Comparative Dynamic Analysis of Existing Construction and Construction with Superstructure

Shpresim Ibraimi[1]

[1]*BSc Civil Engineer, University "Sts. Cyril and Methodius" Institute for Testing Materials and Development of New Technologies "Skopje" AD - Skopje, Macedonia*

ABSTRACT

The impossibility to provide building land in central urban areas imposes the need for new housing. The subject of this paper is to make a comparative dynamic analysis of different reinforced concrete structural systems, the existing and newly designed construction with superstructure of real residential building which is located in Skopje.

The analysis of the structures is executed with the software package SAP2000 in 3D mathematical models. In the models are applied static loads, wind loads according to applicable technical regulations, seismic loads according to Macedonian regulations with the method of equivalent static loads (simplified modal spectral analysis) and linear time history of earthquake record. Afterwards it is executed dynamic analysis of the existing construction, construction with superstructure with the same structural members as the existing construction and the strengthened construction with superstructure (since the dimensioning is executed). Strengthening of structural members is designed with increasing of cross sections by addition of new layer.

By the executed dynamic analysis of the reinforced concrete structural systems is made a comparison of bearing capacity and stress - deformation state of characteristic structural members by comparing: periods, base reactions, maximal horizontal displacements, M-Φ and M-N diagrams for characteristic structural members and maximal normal concrete stress in columns.

By the analysis it's been concluded that the cross sections of strengthened construction had increased their strength, stiffness, deformation and ductility characteristics, and the construction as a whole possesses the required level of security for acceptance of the loads.

Keywords: *dynamic analysis, strengthening, bearing capacity*

STRENGTHENING OF CONSTRUCTIONS IN GENERAL

The goal of seismic strengthening is the improvement of seismic behavior of structures.

The choice of the optimal strengthening strategy relies on good understanding of the dynamic behavior and future use of the structure. The strengthening should be optimally coordinated for the combination of distinctive features of a structure: stiffness, ultimate resistance and deformation capacity.

Strengthening can be achieved by different strategies: placing of reinforced concrete walls or steel tie rods in the existing frames, jacketing of columns, placing of steel plates or carbon fiber tape, etc. The columns should not be a weak point of the structure. Increasing of column flexural strength is achieved by increasing of cross section, placing of vertical reinforcement and stirrups, where it is important their configuration and distance. Shear failure depends on joint reinforcement details. Increasing of column shear strength is achieved by concrete jacketing or placing of steel sheets, steel strips and angles, and carbon fiber tape. In general, for strengthening of structures can be undertaken the following measures: improving regularity, increasing of strength, ductility and decreasing of mass.

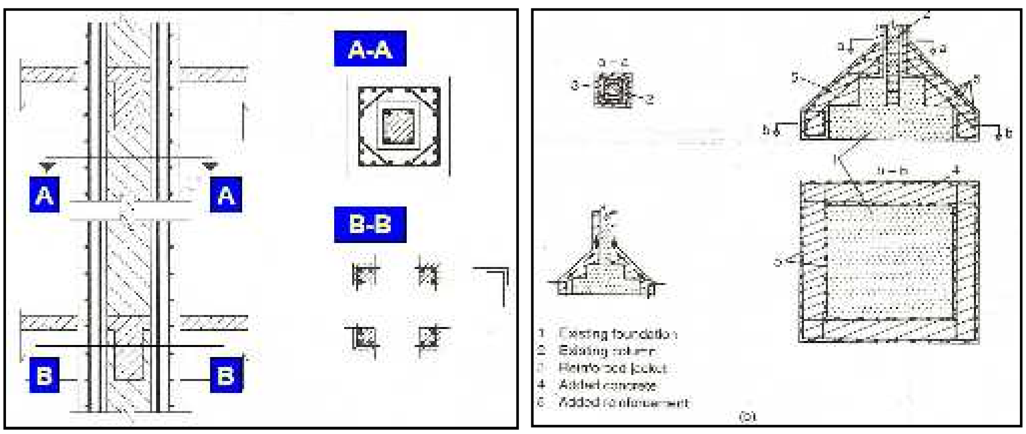

Figure 1 Example of column and foundation strengthening by increasing of cross section

GENERAL VIEW OF CONSTRUCTION AND LOAD ANALYSES

This paper is part of the dissertation: “Dynamic analysis of existing construction and construction with superstructure. Comparison of bearing capacity, strengthening and project of concrete design”. However, here is only presented the comparative dynamic analysis and brief review of construction strengthening.

In the existing building, according to the project task, should be constructed two additional floors. With increasing of floor number will be ruined the previous stress - deformation state, reduced the stiffness and increased the deformations. The construction will not have sufficient bearing and deformation capacity for acceptance of seismic forces. Therefore, it is necessary to strengthened the construction in order to increase its bearing capacity and usability.

The existing residential building has a rectangular shape with basement dimensions 30,0/18,0m. It is consisted of one subterranean level with H=3,10m, ground floor with H=3,10m and two floors H=6,20m.

In structural sense the construction represents spatial reinforced concrete frame construction with frames in both orthogonal directions, six frames in y and four frames in x - direction. The characteristics of materials are given through concrete and steel stress - strain diagrams. For construction analysis is adopted concrete MB30 with modulus of elasticity E=31500 MPa and nominal value of compressive strength f_c=25 MPa, reinforcement bars RA 400/500-2 with modulus of elasticity E=210000 MPa and tensile strength σ_v=400 MPa.

Static and dynamic analysis of the constructions is performed in 3D mathematical models with program package SAP2000. The columns and beams are modeled with beam finite elements, while plates and walls with shell finite elements. The models are analyzed in elastic surface with coefficient C_z=30000 KN/m^3. The allowed bearing capacity of soil is σ_a=400 KN/m^2.

The loads that act in the constructions are calculated and applied in the models with appropriate load cases, which include dead, live, wind and seismic loads.

Wind loads are calculated according to the applicable technical regulations. According to our regulations, wind loads are defined to act straight - line, but with different intensity depending on the height.

Seismic loads - Our existing regulations are based on linear analyses of constructions under the influence of equivalent horizontal seismic forces. The equivalent seismic force is determined as a product of structure weight and one total seismic coefficient:

$$S = K_0 \times K_s \times K_d \times K_p \times G \tag{1}$$

where (for the analyzed constructions)

K_0=1,0 - coefficient of construction category,

K_s=0,1 - seismic coefficient (IX degree according to MKZ),

K_d=0,7/T - dynamic coefficient (category of soil - II; limit values 1,0> K_d >0,47); T - first modal period of construction,

K_p=1,0 - ductility and damping coefficient,

G - total weight of construction

The total weight of the construction is calculated as a sum of dead loads and 50% of live loads. According to our regulations the total seismic force should be maximum 10% of G. The weight of structural members is taken automatically by the program, while other static loads are taken as equal distributed loads. On the basis of load cases are formed load combinations with appropriate safety coefficients.

Additionally, linear time history analysis is performed for the action of real earthquake record. It's been used El Centro accelerogram of 1940, direction north - south with PGA=0,319 g. The accelerogram is with intervals of 0,02 seconds and duration of 31,18 seconds. The input data for the analysis are: determination of record time step, number of steps and modal damping 5%.

In the following text, the analyzed constructions: existing construction, construction with superstructure with the same structural members as the existing construction and the strengthened construction with superstructure will be named as: construction 1, construction 2 and construction 3.

CONSTRUCTIONS ANALYSES

Firstly, it is performed the analysis and dimensioning of the structural members of construction 3. Below the text are given figures of construction 3, half of basement layout and characteristic cross section where are presented the structural member dimensions, strengthening details and ways for execution of the superstructure with brief description. Afterwards are given in detail the exit results from the performed analysis of the constructions.

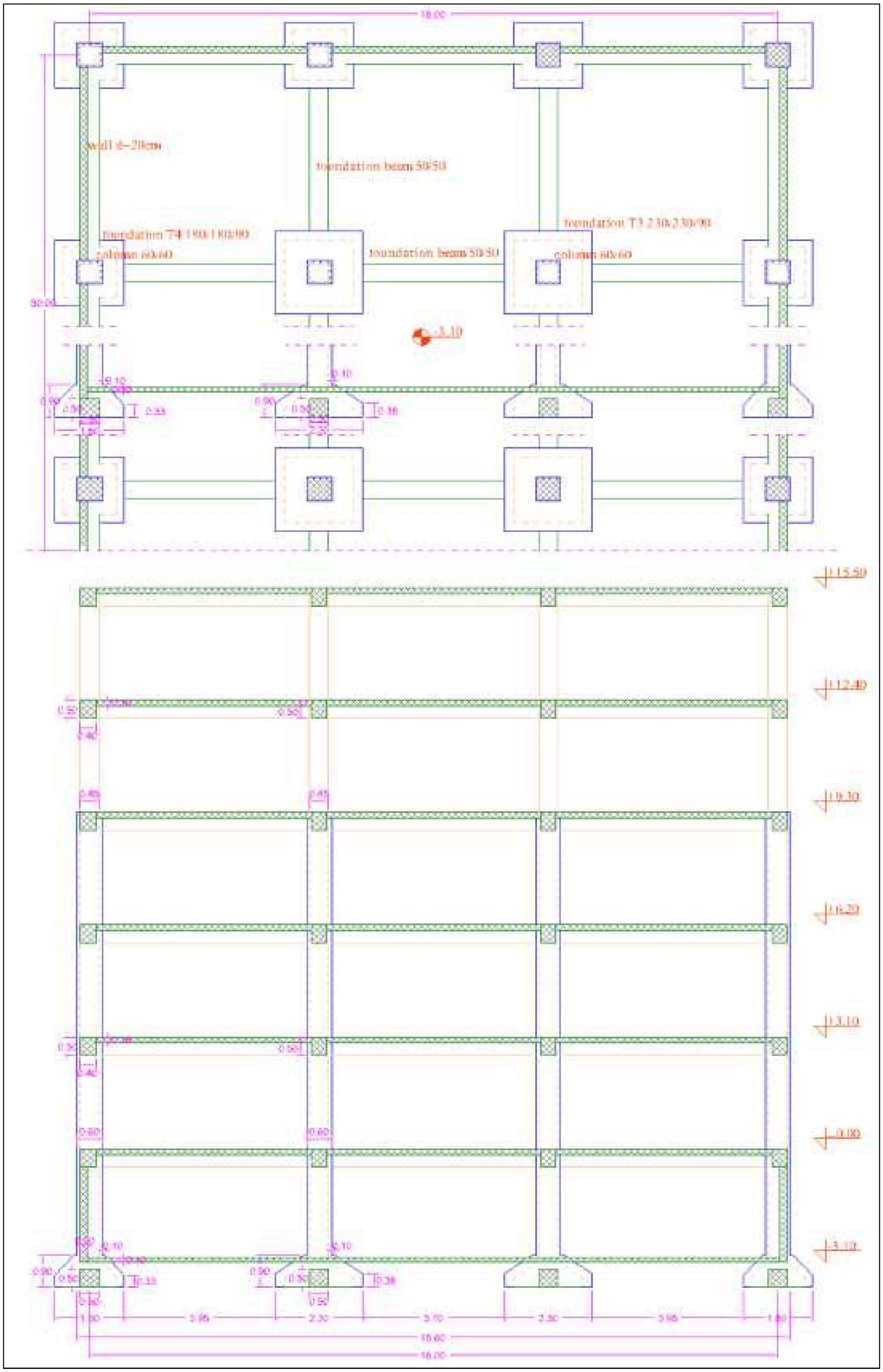
wall d=20cm
foundation beam 50/50
foundation T4 180/180/90
column 60/60
foundation beam 50/50
foundation T3 230/230/90
column 60/60
-3.10
+15.50
+12.40
+9.30
+6.20
+3.10
±0.00
-3.10
1.80
3.95
2.30
3.70
2.30
3.95
1.80
19.80
18.00

Figure 2 Half of basement layout and cross section of construction 3

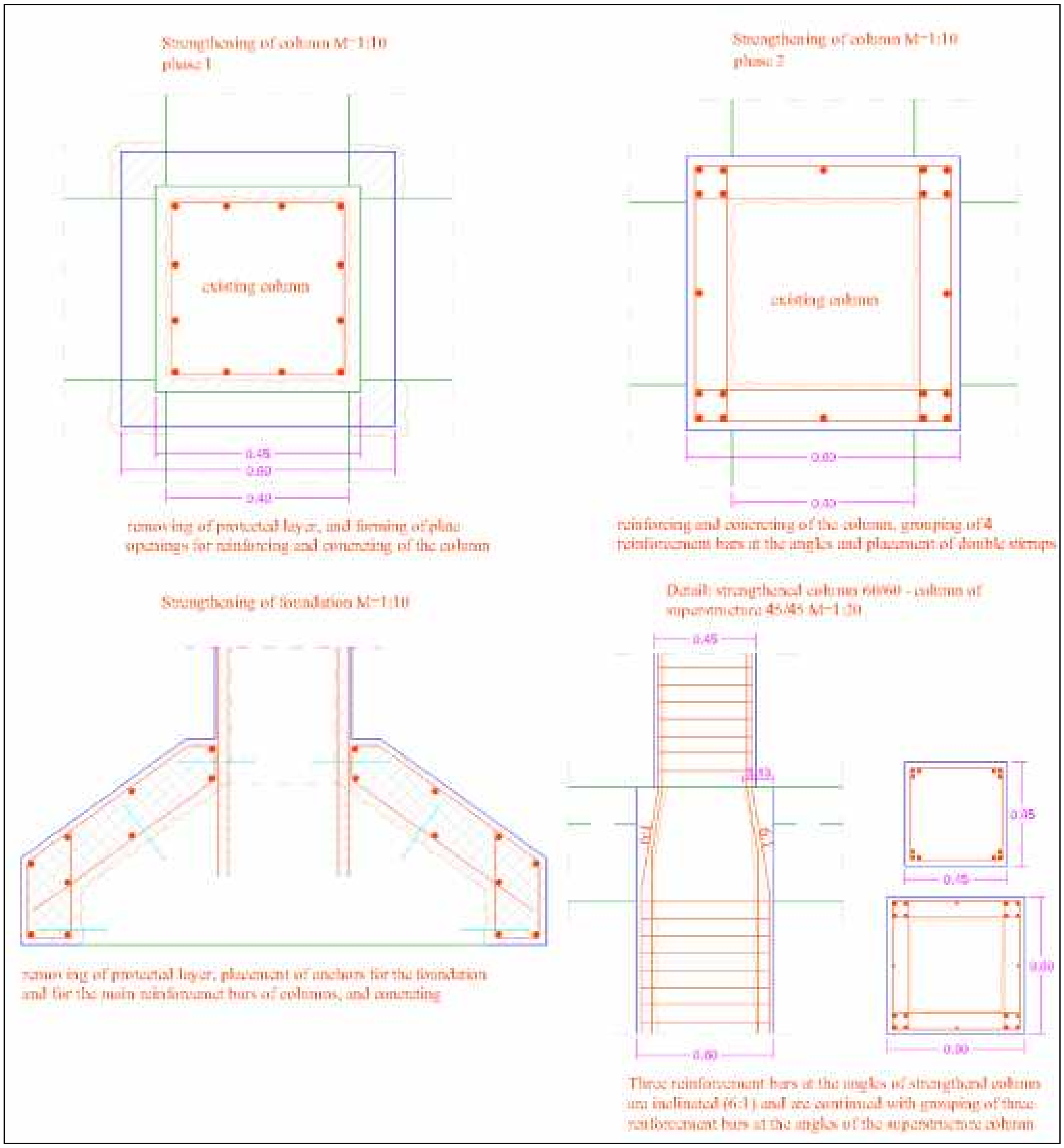

Figure 3 Strengthening details and ways for execution of the superstructure

Construction 1

In performed analysis of the construction are obtained the following results: modal period in y - direction 0,52 seconds and x - direction 0,48 seconds. Total construction weight G equals 17493,60 KN. Base reaction in y - direction equals 1556,29 KN (8,9% of G), while in x - direction 1467,65 KN (8,4% of G). Maximal top horizontal displacement of construction from combination $5=1{,}3g+1{,}5p+1{,}3s_y$ equals 1,17 cm, and is smaller than the allowable displacements $\delta=H/600=930/600=1{,}55$ cm. Maximal real soil stress from gravity loads is smaller than the allowable and equals $\sigma_{soil}=397{,}2$ KN/m^2, while maximal normal concrete stress in columns from gravity loads equals $\sigma_{column}=7{,}6$ MPa.

According to El Centro spectra, the amplification equals 0,92 g, the base reaction in y - direction 13302 KN and top horizontal displacement of construction 8,25 cm.

Construction 2

In this part it's been analyzed construction with superstructure with the same structural members as the existing construction. During designing of the superstructure it's been adopted decrease of gravity loads intensity, and used light materials for flooring and walls (ytong blocks) so as roof construction with "light" elements - wood system.

In performed analysis of the construction are obtained the following results: modal period in y - direction 0,85 seconds and x - direction 0,79 seconds. Total construction weight G equals 24762,9 KN. Base reaction in y - direction equals 1991,4 KN (8,05% of G), while in x - direction 2080,4 KN (8,4% of G). Maximal top horizontal displacement of construction from combination 5 equals 2,62 cm, and is greater than the allowable displacements δ=H/600=1550/600=2,58 cm. It is concluded that modal periods are greater than expected for this type of construction and displacements are greater than the allowable.

The columns should be designed to satisfy the requirements of the so-called "S" factor. Maximal normal concrete stress in columns is greater than the allowable and equals σ_{column}=10,57 MPa. Therefore, should be undertaken the measures to increase the cross section of columns.

Construction 3

Column dimensions of construction 3 are gained from the "S" factor. Axial force at the basement of the construction equals N=2204,74 KN, specified concrete compressive strength β_b=20,5 MPa (MB30), while σ_0 expresses the normal stress in columns.

$$\sigma_0 \leq 0{,}35 \times \beta_b \qquad (2)$$

Therefore, for the column dimensions is gained a/a=56/56 cm. The minimal expansion on one side of the column should equal 7,5 cm, because of the execution reasons. Hence, for the column dimensions are adopted a/a=60/60 cm.

Foundation dimensions are gained from the relation of axial force and soil bearing capacity, while the foundation height from the penetration condition. The adopted dimensions are: middle foundation a/a/h=230/230/90 and end foundation a/a/h=180/180/90.

In performed analysis of the construction are obtained the following results: modal period in y - direction 0,73 seconds and x - direction 0,67 seconds. Total construction weight G equals 25934,70 KN. Base reaction in y - direction equals 2335,91 KN (9,01% of G), while in x - direction 2326,17 KN (8,97% of G). Maximal top horizontal displacement of construction from combination 5 equals 2,34 cm, and is smaller than the allowable displacements δ=H/600=1550/600=2,58 cm. Maximal real soil stress from gravity loads is approximately equal than the allowable σ_{soil}=406,77 KN/m^2, while maximal normal concrete stress in columns from gravity loads equals σ_{column}=6,80 MPa and it satisfies the “S” factor requirements.

According to El Centro spectra, the amplification equals 0,46 g, the base reaction in y - direction 11492 KN and top horizontal displacement of construction 8,72 cm.

The objective of this analysis is to verify whether the stiffness and bearing capacity of the new structural system is in condition with sufficient safety to accept the predicted loads. It is concluded that the new structural system is well selected and reacts favorably.

COMPARISION OF BEARING CAPACITY AND CONCLUSIONS

According to the executed analysis of the different structural systems is made a comparison of bearing capacity by comparing: periods, base reactions, maximal horizontal displacements and normal stress in columns. Also are shown M-Φ and M-N diagrams for column on 1-st floor and lateral displacement curves from comb. 5 and earthquake El Centro.

Table 6 Comparison of characteristic results of analyzed structural systems

			Construction 1	Construction 2	Construction 3
Modal periods	T_1	sec	0.520	0.857	0.734
	T_2	sec	0.480	0.794	0.670
	T_3	sec	0.403	0.670	0.562
Base reactions	S_y	KN	1556.29	1991.43	2335.90
	Earthquake El Centro (y)	KN	13302.29	-13933.31	-11492.44
Maximal displacements	Comb.5=1,3g+1,5p+1,3s_y	cm	1.169	2.615	2.337
	Earthquake El Centro (y)	cm	-8.252	14.385	8.725
	Elastic vertical displacement at the basement (gravity loads)	cm	0.547	0.802	0.674
Normal stress in columns (gravity loads)		MPa	7.60	10.57	6.80

After the strengthening, the construction had reduced its modal periods, maximal displacements and normal stress in columns. The objective of strengthening is to improve strength, stiffness, deformation capacity and ductility characteristics of structural members. Basic indicators for expressing structural member capacity are the diagrams M-Φ and M-N.

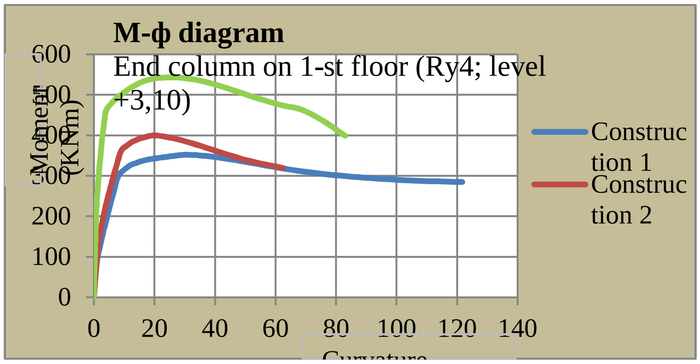

Figure 4 M-Φ diagrams for characteristic columns

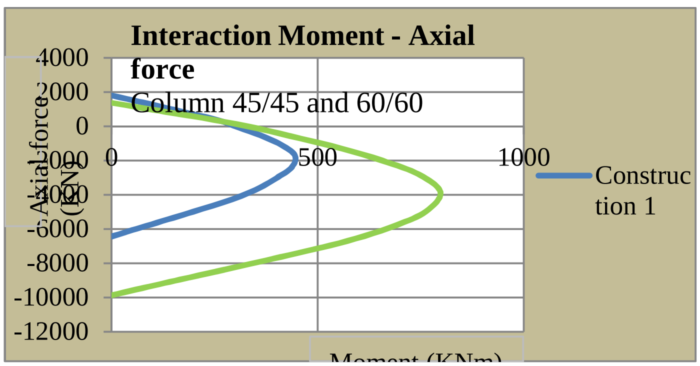

Figure 5 Interaction M-N for characteristic columns

The comparison of deformations are shown by lateral displacement curves for different load cases, combination 5 and earthquake El Centro, where it is noted an significant decrease of deformations in construction 3.

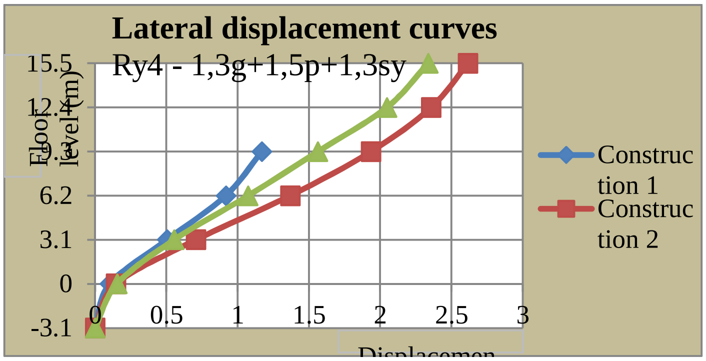

Figure 6 Lateral displacement curves - combination 5

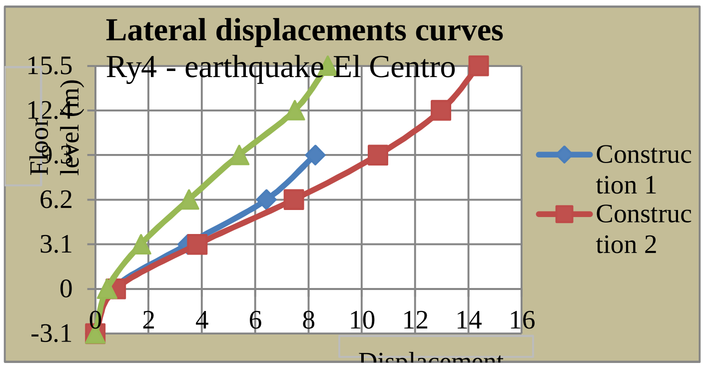

Figure 7 Lateral displacement curves - earthquake El Centro

By the analysis it's been concluded that the construction 3 had increased its capacity characteristics and possesses the required level of security for acceptance of the loads.

REFERENCES

[101] Ibraimi, Sh (2012) Dynamic analysis of existing construction and construction with superstructure. Comparison of bearing capacity, strengthening and project of concrete design, dissertation in Selected chapters of reinforced concrete constructions, postgraduate studies, Civil Engineering Faculty - Skopje

[102] Markovski, G (2011) Selected chapters of reinforced concrete constructions, lectures from postgraduate studies, Civil Engineering Faculty - Skopje

[103] Japan Concrete Institute (2007) Seismic Rehabilitation of Concrete Structures

[104] Atanasovski, S (1992) Reinforced concrete constructions I, Civil Engineering Faculty - Skopje

[105] Federal office for the environment FOEN (2008) Seismic retrofitting of structures /Strategies and collection of examples in Switzerland/