Seismic Performance Assessment: Sarajevo Case Study

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ABSTRACT

A seismic safety assessment of the two reinforced concrete buildings, located in Sarajevo, Bosnia territory, is conducted in respect to ATC-40 method. Within the framework of the performance based earthquake engineering, at the first stage, seismo-tectonic setting of the territory was discussed, then, by using historical seismicity of the region, the seismic hazard analysis for the Sarajevo City in Bosnia is performed in probabilistic manner. The site specific uniform hazard spectra at 5% damping for 475-year return period is employed as an earthquake demand. Then building stock information of Bosnia and Herzegovina is discussed. Lastly, two typical modern building's performance assessments are carried out.

Keywords: *Sarajevo Tectonic Setting, Seismic Hazard, Building Stock of Bosnia, Performance Evaluation*

INTRODUCTION

During the last two decades, performance based design and assessment methods have become rather more popular than the era they were firstly proposed. In the near future, it is likely that when new generation seismic codes are released, performance based approach will be the most common tool for the design of new structures [1]. Assessment of existing structures is of prime importance in countries where the building stock has been constructed within the decades in which the aseismic design rules were not the main concern of the designers and the authorities [2].

Performance-based earthquake engineering seeks to improve seismic risk decision-making through assessment and design methods that have a strong scientific basis and that express options in terms that enable stakeholders to make informed decisions. Given the inherent uncertainty and variability in seismic response, it follows that a performance-based methodology should be formalized within a probabilistic basis. The framework has four main analysis steps: Hazard analysis, structural/nonstructural analysis, damage analysis, and loss analysis. The first assessment step entails a hazard analysis, through which one evaluates one or more ground motion Intensity Measures (IM). For standard earthquake intensity measures (such as peak ground acceleration or spectral acceleration) is obtained through conventional probabilistic seismic hazard analyses. Typically, IM is described as a mean annual probability of exceedance, which is specific to the location and design characteristics of the facility [3].

In this study, within the framework of the performance based earthquake engineering, at the first stage, a probabilistic seismic hazard analysis of Sarajevo City in Bosnia and Herzegovina (BiH) was performed. Two case study structures have been analyzed by nonlinear static analysis methods. ETABS software, capable of modeling RC structures with lumped plasticity models, is used for analyses [4]. Both case study structures satisfied the Immediate Occupancy performance level, because the structure has high shear wall percentages.

SEISMOTECTONICS OF BOSNIA REGION

Bosnia's seismo-tectonics seems to follow the Mediterranean marine regime. Earthquakes occur mostly in the outer Dinaric Alps (southern Bosnia), while the strongest earthquakes occur within the Sarajevo Fault system in southern and North western Bosnia [5].

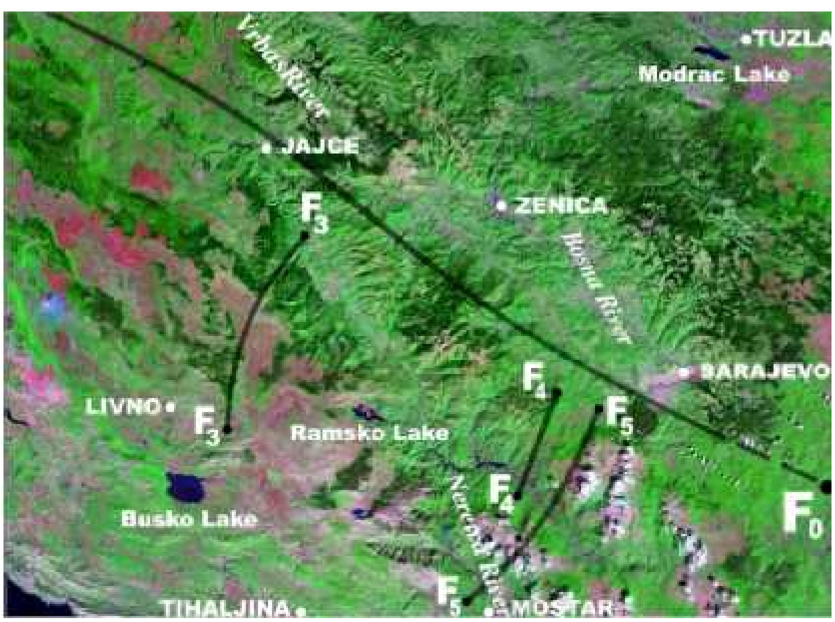


Figure 1 Traces of the Livno Fault (F3-F3) and Mostar Fault (F5-F5) as parts of the region's largest, Sarajevo Fault F0-F0 [5].

The last century's strongest, Tihaljina earthquake of 1923, took place in the locality of the intersection of two deep faults, some 50 km southward along the extension of the Livno Fault F1-F1, and 30 km southward along the extension of the Mostar Fault F5-F5 (Figure 4). Recently, as it is generally expected from long such faults, M6+ earthquakes occurred around the midsection of the Sarajevo Fault at the proximity of the Gradiška Fault – in 1888, 1935,1969 and 1981 between the cities of Banja Luka and Jajce. Thus it would appear that a strong earthquake of M6 or above is overdue all through the midsection of the Sarajevo Fault joint with the Gradiška Fault [5].

SEISMIC HAZARD ANALYSIS AND SEISMIC CODES

The seismic hazard analysis approach is based on the model developed originally by Cornell [6] who quantified it in terms of the probability of exceedance of the design level peak ground acceleration (PGA). The procedure for conducting a probabilistic seismic hazard analysis includes seismic source characterization, size distribution and rate of occurrence determination for the source, ground motion estimation and, lastly, probability analysis.

In the current study, earthquake sources are characterized as area source zones. Area seismic sources are often defined where specific fault data are not known, but seismicity does exist. Area sources assume that the rate of occurrence is uniform throughout. Therefore, every location within the area has equal probability that an event will occur.

All seismic sources, that can generate strong ground shaking in Sarajevo and surroundings, are classified into 6 areal seismic zones: (1) SAVA (2) VELE, (3) HERV, (4) TREB, (5) DRIN, and (6) IDIN [7]. The zonation is shown in Figure 2, and the seismicity parameters of each zone are summarized in Table 1.

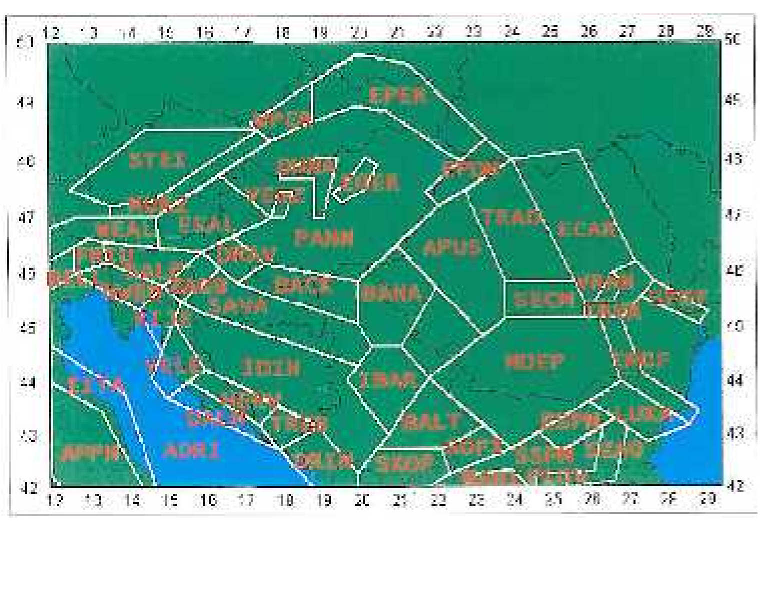


Figure 2 The seismic source zone model used in this study. See Table 1 for details or each zone [7].

Table 1 Summary statistics for the seismic source zones used in the analysis [7].

Code	Area	Start year	Number of events	*a*	*b*	Mmax	Events/km²	Mean depth	Max depth
SAVA	27445	1502	34	3.434	-0.971	6.0	0.1293	13	33
VELE	0.862	1280	23	3.048	-0.973	5.7	0.1661	14	30
HERV	8259	1853	66	3.243	-0.848	6.1	0.8592	20	63
TREB	5662	1866	42	3.239	-0.906	6.1	0.7278	16	57
DRIN	12770	1563	63	3.597	-0.956	7.0	0.4643	15	46
IDIN	56817	1386	102	4.423	-1.091	6.0	0.2016	18	136

In Bosnia region, previously recorded strong ground motion acceleration records are limited. Therefore, in the current analysis, worldwide applicable three empirical attenuation relationships are utilized to perform the seismic hazard analysis. Attenuation relationships for rock sites and soil sites employed in this study are Abrahamson-Silva [8] and Abrahamson-Silva [9], respectively.

After the compilation of the seismic hazard analysis data, the procedure for conducting a probabilistic seismic hazard analysis, by using EZ-FRISK [10,11] software, was employed to produce the PGA as a function of return periods and uniform probability response spectra for selected return periods (Figure 3).

The results of probabilistic seismic hazard analysis for Sarajevo are presented in terms of spectral responses at 5% damping for the return periods of 475 years (Figure 3). The results are used in calculation of demand spectra in performance assessment.

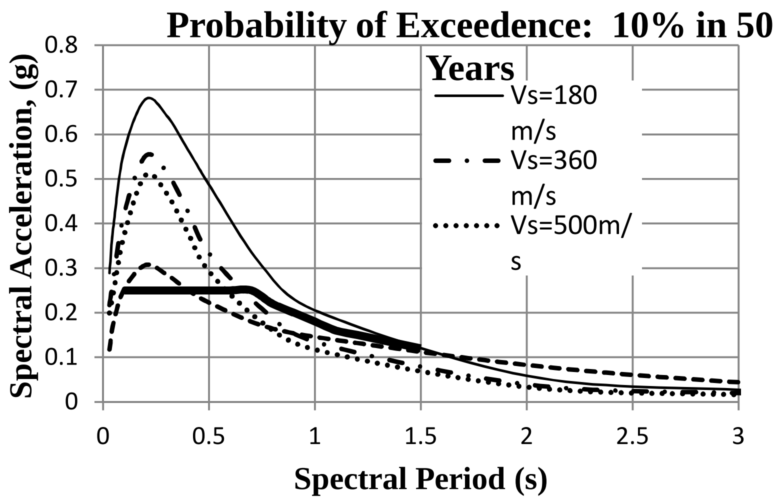


Figure 3 Uniform hazard spectra for 475-year return period

In former Yugoslavia the first temporary codes for Construction in Seismic Regions were passed only in 1964. In 1981, Technical Regulations for Design and Construction of Buildings in Seismic Regions was published and enforced [12]. Rulebook for Technical Standards for Masonry Walls was made available in 1991. Currently BiH is using Eurocode 8 - Design of structures for earthquake resistance [13].

According to the current Seismic hazard map of BiH (Figure 4) the county is divided into four (4) zones. Most of the Country lies in the zone six (6) and seven (7), while zones eight (8) and nine (9) of the Mercalli Intensity Scale cover only small parts of the Country. The largest part of the country the Peak Ground Acceleration (PGA) is in the range of 0.03g to 0.12g (zones 6 and 7), while small part of the country has the PGA value in the range of 0.12g to 0.35g (zones 8 and 9).

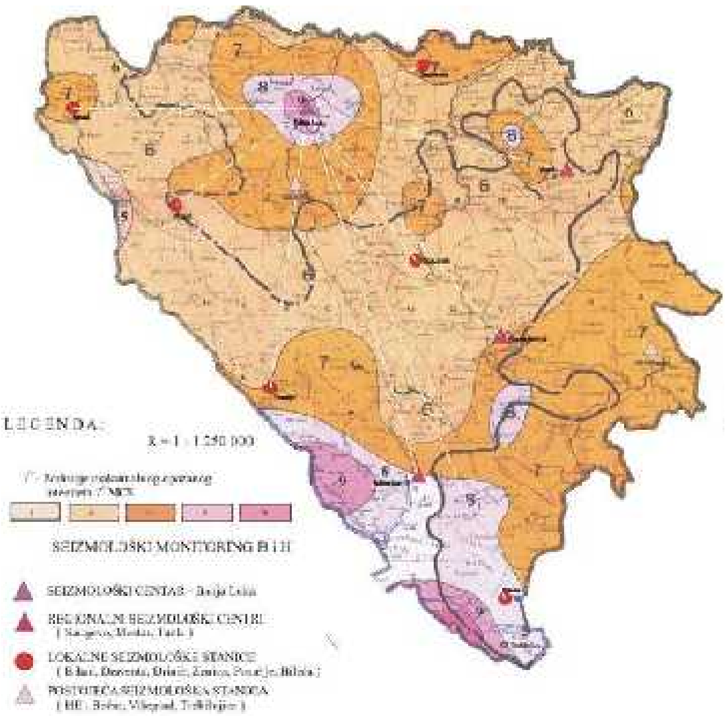


Figure 4 Seismic Hazard Map of Bosnia and Herzegovina [14]

In this study, a uniform hazard spectra for 475-year return period is calculated by using probabilistic seismic hazard analysis procedures for Sarajevo City, which is located in zone seven (7) according to the current seismic hazard map of BiH. As seen in Figure 3, the curves are fairly coincided in rock type of ground. On the other hands, the current seismic code spectra must be updated according to site's specific ground response analysis procedures for other ground types.

BOSNIA AND HERZEGOVINA BUILDING STOCK

The architecture of BiH is largely influenced by four major periods where political and social changes determined the creation of distinct cultural and architectural habits of the region.

The Ottoman Empire architecture, in most cities in Bosnia is present in the city centers – old towns. Buildings from this period are one story buildings, made in "bondruk" system, using wood as the main construction material. Foundations were built out of stone, ground floor out of clay, unburnt brick and wooden ties, first floor out of wooden frame and roof almost always out of wood.

In 1878 Bosnia was up for another cultural diversification as Austro-Hungarian Empire annexed the country. In the short time that Austrian Empire ruled Bosnia they had an immense influence in future urban planning and architecture. Hospitals, schools, hotels, museum, theatres were built. In 1918 Sarajevo had 7 274 residential building. For the first time materials like brick, tiles and concrete were used in building construction.

Main characteristic of post World War II period is homogeneity of materials that replaced traditional heterogeneity and concrete became a material of choice for construction. The greatest numbers of residential buildings that exist in Sarajevo today were built in this period, mostly using concrete. As far as private residential buildings are concerned, they too are almost all the same. They are usually two stories high, with tiled gabled or ripped roof, Reinforced Concrete construction with brick as infill.

Modern architecture in Sarajevo can be characterized as period of great diversity and freedom both in design and construction sense. Use of almost all types of materials is present. The only difference that we can highlight is the increased use of glass in building facades which changed the visual image of Sarajevo.

Typical Beams, columns and Slabs dimension

In modern building, dimensions are calculated and given in project documentation, based on standards, perimeters and equations, with proper safety coefficient. Document with construction elements dimensions is required material in every building's documentation.

In individual building, dimensions of columns are same to dimensions of outer wall in traditional building methods. In Bosnia, dimension of outer wall depends on the dimension of building blocks. It is usually about 25-30 cm. Column can be with square, circular or rectangular cross section. Minimum dimension of square section is 30x30 cm; and the smallest diameter of circular column is 30 cm.

Beams are usually built together with slabs. The height of beam is l/16 of span width L. Height of beam is actually 2 or 3 times bigger than its width. Beams are also used in cornice above walls. They are thinner than these beams above open spaces.

The reinforced concrete slab thickness depends on raster dimension and column disposition. But, in practice, 15 cm slab thickness is generally used.

Building Use

Regular story height in Bosnia and Herzegovina is created based on to satisfy every physical need of human being on the one hand, and to have economical heating costs on the other hand, because it is known that heating of room depends on room's volume. Most of the buildings in Bosnia has commercial first story, even many of individual houses are built with commercial ground floor, just to have opportunity for local business development.

But in Bosnia, there are many buildings from communism period, and one of the characteristic of these buildings that they do not have commercial ground floor. The ground floors of these buildings are also living spaces, so they have same floor height as floors above.

So, minimal floor height is 240 cm, measured from floor to ceiling, but 250 cm is most used value. Also floor height in other buildings that were built after was 250 cm. There are also buildings from Austro-Hungarian period that have big height of ceiling in both living and office rooms. Modern buildings are being built with commercial ground floor with usual height dimension of 320-350 cm measured from floor to ceiling. Also usual floor height of basement is minimum 220 cm in individual and 240 cm in collective housing.

Typical Load bearing systems in Sarajevo

Load bearing systems show differences based on the typology of the buildings. Typical load bearing system in Sarajevo post World War II period is the reinforced concrete frame system which encounters red mostly in commercial buildings, schools, hospitals, and collective residential buildings.

In construction of individual houses, masonry structural systems are characteristic. Also, in Sarajevo mixed systems are available, which is the combination of load bearing walls and columns in some commercial buildings, cultural and residential buildings.

Construction Material Properties and Ground Types

In former Yugoslavia for reinforcement has been used and applied JUS – standard [15]. JUS standard was a compilation of Austrian O-NORM and German DIN standards, with small modifications.
The main classification of reinforcement in accordance with JUS is based on GA-smooth rebars and RA -ribbed rebars. The mechanical properties of reinforcement bars are given in Table 2.

Table 2 Mechanical Properties of Reinforcement Bars in BiH.

Mark and Type of Bar	Diameter Ø (mm)	Yield Strength R_e or R_{02} (MPa)	Ultimate Strength, R_m (MPa)	Yield Strain (%)	Elasticity Modulus (x10^5) (MPa)
(Č 240/360) - GA	5 – 40	240	360	20 1) 18 2)	2 – 2.1
(Č340/500) - GA	8 - 40	340	500	20 1) 18 2)	2 – 2.1
(ČBR 400/500) – RA	6 - 40	400	500	10	2 – 2.1

(ČBM 500/560) - Mesh	4 - 12	600	560	6	1.9 - 2

1) forØ≤ 18 mm; 2)for Ø ≥ 20 mm;

In recent years, countries that were formerly part of Yugoslavia accelerated standardization and it is the EN standard.
The most used concrete strength class in Sarajevo is C25/30 which is called by the PBAB (Bosnian Codes for Concrete and Reinforced Concrete) MB30

Table 4 Concrete strength properties in BiH

MB	$f_{c,15/30}$ *(MPa)*	$f_{k,15}$ *(MPa)*	*C*	$0,95 f_{k,15}$ *(MPa)*	$1,20 f_{c,15/30}$ *(MPa)*	*MB*
10	8,3	10,5	**8/10**	9,5	9,6	**10**
15	12,5	15,8	**12/15**	14,25	14,4	**15**
20	16,7	21,0	**16/20**	19	19,2	**20**
25	20,8	26,3	**20/25**	23,75	24	**25**
30	25	31,6	**25/30**	28,5	30	**30**
35	29,2	36,8	**30/37**	35,15	36	**35**
40	33,3	42,1	**35/45**	42,75	42	**40**
45	37,7	47,4	**35/45**	42,75	42	**45**
50	41,7	52,6	**40/50**	47,5	48	**50**
55	45,8	57,9	**45/55**	52,25	54	**55**
60	50	63,2	**50/60**	57	60	**60**

Generally, the ground types of the plain area of Sarajevo can be classified as in the category C, but on the hillside places, B type ground category is used.

Table 5 Ground types in Sarajevo [13, 16]

Ground Type	Description of Stratigraphic Profile	Parameters		
		$V_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or mediumdense	180 – 360	15 - 50	70 - 250

	sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.			

NUMERICAL STUDIES FOR CASE STUDY BUILDINGS

The first case study structure is a typical school building located in Ilidza, Sarajevo, BiH. The cast-in place reinforced concrete building, constructed in 2007, has 6 floors, consist of 1 ground story, 4 regular stories and 1 rooftop terrace. Building layout dimensions is 31.5m by 36m, the regular story height is 3.75m ant the total building height is 19.40 m (Figure 5). The typical floor framing consists of the reinforced concrete two way slabs with 18 cm thickness. The interior and exterior beam dimensions are 30x70 cm. The typical columns are rectangular in cross section 60x60, 100x50 and 50x50cm in sizes. The concrete strength were tested 25MPa for the slab, beams and columns. The smooth reinforcing bar strength was obtained as 400MPa for the all structural elements. The structure is located on the relatively stiff soil deposit which can be classified as NEHRP B [11] type soil profile. Foundation system is observed as the mat foundation with 60cm slab.

In both directions, about 1.5% of shear walls area is provided in the structure, which refers to the rigidity of the structure, which is one of the main reasons behind its elastic behavior when exposed to the earthquake forces.

Figure 5 Case study 1, International Burch University Block A, View and Cross section

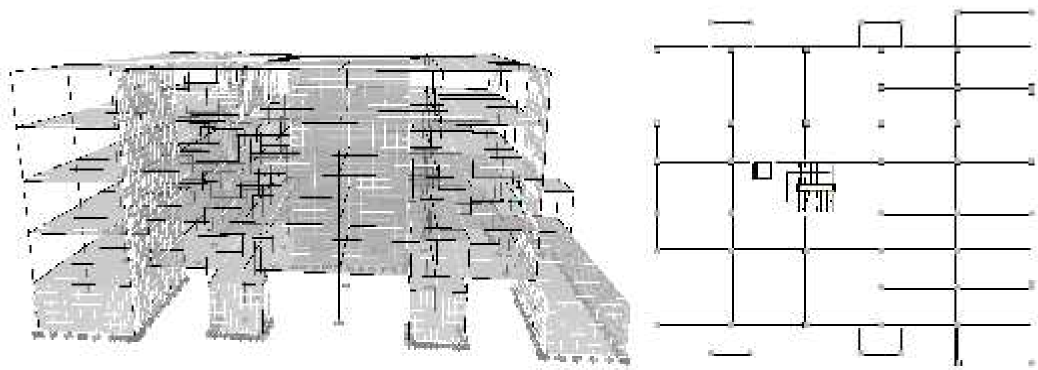
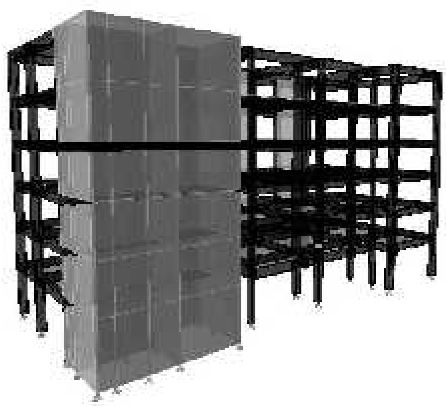


Figure 6 Case study 1, International Burch University Block A, Computer Etabs Model



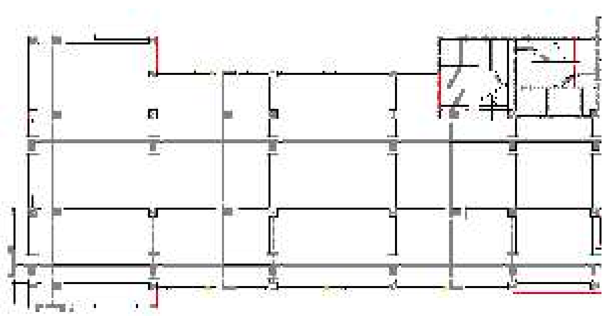


Figure 7 Case study 2, Regional Tax Office, View and Cross section and Computer Etabs Model

The second subject building is located in Sarajevo, BiH. The cast-in place reinforced concrete building designed according to requirements of the according to EC8 design code, has six floors. The building is fairly regular in plan and height. The overall plan dimensions are 41.7m by 18.8m in plan (Figure 7) and 3.47m story height. The total height of the building is 24.60m. The reinforced concrete two way slab thickness is 17 cm at each floor of the building. The typical beams dimensions are 50cm width with a depth of 70 cm. The cross sectional dimensions and reinforcement of typical column sections are 60x60cm with 16-Φ25 and 40x60 with 18-Φ25 at the ground floor. The transverse reinforcement spacing in columns is about 10 cm at the confinement zones and 15 cm at the column central zones. The concrete strength were tested 30 MPa (MB30) for the slab, beams and columns. The reinforcing bar strength was obtained as 400MPa (RA400/500) for the all structural elements. The structure is located on the relatively soft soil deposit which can be classified as NEHRP D type soil profile. Foundation system is observed as the mat foundation system with 70cm thickness slab. Shear walls area is equal to 1.69% from the story area (11.4 m^2 from 673 m^2).

DISCUSSION OF RESULTS

Most of the building documents were destroyed during the war of 1992-1995 periods, therefore, in this study, modern buildings, designed and constructed recently, are considered for the case studies. The case study structures consist of high amount of shear wall percentages. In performance evaluation, this leads to structures behave elastically.

Both numerical analyses were performed by using the ETABS software where the performance evaluations ware carried out by means of ATC-40 methods. The performances of both structures are determined as IO (Immediate Occupancy) performance level. Since, structures have very high rigidity (Table 6, Table 7), the results are not surprising. The calculated target displacements are listed in Table 8.

Table 6. Dynamic structural parameters in case study 1

		Modal Participating Mass Ratios		
Mode	Period	UX	UY	RZ
1	0.254829	[illegible]	[illegible]	[illegible]
2	0.230068	12.5833	37.5926	18.9723
3	0.204372	2.5029	30.3385	30.5187
4	[illegible]	[illegible]	[illegible]	[illegible]
5	0.075898	3.7971	3.4118	12.025
6	0.063882	0.2004	13.5501	2.9271

Table 7. Dynamic structural parameters in case study 2

Mode	Period	Modal Participating Mass Ratios		
		UX	UY	RZ
1	0.451108	5.2	32.9534	40.3564
2	0.256097	63.39	13.5168	0.5735
3	0.243045	8.8968	29.0258	32.5003
4	0.140734	6.5295	1.3778	2.7806
5	0.134644	1.1582	1.4279	4.8506
6	0.122866	0.3554	2.6273	1.8367

From the field observation in Sarajevo, it is observed that structural irregularities are very common in construction practice. The selected case study structures are also rather irregular. From investigation of Table 7, modal participating mass ratio of case study structure 2, first free vibrational mode is calculated in RZ direction. This means that, structure's first vibrational mode is torsional. As a result, performance evaluation of these types of buildings is not realistic.

Table 8 Target displacements and performance levels of case study buildings

Buildings	Target displacements		Performance Levels	
	x-direction (Horizontal)	y-direction (Vertical)	x-direction (Horizontal)	y-direction (Vertical)
Case Study 1	6.56 mm	5.92 mm	IO	IO
Case Study 1	16.0 mm	21.0mm	IO	IO

CONCLUSION

In this study, Firstly, seismic hazard analysis of Sarajevo City in BiH was carried out. Then two building ware selected as a case study to perform performance evaluation according to ATC-40 method by using ETABS software.

The calculated seismic hazard curve coincides with code proposed spectral curve at rock type grounds. But for the stiff and soft soil sites, it is clear that current code proposed curve is not satisfactory.

Due to safety reasons, most of structures are over-designed and have a high ratio of rigidity. But, structural simplicity, structural symmetry, torsional resistivity are not satisfactory in Sarajevo building stock.

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