Seismic Strengthening of the Parliament Building of Republic of Macedonia: Necessity, Solution and Construction

Z. Bozinovski, V. Shendova, G, Necevska Cvetnovska, R. Apostolska, E. Gjorgjievska & G. Jekic
Institute of Earthquake Engineering and Engineering Seismology, (IZIIS)
"Ss. Cyril and Methodius" University, Skopje, Republic of Macedonia

SUMMARY:
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 behaviour 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.

Keywords: existing seismic stability, historic masonry structure, NDT, capacity analysis approach, strengthening

1. INTRODUCTION

For the needs of enlargement of the premises necessary for the functioning of the Parliament Building of Republic of Macedonia, (RM), a Preliminary Project on Enlargement, Building of Another Storey and Adaptation has been elaborated. Considering the fact that this structure of the highest category was built 70 years ago and was enlarged, adapted and reconstructed on several occasions, the evaluation of its existing stability has been a complex, specific and responsible task. In order to identify the bearing structural system, all the available data (technical documentation, written and photo documentation, statements by professionals) have been used and the necessary research regarding the existing conditions of the structure has been carried out. Based on preliminary analyses and in compliance with the requirements of the valid national technical regulations in the country and positive European standards, there have been defined the possibilities and the conditions for additional loads on the structure arising from the planned enlargement, building of another storey and adaptation. Within the Project on Strengthening of the Structure of the RM Parliament Building, a professional team from IZIIS, Skopje has carried out a detailed analysis of the stability of the existing bearing system, has proved the necessity of structural strengthening, has proposed and analyzed variant strengthening solutions and has selected the most adequate possible solutions for which an analysis of the stability of the strengthened structural system of the building has been performed.

2. RATIONALE ON THE NECESSITY FOR STRUCTURAL STRENGTHENING

2.1. Knowledge Acquired from the Inspected Technical Documentation

The original structure of the present Parliament Building of the Republic of Macedonia was built in the period 1936 – 1939 as a massive masonry structure in the form of an irregular pentagon with an inner courtyard (Fig. 2.1) consisting of a basement, a ground floor and two storeys.

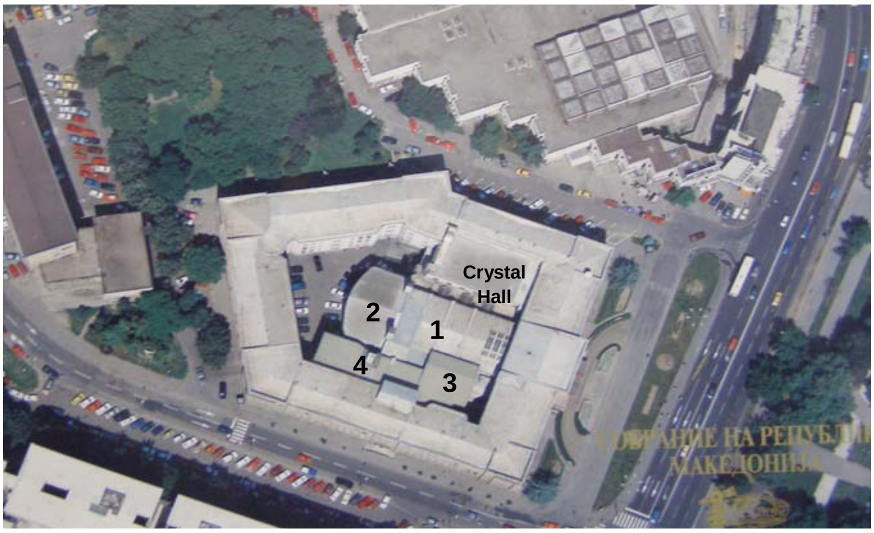

Figure 2.1. Air shot of the RM Parliament Building

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.

In 1954, the first enlargement and adaptation of the original structure were performed. Continuing from the Main Hall, Hall 2 was built as a separate reinforced concrete structure. In the same period, adaptation of the northwest and northeast corner of the structure was performed. By removal of parts of the existing masonry and incorporation of new reinforced concrete columns, the Crystal Hall (Fig. 2.1) was constructed in part of the interior courtyard. At places where the existing masonry was removed, strengthening by replacement horizontal steel profiles was done.

During the Skopje earthquake in 1963, the Parliament building structure suffered extensive damage. Complete information on the scope and intensity of damage as well as a detailed description of the applied mode of repair is given in the documentation of the CP Konstruktor company from Maribor. Although the building was in the zone suffering the most extensive damage and complete failure of structures during the earthquake, the Parliament Building suffered a large number of structural damages mostly at the ground floor. Its stability was disturbed but the damage was estimated as repairable. The repair of the building involved: injection of the bearing walls with mixtures based on cement mortar and with different fluidity depending on the crack widths; injection of concrete elements; repair of concrete elements with “prepact” procedure at parts which were crushed; rebuilding of crushed parts of bearing walls; tearing down and rebuilding of partition walls in cement lime mortar; strengthening of partition walls by complete pointing with cement lime mortar; prestressing of several walls at the first storey; strengthening of the parapet walls and repair of the damaged chimneys. Considering the extraordinary possibility for inspection and access to the principal bearing system, it is important to note what the contractor stated, namely that “sound massive brick walls in combination with concrete belt courses and columns” were at stake. During these interventions, the structure was not structurally strengthened.

Parallel with the repair of the structure, experimental laboratory tests on wall elements were carried out at ZRMK, Ljubljana, aimed at verification of the selected procedure and providing elements for analysis of the effect achieved by the repair. Based on these results by which it was shown that only the shear bearing capacity at the cross-sections of the walls was increased from τ =0.7kg/cm^2 to maximum τ=1.4kg/cm^2) as well as based on field data, it was confirmed that the structure was not only repaired but was with an increased bearing capacity and resistance to gravity and seismic effects. Presented as an evidence is the approximate computation of the stability of the structure under seismic effects, which despite "the complexity of the building and lack of accurate data particularly on the reinforced concrete elements, provides approximate but still sufficiently accurate estimation of the safety factor". The results from this static analysis show that, for the entire seismic force computed according to the then valid regulations as 12% of the total weight of the structure, the global safety factor of the entire structure can be estimated to amount to 2. However, if the same logic is used today, the total shear base coefficient would be 0.30 (according to valid technical regulative), i.e., the value of the global safety coefficient would be less than a unity.

In the period 1964 and 1965, the repair of the halls within the Parliament building along with their adaptation continued. There is no technical documentation from which one can precisely define as which positions were at stake, but in the part of the construction works, it is evident that, during the repair of the halls, strengthening by new RC horizontal and vertical elements was anticipated.

From oral sources (there is no written documentation), it is known that, in 1967, in the part from the inner courtyard between the east unit and Halls 1 and 2, Halls 3 and 4 were added as individual reinforced concrete structures resting on visible reinforced concrete columns running from the basement to the level of the first storey.

In 1996, during the reconstruction of the basement premises in the northeast corner of the structure when there was access to a number of elements of the principal bearing system, a Study on the Technical Conditions for Building of Another Storey on the structure was elaborated by the domestic stock holding company. In the concluding remarks, the preparers of this study, taking into account the sound structure of the original building and the enlargements and reconstructions of the later period, the proper quality of the built-in materials, the well done repair of the structure with reference to the increased stability coefficient as well as the evaluation that the later reconstructions and adaptations did not disturb its stability, pointed to the possibility and feasibility of building of another storey over the original building. Based on the conclusions drawn in this study, a Preliminary project involving enlargement and building of another storey over Hall 2, building of another storey over the pentagonal outline, the Crystal Hall, Hall 3 and over the corridor between Halls 3 and 4, was prepared. In the project, most of these structures were planned to rest on the existing structural elements.

2.2. Performed Technical Measurements and Investigations

Starting with the essential difference between "plain" and "confined" masonry regarding behaviour under seismic effects and hence the allowed limited number of stroreys in seismically active regions on one hand and the detailed inspection of the submitted technical documentation on the other hand, the main purpose of the performed technical measurements and investigations has been to identify the principal structural system of the pentagonal outline, evaluated as the most critical for the planned building of another storey. This specifically means finding and identifying the mentioned reinforced concrete vertical belt courses that would accommodate the bearing system of the existing structure in the "confined masonry".

Due to the size of the structure, it has been decided that the investigations be carried out only at the ground floor and on the southwest unit which is representative for most of the structure. Taking into account the everyday functioning of the structure and the impossibility to reach the bearing elements without destroying the interior, it has been decided that the greatest number of data be obtained by application of modern equipment for non-destructive tests (Proceq Profometer 5) and then prove the indications by a minimal number of research boreholes meaning opening of grooves down to the bearing elements (Fig. 2.2).

Figure 2.2. Research boreholes in corridor pilasters (left – brick, right – RC column)

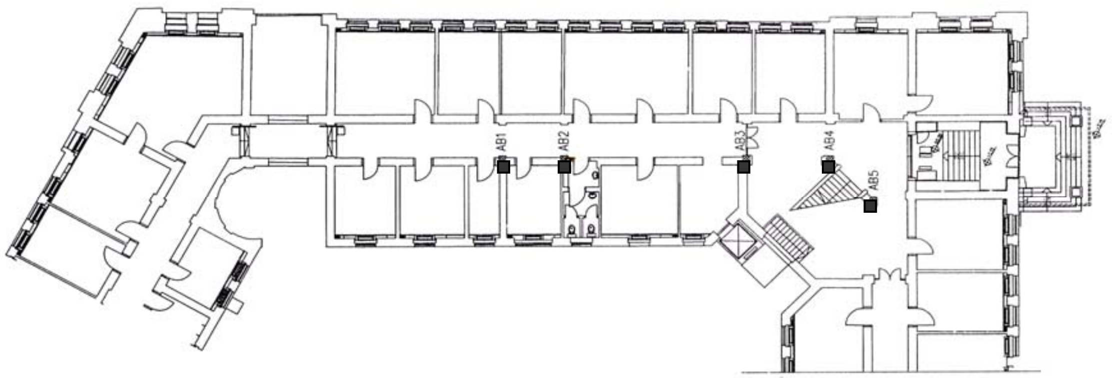

Figure 2.3. Position of identified RC vertical belt courses in the southwest unit

The selected unit has completely been inspected along its entire length for the purpose of obtaining as many as possible data. Based on the conclusions drawn from these investigations and from the subsequent research boreholes, the position of the existing RC vertical units in the measured southwest unit has been defined (Fig. 2.3).

2.3. Statements on the Existing Conditions of the Structure

Despite the presence of vertical reinforced concrete elements that are more extensively present at the main entrance (the north unit) and in the main hall, the baring system of the pentagonal outline belongs to the category of “plain masonry” since the scope, the position and the quality of built-in material (concrete and reinforcement) of the RC vertical elements cannot satisfy the conditions prescribed for the bearing system constructed of “confined masonry”

During all the later enlargements, reconstructions and adaptations (the Crystal Hall, Halls 2, 3 and 4), reinforced concrete structural systems have been used. Still, there should be defined with certainty whether these structures represent individual structural units separated from the existing structure by expansion joints, or parts of them rest on the existing original masonry, particularly due to the fact that they represent different structural systems with different behaviour under seismic effects.

As can bee seen from the existing technical, written and photo documentation on the conditions of the structure of the RM Parliament Building, one gets a general impression that the entire knowledge on design and application of materials compliant with the then valid regulations was used in its construction, enlargement, reconstruction and adaptation. After the earthquake, the structure was repaired by not structurally strengthened. The structure has been well and permanently maintained, adapted and renovated.

Hence, it can be said that the existing structure of the RM Parliament Building is with a limited bearing capacity and unknown deformability capacity - parameters important for the assessment of the existing stability.

2.4. Possibilities and Conditions for Building of Another Storey on the Structure

Based on the obtained knowledge and in compliance with the technical regulation for construction of structures and for the purpose of consistency in treating this building, it has been concluded that, within the frames of the project on enlargement, building of another storey and adaptation of the building it is necessary to perform (1) geotechnical investigations with definition of seismic parameters, (2) evaluation of the seismic resistance of the existing structure for definition of the seismic parameters and (3) definition of a technical solution for structural strengthening.

3. ANALYSIS OF SEISMIC RESISTANCE OF THE STRUCTURE

3.1. Methodology for Analysis of the Structure

The analyses have been performed for three general conditions of the structure: existing conditions, conditions of the structure with an additional storey and conditions of a strengthened structure with included effects of the built additional storey. The procedure for analysis and design of stable and economic walls structural systems developed at IZIIS–Skopje has been used, which employs the recent knowledge on this type of structures, enriched with the knowledge gained through analytical and experimental investigations that have been performed worldwide and particularly in our country. Generally, the procedure consists of (i) static analysis, (ii) analysis of elements up to ultimate capacity of strength, stiffness, deformability and capability of the elements and the system as a whole to dissipate seismic energy by linear and nonlinear behaviour, (iii) analysis of the dynamic response of the system under real seismic effect, expected at the considered location.

Definition of ultimate bearing capacity of the structure consists of definition of the ultimate storey shear force which, compared with the equivalent seismic force, provides the safety factor against occuring of first crack and failure. The mathematical model used in the analyses is based on modeling of all individual walls in the considered direction. The interpretation of the results obtained in this way enables consideration of the behaviour of each wall taken separately and the structure as a whole. For the described procedure, a software has been elaborated for obtaining the safety factors referring to occurrence of the first cracks and the safety factors against failure for each of the analyzed walls and the structure as a whole. In accordance with the RM regulations, the values of 0.30 and 0.24 has been adopted for the total shear base coefficient for the existing and the strengthened structure, respectively.

For the structures of the individual units, nonlinear dynamic analysis has been performed by modeling of concentrated masses which assumes concentration of distributed structural characteristics at characteristic levels (storeys). During such an analysis, a corresponding storey hysteresis model is used. This model is obtained by summing up the elasto-plastic characteristics of each of the bearing walls, whereat the bearing capacity of each of them is limited to the smaller value of bending or shear bearing capacity. As a result of the dynamic analysis, storey displacements, as well as ductilityies demanded by the earthquake are obtained and these should comply with the defined design criteria.

For the considered location of the structure, detailed regional and local, seismotectonic, geophysical and geomechanical investigations have been done and the seismic parameters along with intensity and frequency content have been defined. During analysis of the principal bearing structural system, there have been defined three levels of seismic intensity, for different return periods, for which the criteria of stability of the structure have been defined:

- Level I: For earthquakes of low and moderate intensity, the behaviour of the structure is in the elastic range or in initial nonlinearity with the ductility demand of $1< \mu <1.5$;

- Level II: For the design earthquake, the structure is generally in the initial nonlinear range of behaviour with possible limited nonlinear deformations of the individual elements of the system, which means limited stiffness degradation and energy dissipation (nonlinear behaviour with ductility demand of $1.5 < \mu < 2.5$);
- Level III: For maximum expected earthquakes, the structural elements are deep in the nonlinear range of behaviour but within the limits of the deformability capacity, while the stiffness and the resistance of the structure are considerably reduced. However, these earthquakes must also not disturb the entire stability of the bearing structure, i.e., the inflicted damage should be repairable (deep nonlinearity with ductility demand of $\mu > 2.5$).

For the considered structure, there have been defined seismic parameters with expected earthquake intensity of 0.27g, 0.38 g and 0.42g for a return period of 100, 475 and 950 years, respectively. To obtain the dynamic response, four different types of earthquakes have been used (El Centro N-S, 1940, Petrovac N-S 1979, Bitola N-S 1994, Robic N-S, 1968).

3.2. Analysis of Existing Conditions of the Structure

The existing structure generally consists of a massive masonry structure in the form of a pentagon composed of bearing walls made of solid bricks in lime mortar, with a fine ribbed roof structure. The additionally built structures represent mixed structures constructed of solid bricks and reinforced concrete or purely reinforced concrete structures. From the existing documentation and in situ inspection, it has been concluded that there are certain expansion joints between the individual parts of the structure, but the extent of their functioning can not be defined precisely.

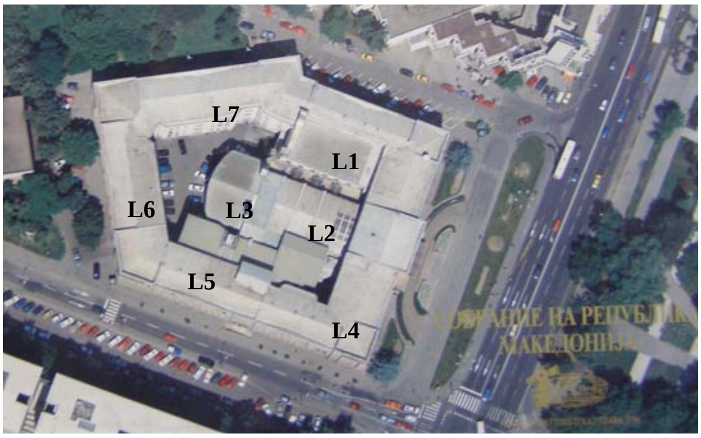

Figure 3.1. Individual structural units of the building (Units L1 – L7)

For the needs of further analysis, the structure has been divided into seven units in accordance with the defined expansion joints (Fig.3.1) from the aspect of the most unfavourable conditions for their individual functioning.

For the existing structure of the individual units loaded with vertical loads and equivalent seismic forces according to the regulations, detailed analysis has been done in compliance with the described methodology. For the quality of masonry, the following values have been adopted: ultimate compressive strength, fc=1200–2200 kPa, ultimate tensile strength, ft=120–220 kPa, proved by control experimental tests on a specimen taken from the existing masonry. For the existing reinforced concrete elements, concrete class MB16 to MB22 reinforced with plain reinforcement GA240/360 and a total minimal reinforcement percentage of 1%, have been adopted.

The analysis of the bearing and deformation characteristics of the structure shows that the shear base coefficient is 6-18%, much smaller than that required one by the regulations, (30% of the total weight of the structure). The capacity of the relative storey displacements of the structure is relatively low.

Relative storey displacements of such order do not satisfy the requirements for earthquakes that may occur in this area with corresponding intensity and frequency content. Considering the fact that an additional structure is to be built over the existing structure, the need for strengthening of the structure becomes even more topical and economically justified.

3.3. Analysis of Conditions of the Structure with Additional Storey

For the conditions of individual units with additional storeys loaded with vertical loads due to the additional storey (where planned to be constructed) and equivalent seismic forces according to the regulations, a detailed analysis has been performed in accordance with the described methodology, the results from which are summarized in Table 3.1. Three possible conditions of mathematical modeling have been defined as follows:

- Conditions of separated walls, (SW), where the individual elements of the bearing walls between the openings are modeled as independent;
- Conditions of connected walls, (CW) where the bearing walls are modeled as an entirety, neglecting the openings, but with consideration of the expansion joints;
- Conditions without dilataions, but with connected walls (pentagon-P).

Table 3.1. Summary results from the analysis of the structure with the built additional storey

Unit	Required shear base coefficient (% of total weight)	Bearing capacity (% of the toatal weigth)		Demand ductility (max)		Existing ductility (max)	
		x-x	y-y	x-x	y-y	x-x	y-y
Condition - Separated walls (SW)							
L1	30	14.95	14.39	3.72	2.93	2.05	1.42
L2		16.75	22.18	3.58	4.00	2.42	2.30
L4		12.34	10.34	2.90	2.77	1.71	1.92
L5		11.54	12.50	3.33	2.81	1.63	1.72
L6		18.68	7.09	2.21	3.60	1.53	1.97
L7		13.08	13.13	3.10	3.20	1.71	1.65
Condition - Connected walls (CW)							
L1	30	20.20	16.10	2.10	2.57	1.42	1.56
L2		17.70	27.30	2.53	4.30	2.37	3.60
L4		18.00	15.80	2.10	2.10	1.52	1.92
L5		20.40	13.10	1.75	2.90	1.46	1.48
L6		30.80	6.70	1.77	3.00	1.27	1.24
L7		21.10	17.80	1.99	1.50	1.55	1.47
Condition without dilatation (pentagon-P)							
P	30	17.8	17.00	2.50	2.55	1.62	1.63

From the presented output results, it can be concluded that the bearing capacity is considerably lower than that required according to the regulations, while the deformability capacity is relatively low. From the force-displacement storey diagrams, in addition to the relatively low capacity of deformability, the insufficient capacity of seismic energy dissipation is also evident. With some minor differences, this also refers to all three analyzed cases. Therefore, the state of separated walls (SW) has been analyzed in further procedure as the most representative and most suitable for the behaviour of such type of structures under dynamic loads. Consequently, for the newly designed conditions with the built additional storey, the existing structure does not possess sufficient strength, stiffness and deformability according to the existing technical regulations. It can be overcome with structural strengthening.

4. TECHNICAL SOLUTION FOR STRENGTHENING OF THE BUILDING STRUCTURE

Based on the required strength and deformability characteristics of the elements and the system as a whole, in accordance with the Rulebook on Construction of Structures in Seismically Prone Regions in RM, on one hand, and the possibilities for adding new elements in the structure, on the other hand, a number of variant solutions for strengthening the structure have been proposed and analyzed. Analysis of the stability of the structure and comparison of the obtained capacities with those required by the regulations have also been performed. The most appropriate (from the aspect of stability and economy) technical solution for strengthening has been selected. During the selection, particular attention has been paid to the possibility of achieving optimal strength, stiffness and deformability by minimal interventions. It has also been endeavoured to avoid structural intervention in the functionally necessary premises and premises with interior of particular value and importance. With the solution of strengthening of the principal structural system, classical methods and strengthening elements have been anticipated for the purpose of use of materials with characteristics similar to the existing ones. Fig. 4.1 shows the strengthening solution for the representative unit, L7. Generally, the strengthening of the existing bearing system consists from the following:

- Connection of the bearing walls with reinforced concrete horizontal belt courses over the last storey, i.e., by horizontal ties at the level of the floor structures, for the purpose of providing integrity to the bearing structural system in both orthogonal directions and enabling synchronous behaviour during dynamic excitations;
- Increase of the strength and deformability characteristics by jacketing of parts of the bearing walls. The jackets, as vertical bearing elements, are connected with the horizontal belt courses and ties and are founded on new reinforced concrete foundation cushions;
- Replacement of existing partition walls or insertion of new easily reinforced and relatively thin reinforced concrete walls connected by horizontal belt courses and ties and founded on own reinforced concrete foundation;
- Increase of the proportions and the reinforcement of existing reinforced concrete columns connected with horizontal belt courses and ties and founded on enlarged existing foundation;
- Injection of possible cracks in the walls upon removal of the mortar;
- Guniting of existing walls constructed of solid bricks in case a network of cracks occurs upon removal of the mortar.

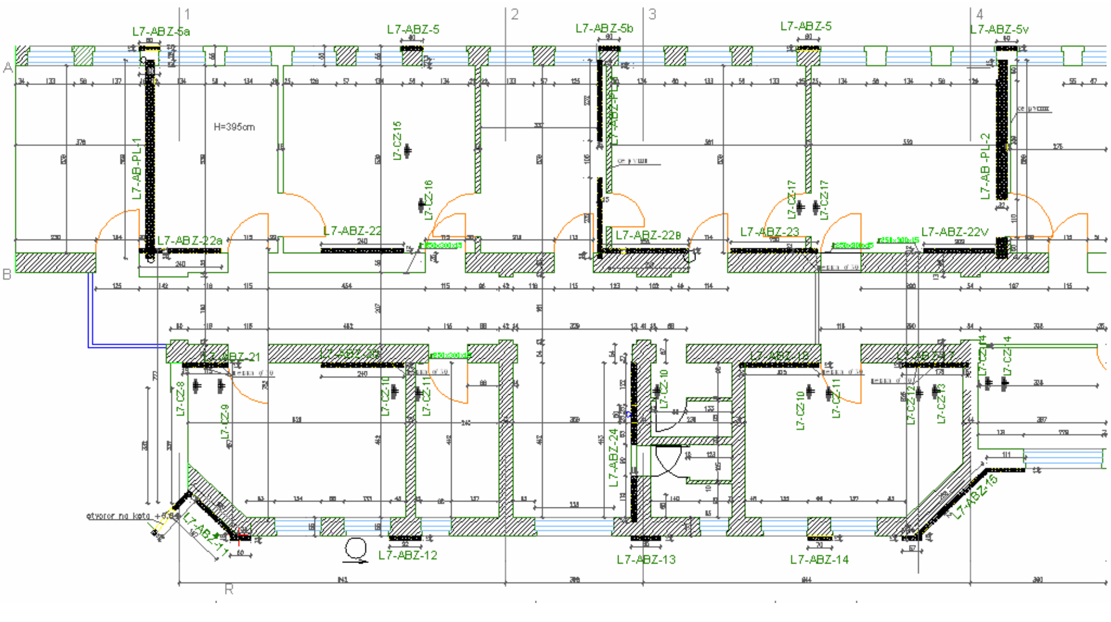

Figure 4.1. Strengthening of representative unit – L7

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. The representative conditions of separated walls have been analyzed and the summary results presented in Table 4.1. 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 Fig. 4.2. 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.

Table 4.1. Summarized results from the analysis of the strengthened structure

Unit	Required shear base coefficient (% of total weight)	Bearing capacity (% of the toatal weigth)		Demand ductility (max)		Existing ductility (max)	
		x-x	y-y	x-x	y-y	x-x	y-y
Состојба разделени ѕидови PS							
L1	24	24.8	23.7	2.10	2.40	2.80	2.75
L2		27.8	24.0	1.60	3.70	3.09	4.82
L4		22.1	21.9	2.30	2.10	2.54	2.22
L5		23.1	23.7	1.80	2.20	2.74	2.75
L6		31.2	34.0	1.60	1.10	1.95	2.33
L7		24.5	23.2	2.00	2.60	2.23	2.71

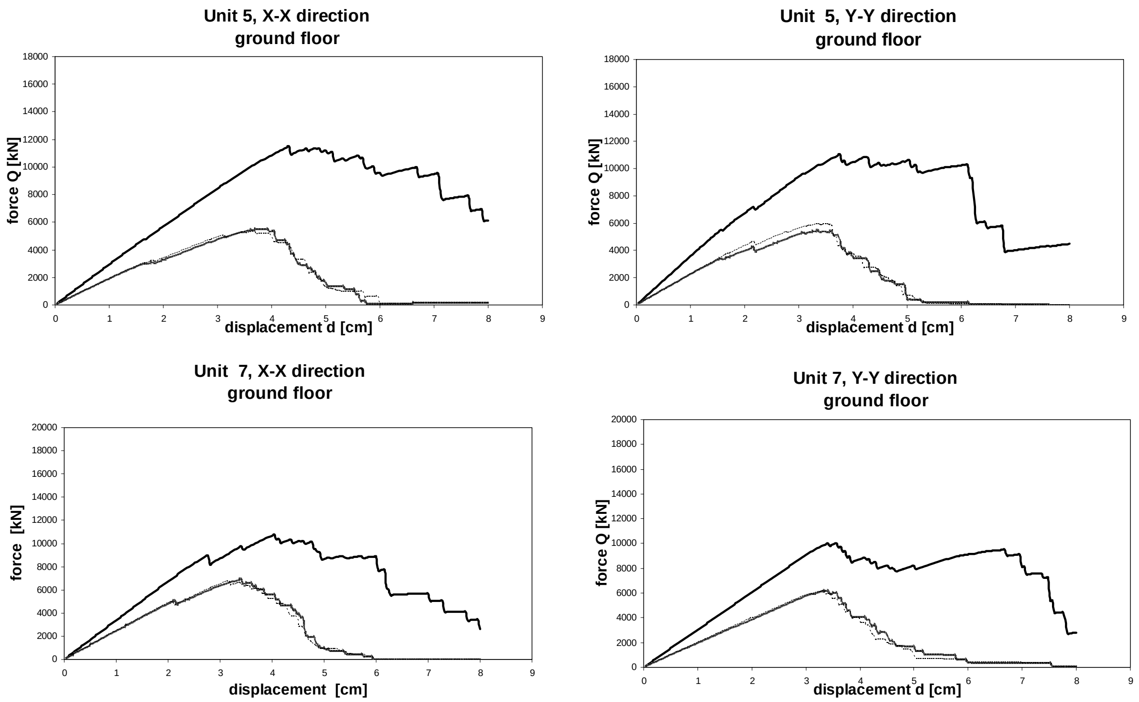

Figure 4.2. Comparative Q-d diagrams for characteristic units
(--- existing state, ___ with additional storey, ▬ strengthened structure)

A special parameter, which is very important for the behaviour and the stability of such type of structures during an earthquake is the capability of the structural elements to dissipate seismic energy by behaving in the nonlinear range. The presented comparative diagrams (Fig. 4.2) show that the capability for dissipation of seismic energy is considerably increased in the case of the strengthened structure compared with the existing structure and the structure with the built additional storey. The presented output results show that optimization of strength, stiffness and deformability capacity as well as capacity for dissipation of seismic energy has been done, which globally means a considerable increase of the stability of the structure under gravity and external seismic effects.

5. REALIZATION OF STRENGTHENING OF THE BUILDING STRUCTURE

The process of strengthening of the bearing structure of the RM Parliament building which is carried out parallel with the regular functioning of the building, represents a complex, specific and responsible task. The strengthening of the building that started in April 2010 is being carried out quite successfully despite a lot of limitations. Strengthening of units L1, L2, L3, L7 and partially unit L6 (Fig. 5.1) was realized by February 2012. The process is being carried out under continuous supervision involving:

- More precise inspection of the geometry of the individual units as the necessary basis for more precise positioning of the strengthening elements along horizontal and vertical line;
- Direction of activities and prescribing of order, regime and technology of incorporation of the strengthening elements for the purpose of providing the necessary stability of the structure at any moment of the construction works;
- Elaboration of variant solutions for modification of individual elements due to newly created and limiting conditions regarding on site construction;
- Definition of final solutions based on control computations and engineering knowledge with elaboration of precisely defined construction details harmonized with the possibilities of the contractor and the construction conditions;
- Definition of technical solution for strengthening and elaboration of construction details of new positions not encompassed by the existing project, prior to the beginning of the works in order to conceive the necessity for structural interventions.

Figure 5.1. Strengthening of a characteristic column with a plastic hinge, Unit 3

6. CONCLUSIONS

The Parliament Building of the Republic of Macedonia has existed for more than 70 years. After the earthquake of 1963, the structure was repaired but not structurally strengthened. In the period of its existence, the building has been subjected to a lot of modifications, building of another storey and adaptations and hence extensive interventions in the bearing structure.

Within the frames of the Project on Enlargement, Building of Another Storey and Adaptation of the Parliament Building of RM, a detailed analysis of the stability of the existing bearing system has been performed, the necessity for structural strengthening has been proved, variant solutions for strengthening have been proposed and analyzed and there has been selected the most appropriate (from the aspect of stability and economy) technical solution for strengthening that satisfies the strength and deformability requirements according to the valid technical regulations.

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