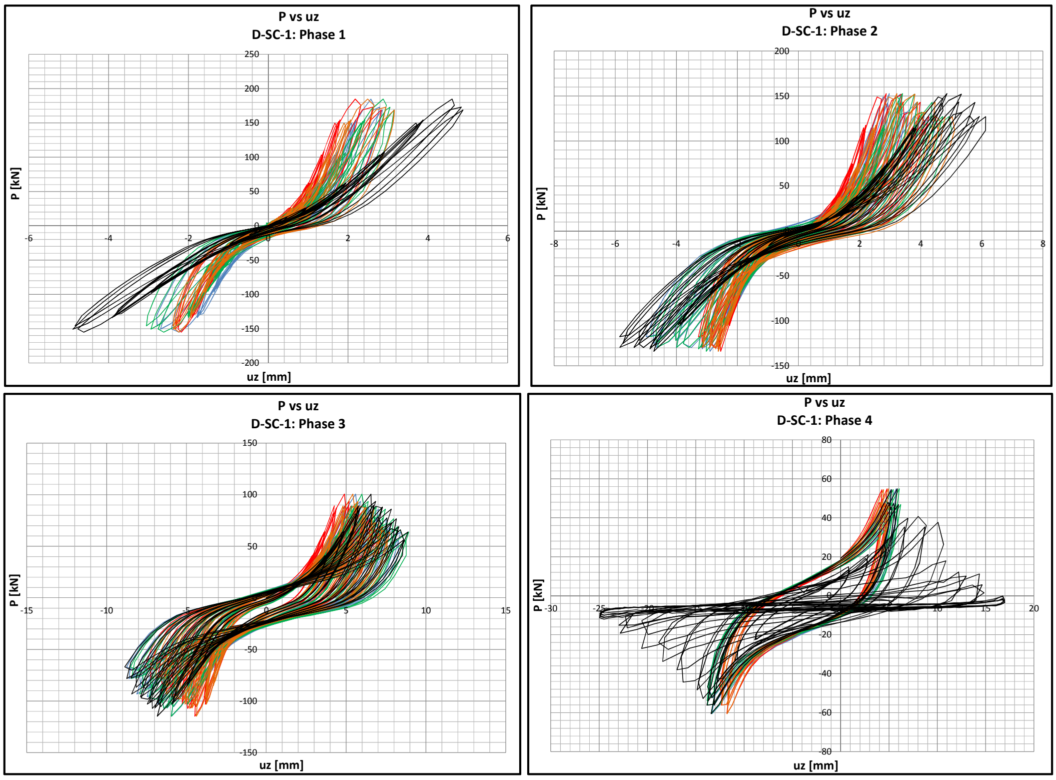

Figure 8. Load-displacement curves for the four phases of applied dynamic loading for specimen D-SC-1

HORIZONTAL JOINT BETWEEN PANELS

Horizontal joints differ from vertical joints in two main aspects: The joints are filled in with grout, and there is an axial force in the panel due to the self-weight of the structure. The set-up is the same as before, with the exception that horizontal prestressing bars are included and the load capacity of the dynamic jack is supplemented by two additional jacks since the capacity of the joint is larger. The total prestressing force is 100 kN (25 kN per prestressing bar).

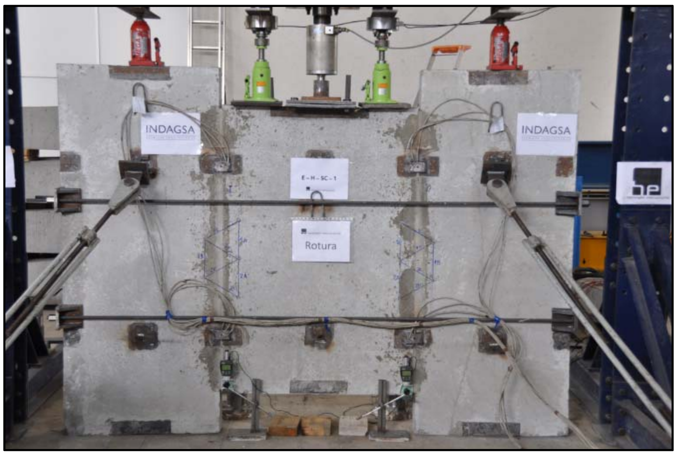

Figure 9. Test setup for the horizontal joint. Notice the horizontal prestressing bars placed to simulate vertical axial load and the fact that the joint is grouted.

Static Test

The specimen of Figure 9 (Test identification code: E-H-SC-1) was loaded up to a total load of 480 kN. This load was achieved after loading and unloading with the dynamic jack using the following sequences: 66 kN, 0 kN, 132 kN, 0 kN, 152 kN, 0 kN, 174 kN, 0 kN and 192 kN. The extra loading, up to 480 kN, was achieved by using the two additional jacks. This was the maximum load capacity available and it was achieved without any signs of structural distress. Given this result, it was decided to remove the prestressing and repeat the loading sequence. This time, failure was achieved after reaching once again the maximum loading capacity, following the same sequence described before. The corresponding load-displacement curve is shown in Figure 10. It is remarkable how the fact that the joint is grouted increases the loading capacity from the 176 kN of E-SC-1 to 480 kN of E-H-SC-1. Also, ductility is significantly improved, as can be seen by comparing Figure 6 to Figure 10.

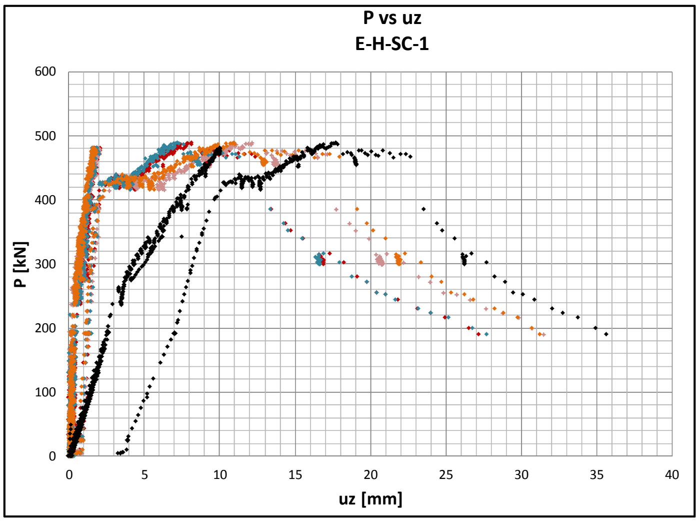

Figure 10. Load-displacement curve of test E-H-SC-1

Dynamic Test

Due to the fact that the dynamic jack capacity was only 200 kN, specimen D-H-SC-1 was brought to failure by repeated loading carried out in 6 phases which had to be repeated several times (See Table 3). Of course, given the loading limitations, prestressing was not applied.

Table 3. Load phases for dynamic load test of horizontal joint D-H-SC-1

			Imposed displacement amplitude [mm]					
Load level	Nbr of cycles	Frequency [Hz]	Phase 1(*) (1 repetition)	Phase 2 (3 repetition)	Phase 3 (3 repetition)	Phase 4 (23 repetition)	Phase 5 (2 repetition)	Phase 6 (7 repetition)
1	3	0.2	0.35	0.27	0.28	2.90	3.10	3.20
2	3	0.2	0.70	0.53	0.56	-	-	-
3	3	0.2	1.40	1.06	1.12	-	-	-
4	3	0.2	2.10	1.60	1.68	-	-	-
5	3	0.2	2.80	2.13	2.24	-	-	-
6	3	0.2	3.50	2.66	2.80	-	-	-
(*) Jack capacity is exeeded and jack engine shuts down								

Figure 11shows the load-displacement behaviour for different phases of loading. The progression of damage can be clearly seen. Failure occurs only after a large number of cycles has been applied and the mortar filling of the joints has been so damaged that the resistance becomes similar to that of the vertical joint.

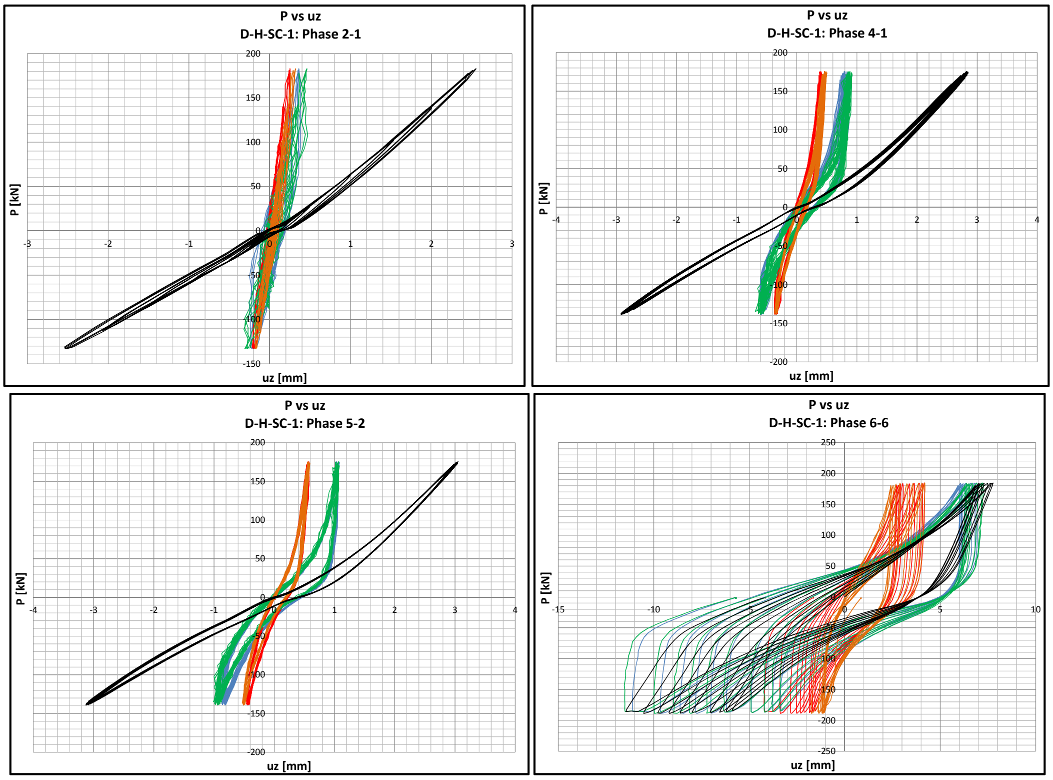

Figure 11 – Load-deflection curves for several of the loading phases of test D-H-SC-1

CONCLUSIONS

In this paper an experimental joint aimed at characterizing the joint between prefabricated panels has been presented. Both vertical and horizontal loads have been tested in static and dynamic load conditions.

From the results obtained, the following conclusions can be drawn:

- Static tests carried out show a very rigid and not very ductile behaviour of the vertical un-grouted joints. However, when subjected to dynamic loading a significant hysteretic behaviour is observed indicating that the connection has the capacity to absorb significant energy.
- Regarding horizontal grouted joints, their behaviour is much improved due to the presence of the grout, which contributes shear strength and the presence of the axial load. In order to achieve the ultimate load, the prestressing simulating axial load had to be removed. The static load test shows a sharp improvement both in load-bearing capacity (from 176 kN to 480 kN) and ductility.
- Dynamic load tests carried out with a 200 kN capacity jack on the elements representing the horizontal joint had to be repeated many times in order to achieve damage. Failure occurred only when the mortar between the prefabricated elements in one of the joints had been mostly removed by the repeated application of load.
- In all cases, failure occurred involving the connection of the L70x7 profile and the concrete, either by concrete crushing of by the failure of the weld between the profile and the anchoring rebar.
- The tests carried out provide valuable information for design of this type of element and cannot be substituted solely by numerical simulation. Such tests are needed to properly calibrate finite element models to adequately represent the joint behaviour.

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