APPENDIX: DAMAGE ASSESSMENT TO WAR AND NATURAL DISASTERS IN BOSNIA AND HERZEGOVINA

DAMAGE ASSESSMENT FOR MASONRY AND HISTORIC BUILDINGS IN BOSNIA AND HERZEGOVINA

M. HRASNICA*
Civil Engineering Department, Patriotske lige 30,71000 Sarajevo, Bosnia and Herzegovina

Abstract. Opposite to some common opinions the widest spread structural system of the multistory buildings in Bosnia and Herzegovina is structural wall system with masonry walls and reinforced concrete walls. The country is situated in seismic active region of South-East Europe, divided in seismic zones with PGA of 0.1–0.2 g for 500 year return period, in some parts even PGA of 0.30–0.35 g. Traditional art of building comprises masonry structures from adobe and simple masonry to the one with manufactured brick units. The buildings older than approximate 60 years have usually wooden floors; later the R.C. floors have become the standard art of construction. After the earthquakes in Skopje in 1963 and especially after the earthquake in Montenegro in 1979 the confined masonry became more and more typical art of the masonry structures. Lessons learned form those earthquakes proved the vulnerability of unreinforced masonry buildings. Most of the multistory structures, especially residential buildings, in 1970s, 1980s and 1990s were constructed with R.C. walls, some of them with satisfactory level of earthquake-resistant design. Historic buildings are mostly built as robust unreinforced masonry structures with wooden floors, if any. Seismic vulnerability of buildings with masonry and R.C. walls were analyzed according to the recommendations of European Macroseismic Scale EMS-98 and damage grades were estimated. It is shown that some of the typical masonry buildings could suffer substantial damages when exposed to the earthquake motion, which corresponds to seismic zones in the country. Some structural elements of historical buildings, as domes and arches, crack already by moderate earthquake but without loss of stability. Some analytical procedures and construction methods for retrofit and strengthening are shown.

* To whom correspondence should be addressed. e-mail: hrasnica@bih.net.ba

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1. Introduction

The existing buildings in Bosnia and Herzegovina are traditionally built as masonry buildings, which include most of historical buildings. After the World War II reinforced concrete structures prevail by the new erected buildings, but masonry structures are further built with apply of new materials. If one wants to assess possible damages, especially those caused by an earthquake, the existing older buildings are more vulnerable compared to the buildings constructed according modern technical codes. Several strong earthquakes that happened in the few last decades, underlined the importance of seismic vulnerability assessment including evaluation of possible strengthening and retrofit measures.

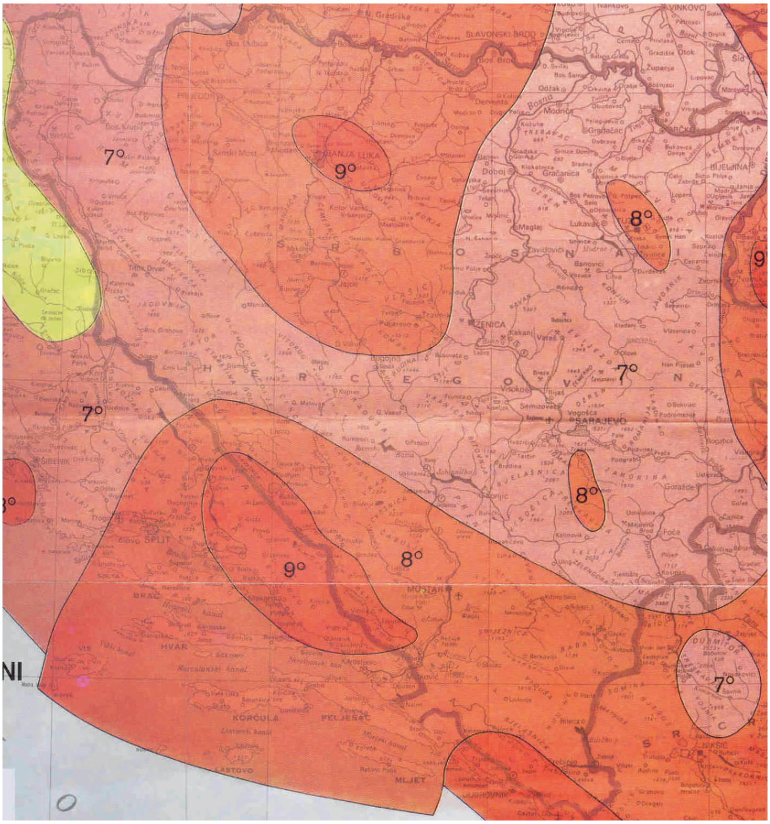

Figure 1. Seismic zones in Bosnia and Herzegovina

The territory of Bosnia and Herzegovina is situated in active seismic region of South-East Europe. Shown on the seismic intensity map of Bosnia and Herzegovina for the reference return period of 500 years (Fig. 1) the greatest part of the country lies in the zones of seventh and eighth intensity degrees according to MCS-scale or the new European Macroseismic Scale EMS. Relatively small part of the territory is situated in the seismic intensity zone 9. Referred to peak ground acceleration (PGA), PGA between 0.10 and 0.20 g corresponds to the greatest part of the territory and even PGA of 0.30–0.35 g in smaller part of the country.

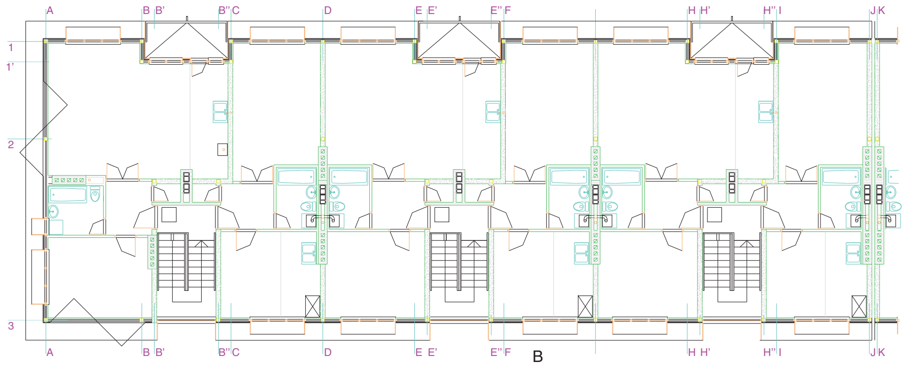

Figure 2. Typical multistory masonry building (Groundfloor + four or five stories), regular structure

Traditional art of construction was masonry building, built as unreinforced masonry (URM) with wooden floors. By the mid 1930s of the last century the first art of half-prefabricated reinforced concrete floors were applied, which was continued after the World War II. The most masonry buildings had up to five stories, but without vertical R.C. confining elements. Seismic resistance was provided by structural walls laid in two mutually orthogonal directions viewed in a plan. Whereby, smaller number of walls in longitudinal direction was caused by functional demands (Fig. 2). After the earthquake in Skopje in 1963, first seismic codes were published and vertical confining R.C. elements were introduced in masonry building. Presently, confining masonry is the common art of masonry structures.

Unlike some enrooted views structural system with walls prevails in reinforced concrete structures of multistory buildings (Fig. 3). It is similar to some Middle European countries, while further to South and South-East, for example Greece and Turkey, frames are usual earthquake resistant system. R.C. walls are predominantly used in last 40 years, especially for multistory residential buildings. During the earthquake in Montenegro 1979 they showed relatively good seismic performance. Most residential areas in the cities, built in 1970s, 1980s and

1990s have this structural system. In older buildings of this type, there was no special detailing concerning acceptable seismic response. Most walls have relatively small amount of transverse reinforcement and generally the criteria of capacity design (Paulay et Priestly, 1992; Bachmann, 1995) are not fulfilled.

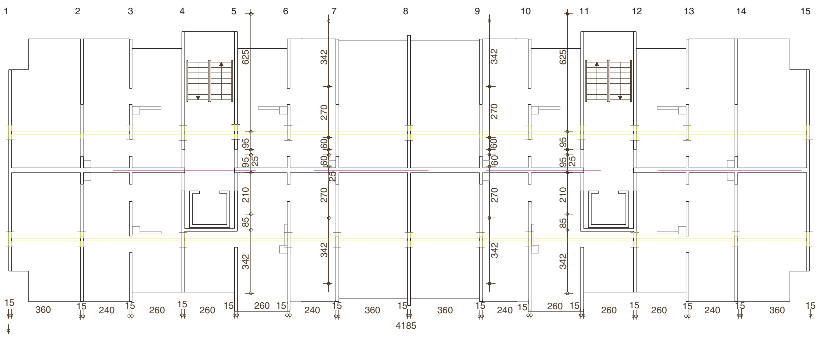

Figure 3. Typical multistory R.C. walls building (Groundfloor + seven/eight stories), regular structure

Reinforced concrete frames filled in with masonry are rarely used in building practice in Bosnia and Herzegovina (should not be mixed with confined masonry, see previous paragraph). The weakness of this system is well known; relatively stiff masonry infill during stronger earthquake could cause serious damages of R.C. frame columns. The earthquakes in Turkey (South-East European Region) in the last 10 years showed significant damages of this structural system.

2. Damages Caused by Past Earthquakes in the Region

Several strong earthquakes hit the region of South-East Europe in the last few decades, some of them in Bosnia and Herzegovina or neighborhood countries. They caused loss of human lives, a lot of injured inhabitants of the hit areas and substantial damages to the building structures.

Some of the recent earthquakes, which caused damages of the buildings, also influenced development of seismic codes for the whole Europe, are listed below:

Earthquake in Skopje, Macedonia in 1963, seismic intensity ninth degree, after this earthquake the first modern seismic code was introduced.

Earthquake in Banja Luka, Bosnia and Hercegovina 1969, seismic intensity eighth to ninth degree, hypocenter was in the country.

Earthquake in Friuli, North-East Italy, seismic intensity ninth to tenth degree, damage analysis are used in development of European Macroseismic Scale EMS.

Earthquake on the Montenegro Coast in 1979, seismic intensity ninth degree, after this earthquake the new seismic code was improved.

The most severe consequences after a strong earthquake are total or partial collapse of the building structures, which were observed for Skopje and Banja Luka earthquake (Figs. 4 and 5). Five-story masonry building without vertical R.C. confining elements could not withstand strong forces induced by the earthquake of the seismic intensity nine and collapsed (Fig. 4). Similar observation can be confirmed by failure of the corner building (Fig. 5).

Figure 4. Total collapse of URM building, Skopje 1963 (Petrovski, 2004)

Figure 5. Partial failure of the masonry building, Banja Luka 1969

Common damages of masonry structures caused by earthquake are diagonal cracks in the walls (Fig. 6). This type of damage on masonry structures was observed after many earthquakes, from minor cracks after less severe ground motion to larger cracks due to strong earthquakes, as illustrated on the figure below. This can lead to the buckling of the damaged wall and collapse of the whole building. The reasons for the diagonal cracks in the masonry walls are in their small resistance in tension. Due to the high level of the horizontal forces induced by an earthquake a sort of truss resistance mechanism is formed in the masonry walls or piers. The truss chords are floor structures, which in the case of R.C. floors can transmit the horizontal forces in efficient way, while the diagonals are formed in the masonry wall itself and fall in tension. The most of the existing masonry buildings in southeast Europe belong to the unreinforced masonry structures and this tradition is preserved. The improvement is made by almost regular built in of the vertical reinforced concrete confining elements, which improve overall structural ductility significantly.

Figure 6. Diagonal crack in masonry walls and loss of corner wall URG masonry' R.C. floors (EMS)

The other, also very frequent type of damage in masonry buildings due to the seismic action is loss of connection between two mutually perpendicular walls in plan. This is also shown on the Fig. 6, where partial loss of connection between two external walls at the corner of building was observed. This building was built as URM with R.C. floors but without vertical confinement.

Traditional stone masonry houses were very often built in the Mediterranean region, where continuous seismic activity is permanently registered. Most of the houses are built with wooden floors. The damages at one of such buildings due to Montenegro earthquake are shown on the Fig. 7. The stone masonry wall collapsed, which caused partial collapse of the floor and the roof structures, leading generally to heavy structural damage of the building.

Figure 7. Stone masonry building with wooden floors, earthquake in Montenegro 1979 (EMS)

The masonry buildings are generally brittle structures, which show relatively satisfactory behavior up to moderate seismicity. In that case most damages can be predicted and also repaired. But, exposed to very strong earthquakes most of the traditional buildings suffer heavy structural damages, whose reparations are not reasonable. Exceptions are important historical buildings. The advantage of the existing masonry building is the structural regularity. Most of them have no large structural eccentricity, viewed in the plan, or there is no important stiffness irregularity along the height of the building, which is not rare in the modern reinforced concrete multi-storey structures (Tomaževič, 2006).

Reinforced concrete walls are generally less vulnerable compared to masonry walls for an equivalent earthquake motion. If they are designed according the newest seismic codes or modern guidelines for the earthquake resistant design, their seismic response could be predicted. That means dissipation of energy induced into the structure by an earthquake, damages on the previously defined parts of the structural elements, and no collapse. These principles are part of the capacity design philosophy, which was developed for earthquake resistant design of the structures. Large number of the damages on the reinforced concrete buildings, which were registered during recent strong earthquakes, are cones-quences of the irregular structural system. Non-uniform distribution of stiffness along the height of the building, so called soft-story phenomena, was probably the most mentioned reason for the heavy damages. Especially soft ground floor, very popular among the architects of the buildings. The second place probably belongs to non-uniform distribution of vertical elements, viewed in the plan. Poor detailing, especially absence of the transverse reinforcement in the joints and corner area, as well as absence of appropriate reinforcement ratios could also cause important damages to the structure.

Figure 8 shows collapse of the fresh built reinforced concrete building with structural walls during Montenegro earthquake in 1979. The hotel building had been finished just before the earthquake happened, which means that it was constructed according the latest seismic code. But, two structural irregularities were fatal for it. First, flexible ground floor (soft-story) proved to be very sensitive to strong earthquake motion and then non-symmetrical distribution of the structural walls in the plan of the building. After the lessons from this earth-quake the local seismic codes were modified, especially regarding restrictions for the buildings with soft-story.

Figure 8. Soft-story and non-symmetrical structure Montenegro 1979

Typical damage at the bottom of the vertical reinforced concrete element is shown on the Fig. 9. Beyond the yield limit at the bottom of the wall, the plastic hinge is formed. It is marked with the cracks on both sides and very often with spalling of concrete cover. This area is especially vulnerable if there is no enough transverse reinforcement. One of the consequences could be buckling of the vertical reinforcement, which was observed after different earthquakes, even by very robust bridge piers, as it happened during Kobe earthquake in 1995.

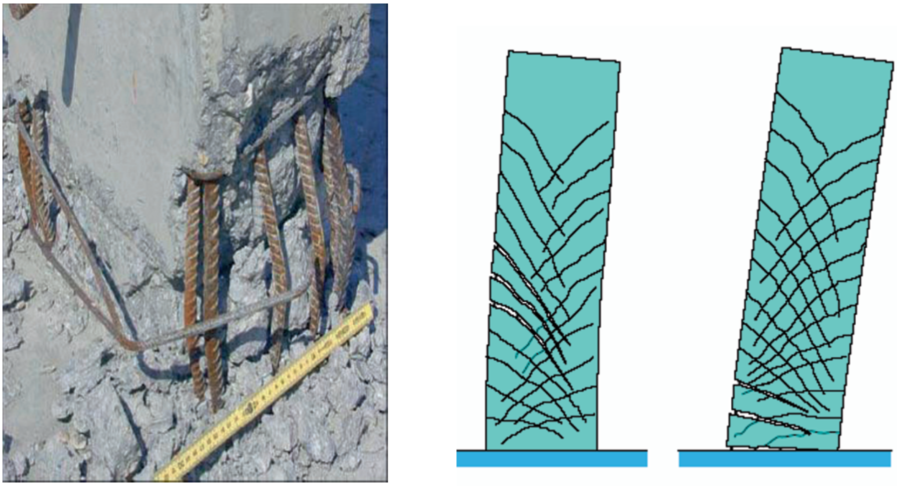

Figure 9. The bottom of the R.C. element, plastic hinge area

Similar damages could be expected during stronger earthquakes in buildings with R.C. walls in Bosnia and Herzegovina.

Masonry infilled reinforced concrete frames represent the specific structure made of relatively ductile R.C. frame, which is designed to carry both, vertical and horizontal loading, and relatively stiff masonry infill wall, which is built as nonstructural element after completing the frame. Due to the infill the structure becomes much stiffer for the horizontal loads. Masonry infill is activated in the case where the building is subjected to seismic loading. At the contacts between the masonry infill and R.C. elements interaction forces could be developed, which can cause unexpected behavior and damages of the main structural system (Fig. 10).

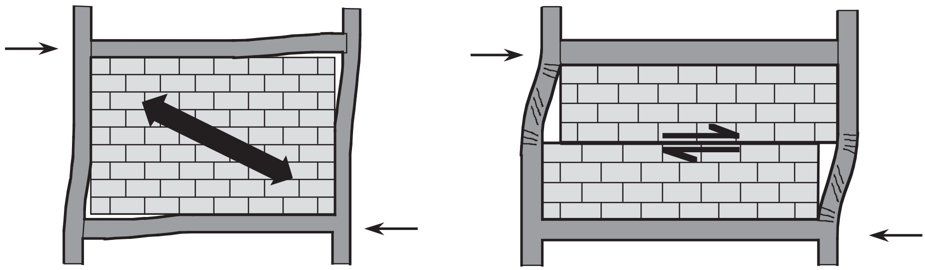

Figure 10. Damages to R.C. frame due to masonry infill wall

During stronger earthquake contact between stiff masonry infill and relatively flexible frame structure could be lost or dangerous sliding of masonry infill along the horizontal mortar joints could occur. As the consequences frame columns are subjected to additional shear forces, which were usually not taken in account by design. The undesirable shear failure mechanism can be developed in the frame columns, leading probably to the partial collapse of the structure. In some cases, for example under the large window openings masonry infill is partially built in. Due to strong horizontal seismic action high shear forces are developed in the free part of the frame, causing severe damages or shear failure of the column.

Figure 11. Damages on the R.C. frame structure due to masonry infill (SGEB, 2004)

As an example, the damages of the masonry infilled frame structure during earthquake in West Turkey 1999 are shown on the Fig. 11. Frame columns suffered very high structural damages.

It can be concluded that masonry infilled frame structures can perform in an undesirable way during strong earthquake motion producing brittle shear failure of the reinforced concrete frame columns. In the case of lower seismicity the composite structure made of reinforced concrete frame and masonry wall can keep its integrity and act as considerably stiff structure, in some way comparable to reinforced concrete walls, reducing horizontal displacement of the floor structures and preventing the damages of the nonstructural elements.

In Bosnia and Herzegovina R.C. frames filled with masonry are not often constructed. The common type of masonry structures in the last few decades is confined masonry, which is widely accepted, especially for residential houses.

Taking in account damage assessment of building structures, considered in this chapter, it is of great interest to classify typical building structures according to their seismic vulnerability.

3. Vulnerability Classification According to European Macroseismic Scale

Within European Macroseismic Scale (EMS) structural systems of buildings are classified according to vulnerability classes depending on structural type. Vulnerability classes are A–F, where class A is for the weakest seismic structures and class F for those that are expected to have very good seismic performance (Table 1).

TABLE 1. Vulnerability classes according to EMS

	Type of structure	Vulnerability Class A	B	C	D	E	F
MASONARY	rubble stone, fieldstone	○					
	adobe (earth brick)	○	—				
	simple stone	- -	○				
	massive stone		- -	○	- -		
	unreinforced, with manufactured stone units	- -	○	- -			
	unreinforced, with RC floors		—	○	- -		
	reinforced or confined			- -	○	—	
REINFORCED CONCRETE (RC)	frame without. earthquake-resistant design (ERD)	- -	—	○	- -		
	frame with moderate level of ERD		- -	—	○	—	
	frame with high level of ERD			- -	—	○	—
	walls without ERD		- -	○	—		
	walls with moderate level of ERD			- -	○	—	
	walls with high level of ERD				- -	○	—

The classification of damage degrees is listed here separately for masonry buildings and reinforced concrete building with walls, two typical building systems in Bosnia and Herzegovina. Damage degrees are from 1 to 5 that means from irrelevant damages or only damages of nonstructural elements that correspond to damage 1, to destruction or even building collapse that corresponds to damage degree 5.

Classification of damage to masonry buildings:

– Grade 1: Negligible to slight damage (no structural damage). Hair-line cracks in very few walls. Fall of small pieces of plaster
– Grade 2: Moderate damage (slight structural damage). Cracks in many walls. Fall of fairly large pieces of plaster

- Grade 3: Substantial to heavy damage (moderate structural damage). Large and extensive cracks in most walls, roof tiles detach
- Grade 4: Very heavy damage (heavy structural damage). Serious failure of walls, partial structural failure of roofs and floors
- Grade 5: Destruction (very heavy structural damage). Total or near total collapse

Classification of damage to R.C. buildings with walls:

- Grade 1: Negligible to slight damage (no structural damage). Fine cracks in walls at the base
- Grade 2: Moderate damage (slight structural damage). Cracks in structural walls
- Grade 3: Substantial to heavy damage (moderate structural damage). Cracks at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods
- Grade 4: Very heavy damage (heavy structural damage). Large cracks in the walls with compression failure of concrete and fracture of rebars
- Grade 5: Destruction (very heavy structural damage). Collapse of ground floor or parts of building

Damage degrees of some structural types depend also on earthquake intensity. So, the class of building vulnerability, which depends on the structural type, can be related to damage degrees, which can be expected for different seismic intensities. Within the European Macroseismic Scale there are short descriptions of effects that could be expected for the specific degree of seismic intensity. Further, the focus is on buildings with masonry walls and R.C. walls, typical for multistory buildings in Bosnia and Herzegovina.

4. Seismic Vulnerability Classification of Masonry and R.C. Walls Buildings

The buildings are classified here according to their structural type, seismic intensity, and expected damage degree. In the case of earthquake, the most endangered buildings are those built before the introduction of seismic codes, but that depends very much on regularity of their structures.

Masonry buildings made of rubble stone or earth brick generally belong to vulnerability class A and already for seventh degree of seismic intensity serious damages can be expected, including instability of walls or falling down of ceiling. Such buildings have no many floors, usually ground floor and a story; they are situated in village, often in inaccessible environment.

Further on, there are masonry buildings constructed with bricks produced in factory, but without vertical confining elements. We speak about unreinforced masonry (URM) without confinement. Older buildings have usually wooden floors, while buildings built after World War II generally have R.C. floors. The first belong mostly to vulnerability class B where very heavy damages can be expected for the earthquakes whose intensity corresponds to the seismic zone 8. Masonry buildings with R.C. floors according to EMS classification could stand heavy damages of the structure including falling down of some walls for the intensity degree 9 and they belong mostly to vulnerability class C.

Masonry buildings with reinforced concrete confining elements, usually called confined masonry, are generally classified according to EMS in relatively low class of vulnerability, class D. For ninth degree of seismic intensity significant cracks can appear, roof tiles detach, chimneys can fall down, but there should not be collapse of entire walls. The advantage of confined masonry is evident. After the new seismic codes were introduced this became usual type of masonry building. Yet, most of the existing buildings belong to unconfined masonry.

TABLE 2. Damage grades of typical multistory buildings with wall system in Bosnia and Herzegovina

Type of masonry and R.C. wall buildings	Seismic zone according to EMS		
typical structures in B&H	Zone VII	Zone VIII	Zone IX
Masonry buildings made of earth brick or field stone	3–4	4–5	5
Unconfined masonry, older than approx. 60 years mostly with timber floor structure	2–3	3–4	4–5
Unconfined masonry, younger than approx. 60 years reinforced concrete floors	2	2–3	3–4
confined masonry with R.C. floors, mostly newer masonry buildings	1	2	2–3
Reinforced concrete building with R.C. walls moderate earthquake-resistant design	1	2	2–3
Reinforced concrete building with R.C. walls high level of earthquake-resistant design	–	evt. 1	1–2

There are no reinforced masonry buildings till now in Bosnia and Herzegovina, although this type of structures is favorable, regarding seismic resistance of masonry buildings.

Reinforced concrete buildings with structural walls may be divided into those designed and constructed without or with moderate seismic detailing and those having high level of earthquake resistant design, usually constructed according the newest seismic codes. As the application of structural systems with R.C. walls began in this region by the end of 1960s and the beginning of

1970s of the last century, the existing buildings meet at least some of seismic design criteria, and that places them in average in vulnerability class D. This means that even for the seismic intensity of ninth degree R.C. walls should not collapse, although they would have heavy damages in the form of large cracks, spalling of concrete, especially concrete cover, or instability of some reinforcement bars. R.C. walls designed and constructed according to the newest seismic rules (EC8, 2003) and recommendations would show only smaller, very fine cracks for the earthquake motions corresponding to seismic zones 7 and 8, and only for ninth degree there could be some larger cracks and spalling of concrete cover. All damages are expected to appear in the most stressed part of the wall, at its bottom.

All considerations for different masonry and reinforced building are summarized in Table 2. Taking into account structural type, their vulnerability classification and considerations about expected damages for different seismic intensities the appropriate damage grades are estimated for typical buildings and seismic zones in Bosnia and Herzegovina.

Previous classifications refer to some average design and constructed masonry and reinforced concrete buildings. In the cases of worse construction heavier damages than those described must be taken in consideration. Presented vulnerability classification of masonry and R.C. walls buildings corresponds to relatively regular structures. That means: the layout of the structural walls in a plan is approximately symmetrical and the stiffness is almost uniform or proportional along the height of the building. It has to be stated, that each irregularity increases seismic vulnerability of the structure. It was confirmed in past earthquakes in the region of South-East Europe. Irregular distribution of walls in a plan of the building can produce large eccentricity between mass center and stiffness center (Hrasnica, 2005a). Non-uniform stiffness distribution along the wall height can form soft stories and it is well known source of earthquake damages. The buildings with flexible ground floor are especially vulnerable, which was confirmed in recent strong earthquakes.

5. Damage Assessment of Historical Buildings

Whole Mediterranean area belongs to seismic active regions, which was confirmed by past earthquakes. At the same time Mediterranean countries are rich in historical and cultural buildings and monuments. Those buildings have great importance and value for specific countries and their inhabitants. So they merit special care and protection. This concerns in the same way the historical buildings in Bosnia and Herzegovina. Besides the risk of seismic damages, a lot of them were damaged or even destroyed during the last war.

Assessment of historical buildings presents specific problem considering the ways they were built and the materials, which were used. The damages are sometimes cumulated through many years and many causes, e.g. few moderate or stronger earthquakes.

Another specific problem arises by reparation and necessary strengthening or retrofit, for example to achieve earthquake resistance demanded by modern seismic codes. Speaking about historical buildings and monuments the aim is to preserve and reveal their aesthetic and historical values and to use original materials and original way of construction, if possible. But, where traditional techniques prove inadequate some modern construction and conservation techniques must be implemented. The same problems occur with traditional construction materials. In order to provide necessary resistance and ductility and fulfill the demands of new building codes the contemporary building materials have to be carefully implemented in the structures of those buildings. Many important principles for the assessment of historical buildings and monuments are summarized in the Venice Charter.

Figure 12. The old city of Bam in south-east Iran before the earthquake

The large majority of all historical buildings are built as masonry structures, a lot of stone masonry, but in some regions bricks masonry as well. They are traditionally built as unreinforced masonry without confining elements. In some regions timber confinement was used. Typical curved structural forms as domes, arches and vaults are often part of historical buildings especially the religious one. As they are built as unreinforced masonry structures, the historical buildings are relatively stiff and show generally brittle behavior. So, the first damages in form of cracks appear already by moderate earthquakes on softer structural elements as domes and arches, or ceilings by wooden floors and on partition walls, if there are any. At the same time the main structure, as dick walls and abutments, is in linear range of the behavior, with no or almost no cracks. But, it's generally not true for very strong earthquake motion.

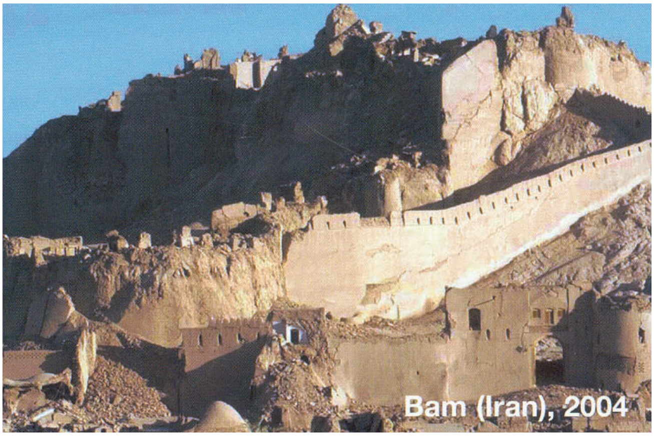

Figure 13. The old city of Bam in south-east Iran after the earthquake 2004

How the strong earthquake can destroy old monumental masonry structure is illustrated on the example of the old city of Bam in southeast Iran. On the Fig. 12 is the view of the city before the catastrophic earthquake in 2004 and on the Fig. 13 after it. The unreinforced masonry structure couldn't withstand high seismic intensity in spite of the probably rather stiff and robust structure.

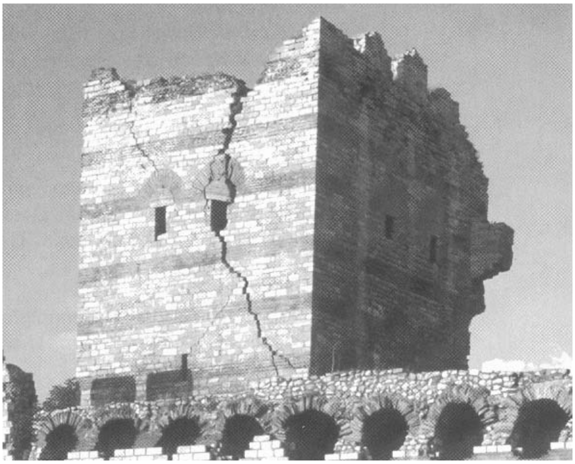

Figure 14. Large diagonal crack in the old tower in Istanbul (Wenk, 2004)

Damages can be accumulated during the history of these old buildings, especially when they are situated in seismic active region. Sometimes it took the time before the decisions are made how to repair these structures and to preserve their aesthetical and cultural values. On the Fig. 14 is the old tower of the city wall in Istanbul, Turkey, with typical diagonal crack in the masonry wall.

As it was already stated some parts of the old historical buildings are more vulnerable to seismic actions. Masonry structures have rather small resistance in tension and cracks open perpendicular to the direction of seismic forces. Typical example is schematically presented on the following Fig. 15, where the cracks on the dome are opened orthogonal to ring tension forces.

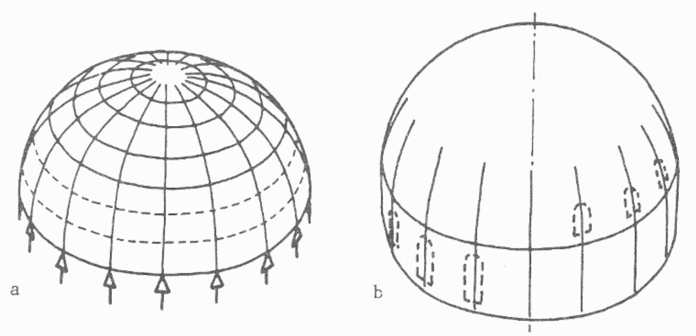

Figure 15. Schematic presentation of dome structural system and cracks in the dome masonry structure

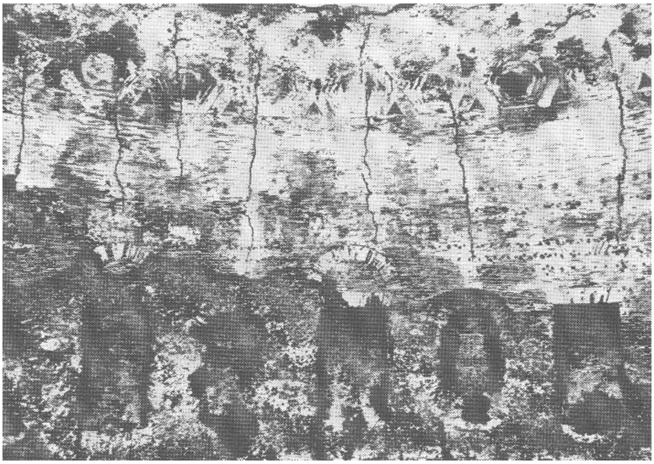

Figure 16. Radial cracks in the old dome masonry structure (UNDP, Vol. 6)

The structural form of the dome as three-dimensional structure is shown on the left side of the Fig. 15; the radial arches in compression and circumferential tension. Masonry dome is usually set on the drum below and very often they are interrupted with window openings. It cracks radially as shown on the right side of the Fig. 15, forming ring of the arches. The illustration of the cracks in an old dome masonry structure is on the Fig. 16.

During last war in Bosnia and Herzegovina many historical buildings, valuable as important cultural heritage, were damaged and even barbarically destroyed. Here, as example, cross-section of the masonry structure of Ferhadija mosque in Banjaluka with its dome, drum and arches (Fig. 17). The mosque is completely destroyed and should be rebuilt respecting former materials, structure and all geometrical dimensions.

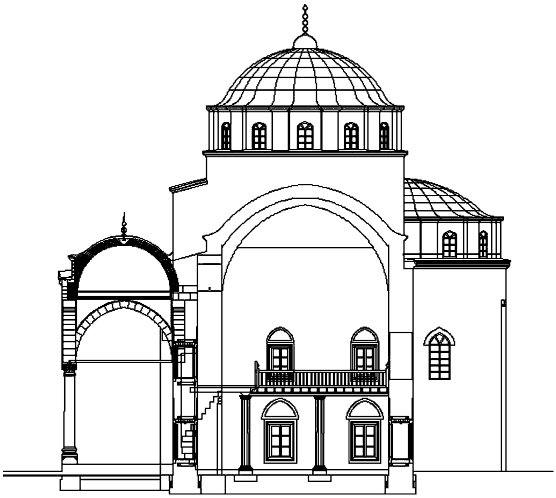

Figure 17. Cross-section of Ferhadija mosque in Banjaluka, Bosnia and Hercegovina (Hrasnica, 2005b)

The building is situated in a seismic zone 9 that means PGA of 0.30–0.35 g. The whole structure should be built in the same way as original one. The main building structure was stone masonry and the dome was brick masonry. The loading from the dome roof is transmitted over the drum further to the arches and walls. The whole building should be constructed as unreinforced masonry and can be classified as rather seismic vulnerable structure (see Tables 1 and 2) with damage grades from 3–5 for the strongest earthquakes. The challenge is how to reinforce and strengthen the mosque structure with respect to aesthetical and cultural value. Traditional methods are reinforced concrete confining elements built in masonry structures or steel ties to keep the integrity of the structure. Modern methods include implementation of new materials as carbon fibers or pre-stressing with high resistance steel wires and ropes.

Another possible but very expensive method in the high seismic areas is base isolation, where the rigid structure of the whole historical building is posted on special elastomeric or similar bearings, which function as isolators and damping elements.

6. Seismic Evaluation and Damage Assessment of Existing Buildings

The existing buildings are more vulnerable to seismic actions than those designed and built according to modern seismic codes. Important percentage of existing buildings represents masonry buildings, which include most of the historical monuments and buildings. The prediction of their seismic performance is very important to assess possible damages. The properties of those buildings and their typical damages were analyzed in the previous chapters. They were also classified according their seismic vulnerability and damage grades, which can occur for different levels of seismic intensity.

The efficient methods for evaluation of existing buildings are pushover analysis and capacity spectrum method (Freeman, 1998; Hrasnica, 2005a). Assuming that the structure responds predominantly in the first eigenmode, using nonlinear static procedure the capacity curve of the building is developed. On the other side, earthquake demand is represented by design spectrum (Fig. 18). The intersection point of two curves simulates the performance point of the structure for the given conditions.

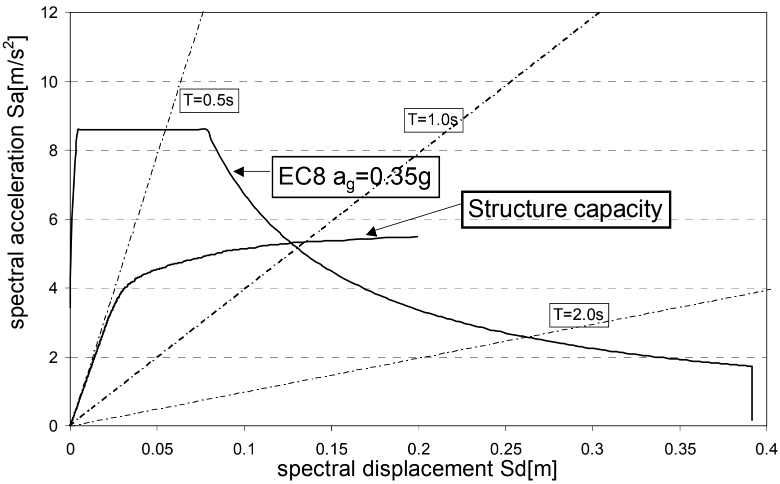

Figure 18. Structure capacity versus earthquake demand

The both curves are presented in acceleration-displacement-response-spectrum ADRS-format. On the Fig. 18 earthquake demand is represented by Eurocode 8 design spectra for the elastic behavior.

This procedure gives very good insight into the structural behavior from the engineering point of view. Position of the structure capacity curve regarding earthquake demand curve shows what kind of measures should be undertaken to improve seismic performance of the building, if it's necessary. Retrofit of the structures concerns three basic structural properties: strength, ductility and stiffness. Each of them is important for the desirable structural performance during an earthquake. The strength is connected with minimum design capacity, ductility level is important for dissipation of energy induced into the structure by an earthquake and stiffness is important to limit deformations.

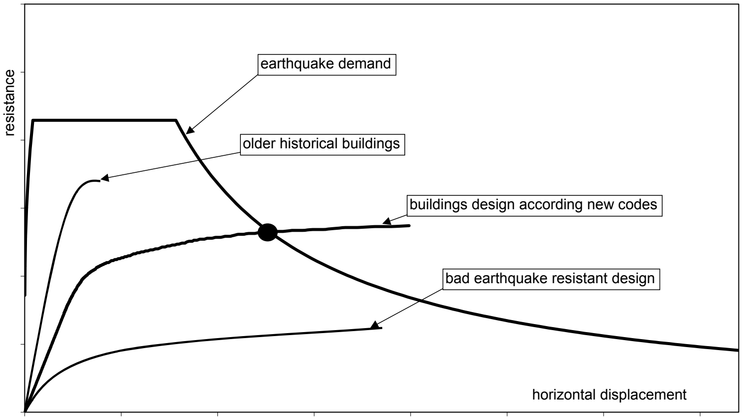

Figure 19. Capacity of different structures regarding their earthquake resistance

On the Fig. 19 the capacity curves for three different structures are compared referring to earthquake demand. The first curve, which does not intersect the demand curve represent behavior of brittle structures with low ductility. This is typical for older historical buildings constructed as robust unreinforced masonry structures. The fundamental period of such structures is usually in the range of high spectral acceleration. If the capacity curve does not go over seismic demand the structure generally cannot survive that earthquake intensity. On the contrary side there are very soft structures, with high ductility but without minimum of required resistance. The capacity curve also does not intersect the seismic demand, here in long period range. It is also example of bad earthquake resistant design.

In order to achieve good earthquake resistant design the structure should have required resistance and appropriate ductility level to assure dissipation of seismic energy. Unreinforced masonry buildings and most of the historical buildings built in a traditional way don't fulfill these requirements.

In the Table 2 (Chapter 4 of this paper) the damage grades for different seismic zones are summarized. To decrease damage grades of the traditional masonry and historical buildings it is obviously necessary to improve their ductility, in the way that the capacity curve intersect the demand curve at the reasonable level of horizontal deformations.

There are many possibilities for repair and retrofit of the masonry or reinforced concrete structures in order to improve their seismic performance. As generally most vulnerable to earthquake a lot of existing masonry buildings should be repaired and strengthened. Two common methods are illustrated here for convenience. Vertical reinforced concrete confining elements built in unreinforced masonry structure improve structural ductility and whole integrity of the building (Fig. 20). The construction begins in the lowest story and continues upward. Good connection between existing masonry and new concrete is of crucial importance.

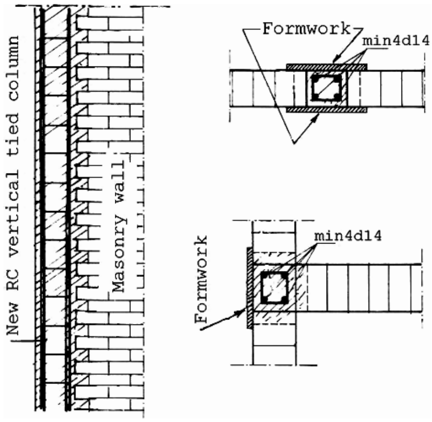

Figure 20. Built in of new R.C. vertical confining elements in existing building

Another very common construction method for masonry strengthening is reinforced concrete jacketing (Fig. 21). It is also logical procedure and at the same time the cracks in the masonry are repaired and covered. The reinforced concrete jackets, 3–5 cm dick, are added, if it’s possible on the both sides of the masonry wall. First, wire meshes are fixed by ties on the surfaces of the existing wall and than concrete is added by the shotcrete or some similar method. If the concrete is poured the thickness of the jackets is at least 10 cm.

Vulnerability assessment is important to make decision about retrofit and strengthening of the existing buildings. Seismic evaluation and comparison of structural capacity of existing buildings with seismic demand according to modern seismic codes will result in the necessity of retrofit for the majority of existing buildings, especially for unreinforced masonry buildings. Among them are without doubt very valuable historical buildings, some of them belonging to the world cultural heritage. On the other hand damage statistics from major earthquakes (Otani, 2003) give us the data that after Mexico earthquake in 1985, which was reported as severe, roughly 94% of the buildings suffered light to minor damages and after Japan earthquake in 1995 about 88% of the buildings survived with light to minor damages. What kind of building structures will suffer heaviest damages; depends not only on structure itself, but local geological and seismological conditions play also important roles. Generally the vertical structural elements have priority when one decides about retrofit and strengthening, because the collapse of building is normally caused by the failure of vertical carrying elements, such as columns and walls. Another important task is to avoid brittle failure of structural elements, as shear failure, which should be examined in retrofit analyzing procedure.

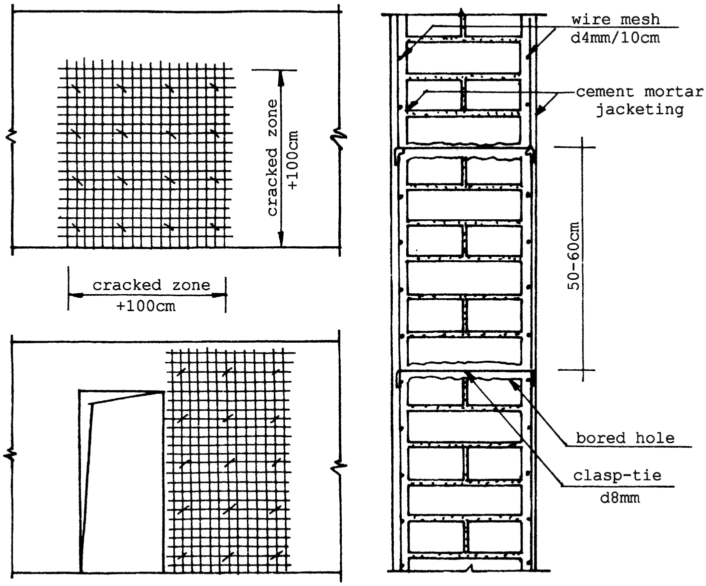

Figure 21. Reinforced concrete jacketing of the existing masonry walls (UNDP, Vol. 5)

7. Conclusions

The existing buildings don't fulfill the requirements of the modern seismic code and they are more vulnerable to an earthquake than the new one. A lot of the existing buildings are built with unreinforced masonry structures. This includes also most of the historical and monumental buildings.

Presented vulnerability classification of typical multistory buildings with masonry and R.C. walls corresponds to regular structures and in average good construction. Irregularities of structural system increase vulnerability class of the building, as well, and it has to be taken in account when making final decision about damage grade of some building for the corresponding seismic zone.

Considering the results from previous chapters, it can be concluded, that for seismic zone 7 (PGA = 0.10 g) prevailing on the seismic map of Bosnia and Herzegovina typical masonry and R. C. wall buildings should not suffer heavy damages or collapse. With the increase of earthquake intensity the possibility of more significant damages also increases, especially in masonry buildings. So, heavy damages of unconfined masonry buildings are real in seismic zone 9. Significant damages can be expected in irregular building structures and in masonry with R.C. confining elements. R.C. walls are, as expected, less vulnerable to earthquake compared to masonry buildings. Their vulnerability significantly increases in the case of irregular structural system. When the earthquake is with PGA between 0.20 and 0.35 g (seismic intensity zones 8 and 9) significant damages of buildings with soft-stories, especially with flexible ground floor, cannot be avoided.

Historical buildings should be classified in the same vulnerability classes as unreinforced masonry buildings. They are generally stiff and show brittle behavior. Significant damages are to be expected during stronger earthquakes, which were confirmed in the past. Some structural elements as dome and arches crack already at lower seismicity level, but those damages are not severe for overall structural stability.

Evaluation of existing building can be efficiently done using pushover analysis and capacity spectrum method. Comparison of structural capacity and seismic demand gives conclusions about retrofit of the structure. Some common method for damaging repair and strengthening of the masonry structures are presented. Strengthening and retrofit have to focus primarily on vertical structural elements, as wall and columns, as well as avoiding brittle shear failure.

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