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AFTER EARTHQUAKE DAMAGE AND BEHAVIOR OF BUILDINGS IN GJILAN REGION

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Abstract. *Various types of structures were assessed after an earthquake that struck Gjilan on April 24th 2002 with a purpose of identifying seismic deficiencies that might impact the general stability of the buildings located within the downtown City. The overall seismic performance goal identified by our team for these buildings is life safety. To achieve this goal, partial collapse of structure and/or of any cladding element that could result in a life safety concern should be prevented during a major earthquake. The largest issue identified is the unreinforced or inadequately reinforced brick masonry construction and those combined with skeletal, particularly buildings with soft ground stories all located along and at both sides of the main avenue. Based on our study, recommendations were given in whether saving some of the building would be feasible, since any attempt on this, especially for those constructed after the Second World War, would be costly. The newer one, (i.e. those constructed after the mid 1970's) should easily perform at a life safety level and meet the local performance goals). Earthquake forces are generated by the inertia of buildings as they tend to respond to ground motion. There are attempts by engineers to simply consider earthquakes as equivalent static forces and mitigating in this way the earthquake response. Such practices should be avoided as much as possible in the nowadays design practices.*

Keywords: *earthquake, building damage, seismic performance*

1. Introduction

It is well known that as a consequence of earthquakes there is ground motion experienced on the surface resulting from the transmission of energy waves released from source and then undergoing certain modifications while travelling through soil layers as the energy reaches the earth surface.

Many of these are of small intensity and do not cause significant damage to structures. However, there are cases when earthquakes of larger intensity in the urban areas cause considerable damage to the buildings and sometimes even a loss of life.

Kosova has experienced destructive earthquakes throughout its history. Based on the existing seismic hazard maps of Kosovo for repeating periods of 100, 200, 500, 1000 years, in Kosovo earthquakes of maximal magnitude of 9 degree are possible to occur.

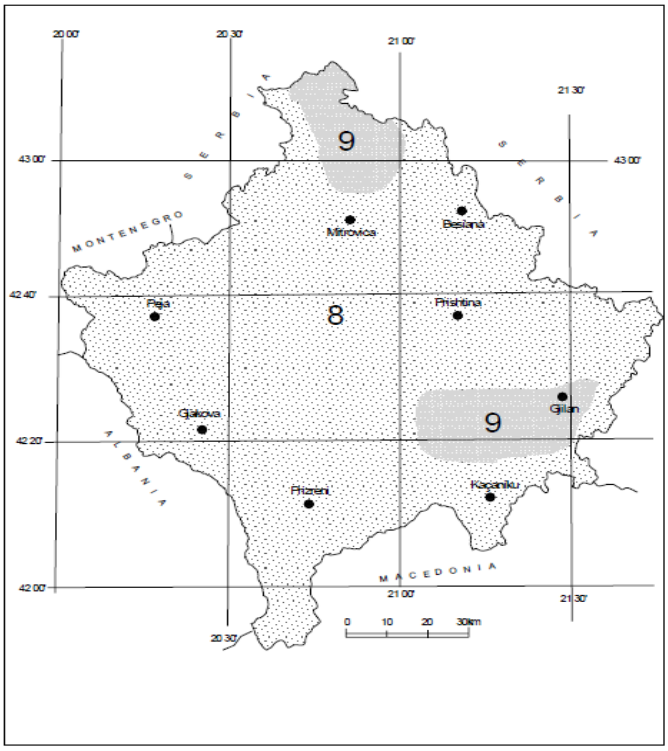

Figure 1 Hazard intensity map of Kosovo, for return period of 500 years

The city of Gjilan with its typical characteristics in the seismological and architectural aspects, represent a unique case-study for developing a research in concern to seismic evaluation of engineering structures which would be directly applicable for the whole territory of Kosovo. The important objective of this paper is (i) to study performance of different types of construction, (ii) to identify causes of damage, and (iii) to highlight significant observations from the damage that are relevant for future protection and construction.
Such studies for Gjilan city may serve as a real basis for eventual interventions in existing buildings with a purpose of retrofitting the same in order to reduce the seismic risk in general.

2. Damage survey

On April 24, 2002 at 12:55 an M=5.1 (moment magnitude) earthquake measured in Richter scale struck the Gjilan area. Numerous aftershocks were recorded within the day and after that following the main earthquake event. Shaking was also felt in the north of the city and the neighboring countries. However, related damage was mainly reported from the East and South East districts of Kosova.
The damage survey of various structures with respect to structural/ nonstructural damage, materials of construction, type and quality of construction was made.

3. Types of construction

From the architectural point of view the city of Gjilan could be characterized with several building types based on their lateral force-resisting system. Most of existing buildings in Kosova constructed until 1960 are usually made of unreinforced masonry. Old masonry buildings are an important part of building stock of Gjilan city.
These buildings are still being used and their main functions at present days are mostly housing, commercial, services, etc. No earthquake resistant design is applied in the past for such structures. The layouts of buildings and of their structural systems differ from one to another facility.
It is also important to mention that the structural systems of existing buildings in Gjilan, are in general and to a great extent similar with such buildings at other cities in Kosova.

4. Earthquake damage to buildings

Building assessed vary from institutional, public, industrial, residential, mix use buildings, monumental, etc., and their structural system and way of construction also varies from the period of time such structures are constructed.

4.1 Damage of structures constructed after the second world war and up to 1950s

It was common practice in the region to construct residential adobe, brick and stone masonry buildings immediately after the First World War, and by using un-reinforced masonry up to 1960's. Mostly the adobe and stone-masonry buildings suffered substantial damage during the earthquake event and several of these were evacuated.
The damage patterns seen in the older residential neighborhoods of the city surrounding the downtown area were mostly chimney damage, gable wall damage, with several indications of cracking along foundation lines, over the door door window openings, etc.
The most significant structural damage was observed in the old downtown area of the city, as well as all around it in a diameter of approximately 20 km, and especially in Malishevë village east of the city centre where more severe cases of structural damage were found and some structures almost collapsed. In addition, out-of-plane tilting of several masonry walls was observed at some places.
While this type of collapse to an un-reinforced masonry building is not uncommon for strong earthquakes, it is interesting to note that the lateral resistance of these structures was relatively weak considering this quite moderate ground shaking.
Gjilan had never had a governmental-funded program focused on downtown revitalization. Even when building and premises received symbolic funds under the program for building improvements, retrofits were never included.
Initially following the earthquake, there were major damages found to the City Hall serving to UNMIK Administration at Gjilan centre. This structure, built in 1950 suffered significant damage to its brick façade, particularly near the roof line of the building as well as significant cracking in the walls made of burnt clay bricks with a random bonding throughout the building and considerable contents damage to display cases in the lobby. To a higher extent damage was found on rubble wall (opus incertum) at the east wing of this U shape building. The old Municipal building was red-tagged within 24 hours of the event.

Another structure assessed among public facilities was a single storey building of Vehicle Registration Centre comprised of mainly offices and a storage area combined of clay bricks,

adobe and stone masonry walls and that due to lack of confinements and floor/roof diaphragms encountered severe damages hence the same was suggested to be demolished.
In rural areas, low-cost school buildings are generally constructed by the state government using stone masonry with mud mortar. Several such buildings suffered severe damage due to the earthquake event.

Figure 2 & 3 North side of the Municipal Building with the attic wall fallen down and interior wall damage

No earthquake-resistant features such as horizontal bands at various levels nor tying stones at the corners are found in such constructions. This resulted in the formation of severe cracks near the corners and at the location of openings when subject to these although mild shaking (Figure 4).

Figure 4 & 5 Typical damage of the school structure Kremenata – Kamenica

4.2 Structures erected after 1960s

Commonly introduced system in the region and especially when it comes to public and mix use buildings within the close urban area are those constructed out of full burnt-clay bricks laid on cement/lime mortar. In some cases poor materials used for boundary between mortar and masonry unit added additional failure potential. Anyhow, non-reinforced masonry when subject to lateral loads, lacking it at all or possessing little ductility is not expected to behave elastically as is required the material to behave in an earthquake and is certainly considered vulnerable.
Mainly two types of buildings in terms of structural system constructed of are found at both sides of the main avenue of the city centre:

i. Masonry massive structures such as City Theatre, the Court House, Regional Police, City Library, all two to three storey structures, as well as some of residential buildings, all constructed at approximately same time generally made of materials that have a very low

tensile strength, showed cracking within elements and separation between elements. Nevertheless, these signs are not necessarily an indication of danger as masonry structures are intended to work only (or mainly) with compression stresses. Despite of the characteristics of the composite materials these masonry structures a made of such as: bricks (sun dried, artificially dried, etc.), mortars (cement, lime, etc.), the bonding elements (dry joints, mortar joints, etc.) and the way in which the elements are geometrically related to each other, these structures relatively good relied upon the effect of the rigid floors or roofs that they support and that ensured that lateral load distribution hence the overall stability of the structure as well.

In general, the vulnerability is also affected by the number, size and position of openings. Large openings, small piers between openings and quoins as wells as long walls without perpendicular stiffening and without RC Confinement (especially attic walls) contributed to more vulnerable buildings.

From the regularity point of view of earthquake resistance, most of these buildings fulfilled the basic requirements of an adequate plan with no variations encountered in stiffness since they are more or less symmetrically arranged. In view of external symmetry in plan and elevation these also are pretty standard and with no departure from regularity, but in a scale of global sense and global parameters as the regularity is not only limited to the geometry but to dimensions, ratios and materials used, as well as to natural characteristics of a building, the vulnerability of all these building to earthquake shaking is not really reduced, since nowadays for engineered structures it is expected measures to be taken to ensure that regularity also corresponds with rules of earthquake resistant design. These and other old mainly mixed use buildings, had minor to moderate content damages, and were temporarily condemned until inspected by teams of engineers.

ii. All along the main avenue there are often encountered cases of four to six storey buildings in which the lowest level is significantly weaker than the others; some are quite open, with columns supporting the upper stories and with no walls on ground level. Such cases are known as soft stories, and are highly prone to collapse. Another disadvantage of these structures is the fact that all of them are made of thick clay brick walls above contributing in this way to the increase of mass concentrated on the upper floors.

There are also examples where conversion of the ground floor of a building into a restaurant or shop had weakened it (creating a soft storey); subsequent construction on an extension to the existing building that had likely made the ground plan more irregular, and introduced irregularities of stiffness and period within the overall structure. There are also old masonry buildings that have been extensively modified over a long history, resulting in offsets of floors at different levels, foundations at different levels, and so on. It was relatively easy to identify gross irregularities within the mix use buildings located along the main avenue, trade + residential; for example, buildings with ground plans designed as an L shape or similar are often encountered and are subject to torsional effects which may have greatly increased the damage suffered.

Figure 6 & 7 Collapsed attic wall fallen down from roof of mix use building & Intervention on the soft story of five story structure, actual Raiffaisen Bank building

4.3 Reinforced Concrete Structures erected at about 1980s and beyond

RC masonry and RC Frame buildings are only introduced after sixties until some major developments in building materials industry started and such traditional constructions performed well during ground-shaking.
RC-frame buildings with masonry infill are mostly used in private as well as government constructions. The application of adequate formal design practices in Region even for RC-frame buildings started only after 1970s. Before this, except for a few RC buildings involving major projects, analysis and design were generally not carried out in details; structural drawings seemed to have been prepared simply based on previous experiences of engineers. Some of the new RC buildings, mainly not engineered suffered varying degree of damage during this earthquake; however there were sporadic and mainly of non-structural elements damages encountered at institutional RC buildings.

Figure 8 & 9 Non-structural damage of infill walls at high school Arberia, Gjilan

Even within this type of structures, cases are found of buildings that previously had a good level of regularity but are adversely affected by subsequent modifications, as is the case of the ex Micro Enterprise Bank near the Bus Station, where an extra stair well was created at one corner of the ground floor during recent reconstruction just before the earthquake happened and that had displaced the centre of rigidity of the structure. As a consequence of this the column at the opposite corner encountered serious shear damage at its base due to the shake.
Another type of RC buildings introduced after 1980s by a local construction company "Morava e Binçës", government constructions, with prefabricated paneled walls performed extremely well. Public facilities and industrial buildings coped well with the earthquake shock and the same sustained only minor non-structural damage, with a few ceiling tiles falling, and minor structural damage, with some cracking mainly on partition walls, ceilings, and between non structural elements.

The largest industries in the affected region were battery, radiator, the textile and tobacco that found little structural damage to buildings and mainly non-structural damages. The area was one of Kosova's most productive regions, accounting for.

4.4 Monumental buildings

The other worst damage and perhaps due to its complexity of structural and non structural composition that made it likely prone to damages was to the historic Mosque at the downtown centre of the city. This building dating from the early 1900s and listed on the National Register of Monuments suffered severe serious damage. The un-reinforced brick masonry structure of minaret collapsed and fell out-of-plane causing so serious damage to the roof and to its central dome, and the top reinforced concrete perimeter belt and the bearing peripheral walls cracked heavily. Unfortunately, due to careless approach of respective institutions this unique and important element of the cultural heritage of the city, three year later was completely demolished. Minor to moderate damages were also found to the church and other mosques within the city but fortunately enough they all survived.

Figure 10 & 11 City Mosque encountered serious structural damage & collapsed minaret over its roof (pictures taken two years after the earthquake incident)

5. Conclusions

i. The damage seen in and around the city was clearly disproportionate to the size of the earthquake, which was a moderate 5.1 on the Richter scale. This very clearly establishes the high level of seismic vulnerability of the area.

ii. Of a great concern re masonry structures prone to earthquake damage, mainly public such as the City Library, Court House and Police Station, the Theatre, High Technical School, etc., as well as all, four to five storey residential buildings at downtown center with flexible ground floors, hence remedial measures in terms of seismic retrofit are deemed necessary.

iii. No surprises are seen in the damage patterns in the area except at the above mentioned village of Malishevë, and the damage amplifications due to subsequent modifications, as a result of the earthquake event. The damage to the residential and commercial un-reinforced masonry buildings was typical, as was the damage to the residential un-braced masonry chimneys.

iv. The damage is primarily attributed to poor design and to poor construction practices, as well as to the lack of quality control during the construction periods.

v. Damages caused by this comparatively small earthquake event clearly indicate that the region is prone to disaster in the future.

vi. Most likely, it was expected the earthquake to stimulate an increase in demand for ERD in the immediate future although the opinion is that this effect did not yet reach the required level of an alert.

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