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The Behavior of Different Precast Concrete Structures Under Seismic Action

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Abstract

The paper aims to establish the differences of stiffness between five types of precast concrete structures. Based on that, the results will be analysed to present the seismic areas where the proposed types of structures can be applied. Therefore, we are going to use a simplified method to compare between those five types, based on the empirical principle that refers to the rigidity of frameworks that form the structure. In this way, the approach for structural design methods will be able to be optimized at an early stage of the project methods.

Thus, to validate the results and set the behaviour of the structures, we will rely on two well-known types of structures "frames and walls solutions" which are already used in precast concrete industry. However, in the near future, and starting from this topic we will analyse some details for precast elements connection, such as frames connection or joints between walls.

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Keywords: stiffness; precast concrete; structural analysis; seismic action; structural behavior.

1. Introduction

As it has been mentioned above, the main purpose is to establish the differences of stiffness between five types of precast concrete structures. In order to achieve real results that allow us to set the structure capacity for lateral loading, we counted on two well-known types of structures "frames and walls solutions" which are already used in precast concrete industry, Therefore, in the near future and based on this important topic, we are going to analyse

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some details for precast elements connection, (e.g. frames connection, joints between walls).

Nomenclature of the five types of the structures

P1	Fixed Frames, with cross section of 50x100 [cm]
P2	Fixed Frames and hinged connection beams. Cross section 50x100 [cm]
P3	Hinged Frames, with cross section of 50x100 [cm]
P4	Continuous wall, with thickness 30[cm]
P5	Continuous wall with openings and thickness 30 [cm]

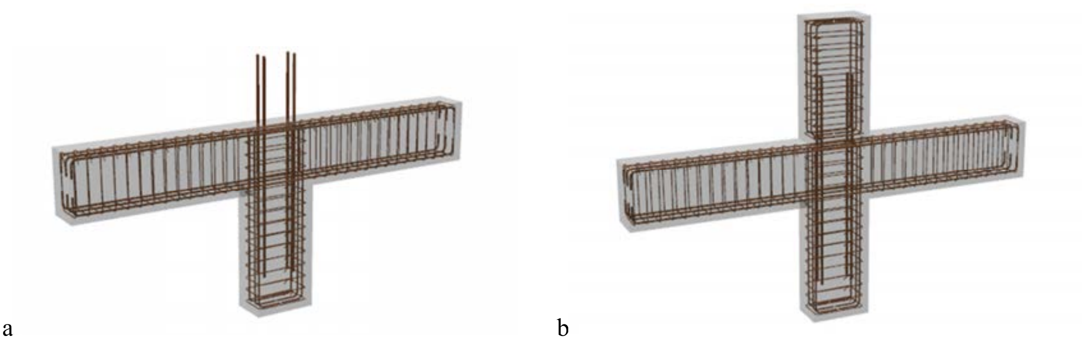
2. Basic Knowledge.

The basic knowledge is the two well-known (enshrined) types of structures that already are used in precast concrete industry, these types are called frames solution and walls solution.

2.1. Structural Description for the main structural types

In order to highlight the influence of these two structures, their analysis will be detailed, and then briefly presented. However, the first analysis is the fixed frame solution for precast elements.

For this solution, we have chosen fixed joints for structural analysis as it is illustrated in Fig.1. [4] This solution is corresponded to P1 solution according to the nomenclature of this current paper (Fixed Frames, with cross section 50x100 [cm])



a b

Fig. 1. (a) Frame solution joint before assembly; (b) Frame solution joint in service [4]

- The second analysis is the continuous wall solution for precast elements. This solution has been equated according to nomenclature solution P5 (Continuous wall with openings and thickness 30 [cm]).

Then the joints that we took into account when we analyzed the structural behavior for these established solutions [4], will be illustrated as shown down in Fig.2.

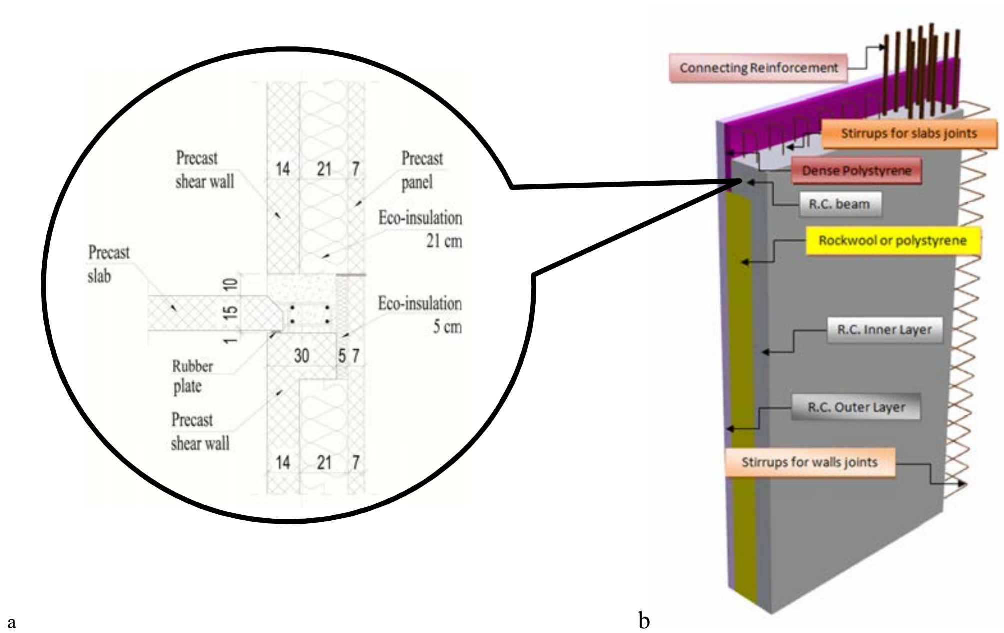


Fig. 2. (a) Horizontal wall joint; (b) Vertical wall joint

2.2. The behavior of well-known structural systems

For these two solutions, we have chosen to analyze the building with ground floor and five storeys. These structures have been subjected to seismic activities defined for DCM (Ductility Class Medium) and DCH (Ductility Class High), according to (Euro code 8) [3].

According to P100-2013 (Romanian Seismic Code) [2], The Frame Solution is very flexible and the second one is stiffer. These information about the structure behavior are known without any advanced structural analysis, they are obtained just from predicted behavior of the structure according to Romanian National Seismic Code "a prediction in terms of life safety in case of seismic hazard".

Depending on the structure type, both of the buildings were considered as having the following behavior (according to Romanian seismic code: P100-2013):

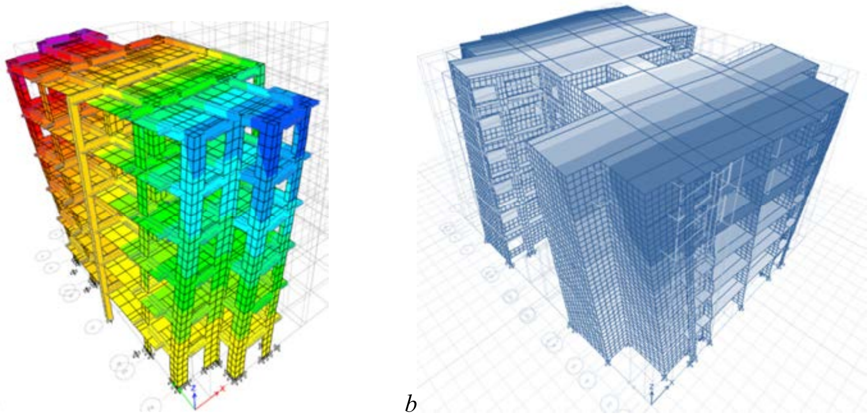
- Frame solution: has been considered as a flexible system, the vertical and lateral loads have mainly been resisted by spatial frames, in which shear resistance at the building base exceeds 65% of the total shear resistance of the whole structural system.
- Wall solution: has been considered as ductile wall system (coupled wall), the vertical and lateral loads are mainly resisted by vertical structural walls, either they are coupled or uncoupled, even here shear resistance at the building base exceeds 65% of the total shear resistance of the whole structural system.

Therefore, at the beginning of the research, we have started by assuming that both structures are suitable for type 1 (according to Table. 1).

Table 1. Behaviour factor q, according to P-100-2013. [2]

Structure Type	DCH	DCM	DCL
1.Frames, dual systems, coupled walls	5 $\alpha u/\alpha 1$	3,5 $\alpha u/\alpha 1$	2
2.Wall and hinged frame	4 kw $\alpha u/\alpha 1$	3 kw $\alpha u/\alpha 1$	2
3.Flexible structures (torsion)	3	2	1.5

After the advanced structures have been analysed we noticed that the first type of structure is more flexible than the second type [1] as clearly illustrated in Fig.3.where the colours refer to the value of the displacement. Consequently, that was the reason for the first system to be considered, from a structural point of view, as suitable solution for ductility class DCM, whereas the second type is more suitable for the ductility class DCH. In order to clarify this aspect, we have analysed further these five types of structures, but this time with 22 stories instead of six stories.



a *b*

Fig. 3.The well-known types of structure, where: (a) Frame Solution; (b) Wall Solution

3. The behavior of different precast concrete structures

In order to observe the difference between those five types and other current used solutions, we have analysed several cases as presented in the first chapter.

3.1. Structures descriptions

To emphasis the results of the five tests, the structure of elevations for each of the five types ware analyzed. For that we've used an empirical method in order to simplify it, thus each floor has applied a constant force level and equal to 350 [kN]. Based on the described load cases and displacements results of each floor, the floors drifts were derived and the stiffness of each level has been estimated empirically, by using the following formula:

$$K = \frac{F[kN]}{\delta[m]} \tag{1}$$

where:
K – Storey stiffness
F – Storey Force in [kN]
δ – Storey Drift
$\delta=\delta[story_{i+1}]-\delta[story_i]$
$\delta[story_{i+1}]$ – Top Story
$\delta[story_i]$ – Bottom Story

Next we will present the storey deflection results for different types of panels that were subjected to constant force.

3.2. Structures displacements results

Three types of structures (see Fig. 4-5), which are similar to the Frame Solution have been presented as flowing:

- P1- Fixed Frames with cross section 50x100 [cm]
- P2 - Fixed Frames and hinged connection beams wit cross section 50x100 [cm]
- P3 - Hinged Frames with cross section 50x100 [cm].

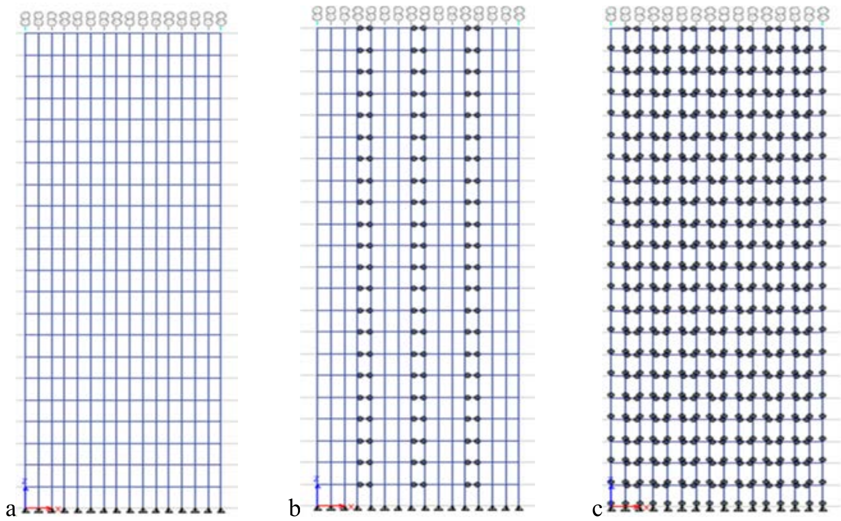


Fig. 4. (a) Fixed Frames P1; (b) Fixed Frames P2; (c) Fixed Frames P3

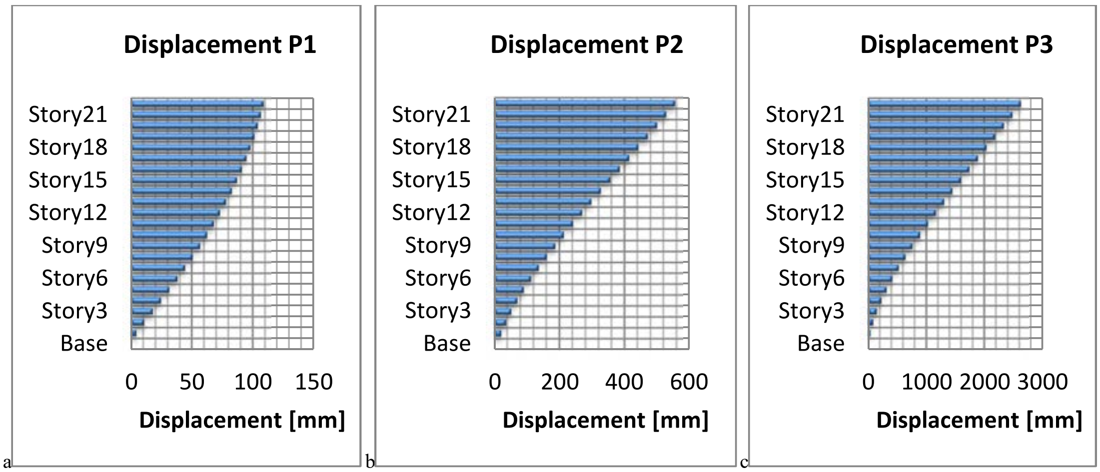


Fig. 5. (a) Displacement for P1 [approx. 108mm], (b) displacement for P2 [approx. 555mm], (c) displacement for P3 [approx. 2524mm] [Etabs 2013 Results]

Moreover, similar solutions to continuous wall will be presented, highly utilized and highly secure solution from a structural point of view, but these solutions need doors and windows openings, especially in facades. Alongside, we will see different solutions from the current performed study. If required openings (e.g. windows and/or doors) are opened in the facades, the answer of the structural system regarding the displacements will be increased almost by double (see Fig. 6).

According to the nomenclature of the paper, these two types of structures will represent:

- P4 - Continuous Wall, with thickness of 30[cm].
- P5 - Continuous Wall with openings with thickness 30 [cm].

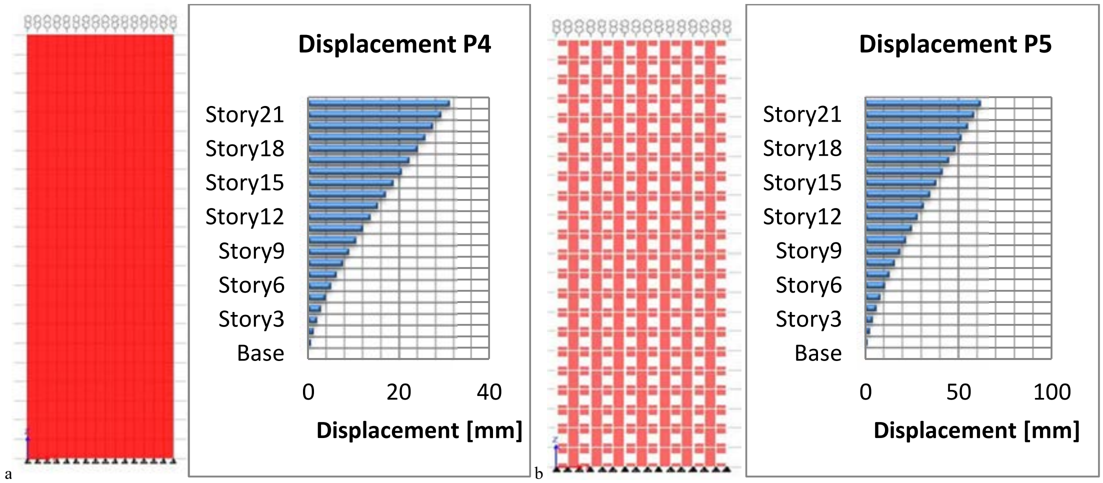


Fig. 6. (a) Displacements for solution P4 [approx. 31mm]; (b) Displacements for solution P5 [approx. 62mm]

Table 2. Displacements results per each type of structure [mm]

Story	P1	P2	P3	P4	P5
Base	0	0	0	0	0
Story1	4.2	20.1	34.3	0.6	1.1
Story2	10.7	35.3	84.3	1.2	2.4
Story3	17.6	51.5	148.7	1.9	4
Story4	24.5	69.7	226.1	2.8	5.9
Story5	31.2	89.9	315	3.8	8.1
Story6	37.8	111.8	414.2	5	10.4
Story7	44.2	135.3	522.5	6.2	13
Story8	50.4	160.2	638.7	7.6	15.7
Story9	56.4	186.2	761.8	9	18.6
Story10	62.1	213.1	890.7	10.5	21.7
Story11	67.6	240.7	1024.5	12	24.8
Story12	72.8	268.9	1162.3	13.7	28
Story13	77.7	297.5	1303.3	15.3	31.3
Story14	82.4	326.4	1446.9	17	34.6
Story15	86.7	355.4	1592.4	18.7	38
Story16	90.8	384.5	1739.1	20.5	41.4
Story17	94.5	413.4	1886.6	22.2	44.8
Story18	97.9	442.3	2034.5	24	48.2
Story19	101	470.8	2182.4	25.7	51.5
Story20	103.8	499.2	2330	27.4	54.9
Story21	106.2	527.1	2477.1	29.2	58.2
Story22	108.5	554.8	2623.6	31.1	61.7

3.3. Structures Stiffness and capacity design results

In regard to the above statements and according to structural stiffness, we can easily deduce the behaviour of these systems as shown down in Fig.7.

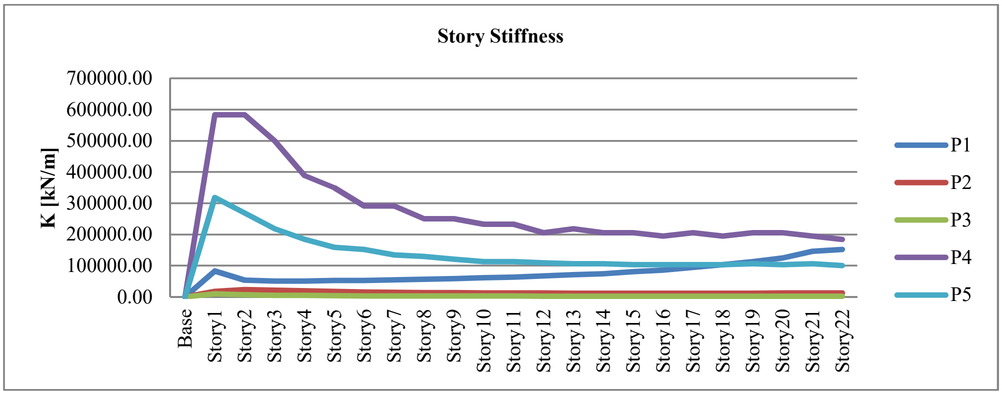


Fig. 7. Story Stiffness

According to the structural response provided by wall solution P4, considering the stiffest structural system comparisons with the rest of solutions. For wall with openings, we notice that after the windows openings were done, stiffness level decreased and displacements have almost doubled comparing with P4 model. Based on data obtained above (see Table.2.) we can observe the differences in stiffness and displacements' response of structures and we can establish table of values representing the percentages of the structural behaviour system.

For establishing the stiffness limits, we will consider P4 as 100% stiffness and then the rest of the structures will be set according to P4 results.

Table 3. Stiffness percentages with P4-Solutions like references

Story	P1	P2	P3	P4	P5
Ground floor	0.00	0.00	0.00	0.00	0.00
Story1	14.29	2.99	1.75	100.00	54.55
Story2	9.23	3.95	1.20	100.00	46.15
Story3	10.14	4.32	1.09	100.00	43.75
Story4	13.04	4.95	1.16	100.00	47.37
Story5	14.93	4.95	1.12	100.00	45.45
Story6	18.18	5.48	1.21	100.00	52.17
Story7	18.75	5.11	1.11	100.00	46.15
Story8	22.58	5.62	1.20	100.00	51.85
Story9	23.33	5.38	1.14	100.00	48.28
Story10	26.32	5.58	1.16	100.00	48.39
Story11	27.27	5.43	1.12	100.00	48.39
Story12	32.69	6.03	1.23	100.00	53.13
Story13	32.65	5.59	1.13	100.00	48.48
Story14	36.17	5.88	1.18	100.00	51.52
Story15	39.53	5.86	1.17	100.00	50.00
Story16	43.90	6.19	1.23	100.00	52.94
Story17	45.95	5.88	1.15	100.00	50.00
Story18	52.94	6.23	1.22	100.00	52.94
Story19	54.84	5.96	1.15	100.00	51.52
Story20	60.71	5.99	1.15	100.00	50.00
Story21	75.00	6.45	1.22	100.00	54.55
Story22	82.61	6.86	1.30	100.00	54.29

4. Conclusions

Considering the drift limits $\delta_{\lim}$ equal to 0.75% of the Story height that means the level $K_{\lim}$ is equal to 7777.778[kN/m] (according to Eurocode 8)[3].

$$K_{\lim} = \frac{F[kN]}{\delta_{\lim}[m]}$$

If we assume that the lateral force will be three times bigger in reality, we will predict the behaviour factor for each storey level, where the ratio will be $K_{limit}/K_{*}3$.

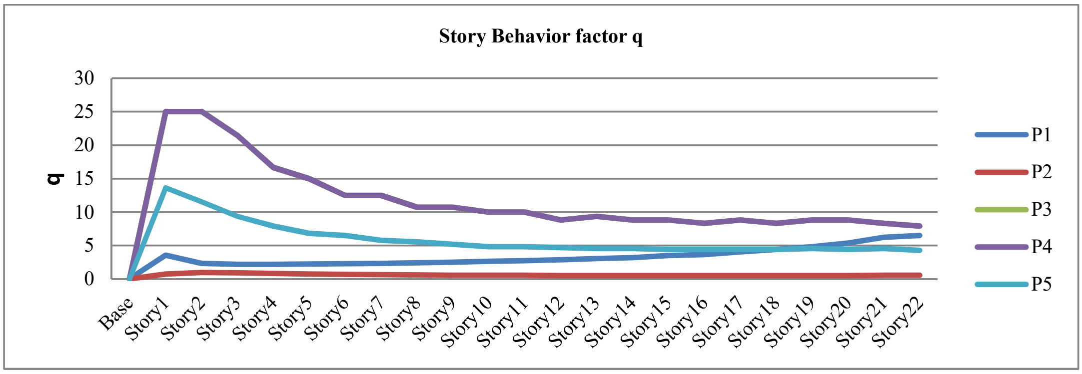


Fig. 8. Story behaviour

Considering the possibility to have all the walls in the structures without openings, we will consider the behaviour factor for the wall solution equal with a value between P4 and P5 solutions. In this case the results are provided in Table.4., where the resulted average for the behaviour factor is equal to 6.

Table 4. Minimum Behaviour factor q for different type of structure

Structure Type	Description	q
P1	Fixed Frames with cross section 50x100 [cm]	2
P2	Fixed Frames and hinged connection beams with cross section 50x100 [cm]	1
P3	Hinged Frames with cross section 50x100 [cm]	0
P4	Continuous wall with thickness 30[cm]	8
P5	Continuous wall with openings and thickness 30 [cm]	4

If we will use this method, we have to take into account that the loading for each level and geometry of the structure is crucial in predicting structural behaviour. [1]

According to results of structural behaviour the frame solution it can be used in DCL (low ductility class), but only if all the joints between beams and columns are fixed and regarding the wall solution, may be considered suitable for DCH (high ductility class).

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