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# DIAPHRAGM BEHAVIOUR OF THE FLOOR WITH PRESTRESSED BEAM AND FILLER BLOCKS

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## SUMMARY

The paper presents the results of a numerical analysis, in elastic range, concerning the behaviour of the dual structures (shear walls and frames) having floors with prestressed beams and filler blocks subjected to seismic loads. Some important parameters such as: the thickness of the floor slab, the vertical elements rigidity ratio, the ratio of the design ground acceleration to the acceleration of gravity were taken into consideration for the numerical analysis. Also, three types of floors with prestressed beams and filler blocks were tested under reversed horizontal cyclic loadings up to failure. The experimental results were compared with numerical results (using FEM) in elastic and inelastic range.

## INTRODUCTION

The floors slabs of buildings have an important role in transmission and distribution of the horizontal loads (wind or earthquake) at the vertical elements of resistant structures. In current design practice of building structures the floors subassemble are usually designed for gravity loads. Romanian codes P100-92 [6], P85-96 [7], as well as many foreign codes (e. g. Eurocode 8 [4]) consider the slabs floor of structures such as “rigid diaphragm”. Even if this hypothesis simplifies the analysis of the structures subjected to seismic loads, it is not always a real one. The object of this paper is the numerical analysis of the behaviour of the dual structures (shear walls and frames) having floors with prestressed beams and filler blocks (PBFB) subjected to seismic loads. Also, it presents the experimental results of three types of PBFB floors (which are using again in our country) were tested under reversed horizontal cycles loadings up to failure.

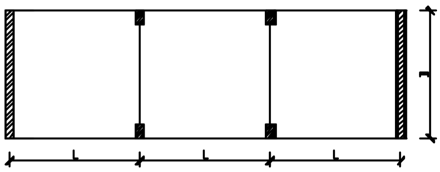


**Figure 1. The disposal of vertical structural elements for model EXP 5**

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In order to find out the influence of the differents parameters on the amplitude of horizontal displacement were considered two rectangulare lay-out buildings without openings in the slabs. These are five levels buildings which consists of two peripheral RC walls and two or four RC frames (fig. 1 and 2).

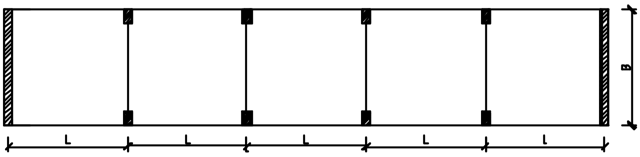


**Figure 2. The disposal of vertical structural elements for model EXP 5A**

The different lateral deflected shapes of the shear walls and the frames due to important forces in plane of floors. The interaction forces between shear walls and frames are shown in Figure 3.

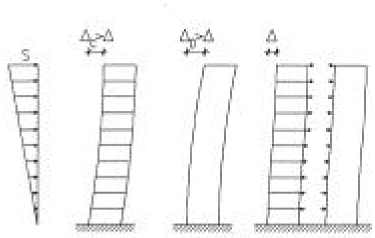

**Figure 3. The wall-frame interaction**

## NUMERICAL ANALYSIS

The numerical analysis has been carried out on the structures presented in Figures 1 and 2 (L=B=6.0 m). The finite element mesh used to model the structure EXP 5A and the mechanical model are given in Figure 4.

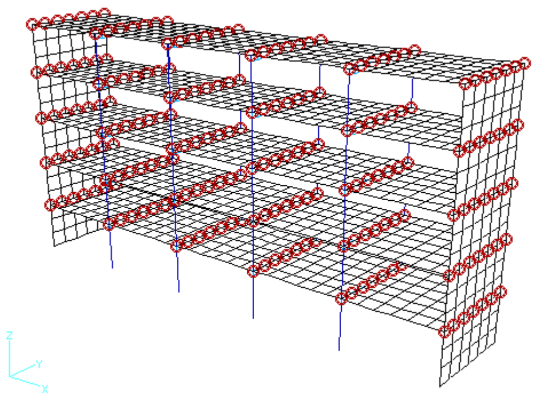

**Figure 4. Finite element mesh and mechanical model for structure EXP 5A**

The parameters taken into consideration for the numerical analysis were:

-the thickness of the floor slab;

-the presence or the absence of the floor beams;

-the vertical elements rigidity ratio;

-the ratio of the design ground acceleration to the acceleration of gravity.

These parameters and the maximum horizontal floor displacements, in the fundamental mode, are presented in Table 1 for model EXP 5 and in Table 2 for model EXP 5A.

**Table 1**

| Var. No. | Parameters | | | | | $\Delta_C$ [mm] | $\Delta_D$ [mm] | $\Delta$ $\Delta_C$-$\Delta_D$ [mm] |
|---|---|---|---|---|---|---|---|---|
| | Slab thickness [mm] | Beams | $K_D/K_C$ | F.P.V. [s] | $\alpha$ | | | |
| 1 | 80 | no | 85 | 0.277 | 0.20 | 3.7 | 3.2 | 0.5 |
| 2 | 60 | no | 168 | 0.279 | 0.20 | 3.9 | 3.2 | 0.7 |
| 3 | 40 | no | 168 | 0.282 | 0.20 | 4.1 | 3.1 | 1.0 |
| 4 | 40 | no | 168 | 0.282 | 0.32 | 6.6 | 5.0 | 1.6 |
| 5 | 20 | no | 168 | 0.323 | 0.20 | 5.1 | 3.0 | 2.1 |
| 6 | 20 | no | 36 | 0.316 | 0.20 | 4.8 | 2.9 | 1.9 |
| 7 | - | yes | 168 | 1.116 | 0.20 | 48.5 | 1.1 | 47.4 |
| 8 | - | yes | 168 | 1.116 | 0.32 | 77.6 | 1.8 | 75.8 |
| 9 | - | no | 168 | 1.260 | 0.20 | 58.5 | 0.8 | 57.7 |
| 10 | - | no | 168 | 1.260 | 0.32 | 93.6 | 1.3 | 92.3 |

**Table 2**

| Var. No. | Parameters | | | | | $\Delta_C$ [mm] | $\Delta_D$ [mm] | $\Delta$ $\Delta_C$-$\Delta_D$ [mm] |
|---|---|---|---|---|---|---|---|---|
| | Slab thickness [mm] | Beams | $K_D/K_C$ | F.P.V. [s] | $\alpha$ | | | |
| 1 | 60 | no | 168 | 0.438 | 0.20 | 9.2 | 4.9 | 4.3 |
| 2 | 60 | no | 168 | 0.438 | 0.32 | 14.7 | 7.8 | 6.9 |
| 3 | 40 | no | 168 | 0.48 | 0.20 | 11.2 | 4.8 | 6.4 |
| 4 | 40 | no | 168 | 0.48 | 0.32 | 17.9 | 7.7 | 10.2 |
| 5 | 20 | no | 168 | 0.585 | 0.20 | 16.7 | 4.6 | 12.3 |
| 6 | 20 | no | 168 | 0.585 | 0.32 | 26.7 | 7.0 | 19.7 |

$K_D$ – the rigidity of shear wall;
$K_C$ – the rigidity of frame;
$\Delta$ - the maximum horizontal floor deflection;
$\Delta_D$ - the maximum horizontal shear wall displacement;
$\Delta_C$ - the maximum horizontal central frame displacement;
$\alpha$ - the ratio of the design ground acceleration to the acceleration of the gravity;
F.P.V. – the fundamental vibration period.

One of the deflected shape of the model EXP 5A is presented in Figure 5.

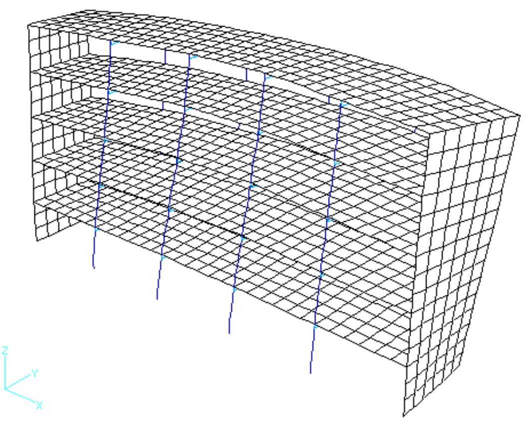

**Figure 5. Deflected shape of EXP 5A**

## EXPERIMENTAL TESTS

The experimental study contains tests on three types of floor with prestressed beams and filler blocks. The first type of floor with prestressed beams analyzed was with polystyrene filler blocks (Figure 6) and the second was with hollow concrete filler blocks (Figure 7). Five cm of concrete was cast-in place over the entire area of the floor for the first type and four cm for the second one.

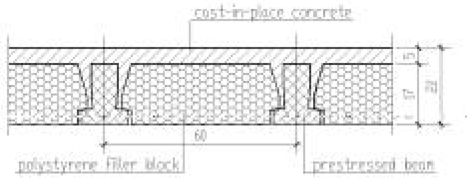


**Figure 6. Floor cross section with polystyrene filler blocks**

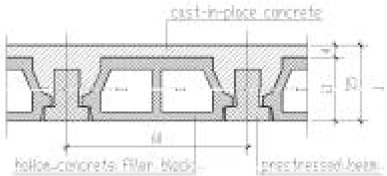


**Figure 7. Floor cross section with hollow concrete filler blocks**

The third type of floor with prestressed beams experimentaly tested was, also, with hollow concrete filler blocks, but without concrete cast-in-place over the entire its area (Figure 8).

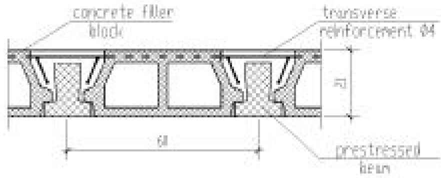


**Figure 8. Floor cross section without cast-in-place over concrete**

The full-scale floor specimens tested at INCERC Cluj were:
- PGCUP-4.3, having 430 cm large and 195 cm depth with polystyrene filler blocks;
- PGCUB- 6.8, 680 cm x 195 cm, with hollow concrete filler blocks.
- PGCUB-T-4.3, 430 cm x 195 cm, with hollow concrete filler blocks and transverse reinforcement between hollow concrete filler blocks through the cast in place concrete over the beams.

One of floor specimen (PGCUB-6.8) is shown in Figure 9.

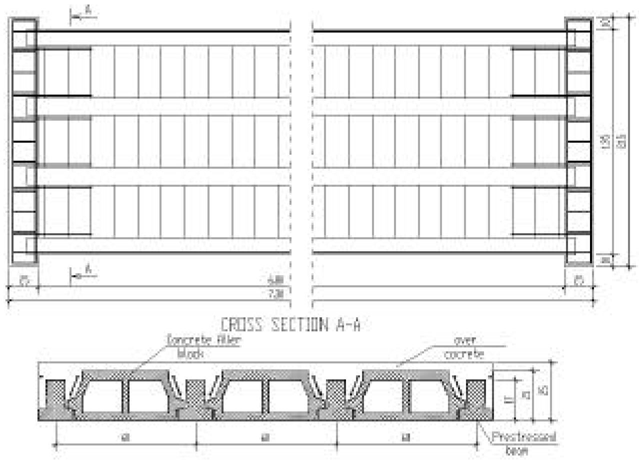


**Figure 9. Floor specimen $P_{GCUB}$-6.8**

The floor specimens were tested as simple supported beams (figure 10 and 11). The horizontal loading was distributed over the entire width of the floor in one or two sections and was applied in repeated, reversed cycles up to failure.

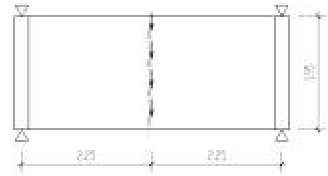

**Figure 10. Loading condition $P_{GCUP}$ 4.3 ($P_{GCUB}$ -T-4.3)**

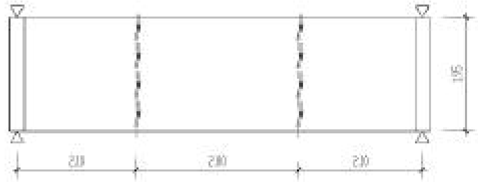

**Figure 11. Loading condition $P_{GCUB}$ 6.8**

The maximum horizontal displacements resulted for different loading levels and corresponding calculated values using the Finite Element Method (FEM) are presented in Table 3.

**Table 3**

| No. | Load | $P_{GCUP}$-4.3 | | $P_{GCUB}$-6.8 | | $P_{GCUB}$-T-4.3 | |
|---|---|---|---|---|---|---|---|
| | | $\Delta^{calc}$ | $\Delta^{exp}$ | $\Delta^{calc}$ | $\Delta^{exp}$ | $\Delta^{calc}$ | $\Delta^{exp}$ |
| | kN | mm | mm | mm | mm | mm | mm |
| 1 | 50 | 0,09 | 0,10 | 0,15 | 0,16 | 0,40 | 0,37 |
| 2 | 100 | 0,18 | 0,20 | 0,30 | 0,34 | 0,80 | 0,75 |
| 3 | 150 | 0,27 | 0,50 | 0,45 | 0,70 | 1,50 | 1,60 |
| 4 | 200 | 1.10 | 1,20 | 1,60 | 1,70 | 7,50 | 7,80 |
| 5 | 240 | - | - | - | - | 23…34 | 25…38 |
| 6 | 300 | 2.70 | 2,90 | 3.50 | 3,70 | | |
| 7 | 400 | 6.90 | 6,10 | 6.60 | 6,70 | | |
| 8 | 500 | 8.30 | 8,40 | 9.30 | 9,20 | | |
| 9 | 600 | 11.30 | 11,60 | 12.30 | 12,50 | | |
| 10 | 630 | 18.10 | 19,30 | - | - | | |
| 11 | 680 | | | 20.9 | 22,50 | | |

The analysis with FEM was extended in inelastic range. The stiffness degradation of the floor during the experiment was taking into account by reducing of the elasticity module values of concrete for beams and hollow concrete filler blocks and by reducing of the section of the hollow concrete filler blocks.

Hysteretic behaviour for the $P_{GCUB}$ 6.8 is presented in Figure 12.

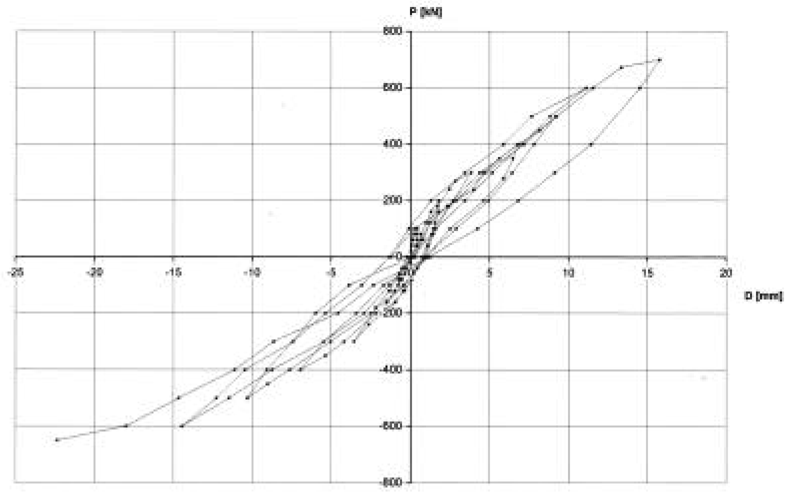


**Figure 12. $P_{GCUB}$ 6.8 . P-D diagram**

The failure modes was differently for each type of tested floor. In this paper it presents the failure mode for $P_{GCUB}$ 6.8. The crack pattern for this specimen shows that, for depth-to-span ratio about 1, most of the cracks in cast-in-place concrete were inclined about 45° (Figure 13). The ultimate load was reached just before the width of a major diagonal crack has suddenly increased. This crack has developed through the cast-in-place concrete precast beams and hollow concrete filler blocks (Figure 14). This failure mode revealed that the composite section of the floor with hollow concrete filler blocks "works" like a homogenous one.

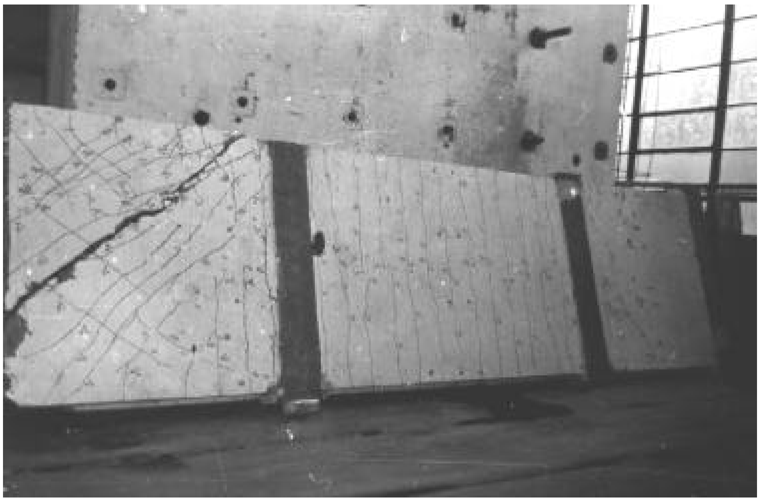

**Figure 13. Floor crack pattern PGCUB 6.8**

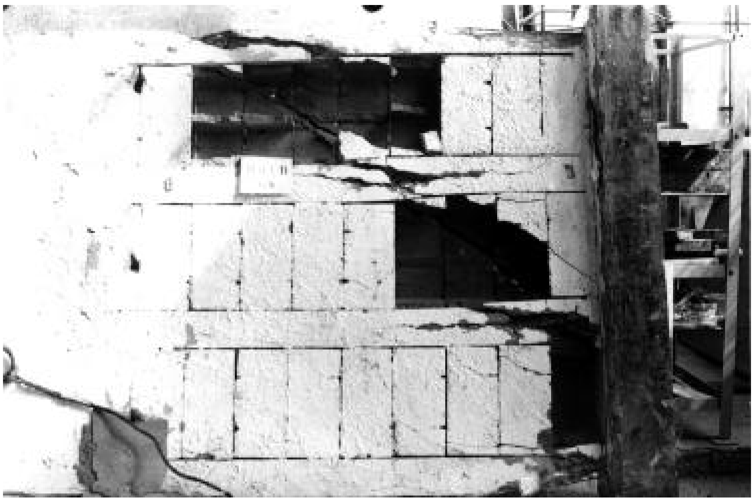

**Figure 14. Failure mode $P_{GCUB}$ 6.8**

**CONCLUSIONS**

Numerical analysis, carried out by FEM, in elastic range, on two five level structures shows that:

1. A 4 cm thick slab for PBFB floor assures the validity of "rigid diaphragm" hypothesis

2. Hypothetical situation of "zero" rigidity of floors leads to increased frame-shear wall horizontal relative displacement up to about 90 mm (for model EXP 5).

The comparative analysis of experimental and analytical results reveals that:

3. The type of floor without cast-in-place concrete over the entire area of floor and with transversal reinforcement had about half horizontal resistance capacity comparative with the types of floors with cast-in-place concrete over the entire area

4. The failure modes were very different for every type of floor, depending on material of filler blocks and of presence or absence of cast in place over concrete;

5. There was a good agreement between the maximum horizontal displacement resulted for different loading levels and the calculated values using FEM.

Computing model for PBFB floors, in inelastic range, was calibrated on the basis of experimental values of displacements. The study is to be continued.

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