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Raising the level of seismic protection of existing RC structures in seismically active regions

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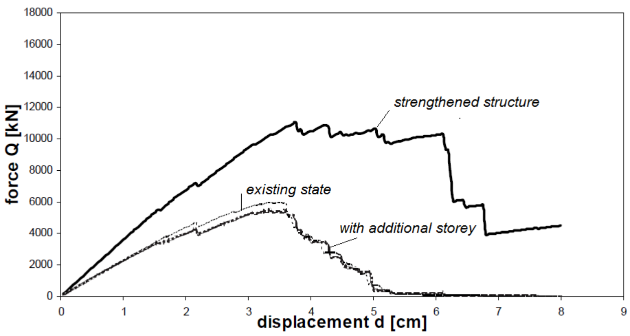
ABSTRACT



RC structural systems appeared in practice after 1950, but with relatively weak and non-earthquake resistant structural elements. Modern RC systems started to be built after 1980. With the coming into effect of modern regulations, there arises the need for raising the level of seismic protection of existing RC structures that are not seismically built. The procedure for analysis and design is similar to the procedure for analysis and design of masonry buildings. For the RC elements, there is a more sophisticated method for definition of the capacity of strength, stiffness and deformability as well as definition of characteristic points in the P-δ working diagram.

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1. Introduction

Design of structures in seismically active regions is done according to strictly defined legal regulations. There is an essential difference between structures of the first category and structures of the 2 – 3 category. For structures of the first category, the equivalent seismic forces are defined on the basis of an optimized structure through the dynamic response of the structure to the defined seismic parameters of the considered location and selected actual earthquake records, for the adopted safety criteria. For the purpose of clarification, we are presenting a few articles of the Rulebook on Technical Norms for Construction of High-rises in Seismically Active Areas related to design and construction of structures in the category to which important buildings also belong as well as some more precise criteria depending on the level of the seismic effect. Article 7 ("Official Register of SFRY", no. 29/83): "For design of structures classified in the I category, the coefficient of the seismic intensity and other parameters must be defined previously, with special investigations for seismic zoning of the construction areas"[1-8].

1.1. Seismic parameters of the site and seismic safety criteria

In practice, given the seismic parameters of a site, the safety of a structure is defined through linear and nonlinear deformations under different levels of seismic effects. The development of nonlinear mechanisms within the structural system leads to enormous increase of deformations wherefore the level of seismic activity is defined as a seismic risk related to ultimate deformations of the principal structural system:

Level I: Under a seismic effect of a low intensity, i.e., earthquakes that occur more frequently. This corresponds to expected earthquakes with a return period of 50 years. The relative storey displacement is within $\delta \leq h/300$ and required ductility is $1< \mu <1.5$;

Level II: Under strong earthquakes, the so called design earthquake level, the system behaves in the non-linear range where moderate nonlinear deformations of the elements and the entire system are allowed. This corresponds to expected earthquakes with a return period of 100 years. The relative storey displacement is within $\delta \leq h/150$ and required ductility is $1.5< \mu <2.5$; Level III: Nonlinear behaviour of the system (maximum expected earthquake). This corresponds to expected earthquakes with a return period of 200-500 years. The relative storey displacement is within $\delta \leq h/100$ and required ductility is $2.5< \mu <4$. [9, 10]

For such defined ground acceleration intensities, selected records of actual earthquakes depending on potential foci of near and far earthquakes, optimization of the bearing structural system is performed on the basis of the dynamic response of the structure to actual seismic effects, with intensity and frequency content. As a result, equivalent seismic forces are defined at plan and along height of the structure. For such defined equivalent seismic forces, in combination with vertical dead and life loads, proportioning of the structural elements is carried out [11-15].

1.2. Procedure of analysis and design

Based on numerous and complex investigations within the frames of the Balkan project UNDP/ UNIDO PROJECT RER /79/015, with participation of all Balkan countries, a procedure for analysis and design of existing structures was defined. The procedure for analysis and design of existing structures, particularly when adaptation, reconstruction, enlargement, building of additional storey, strengthening and revitalization is being carried out for a structure at the same time. The capacity of strength, stiffness, deformability and ability of the elements to dissipate seismic energy is analyzed. Based on the defined seismic parameters at the considered site at which earthquakes with defined intensity and frequency content are expected, the dynamic response of the structure to actual seismic effects is defined. Defined by this analysis are the required strengths, stiffnesses and particularly deformability of the bearing structural system. The analysis for definition of the capacity of the structure and its response to actual seismic effects is done first for the existing one and then for the adapted, reconstructed, enlarged, with additionally built storey, strengthened and revitalized state of the structure. Comparing the required strength-deformation characteristics of the structure in respect to the capacity possessed by the existing structural elements, the need for strengthening of the structure is defined. Out of the numerous variant solutions, the most appropriate from the aspect of stability, economy and possibility for realization, is selected. A complete analysis of the stability of the adapted, reconstructed, enlarged, with additionally built storeys, strengthened and revitalized state of the structure is carried out. In addition to the standard reinforcing details and specification of the material, as-built details for characteristic positions are more specifically defined [16, 17].

1.3. Realization of work

In the course of hand over of the works, a number of irregularities were observed. These are generally reduced to the following: Inappropriate performance of the works on jacketing of both columns and beams. There are non-cast-in-place grooves in the concrete both at the nodes and the open parts of the columns and the beams; Non-provided anchorage of the reinforcement of the columns along the height of the structure; Inappropriate installation of the reinforcement in the beams. Namely not enough anchorage length is provided; The nodes as critical elements and the space around the nodes are not monolith. These are often with non-cast-in-place parts, segregated concrete and a large percentage of voids.

1.4. Methodology of analysis and design of structures

Design of new masonry and RC structures or repair and/or strengthening of existing masonry and RC structures is done by satisfying the requirements of the valid technical regulations, based on the most recent knowledge on seismic design and behavior of this type of structures, controlling the strength, stiffness, deformability and capability of seismic energy dissipation of the bearing elements and the system as a whole. Based on the performed synthesis of results from analytical and experimental investigations of elements of masonry and RC systems in the world and in our country, proposed is a procedure for design and analysis of new structures as well as repair and strengthening of damaged masonry systems exposed to static and dynamic effects.

2. Analysis of the structure

For the structural elements with geometric characteristics, characteristics of materials and position in the structure, analysis of the elements is done and hence analysis of the structure is performed up to ultimate states of strength and deformability. Involved in the analysis are several types of elements characteristic for masonry structures. For several types of walls, as are stone walls, brick walls, stone or brick walls with reinforced-concrete jackets, framed brick masonry with reinforced concrete vertical and horizontal belt courses and stone walls with a concrete coating, there is a simple, but sufficiently exact way of determining the strength and stiffness capacities in the linear range of behavior. The deformations in the same range are defined by the linear strength - stiffness relationship. This way of defining the ultimate states is not sufficiently exact for the reinforced-concrete elements as are columns and walls due to the impossibility of controlling the failure mechanism, particularly from the aspect of defining the deformation at which it occurs. Generally, for all possible elements occurring in the masonry structures, analysis of strength capacity can be done in the simple way of defining strength and stiffness capacity, whereas care should be taken as to deformability, knowing its importance for the behavior of the structure under an earthquake. Considering the complicated behavior of reinforced-concrete elements, a more precise way of determining their ultimate strength and deformability value is given, with control of the mechanism of behavior from the beginning of loading up to failure. This is important because we are often forced to define simultaneously the ultimate states of masonry and reinforced-concrete elements so that, by their superposition, one arrives at storey strength, stiffness and deformability capacities in both the orthogonal directions of the structure.

3. Evaluation of the stability and the need for strengthening

Based on the analysis of the existing state of the building structure and damages to the structure, the elements of occurred damages and the reason of occurred damages are defined. Such considerations are important for selection of possible and necessary measures for repair and strengthening of the structural system. The strength and deformability capacities of the bearing elements and the system as a whole are compared to those required (according to the regulations) and those required for the analyzed structural response under expected earthquakes on the considered site, with intensity and frequency content. If the strength and the deformability capacity is less than the required, it is concluded that the building structure does not have sufficient strength and deformability and therefore it needs repair and strengthening. Each concrete structure is a case for itself and there are several ways of repairing and strengthening it. The solution for repair and/or strengthening depends on: seismicity of the site, local soil conditions, type and age of the structure, level and type of damages, time available for repair and/or strengthening, equipment and man power, restoration and architectural conditions and requirements, economic criteria and necessary seismic safety. Selected are several variant solutions for repair and strengthening [18]. Analysis of each solution is done and an insight into the advantages and disadvantages is obtained from several aspects. Out of these, selected is the most adequate solution from the economic aspect and the stability aspect according to the required seismic protection. Generally, some possible ways of repair and strengthening of different types of masonry elements and buildings is given in the subsequent text. Out of several analyzed possible solutions for repair and strengthening of the main structural system, selected is the most favorable from the aspect of: stability, i.e., fulfillment of the design criteria according to regulations, possibility for realization of the solution, available materials, economic justification, and fulfillment of social requirements and satisfying of aesthetic requirements [19, 20].

4. The parliament building of the Republic of Macedonia

The Parliament Building of the Republic of Macedonia is more than 70 year old. Throughout its existence, a lot of changes, enlargements and adaptations of this building have been done. As a historic building, it is protected by the Law on Protection of Cultural Heritage. Within the project on Enlargement, Building of Another Storey and Adaptation of the Building, the necessity for increasing the seismic safety of main structural system has been defined. Based on the prescribed requirements in the valid technical regulations, the performed investigations and analyses as well as the knowledge on behavior of this type of buildings in seismic regions, the strengthening solution has been defined to improve the integrity and the seismic stability of the structure. The process of strengthening of the structural system of the Parliament Building started in April 2010 and is being carried out quite successfully despite a number of limitations. The principal structural system of the structure consists of massive walls in two orthogonal directions, carefully distributed but with lower presence of bearing walls in transverse direction. The walls at the basement are made of concrete with a thickness of 70 cm, while at the ground floor and the two storeys, they are constructed of solid bricks in lime mortar and proportioned 51 cm, 51 cm and 38 cm, respectively. The floor and the roof structure represent monolith reinforced concrete fine ribbed floor structures. In all the individual units of the building, there are four longitudinal walls of identical thickness, while the bearing walls in transverse direction are regularly situated at the corners of the building and occasionally along the length of the unit. At all the corners of the structure, the dimension of the walls is increased, while there are visible columns along the line of one of the internal walls in the middle and at the end of the units. From the main entrance, there continues the Main Hall (Hall 1) as a constituent part of the original structure representing a reinforced concrete frame structure with a solid brick infill (figure 1).

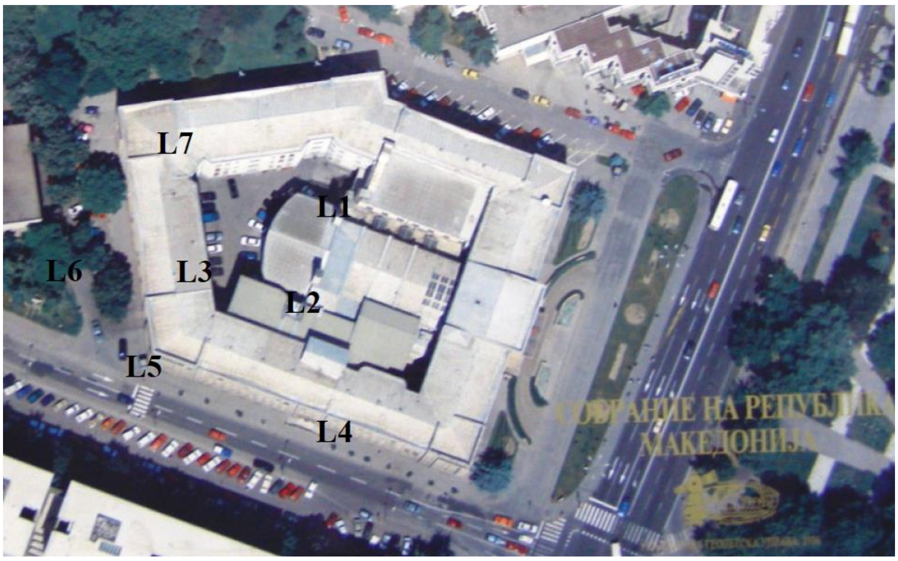

Figure 1. Individual structural units of the building (Units L1 – L7)

4.1. Analysis of the structure in conditions of being strengthened

Analysis of the strength and deformability of the elements and the system as a whole has been made up to ultimate states of strength and deformability for each unit taken separately. Comparative force-displacement storey diagrams for the three analyzed conditions (existing, with additional storey and strengthened structure) for selected units where one can get a very clear insight into the effect of the selected strengthening solution are shown on figure 2. The presented characteristic results obtained for the ground floor level per directions and units point to a considerable increase of both the bearing and deformability capacity of the system.

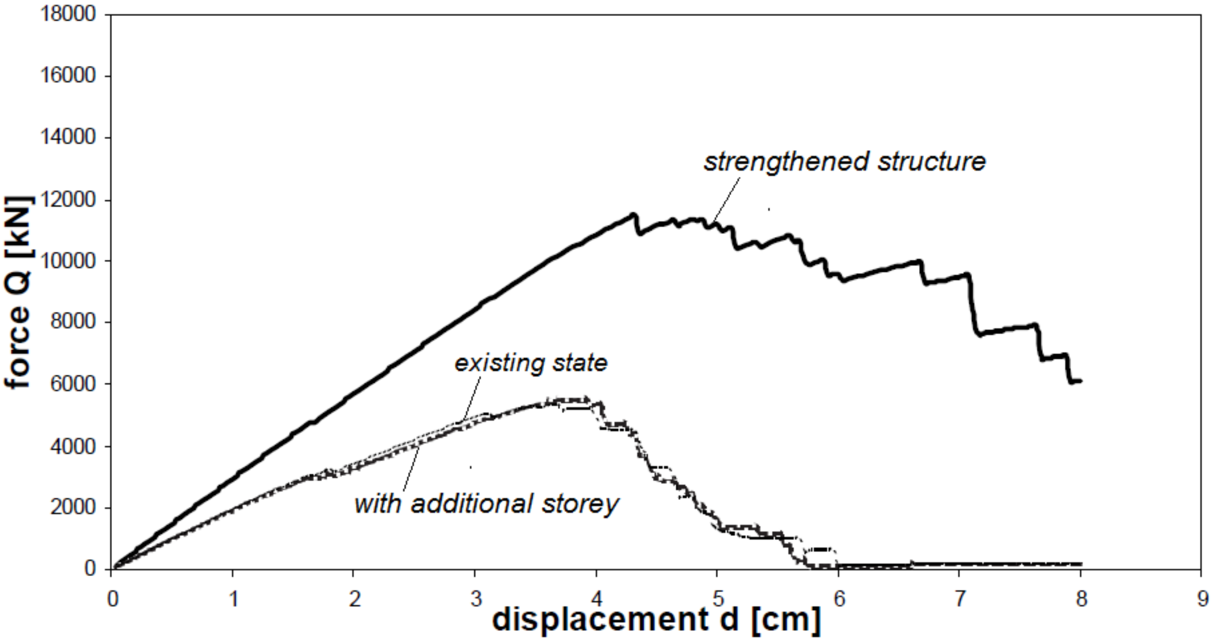

Figure 2. Unit 5, X-X direction ground floor. Comparative Q-d diagrams for characteristic units

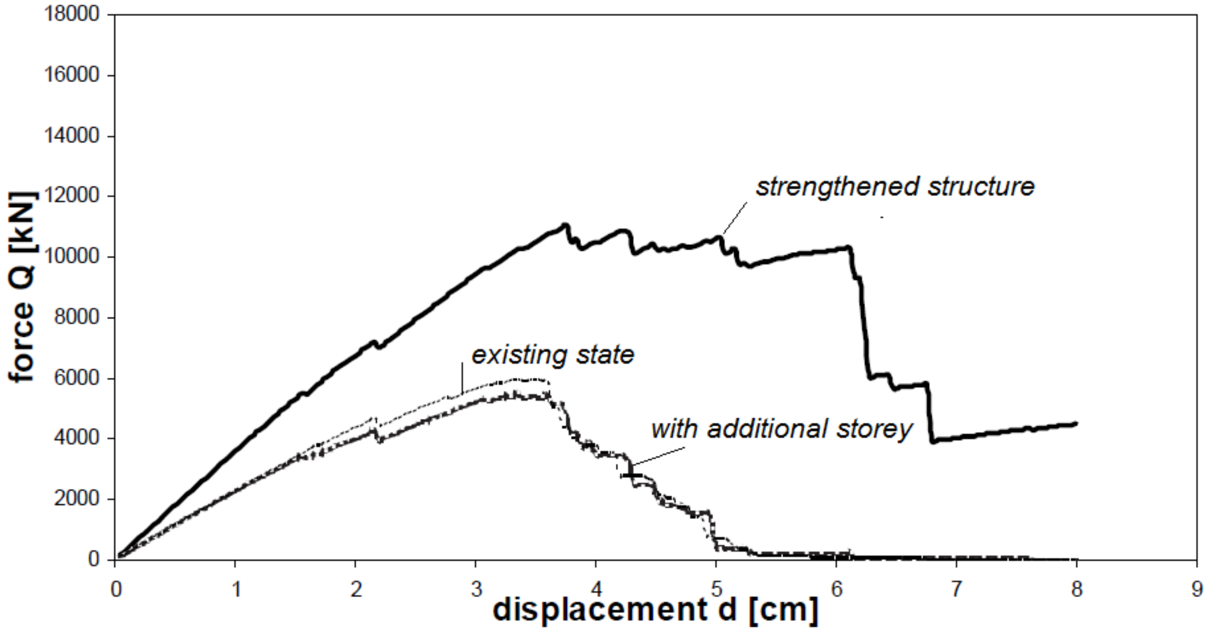

Figure 3. Unit 5, Y-Y direction ground floor. Comparative Q-d diagrams for characteristic units

5. The GENERAL HOSPITAL - OHRID

The structure within the public health institution GENERAL HOSPITAL-OHRID housing the surgical, gynecological, and obstetrical and ORL departments was built in the beginning of the seventies of the last century. Based on analysis of variant structural solutions for strengthening of each structural unit individually, the most appropriate, from the aspect of stability and economy, technical solution for strengthening was selected. This solution satisfies the strength and deformation requirements according to the valid technical regulations and includes the possibility of adding new elements to the existing structure. The results from the performed analyses show that, with the selected technical solution for strengthening of the bearing structural system and the building as a whole, the existing structural system with the strengthening elements was optimized, the dynamic response was harmonized through corresponding selection of elements that increase the capacity of strength, stiffness, deformability and ability for dissipation of seismic energy that led to an increase of integrity and stability of the structure as a whole under seismic effects that are expected on the considered location (Figure 3).

Figure 4. Existing State of the Unit 2

5.1. Technical solution for strengthening of the existing (partially strengthened) building structure

Based on the results from the static analysis, analysis of the elements up to the ultimate states of strength, stiffness and deformability, as well as based on analysis of the dynamic response of the structure for the defined seismic parameters, it was concluded that it was necessary to increase the capacity of strength and stiffness of the structure to achieve the seismic resistance and stability required for it as a structure of the first category. Considering the present, partially strengthened state of Unit 1 and Unit 2, a number of variant solutions for strengthening of the structure were proposed and analyzed. For each variant solution, analysis of the structure was carried out for both orthogonal directions and the strength and deformability capacities of the structure were compared with those required by the regulations. In selecting the most appropriate technical solution of strengthening, care was taken to achieve optimal strength, stiffness and deformability by minimal interventions.

6. Conclusions

Based on the strength and deformability capacities of the bearing elements and the structure as a whole and on the basis of required strength and deformability for expected seismic effects with intensity and frequency content, conclusions are drawn regarding the stability of the structure and its vulnerability level. It is of exceptional importance to bring the strength, stiffness and deformability of the structure within the frames of the requirements according to the valid technical regulations and latest knowledge on the behavior of masonry structures exposed to gravity and seismic effects.

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Повышение уровня сейсмической защиты существующих RC структур в сейсмически активных регионах

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Информация о статье	История	Ключевые слова
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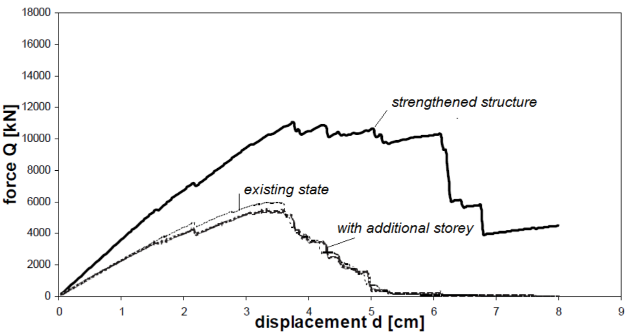
АННОТАЦИЯ



RC - структурные системы появились в строительной практике в 1950-х года, но с относительно слабыми и не сейсмостойкими конструктивными элементами. Современные RC системы начали использоваться после 1980 года. Со вступлением в силу современных правил, возникает необходимость повышения уровня сейсмической защиты существующих RC структур. Процедура анализа и проектирования аналогична методике возведения конструкции кирпичной кладки зданий. Однако для элементов RC существует более сложный метод для определения прочности, жесткости и деформативности, а также для определения характерных точек в рабочей схеме P-δ.

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