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IZIIS methodology for design, repair and strengthening of earthquake resisting masonry and RC structures

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Abstract

During the past earthquakes, we have witnessed extensive structural damage on modern high-rise buildings. The use of flat-slab or partially flat-slab system, inadequate seismic dilatation joints, occurrence of plastic hinges in columns, short columns mechanism, building additional storeys on already designed/constructed structures, inadequate transverse reinforcement in columns and beams and so on. The solution to the problem is in implementing the most recent knowledge in analysis, design and construction. The Institute of Earthquake Engineering and Engineering Seismology has established a methodology to improve the current practice procedures, enabling analysis and design of robust and economical reinforced concrete structures with controlled and conducted ductile behaviour of elements and systems in general, up to ultimate limit states of the strength and deformability. The process of designing stable and economic structures is extremely complex, due to the necessary harmonization of a series of parameters related to the construction on one hand and its response to actual earthquakes on the other.

The methodology and the dynamic response of real reinforced concrete buildings is presented here, through block diagrams and results from analysed examples. The reinforced concrete structures are designed with controlled and dictated ductile behaviour of the structural elements and the structure as a whole, for gravity/static loads and also for seismic/dynamic impacts that are expected for the defined location.

Key words: dynamic response, ductile behaviour, reinforced concrete structures

1 Introduction

The methodology of analysis, design, construction and control of stable masonry and reinforced concrete structures with controlled and dictated behaviour under gravity and seismic effects has been developing continuously since the nineties of the last century. The engineers recognized the need for controlled dynamic response of newly designed structures so that a major part of the designed and constructed structures are with optimized strength and deformability under seismic effects expected on the considered sites.

With the break-up of Yugoslavia and privatization of large construction companies, there have occurred a number of inconsistencies in organization, staff competency and staff availability, for both analysis and design and even more so for realization and control of construction. In addition to this, insufficient control of quality of materials, mainly cement, concrete and reinforcement was common.

The practice of design of controlled dynamic response was effectively stopped. Only IZIIS has been consistently applying modern practices and knowledge, but only in a small number of structures in which it has been involved in the design process.

Due to a lack of continuity in the training of young engineers, by the more experienced engineers, a gap of knowledge appears, in designing earthquake resistant structures. Also, the occurrence of modern software packages that are relatively accessible for use, but utterly unfavourable if a structure is improperly positioned, referring mainly to dimensions and ratios between dimensions of slabs, beams, columns and foundations.

On the other hand, the obligation imposed to institutions and engineering staff by legal technical regulations regarding their contribution to protection of occupants of structures against earthquakes seems to have been forgotten.

Damages and failure of modern buildings during recent earthquakes have shown all the weaknesses due to inconsistent observation of modern knowledge of analysis, design and construction of earthquake resistant structures.

Figure 1. a); b) Failure of modern buildings during recent earthquakes

Most frequently constructed and designed are reinforced concrete structures, frame reinforced concrete structures, reinforced concrete structures with shear walls and prefabricated large panel structures. As recent earthquakes have shown, most vulnerable are stone masonry structures and masonry structures with solid brick with or without horizontal and vertical reinforced concrete belts, and most of the existing structures in our regions are of this type.

2 IZIIS Methodology for design and analysis of new structures as well as repair and strengthening of damaged or non-damaged masonry and reinforced concrete structures

Based on the performed synthesis of results from analytical and experimental investigations of elements of masonry systems and reinforced concrete structures in the world and in our country, IZIIS has proposed and developed a procedure for design and analysis of new structures as well as repair and strengthening of damaged masonry systems and reinforced concrete structures exposed to static and dynamic effects.

State of the art knowledge for designing and constructing, stable and economically justified structural systems, point out that the current practice and regulations do not provide sufficient analysis and checks to achieve the desired goal, controlled and dictated ductile structural behaviour of the structural elements and the system as a whole.

IZIIS has established a methodology to improve the current practice procedures, enabling analysis and design of robust and economical masonry and reinforced concrete structures with controlled and conducted ductile behaviour of elements and systems in general, up to ultimate limit states of the strength and deformability. The process of designing stable and economic structures is extremely complex, due to the necessary harmonization of a series of parameters related to the construction on one hand and its response to actual earthquakes on the other.

The methodology and the dynamic response of real reinforced concrete buildings is presented here, through flow chart shown in Figure 2.

As an example to explain the methodology, here presented are prefabricated large panel reinforced concrete structures, due to their complex behaviour under seismic effects. The purpose of the methodology is to design structural elements with controlled and dictated ductile behaviour up to ultimate states (Figure 3).

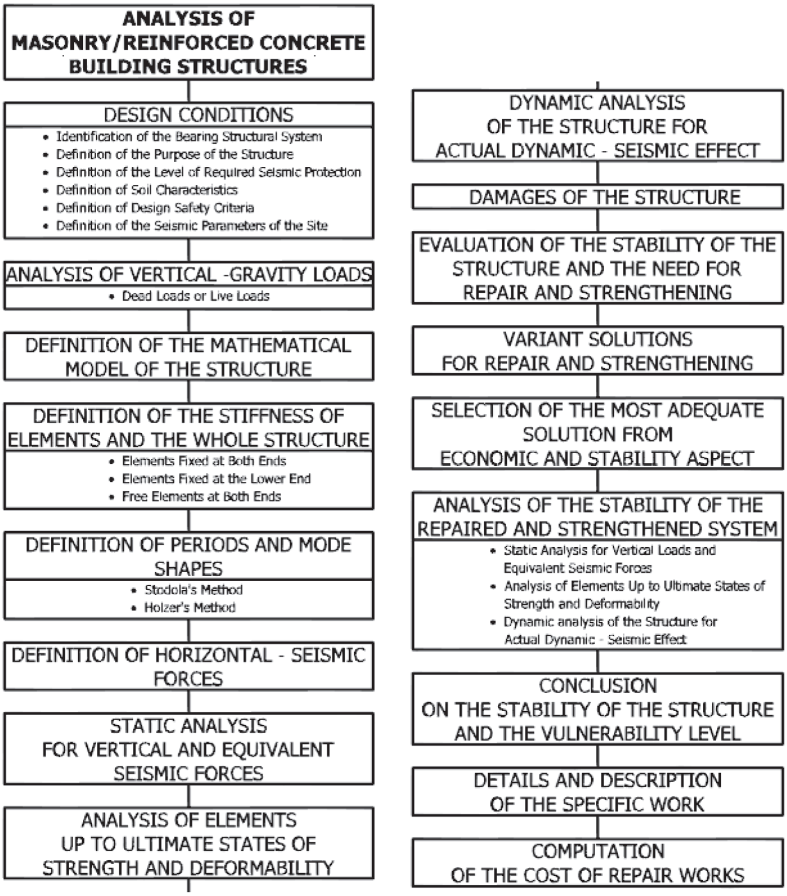

Figure 2. Flow chart of proposed procedure

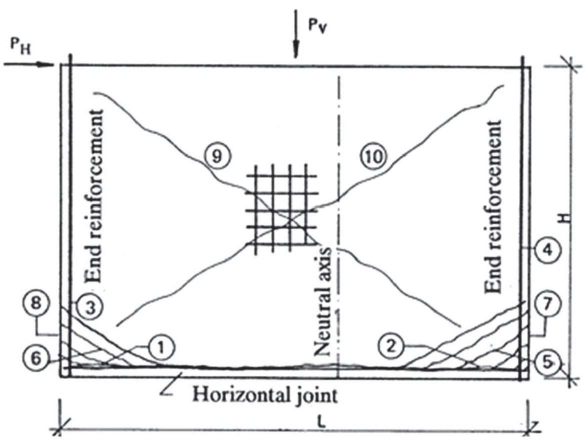

Figure 3. Ductile mechanism of behaviour of panel/wall

The proposed mathematical relationship, through a polygonal strength - deformability diagram provides the possibility to include all the phases of the mechanism of behaviour during the creation and the opening of cracks, yielding of the main reinforcement, crushing of concrete in the compressed part of the joint with more or less sliding along the length of the horizontal or the vertical joint up to complete failure mechanism (Figure 4).

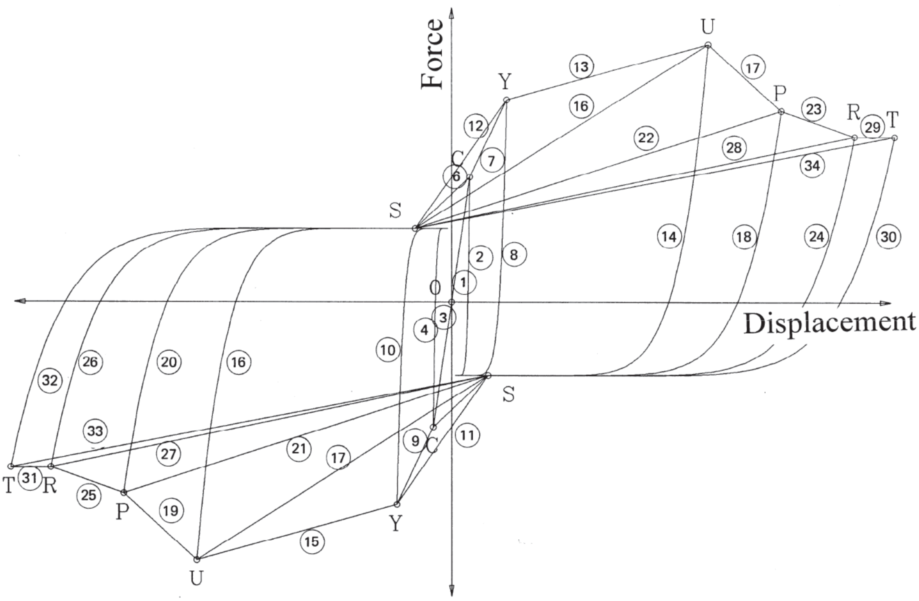

Figure 4. "BOZINOVSKI" hysteretic model P - δ

With the proposed polygonal diagram, the effect of initial stiffness, the effect of stiffness deterioration depending on deformation and number of cycles, the effect of stiffness and deformability in reversible cyclic loading and finally the effect of sliding at each loading cycle could be considered.

3 Example

Characteristic large panel structure (Figure 5) has been selected to demonstrate the proposed procedure. Figures 6 to 10 show some final results from the analysis.

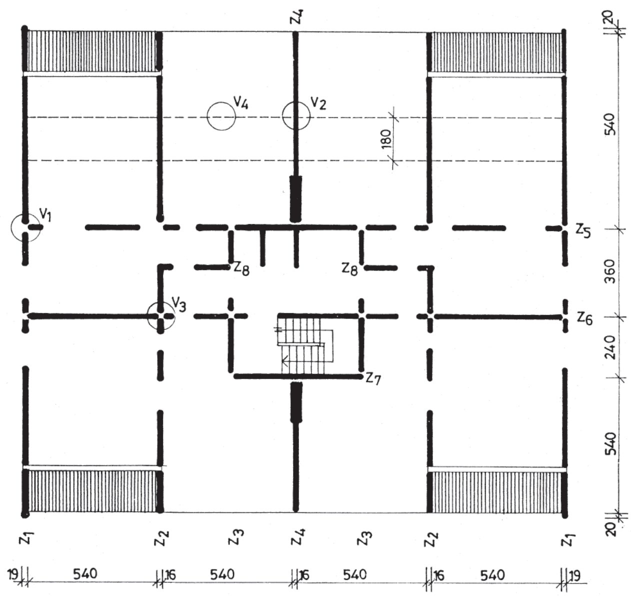

Figure 5. Layout of the three-story panel structure

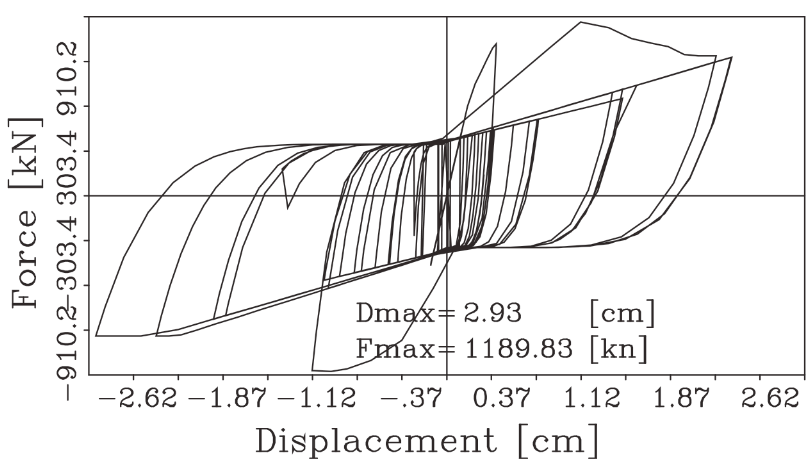

Figure 6. Structural system response for a_{max} = 0.427g(Petrovac N-S), Storey 2. P - d diagram

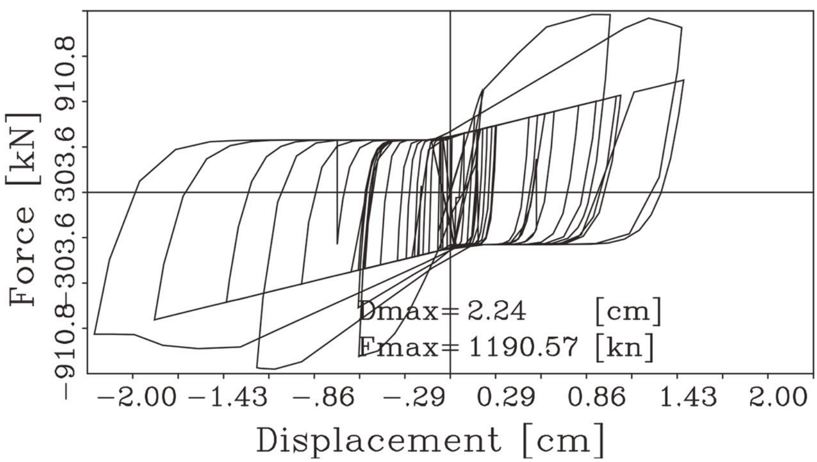

Figure 7. Structural system response for a_{max} = 0.336g(Petrovac N-S), Storey 2. P - d diagram

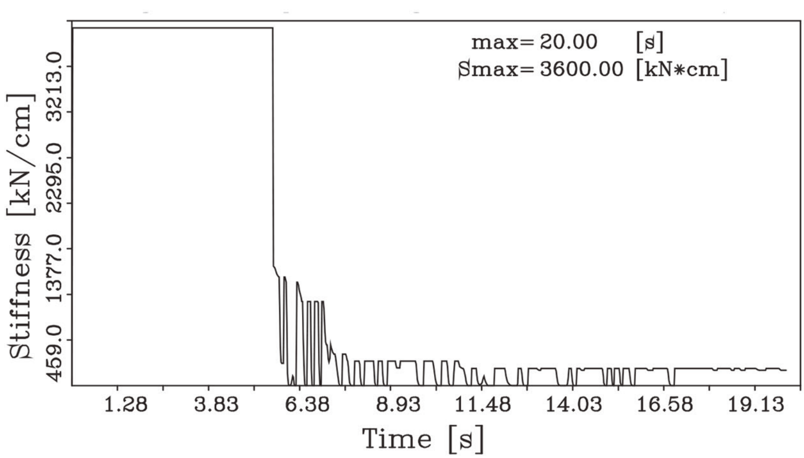

Figure 8. Structural system response for a_{max} = 0.427g(Petrovac N-S), Storey 1. St - t diagram

Most frequently the structures are subjected to foreshock and main shock (Figure 9), so the procedure enables to obtain dynamic response of the structure for several earthquakes in order to show degradation of the stiffness and strength parameters. Fig. 10 and 11 show the results from the analyses for the chosen earthquake.

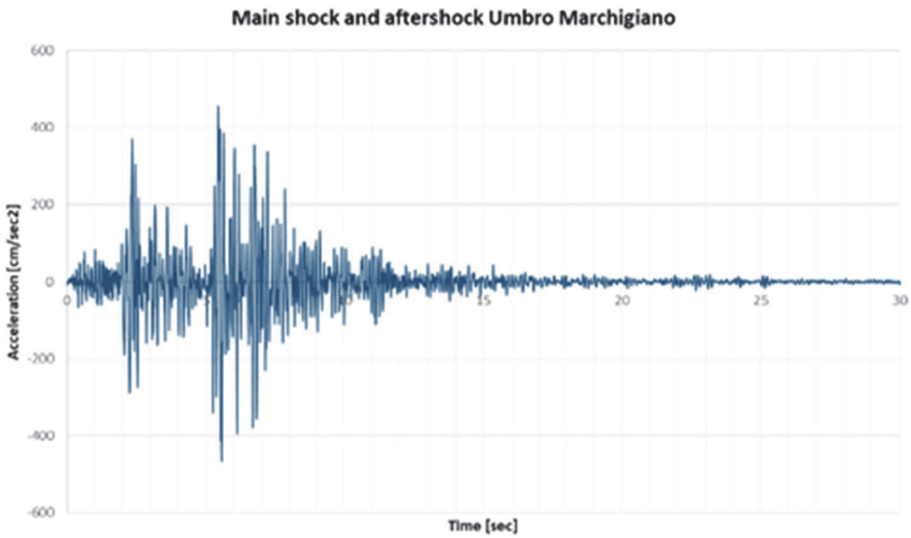

Figure 9. Main shock and aftershock Umbro Marchigiano, time - history

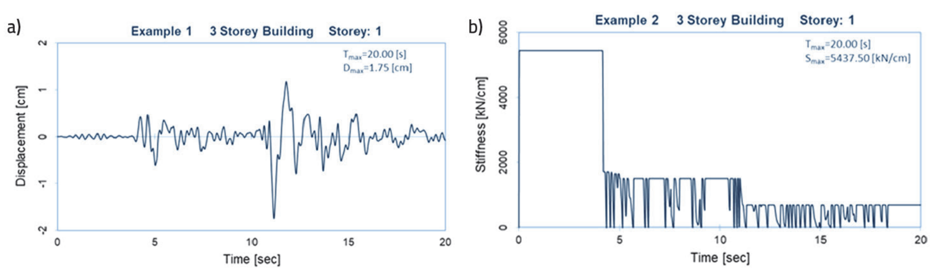

Figure 10. Structural response: a) time - displacement; b) time - stiffness,

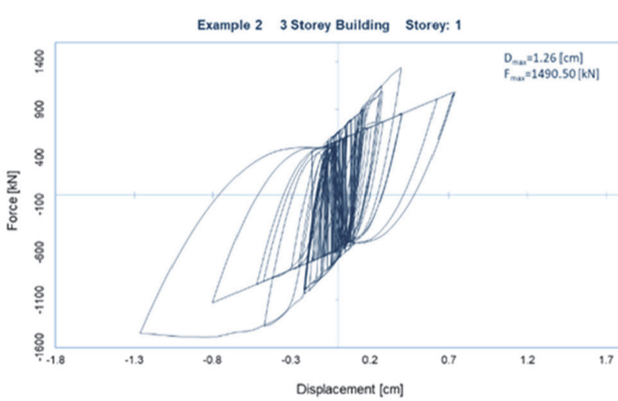

Figure 11. Structural response Force - Displacement

4 Contribution to the methodology for analysis, design, construction and control of stable reinforced concrete structures with controlled and dictated behaviour under gravity and seismic effects

Motivated by the manifested damages and failure of modern high rise RC structures, in addition to analyses that have so far been performed, two characteristic RC structures designed and constructed by different design firms, contractors and producers of concrete and reinforcement, has been analysed.

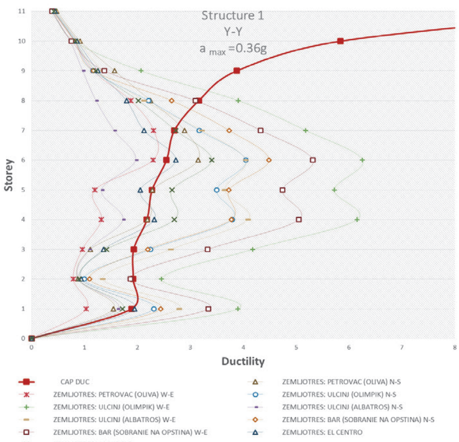

Figure 12. Structural response Storey - Ductility

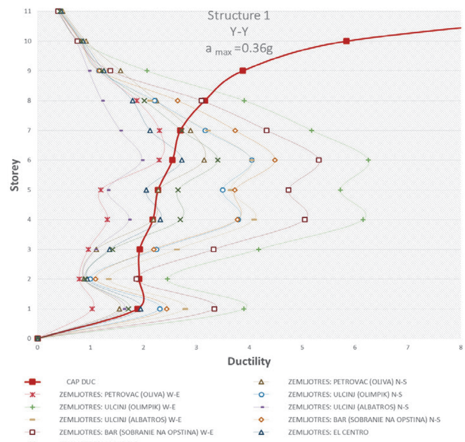

Figure 13. Structural response Storey - Ductility

The results from the analyses show that the structure with more acceptable dimensions of columns and walls and more acceptable concrete classes achieved during construction, exhibited a considerably more favourable behaviour referring to both strength and deformability capacity and dynamic response to real seismic effects. In addition, it is generally concluded that both structures do not completely satisfy the criteria referring to controlled and dictated dynamic response (Figures 12 and 13).

5 Conclusions

In conclusion, we consider that it is necessary that the engineers and the competent institutions recognize the need for explicit realization of the methodology for analysis, design, construction and control of stable RC structures with controlled and dictated ductile behaviour of elements and entire structural systems under external gravity/static and seismic/dynamic effects expected at the considered sites, with intensity and frequency content.

The results from the analyses show that the structure with more acceptable dimensions of columns and walls and more acceptable concrete classes achieved during construction, exhibited a considerably more favourable behaviour referring to both strength and deformability capacity and dynamic response to real seismic effects. In addition, it is generally concluded that both structures do not completely satisfy the criteria referring to controlled and dictated dynamic response.

Based on performed analytical and experimental tests on RC structural systems, modern knowledge and manifested unfavourable behaviour of structures during recent earthquakes, we consider that it is necessary to emphasize, once again, the key moments in the process of design and construction and amend the procedure with an additional step: analysis of stability of the constructed structure. The analysis could be done based on constructed elements with cross-section, reinforcement, quality of concrete and built-in reinforcement. The analysis will define, the stability of a constructed structure and the level of its vulnerability. Depending on the vulnerability of the structure, the constructed structure will be either accepted or structurally improved. It is the best if this phase is done as early as in the process of construction or upon the finishing of the structural part, prior to proceeding with the remaining phases.

The analyses show that it is of a great importance to optimize structures based on dynamic response in the process of design and control dynamic response based on constructed structural elements and integral systems. We are continuing with analysis of a numerous structures, in order to diagnose the weak steps in the process of design and construction and verify the knowledge that has been gained so far.

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