SEISMIC PERFORMANCE OF FLAT-SLAB BUILDING STRUCTURAL SYSTEMS

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ABSTRACT:

Flat-slab building structures possesses major advantages over traditional slab-beam-column structures because of the free design of space, shorter construction time, architectural –functional and economical aspects. Because of the absence of deep beams and shear walls, flat-slab structural system is significantly more flexible for lateral loads then traditional RC frame system and that make the system more vulnerable under seismic events. The results from the analysis for few types of construction systems which is presented in the paper show that flat slab system with certain modifications (design of beam in the perimeter of the building and/or RC walls) can achieve rational factor of behaviour considering EC8 and can be consider as a system with acceptable seismic risk. Modifications with additional construction elements improve small bearing capacity of the system and increase strength and stiffness, improving seismic behaviour of flat-slab construction system. Selected result from the analysis are presented in the paper.

KEYWORDS: flat-slab, seismic performance, perimeter beams, Eurocode 8

1. INTRODUCTION

In design and engineering practice, the selectively defined design of space, design of structure, speed and efficiency of realization represent an extraordinarily important factor for the Investor. This assertion is supported by the fact that the flat-slab RC system has lately been increasingly imposed as a more acceptable and more attractive structural system in the world and in Macedonia as well. What is rational and optimal for these flat-slab structures is that they enable simple design, pure and clear space with absence of beams (the role of the beams is transferred to the RC floor slab), faster construction and time saving.

The system consists of columns resting directly on floor slabs for which sufficient strength and ductility should be provided to enable sustaining of large inelastic deformations without failure. The absence of beams, i.e., the transferring of their role to the floor RC structure which gains in height and density of reinforcement in the parts of the hidden beams, the bearing capacity of the structural system, the plate-column and plate-wall connection, all the advantages and disadvantages of the system have been tested through long years of analytical and experimental investigations. For the last 20 to 30 years, the investigations have been directed toward definition of the actual bearing capacity, deformability and stability of these structural systems designed and constructed in seismically active regions.

The paper displays part of the results from analyses of six types of structural systems for a prototype of a residential building in Skopje for the purpose of defining the seismic behaviour and resistance of flat-slab structural systems [Mircic, 2006].

2.ANALYSIS OF SEISMIC RESISTANCE OF RC FLAT-SLAB STRUCTURAL SYSTEM

2.1. Geometrical Characteristics of the Analyzed Structural Systems

To evaluate the seismic behaviour and resistance of a flat-slab RC system, analyses of a typical prototype of a residential building in Skopje with B +GF +4 + A have been carried out (Fig. 1).

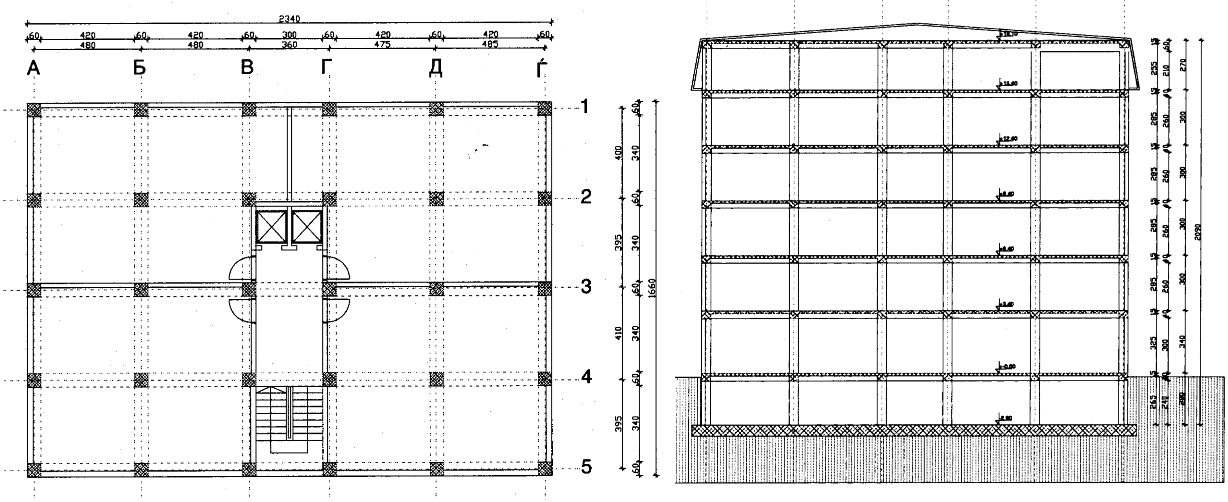


Figure 1. Characteristic plan and cross-section

For the chosen prototype of the residential building six types of structural systems have been analyzed. Geometrical characteristics of each of these structural systems are presented in the table 2.1 and figure 2.

Table 2.1 Geometrical characteristics of the analyzed structural systems

Type of structural system		plate [cm]	columns [cm]	beams [cm]	perimeter beams [cm]	RC walls
Frame	M1	14	60/60	40/40	No	No
Purely flat-slab	M2	20	60/60	No	No	No
Purely flat-slab	M3	25	60/60	No	No	No
Flat-slab strengthed by a perimeter beam	M4	20	60/60	No	40/40	No
Flat-slab strengthed by RC walls	M5	20	60/60	No	No	Yes
Flat-slab strengthed by perimeter beam and RC walls	M6	20	60/60	No	40/40	Yes

2.2 Seismic and Dynamic Analysis and Results from Analysis

To evaluate the seismic behaviour and resistance of the flat-slab structural system, comparative analyses have been made between the models of structural systems M2, M3, M4, M5 and M6 and the referent frame structure – model M1. The effects of the designed modifications upon the dynamic characteristics as well as upon the bearing and deformability of the flat-slab structure have been investigated.

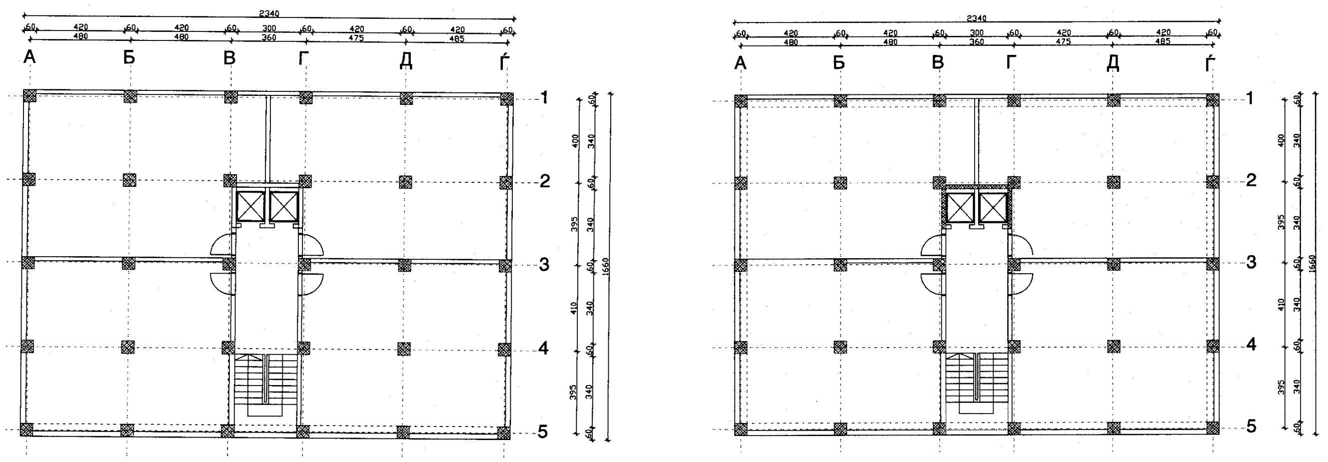


Figure 2. Characteristic plans – purely flat-slab system and
flat-slab system strengthened by perimeter beams and RC walls

The analyses have been performed by using the finite element method and the S***AP2000v10.0.9Advanced*** computer programme [Wilson and Habibullah, 1998]**.** The 3D mathematical model of each of the analyzed structures has been formulated by discretization of the bearing system into finite elements. The vertical loads have been defined in accordance with the valid national technical regulations and the purpose of the structures.

Seismic analysis has been carried out in compliance with the regulations for design of high rises in seismically prone areas, [Rulebook on Technical Norms for Construction of High-rises in Seismically Prone Areas, 1981]. The horizontal loads have been defined in the form of a design spectrum of acceleration in accordance with Eurocode 8, [Eurocode 8, 2004] scaled in such a way that it generates the total shear force at the base to the amount of 10% of the weight of the structure.

Dynamic analysis has been carried out for selected structural systems (model M1, M2 and M4) exposed to the effect of the El centro earthquake with a_{max}=0.32g.

The results obtained from the analyses of different structural systems are presented in the form of: dynamic characteristics (periods and mode shapes), maximal displacements and relative storey drifts in both orthogonal directions, time histories of absolute displacements at the top as well as bearing capacity and deformability of the selected structural systems (model M1 and model M2) [Necevska-Cvetanovska, Petrusevska, 2000].

Presented further are some of the results obtained from the ample analytical investigations. The first mode shape of vibration of the structural system of model M1 and model M2 is given in Fig. 3.

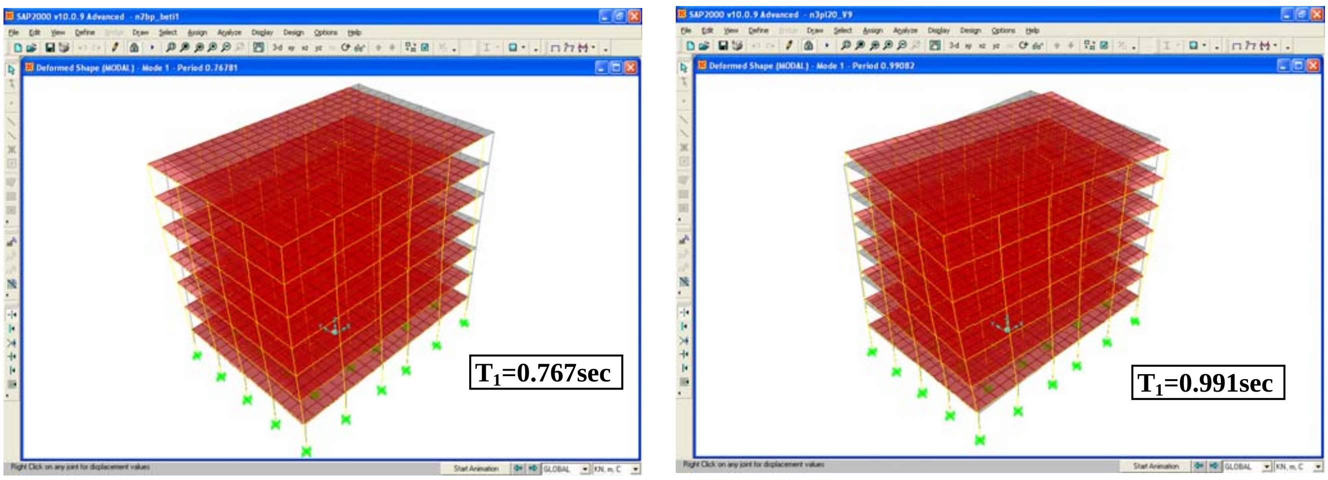


Figure 3. First mode shape for model M1 and model M2

The distribution of maximal moments under vertical loads over the plate of the second story of models M1 and M2 is presented in Fig. 4. Table 2.2 shows the maximal values of moments due to vertical loads above support and in the middle of the spane for the analyzed models of structural systems.

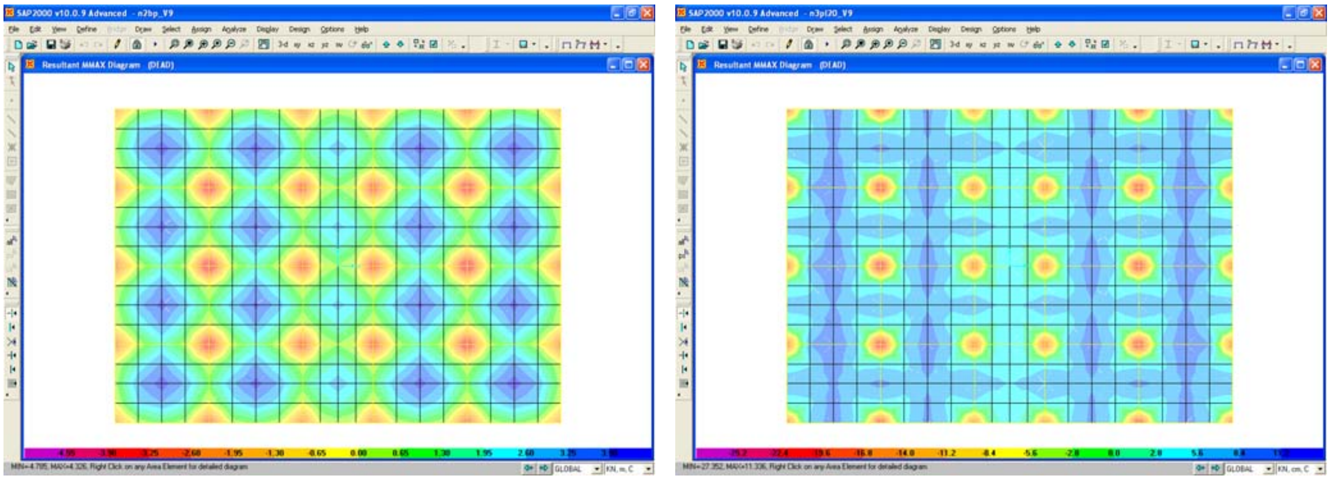


Figure 4. Maximal moments in the plate at the second storey for model M1 and model M2

Table 2.2 Comparison of maximal moments due to vertical loads in the plate at the second story

Type of structural system		Maximum moments [kNm]	
		Mmax, support	Mmax, middle span
Frame	M1	-4.55	3.90
Purely flat-slab	M2	-25.2	11.2
M3 strengthened with a perimeter beam	M4	-19.8	8.8
M3 strengthened with perimeter beam and RC walls	M6	-21.6	9.6

The time histories of displacements at the top of the structure for model M2 and model M4 are presented in Figure 5.

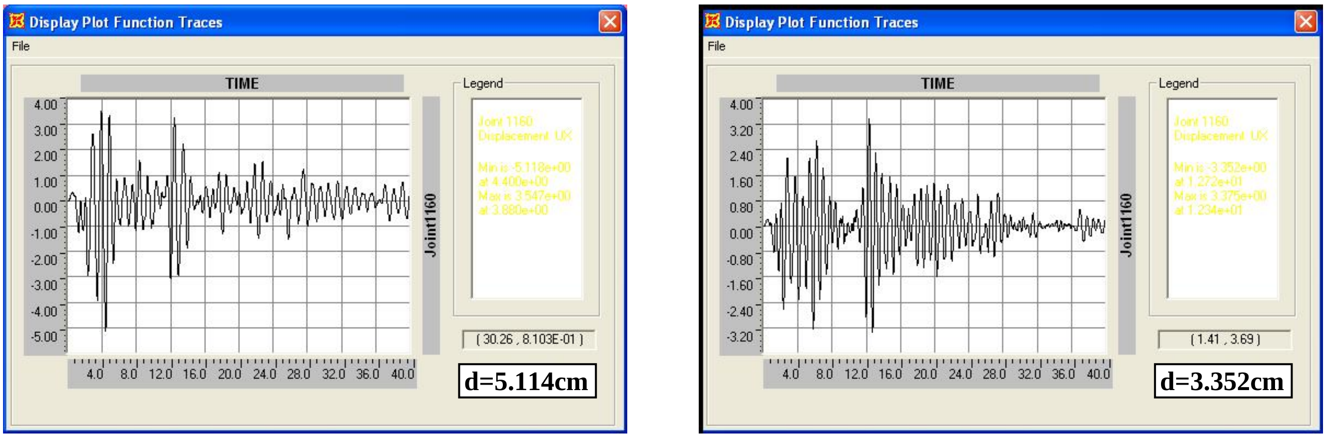


Figure 5. Time histories of maximum displacement

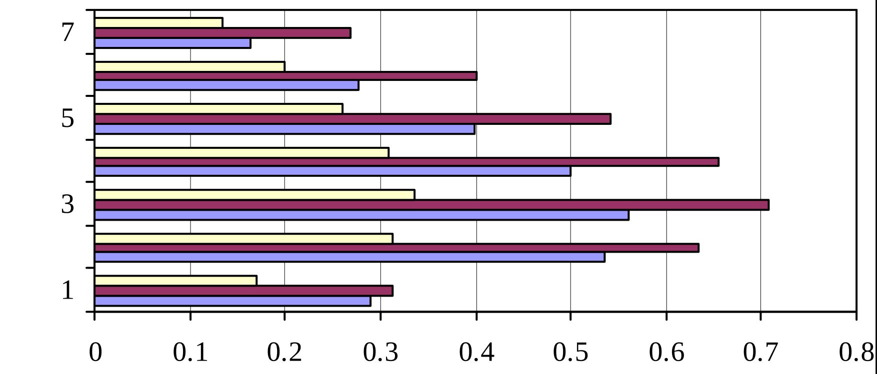
2.3 Analysis of results

After the performed analytical investigations, comparative analyses have been performed for: the fundamental period of vibration (T_1), the maximal horizontal displacements in both orthogonal directions (Table 2.3), the time histories of displacement as well as bearing and deformability capacity for selected structural systems.

Table 2.3. Comparison of periods and maximal displacements of the analyzed models

Type of structural system		plate	T_1	Max. displacements [cm]	
		[cm]	[sec]	X-X direction	Y-Y direction
Frame	M1	14	0.767	2.725	2.662
Purely flat-slab	M2	20	0.998	3.522	3.416
Purely flat-slab	M3	25	0.794	2.743	2.676
M3 strengthened with a perimeter beam	M4	20	0.789	2.786	2.752
M3 strengthened with RC walls	M5	20	0.956	1.970	2.592
M3 strengthened with perimeter beam and RC walls	M6	20	0.740	1.719	2.310

The results have shown that the purely flat-slab system has a greater fundamental period and greater displacements in respect to the frame system. The occurrence of torsion in the first mode shape is also characteristic. The best behaviour has been exhibited by model M6 whose fundamental period is less than that of the frame system, with reduction of displacements of 40%. The relative storey displacements (Fig. 6) show the same tendency.



	1	2	3	4	5	6	7
M3	0.17	0.312	0.335	0.309	0.26	0.199	0.134
M2	0.313	0.635	0.708	0.656	0.542	0.4	0.268
M1	0.29	0.535	0.56	0.5	0.399	0.278	0.163

Figure 6. Relative storey displacements in x direction [cm]

Fig. 7 shows the comparative results from the analysis in nonlinear range referring to bearing and deformability capacity of structural systems carried out for models M1 and M2. The obtained results show that the strength and stiffness capacity of the flat-slab system are lower for 38% in respect to the frame system.

4. CONCLUSIONS AND RECOMMENDATIONS

The purely flat-slab RC structural system is considerably more flexible for horizontal loads than the traditional RC frame structures which contributes to the increase of its vulnerability to seismic effects. The critical moment in design of these systems is the slab-column connection, i.e., the penetration force in the slab at the connection, which should retain its bearing capacity even at maximal displacements. The ductility of these structural systems is generally limited by the deformability capacity of the column-slab connection.

To increase the bearing capacity of the flat-slab structure under horizontal loads, particularly when speaking about seismically prone areas and limitation of deformations, modifications of the system by adding structural elements are necessary.

The realized investigations have shown that the flat-slab structural system with well defined modifications can exhibit a favourable and rational factor of behaviour compliant with Eurocode 8 and can thus be treated as a system with acceptable seismic risk. The modification with certain structural elements improves the low bearing capacity and deformability of the system and leads to more adequate seismic behaviour of the purely flat-slab structure.

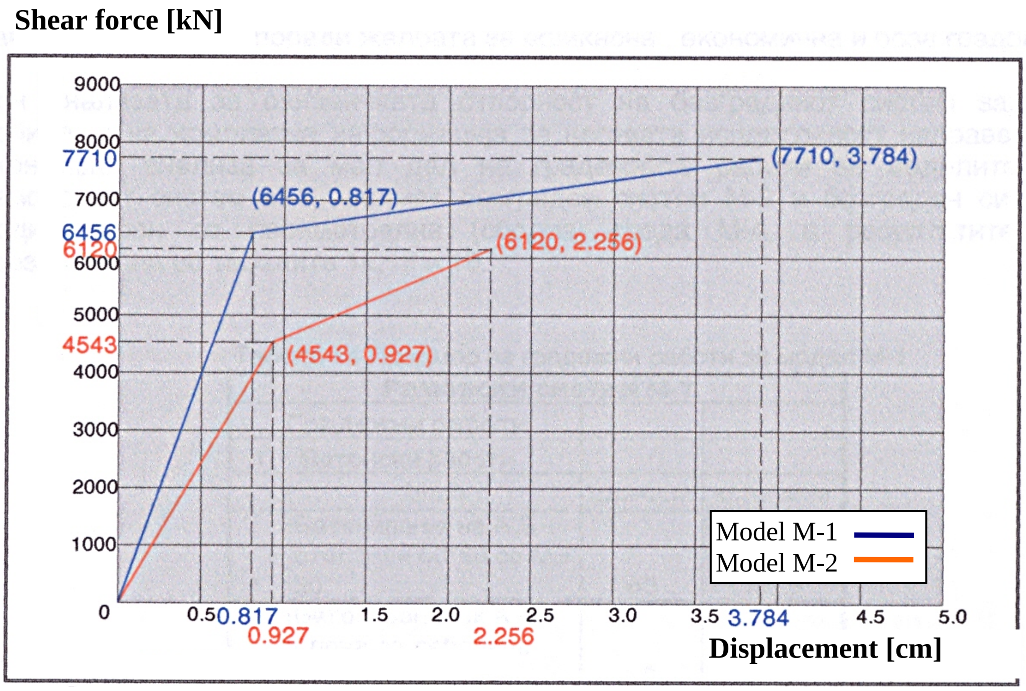


Figure 7. Comparison of bearing capacity and deformability

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