

EARTHQUAKE RESISTANT DESIGN OF TEN  
STORIED MIXED STEEL AND REINFORCED  
CONCRETE STRUCTURE WITH INFILL BRICK MASONRY

by

Miodrag Velkov<sup>I</sup> and Boris Simeonov<sup>II</sup>

INTRODUCTION

On the decision of the investor an architectural conception was adopted for several residential buildings 10 storey high, and steel structure applied as a main structural system. Also, it was insisted that the infill walls are light prefabricated blocks.

This conception brought about serious structural difficulties in the procedure of definition of an adequate economical solution of the main system which should provide a satisfactory earthquake resistant behaviour both of the infill walls and the whole structure, for the expected earthquake effects on that particular site.

After analyses and studies of more variant architectural solutions were carried out, a structural system consisting of steel frame structure and composite steel reinforced concrete core, was selected. The system was analysed and optimised for both static and dynamic loads, and linear and nonlinear response of structural members.

The results obtained by the analysis show that the system satisfies completely the safety and economy criteria.

Seismic Parameters

The city area of Skopje - Yugoslavia is located in a very active seismic zone of high intensity. After the disastrous earthquake of 1963, extensive engineering-seismological investigations of the region and the wider city area of Skopje were carried out. These investigations together with the results of the survey of the seismicity of the Balkan peninsula were used as a basis for definition of the earthquake parameters of the given site. In the dynamic analysis of the mathematical model of the structure, accelerograms and spectra of the two strong earthquakes: El Centro 1940, N-S component with an intensity of 100% and 70% of the actual record and Port Hueneme 1957, N-S component with an intensity  $S_v = 60$  and  $40$  cm/sec; were used as input data.

For Port Hueneme earthquake a correction on time axis was done according to the measured ground predominant period, in a ratio of  $0.35/0.5$  sec.

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<sup>I</sup> Professor, IZIIS, University "Kiril and Metodij", Skopje, Yugoslavia

<sup>II</sup> Associate Professor, IZIIS, University "Kiril and Metodij", Skopje  
Yugoslavia

## Structural Characteristics .

The optimized structural system is a frame structure in two orthogonal directions (Fig. 1). The solution of the building central part is in a form of composite steel reinforced concrete frame core. The adopted frame sections allow the system some moderate drifts and total displacement. Also, the stiffness and strength characteristics of the structural members are satisfied in a way that maximum stresses, strains and the required ductility appear in the frame beams. The nonlinear work of the reinforced concrete beams provides large energy dissipation capacity while the critical zones of the beams are confined by transversal reinforcement. The infill walls are constructed of light prefabricated brick blocks. The strength and deformation capacities of this brick masonry is rather low. In order to avoid the interaction between the main frame system and the infill walls, it was proposed that all contacts between walls and columns and the upper beam are constructed of soft elastic material 1.5 cm thick.

In this way, for relative story drifts smaller than 1.5 cm. the walls are not subjected to stresses or strains (Fig. 2).

## Mathematical Model Analysis

First, the building structure was analysed for gravity loads and earthquake forces defined according to the existing building Codes in Yugoslavia and later optimization of the structure was carried out for the dynamic excitations produced by the two previously mentioned earthquakes. Structural members were analysed for the linear and nonlinear working range of the material. The ultimate moments of beam and column sections were defined applying computer programmes which were developed by the authors following the existing Codes of Yugoslavia. In definition of bearing capacity and deformability of columns the axial force effects were taken into account, while shear effects were neglected. The elastic analysis of frames under static loads and seismic forces taken according to the Codes enabled proportioning of structural members first, and introduction of load factor which express the reserve capacity of sections for additional seismic forces as second. This load factor has shown that the first plastic hinges will occur in frame beams . The nonlinear analysis of the system is based on bilinear hysteresis diagram of horizontal load-story drift. A subasseblage method was used in steel frames for definition of occurrence sequence of plastic hinges and the complete  $Q-\Delta$  <sup>(1)</sup> relationship. For the composite steel reinforced concrete part, the diagrams were obtained from sectional curvatures at reinforcement yielding and ultimate strains of concrete (2)(3).

From the diagrams of particular structural members the bilinear story diagram was obtained, applying scheme presentation for all stories, while Fig. 3 gives a story diagram example.

Standard STRESS and TABS programmes were used in the elastic analysis of the system.

For nonlinear analysis of the mathematical model a computer programme VIBR-4 developed in IZIIS was applied.

## Results and Conclusions

Figs.4(a) and (b) gives some of the results obtained for the optimized model of the structural system.

The maximum displacement and required ductility envelopes have shown that for expected earthquake effects the system enters the nonlinear range with maximum story displacements of the fifth floor of 2.5 cm, for El Centro 1940.

The required ductility of the third and fifth floor is of a magnitude 2.4 and can be provided by the structural members used.

The infill walls stability is provided also, since it works in the linear range or slightly enters the nonlinear one.

So, applying linear and nonlinear analysis, optimization of the structural system is achieved, and the response of the building to actual earthquake effects evaluated.

## REFERENCES

1. Daniels, J., Hartley, and Lu, Le-Wu, "Plastic Subassemblage Analysis for Unbraced Frames", Journal of the Structural Division, ASCE, Vol.98, No.ST8, Aug. 1972.
2. Park, R., and Paulay, T., "Reinforced Concrete Structures", John Wiley & Sons, 1975.
3. Simeonov, B., "Study on Elasto-Plastic Properties of Composite Steel Reinforced Concrete Structures", Publication No.25, IZIIS, Skopje, 1972.



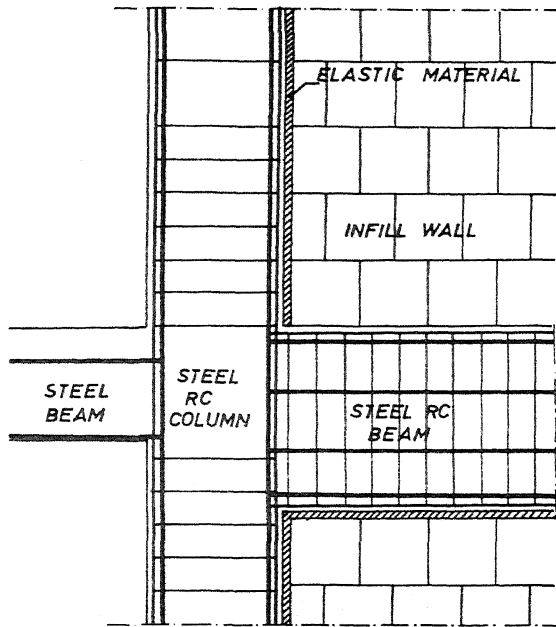


Fig. 2.

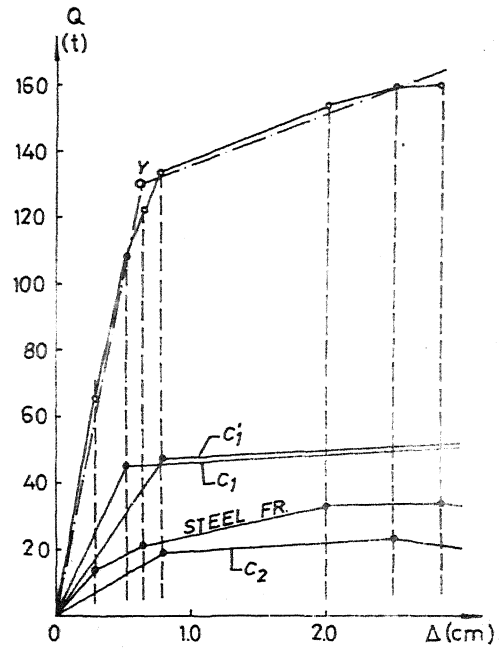
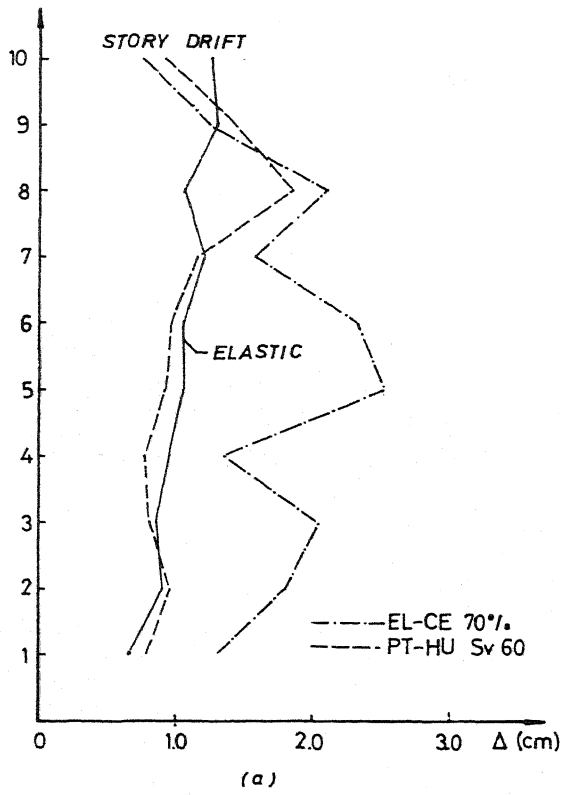
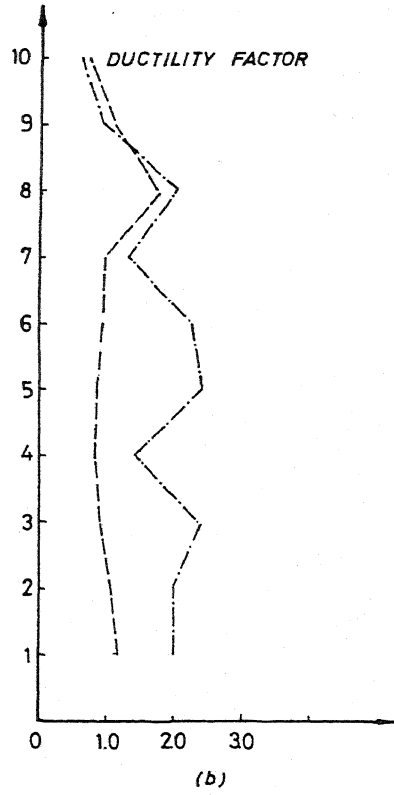


Fig. 3.



(a)



(b)

Fig. 4.