SKOPJE 11\textsuperscript{TH} SEPTEMBER 2016 EARTHQUAKE:
POST-EARTHQUAKE VISUAL SCREENING ON CULTURAL
HERITAGE BUILDINGS

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ABSTRACT

An earthquake with magnitude of 5.1 struck on the outskirts of Skopje on Sunday, 11\textsuperscript{th} September 2016, injuring at least 30 people and causing minor damage to buildings. The epicenter was about four kilometers east-northeast of Skopje, at a depth of 10 kilometers. As a member of the Managing Committee for coordination and management in the Crisis Management Centre, the Institute of Earthquake Engineering and Engineering Seismology, UKIM-IZIIS, Skopje, performed emergency inspection and usability and safety assessment through rapid visual screening method of 625 structures, among were also the cultural heritage buildings. This paper presents the outcome of the post-earthquake visual screening and damage assessment of the historic buildings and monuments in Skopje and its surrounding. Special attention is paid on the effects of different techniques of seismic retrofitting applied in last fifty years, both conservative and modern one, on the seismic performance of the structures of monuments during the last earthquake.

Keywords: Skopje 2016 earthquake; Cultural Heritage; Post-earthquake Visual Screening; Seismic Retrofitting

1. INTRODUCTION

The capital city of Skopje is situated in the Skopje valley on the banks of the biggest Macedonian river Vardar and surrounded by several mountains. In the past on its territory various cultures and spheres of influence intertwined, whose material remains have always attracted the interest of scholarly circles. Each of these cultures left its own mark both in the material and spiritual culture of the people. However, being located in one of seismically most active regions in Europe, these buildings have been also exposed to earthquakes during the long period of their existence. As a consequence they have been repaired, restored, retrofitted or even reconstructed many times and today, besides the status of monuments of culture they have a new purpose and still very important role in the cultural life of Skopje.

1.1 Skopje Architectural Heritage

Today the territory of Skopje and its environs is well known for the large number of monuments, historic buildings and sites. Among the most famous archeological sites in Skopje region are the site of Tumba Madžari, representing the most important Neolithic settlement in the Skopje Valley, the Skopje Fortress Kale which holds the most prominent position in the central area of the city and Scupi.

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the ruins of one of the largest Roman colonial cities in the Balkans situated 4.5 km northwest of the city center, (Pasko 2009, Fig. 1). Representative for the medieval times are the churches dating from the Byzantine period, as topmost architectonic creation with an extraordinary collection of highly valuable frescos, recognizable by their cross in square base, the complex organization of the interior space surrounded by tall masses, vaults and domes and facade walls in typical Byzantine opus. The most famous among them are St. Panteleymon’s Church, Nerezi (XII century), St. Andrew’s Church by the Matka lake, (XIV century), the church of St. Demtrius, Sushica (XIV century), St. Nikita Church, Banjani (XIV century), (Fig. 1), the church dedicated to Dormition of St. Mary, Glumovo (XV century), as well as the Stone bridge, the symbol of the Skopje city, which, in today appearance, has been connecting the two banks of the river Vardar since XIV century, (Serafimova 2009).

![Figure 1. Air shot of Roman colonial city of Scupi, (left) and St Nikita Church, village of Banjani, (right)](image)

However, it seems that the Ottoman presence of five hundred years (XIV to early XX century) left a special mark and permanent traces in the physiognomy of the city which in this period achieved their cultural and economic rise. The building of Ottoman structures reached its peak in the XV and XVI century, when a large number of mosques, baths, covered bazaars, inns and other facilities, mostly visible in the old part of today’s Skopje, were built as a reflection of the economical and political circumstances. Among them, Mustafa Pasha, Sultan Murat and Ishak Bay Mosques are among the oldest and best preserved mosques in the Balkan region, while Kurshumli Inn, Suli Inn and Kapan Inn, all of them from XV century, together with Chifte Hammam and Daut Pasha Hammam represent the commercial and public bath areas, (Pavlov and Petkova 2009, Fig. 2).

![Figure 2. Sultan Murat Mosque, (left) and Suli Inn (right)](image)

### 1.2 Seismicity of Skopje region

Before 1900, the seismic history of Skopje as part of the Vardar zone is reduced to a rather brief description of the earthquake catastrophes of Scupi in 518 A.D. and that of Skopje in 1555. As ground fissures extending over 45 km in length and up to 4 meters in width, the 518 A.D. earthquake seems to be the strongest shock that has ever occurred on this territory. The earthquake of 1555 is said to have demolished a part of Skopje. Both earthquakes are estimated to be of an intensity of XII MCS
(catalogues of the Seismological Institute of Belgrade, referring to the existing literature on earthquakes occurred since 306 A.D.). However, it is believed that the reported values are certainly overestimated, (Petrovski 2013).

During XX century, the region of Skopje was affected by series of damaging earthquakes, centered at the village of Mirkovci, which lasted from August to September 1921 with a magnitude of 4.6 to 5.1 and intensity of VII-VIII degrees MCS scale. Besides the local earthquakes, region of Skopje has suffered several times from earthquakes occurring at a distance. In the early hours of July 26, 1963, Skopje was struck by an earthquake with magnitude 6.1, one of the most severe catastrophes in its history. The entire territory of then SR Macedonia (25,700 km$^2$) was shaken with intensities varying between V and IX MCS, while intensity of IV degrees was also observed in Sofia (Bulgaria) at a distance of about 173 km, and in Thessaloniki (Greece) at a distance of 195 km from Skopje. Thus, the estimation of the macro seismically shaken area by the 1963 Skopje Earthquake outlines a region of about 180,000 km$^2$.

Major earthquake effects were manifested by loss of 1070 human lives and 3300 injuries, destruction and severe damage to a large number of buildings and other public and social facilities, damage to the infrastructure, life-lines, urban furniture, etc. Damage to existing buildings was tremendous. Out of the total building area 80.7% was destroyed or heavily damaged and about 75.5% of the inhabitants were left homeless. Only 19.7% remained non- or slightly damaged, which, in accordance with the damage and usability criteria were usable immediately after the earthquake, (Velkov 2013).

![Figure 3. Failure of resident masonry building (left) and slight damage of wood-framed adobe building (right)](image)

Generally speaking, the brick masonry wall structures of buildings suffered more than any other type. Mixed construction also suffered considerably. Although many of these buildings did not collapse they were left completely shattered, beyond repair. Old adobe structures, particularly those with timber bracing, resisted the shock with some damage but behaved far better than the brick masonry or the mixed structures, (Fig. 3). Reinforced concrete skeleton structures suffered comparatively little damage. Tall skeleton structures performed far better due to the specific frequency content of the earthquake. They were constructed with more care and, in some cases, wind forces were considered in the design. Finally, pre-stressed structures were totally destroyed after the collapse of their supporting columns.

2. SEISMIC STRENGTHENING AND REPAIR OF CULTURAL-HISTORIC MONUMENTS IN SKOPJE AFTER THE 1963 EARTHQUAKE

2.1 1963 Earthquake Effect on Architectural Heritage

In addition to the damage to residential and public buildings the catastrophic 1963 Skopje earthquake inflicted inestimable damage to cultural monuments. The entire monument fund of Skopje was more or less damaged, while part of it was completely destroyed. Damages were manifested by failure of individual parts of structures, large cracks, inclination and deformations of walls, vaults, columns and other structural elements. One of the most severely damaged monuments was the Skopje Kale fortress.
(the defense tower and part of the defense wall were ruined, while the remaining part suffered severe
damage), then the Kurshumli Inn complex (considerable damage, collapse of the entrance part and the
southeast and southwest part of the building as well as cracks in all columns and vaults over gallery),
(Fig. 4). Kazandziler mosque and Suli Inn were completely ruined, (Fig. 5), while Chifte Hammam,
Bezisten and Sultan Murat Mosque that were in the vicinity of Suli Inn were severely damaged (cracks
and collapse of massive walls, tambour and domes, ruined parts of minarets). Being located in the city
itself, all the renowned mosques from the Turkish period were heavily damaged as are mosques Ishak
Bay, Aladza and Mustafa Pasha, (Fig. 5). Somewhat less damaged were the Daut-Pasha Hammam, the
church of the Holy Saviour, the stone bridge and the aqueduct, (National Conservation Center 1983).

The earthquake did not spare also the Byzantine monuments although located in the surrounding of the
city far from the epicenter. Cracks in the walls as well as heavier damage to the dome and the fresco
paintings occurred in the church of St. Panteleymon in Nerezi. Cracks also occurred in the church
within the Marko’s monastery and also in St. Nikita church, Banjani and St Andreas church, Matka.

2.2 Post-earthquake Repair and Seismic Strengthening of Structures of Monuments

During the years following the catastrophic earthquake, there were works on protection of cultural
monuments considering their value and importance. Structural consolidation has been performed in
the first phase, while during the renovation of the monuments, particularly those adapted to modern
needs whose structural systems did not provide the necessary seismic safety, the principle of repair
and seismic strengthening has been applied.

Since the beginning of the XX century, the traditional techniques and typology of construction have
rapidly been replaced by modern methods and new materials used. The skill and the culture of
construction from the past slowly disappears, while the methods of computation and analysis
developed primarily for modern structures have become the only practice of young structural
engineers. This practice is particularly emphasized in urgent situations (for instance, during an
earthquake) in which are promoted new techniques and materials whose quality are very often overestimated without essentially knowing their durability, chemical compatibility with the existing masonry and reversibility, (Gavrilovic 1999, 2003, Velkov 2013). Thus, on the level of that time knowledge, the principle of repair and seismic strengthening involved a reinforced concrete bearing structure, columns and belt courses interconnected and incorporated into the existing masonry. This approach has been used for repair and reconstruction of the Suli Inn, Chifte Hammam, the Old Turkish Post Office and the church of St. Demetrius, (Fig. 6, 7).

![Figure 6. Post-earthquake damage (left) and reconstructed structure of Ishak Bay Mosque (right)](image1)

![Figure 7. Post-earthquake damage (left) and reconstructed structure of Suli Inn (right)](image2)

During the structural consolidation of other damaged structures, reinforced-concrete belt courses, rebuilding of individual ruined parts as well as injection by cement-based emulsion were done, as it has been done for Kurshumli Inn complex, (Fig. 8), Daut Pasha Hammam and others. Reinforced concrete belt courses were incorporated in the massive walls of the mosque, while the central dome was strengthened by a reinforced concrete ring placed between the tambour and the lower part of the dome, as it has been done for the Mustafa Pasha Mosque, Daut Pasha Hammam and others, (Fig. 9). Cement as a material was also applied in repair of the medieval churches and monasteries through injection of the occurred cracks or rebuilding of the ruined parts (the churches of St. Nikita and St. Andreas, Marko’s monastery) and seismic strengthening (the church of St. Panteleymon, Fig. 10).
Figure 8. Kurshumli Inn: strengthening concept and after reconstruction

Figure 9. Repair and seismic strengthening of Mustafa Pasha Mosque (reinforcement in the circular RC ring around the dome)

Figure 10. St. Panteleymon Church: strengthening concept, (left) and repaired and strengthened structure (right)
In the later period, during visual inspection of the monuments strengthened by reinforced concrete, it was estimated that, due to its physical-mechanical and chemical characteristics, the cement mortar may adversely affect the original bonding element – the lime mortar and the fresco-painting area. Therefore, it was as early as the eighties that considerations were given to the opening of a new chapter in engineering that will unite the efforts of architects, engineers, conservators, restaurateurs and all those involved in the delicate task of finding the right way to seismic retrofitting of monuments. Based on the presented ideas and conclusions, the final document of the First International Seminar on Modern Principles in Conservation and Restoration of Urban and Rural Cultural Heritage in Seismically Active Regions held in Skopje 1988 known as “Recommendations – Skopje 88” provides recommendations for further activities directed as above mentioned and prohibit the use of cement as material. Based on these recommendations as well as concrete activities taken by the UKIM-IZIIS, Skopje, starting from 1990 there have continuously been realized projects in the field of earthquake protection of cultural historic heritage for the purpose of finding the most adequate approach and methods through multi-disciplinary and many-faceted experimental and analytical investigations.

2.3 UKIM-IZIIS’ Integrated Approach to Earthquake Protection of Monuments

Extensive research activities have been performed by UKIM-IZIIS, Skopje in the period 1990-2000 for the purpose of evaluation of a procedure for repair and strengthening of valuable historic monuments. Such a procedure is usually based on conventional understanding of retrofitting, although, in our concepts, there are also techniques, which are based on the idea of structural control. These activities includes shaking table testing of models of historical monuments and experimental verification of different retrofitting techniques like traditional “ties and injection”, seismic base isolation, as well as seismic upgrading using composite (CFRP) materials. As a result of several decades of gathering of experience, it can be said that an integral approach to seismic protection of extraordinarily important cultural historic structures has been adopted by the Institute. While complying with the restoration and conservation requirements set in a number of international documents and declarations, this integrated approach to repair and seismic strengthening of historic monuments should encompass the following:

- Definition of expected seismic hazard;
- Definition of soil conditions and dynamic behaviour of soil media;
- Determination of structural characteristics, bearing and deformation capacity of existing structure;
- Definition of criteria and development of a concept for repair and/or strengthening;
- Design of structural methods, techniques, materials and types of excitation;
- Verification of seismic stability of repaired and/or strengthened structures;
- Definition of field works, execution and inspection.

Although the above stated seems to be the "normal procedure", it is the only way of providing high quality in protection of cultural heritage. This task is certainly much more than simply listing of what is to be done since it requires a lot of knowledge and efforts, (Gavrilovic 2003, Shendova 2014).

2.4 Seismic Upgrading of Mustafa Pasha Mosque with CFRP

The author of this paper, as part of IZIIS team, had an opportunity and challenge to design a system for seismic strengthening of the Mustafa Pasha Mosque, for the needs of the conservation project prepared by the University of Gazzi in cooperation with the Ministry of Culture and Tourism of Turkey and the National Conservation Centre in Skopje, (Shendova 2007). Respecting the modern requirements in the field of protection of historical monuments, as is the application of new technologies and materials, reversibility and invisibility of the applied technique, a strengthening concept involving the use of composite materials has been adopted. In realization of this project, the established integrated approach has thoroughly been respected. The concept of structural strengthening aimed at reaching the designed level of earthquake protection has been selected based on: (i) investigations of the characteristics of the built-in materials, (ii) investigation of the main dynamic characteristics, (iii) shaking table testing of the mosque model, (iv) investigations of the soil conditions, (v) detailed geophysical surveys for definition seismic potential of the site.
Based on these investigations and the defined seismic parameters, as well as detailed analysis of the seismic stability of the structure, the solution of structural strengthening has been accepted, (Fig. 11, 12). It consists of incorporation of strengthening elements in the process of architectural conservation in accordance with the existing conservation project, with the main purpose of providing integrity to the structure as well as simultaneous behaviour of the bearing walls at the corresponding levels:

- **Dome:** After removal of the cement mortar layer over the dome placed in 1968, the following was carried out: (i) coating of the formerly constructed reinforced concrete ring in the dome base with an lime based injection mixture and (ii) placement of a CFRP wrap in a layer of epoxy glue along the perimeter of the dome base within a width of 2.9 m. Then the entire dome was externally coated with a protective layer of lime mortar and covered in accordance with the conservation project, (Fig. 11-A, Fig.12, left).

- **Tambour, Bearing walls:** After cleaning of all the facade joints with a depth of 6–9 cm, CFRP bars of defined mechanical characteristics (tensile strength of f_t=1800–2000 MPa) were placed in an epoxy mortar layer and connected in the vertical joints. Then, the joints were filled with pointing lime mortar in accordance with the conservation project, (Fig. 11-B to G, Fig.12, middle).

- **Foundation Structure:** The solution consists of construction of a reinforced concrete wall with a thickness of 25 cm along the perimeter of the foundation walls, on the external side, below the terrain level and down to the foundation level. From conservation reasons, this reinforced concrete wall was physically separated from the existing foundation walls by a polyurethane coating for the purpose of separating the concrete from the existing stone masonry. To ensure interaction between the newly designed RC wall and the existing foundation structure, the solution anticipates placement of anchors made of stainless steel to an alternating length in previously formed openings filled with epoxy mortar (mixture of quartzite sand and epoxy) in accordance with the enclosed scheme, (Fig. 11-F, Fig.12, right).

In the entire part of the structure extending above the terrain level, it is anticipated to remove the cement mortar injected in the cracks after the 1963 earthquake. With the project on conservation of the architecture, it was anticipated that these cracks as well as all the cracks detected after the opening of the external joints be injected with lime mortar with defined mechanical characteristics. Strengthening of the mosque structure in accordance with the designed system was realized in 2007-2009.
3. SKOPJE 11TH SEPTEMBER 2016 EARTHQUAKE

3.1 Earthquake characteristics

Staring from Sunday, September 11, 2016, the city of Skopje and its surroundings was hit by a series of earthquakes with main shock of moderate size moment magnitude of M=5.1. The main shock was felt in the urban area with intensity of about VI to VII degrees according to EMS. Immediately after the occurring of the main shock the Managing Committee for coordination and management in the Crisis Management Centre (CMC) called an urgent meeting with the representatives of the main responsible institutions for crisis management. Among them, UKIM-IIZIS was responsible for fast safety and usability assessment of the buildings, with priority on buildings that are of public and special interest (hospitals, schools, kindergartens etc.). Within this activity performed was rapid visual screening of total of 625 building structures; out of which were 15 cultural heritage buildings and monuments, (Fig. 13).

3.2 Post-earthquake visual screening on Cultural Heritage Buildings and Monuments

As stated above, interventions to different extent have been taken in the past for all monuments in
Skopje region, Table 1 presents the list of the inspected monuments along with the information on their previous interventions and damage level during the last earthquake. Out of the total number of inspected monuments and historic building 13 are on a distance 4-5 km, while St. Panteymon Church and Hussein Shah Pasha Mosque are on a distance of more than 10 km from the epicenter, (Fig. 13). After the fast visual screening vast majority of inspected monumental buildings were assessed as safe and usable, since their damage varies from slight nonstructural one, (failing of pieces of mortar or bricks from the cornices or facade walls, hair cracks in mortar joints on facade walls and ceiling, breaking of glass from large windows), to very localized or negligible structural damage, (initial cracks to the walls and ceiling elements, failing of large patches of mortar from wall and ceiling surface, considerable cracks or partial failure of chimneys). However, there are isolated cases of considerable structural damage manifested as widening and elongating of older cracks or occurring of newly developed cracks, usually in the walls or along the connection between the walls and vaults or domes. The damage intensity was highest in the case of Hadzi Balaban Mosque and Kurshumli Inn, (Fig. 14, 15). In fact these two monuments were the only one for which regular daily inspection of the structure and limited movement was recommended until undertaking repairing and/or retrofitting measures. The Mustafa Pasha Mosque, (Fig. 5, 11, 12) was the only monument that remains totally undamaged.

Table 1. List of inspected cultural heritage buildings and monuments

<table>
<thead>
<tr>
<th>Monument/Historic building</th>
<th>Period of construction</th>
<th>Previous Intervention</th>
<th>Damage description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Church of Holy Salvation</td>
<td>1817-1824 (on XIV century foundation)</td>
<td>Repair, partial reconstruction, conservation, adaptation</td>
<td>Extension of old minor cracks, Occurrence of new minor cracks between walls and ceiling surface</td>
</tr>
<tr>
<td>Suli Inn</td>
<td>First half of XV Century</td>
<td>Reconstruction, strengthening with RC vertical and horizontal belt courses</td>
<td>No new structural damage, Failing down of large windows</td>
</tr>
<tr>
<td>Aladza Mosque</td>
<td>Beginning of XV century</td>
<td>Reconstruction of porch with RC elements, conservation, adaptation</td>
<td>Cracks on north and south main vault, continuing into adjacent domes, failing of mortar from central dome</td>
</tr>
<tr>
<td>Hadzi Balaban Mosque</td>
<td>XV Century</td>
<td>Replacement of original dome destroyed in XVIII century with wooden roof structure</td>
<td>Separation of bearing walls from pendentives</td>
</tr>
<tr>
<td>Bezisten, the central part of Old Bazar</td>
<td>XIX century (on XV century foundation)</td>
<td>Repair, consolidation, adaptation</td>
<td>Extension of old cracks in the walls, visible separation of bearing walls from ceiling structure</td>
</tr>
<tr>
<td>Daut Pasha Hammam</td>
<td>XV century</td>
<td>Repair, consolidation, partly reconstruction with RC vertical and horizontal belt courses</td>
<td>Major cracks in entrance dome, failing of mortar and cornices from facades, extension of old cracks,</td>
</tr>
<tr>
<td>Cifte Hammam</td>
<td>First half of XV century</td>
<td>Repair, consolidation, partly reconstruction with RC vertical and horizontal belt courses</td>
<td>Initial minor cracks in bearing walls and over the openings</td>
</tr>
<tr>
<td>Kurshumli Inn</td>
<td>First half of XVI century</td>
<td>Repair, reconstruction, strengthening with RC vertical and horizontal elements</td>
<td>Structural damages along the walls and vaults, disturbed local stability, failing of partition wall, roof stones and chimneys</td>
</tr>
<tr>
<td>Kale fortress</td>
<td>XIV Century</td>
<td>Repair, consolidation, adaptation, reconstruction with RC elements</td>
<td>Minor cracks as extension of old one</td>
</tr>
<tr>
<td>Building Name</td>
<td>Century</td>
<td>Repair and Strengthening Details</td>
<td>Initial Observations</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>---------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Sultan Murat Mosque</td>
<td>XV Century</td>
<td>Repair, strengthening with RC vertical and horizontal elements</td>
<td>Initial cracks between walls and vaults, failing of mortar, extension of old cracks</td>
</tr>
<tr>
<td>Mustafa Pasha Mosque</td>
<td>XV Century</td>
<td>Repair, dome strengthening with RC ring, upgrading with CFRP in 2006</td>
<td>No visible cracks</td>
</tr>
<tr>
<td>St. Panteleymon Church</td>
<td>XII Century</td>
<td>Repair, strengthening with RC vertical and horizontal elements</td>
<td>Minor cracks in bearing walls Failing of mortar from facades</td>
</tr>
<tr>
<td>Hussein Shah Pasha Mosque</td>
<td>XVI Century</td>
<td>Repair, consolidation, strengthening with RC horizontal elements</td>
<td>Minor cracks in bearing walls Failing of mortar from facades</td>
</tr>
<tr>
<td>Historic building in the Old Bazar</td>
<td>XIX Century</td>
<td>Repair, consolidation, adaptation</td>
<td>Structural damage, disturbed local stability</td>
</tr>
<tr>
<td>Historic building in the Old Bazar</td>
<td>XIX Century</td>
<td>Repair, consolidation, adaptation</td>
<td>Disturbed global stability (old substandard adobe structure)</td>
</tr>
</tbody>
</table>

Figure 14. Post-earthquake damage to Hadzi Balaban Mosque

Figure 15. Post-earthquake damage to Kurshumli Inn

The question arises as to why earthquake damage occurs in monumental buildings that have been previously seismically strengthened. Within the 1965 project for reconstruction of the Kurshumli Inn anticipated were 24 reinforced concrete vertical belt courses to be inserted along the length of the facade walls and connected with the central facade walls with steel ties. In addition, horizontal belt courses were anticipated to be inserted at three levels (foundation level, the level of the vaults over the...
ground floor and the roof level, Fig. 8). Rebuilding of the collapsed parts of the walls and the vaults as well as injection of the cracks was also anticipated. As it can be seen from the characteristic plan and cross-section, the reinforced concrete elements were anticipated to be constructed as invisible, i.e., inside the external wall by its previous grooving. However, the last earthquake of a moderate intensity resulted in certain structural damages of a lower intensity that do not disturb the global stability of the structure but speak for themselves about its vulnerability in case of future earthquakes of moderate and particularly strong intensity. There are two possible reasons for this issue; either the anticipated RC elements have not been constructed in the scope and intensity as they were designed or the construction quality is poor and did not provide the designed idea and level of protection.

Just opposite, very good example of seismic behavior was shown by the Mustafa Pasha Mosque, in which case no visible damage or even minor cracks were observed after the last earthquake. This is certainly due to the recent high quality and professionally performed seismic upgrading of the monument, (Fig. 11, 12). In this way the implemented retrofitting methodology using composite materials, which was previously experimentally verified, undoubtedly proved its efficiency during real earthquake with moderate intensity.

4. CONCLUSIONS AND RECOMMENDATIONS

The capital city of Skopje is well known for the large number of monuments, historic buildings and sites. In their past repair, restoring, retrofitting or reconstruction two general approaches for seismic retrofitting have been implemented in the last fifty years. The first one involved reinforced concrete elements and was very popular in seismic strengthening of the monuments in the period after the Skopje 1963 earthquake, while the second one started at 1988 when the use of cement as a material was prohibited because of its adverse effect on the original bonding element, the lime mortar and the fresco-painting area. The document “Recommendations–Skopje 88”, issued after the First International Seminar on Modern Principles in Conservation and Restoration of Urban and Rural Cultural Heritage in Seismically Active Regions, opened a new chapter in earthquake protection of monumental buildings that unites the efforts of architects, engineers, conservators, restaurateurs, material scientists and archeologists in finding the right and most appropriate way to seismic retrofitting of cultural-historic monuments, (National Conservation Center 1983, Shendova 2014).

The seismic performance of the monuments during the Skopje 2016 earthquake leads to the conclusions that although seismically strengthened by reinforced concrete elements, the monuments are still vulnerable even to the earthquakes with moderate intensity. However, the structure of Mustafa Pasha Mosque, which was recently seismically upgraded by use of modern materials and techniques, shows greater bearing and deformation capacity and much better behavior during earthquake.

Taking abovementioned into account, for all the important monumental buildings the following can be recommended: (i) checking of the level of realization of the projects for reconstruction, repair and seismic strengthening prepared immediately after the 1963 Skopje earthquake in order to identify and document the presence of the strengthening elements, (ii) performing of relevant structural re-analysis in order to evaluate the real seismic safety and stability of existing state and (iii) providing necessary seismic upgrading of the structure respecting the modern requirements in the field of protection of historical monuments. This is only way to provide the designed level of earthquake protection of monuments and historic buildings and during future moderate and strong earthquakes.

5. REFERENCES


