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SEISMIC EXPOSURE OF BRIDGES IN BOSNIA AND HERZEGOVINA AND EVALUATION OF BRIDGES SEISMIC SAFETY

Abstract: At the beginning of the lecture, analysis of earthquake hazard and impact on bridges, as a part of transportation infrastructure system in Bosnia and Herzegovina, is presented. Details about seismotectonics of Bosnia and Herzegovina with maps of faults and activities during last one hundred years are described. Presented details are inputs for evaluation of bridge seismic safety. Procedure for evaluation of bridges safety in Bosnia and Herzegovina is described. Here is presented one case study of cable – stayed pedestrian and motorway overpass in Tuzla city urban environment. At the end of the lecture, impact of bridges safety on resilience of infrastructure system and community are described.

Key words: earthquake hazard, bridges evaluation, bridges seismic safety, infrastructure system

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1. INTRODUCTION

Being one of the oldest industrial sectors, Civil Engineering stands high contributing a substantial amount to the development of the society. It can be said that Civil Engineering is very important support in development and management of the societal infrastructure, as a central task for the continued success of society. The decision processes involved in this task concern all aspects of managing and performing the planning, investigations, designing, manufacturing, execution, operations, maintenance and replacing of objects of societal infrastructure, such as traffic infrastructure, housing, power generation, power distribution systems and water distribution systems. The main objective from a societal perspective by such activities is to improve the quality of life of the individuals of society both for the present and the future generations. From the perspective of individual projects the objective may simply be to obtain a maximal positive economic return of investments.

The development of society demands that we are able to manage the prevailing natural and manmade risks in a conscious, consistent and rational manner. Managing risk means a decision how to allocate the available resources of society, including the joint consideration of all uncertainties prevailing the problem and all possible consequences. Risks in civil engineering can be due natural hazards, malevolence, structural failures and human errors. To ensure health, safety and security of communities, the risk management process for civil engineering systems is necessary. The main goal of the process is risk mitigation or risk reduction. It is very important that the process begin in early phase of the project and continue through service life of the system. The risk analysis process is a continuous process, which means that new risks, occur through service life of the system, should continually be introduced into the process. Because of that, the civil engineer must reconsider all possible sources of the risks, including new trends of the climate changes and consequences of the industrial development.

Natural and man-made disasters are on the rise in recent years, with negative impact on the environment and extensive damages to the urban areas. The society has become more vulnerable and disaster managment is increasingly important. On the other hand, preliminary surveys in Western Balkan countries have shown shortage of skills and insufficient knowledge to solve the growing problems. Because of that, the K-FORCE project is ongoing with the aim to improve resilience to hazards and capability for regional cooperation in risk prevention and response in Western Balkan countries.

Disaster risk managment can be defined as the decision-making phase based on risk assessment, which can be divided in two phases: risk identification and risk analysis. Risk identification means hazard identification or hazard assessment. Hazard identification includes collecting information about harmful situation, which will be data base for risk assessment. Therefore, the first step is to analyze (qualitative and quantitative) the potential hazards in a particular region and the community's approach to their treatment. In such an analysis, it is important to conduct a hazard analysis of key sensitive points that affect the resilience of the community.

The backbone of any country's economy consists of its assets of constructed facilities, such as highways and bridges. Transport infrastructure systems are the backbones of modern societies, and ensuring their reliability and resilience is critical to the health, safety, and security of communities. So, reliable detailed assessment of constructed facilities is vital. In the procedure of assessment risk analysis is one of the most important step.

Bridges are some of the most critical components of transportation infrastructure systems. For these structures, failure is defined as any interruption of pedestrian or vehicular traffic across or under them due to structural distress. Direct consequences of failure can range from injury to loss of life and property in the case of collapse, and indirect consequences such as disruptions to economic activities and reduced access to emergency facilities in the event of collapse or closure. There are over a thousand bridges in significant strategic routes in Bosnia and Herzegovina, which can significantly affect the sustainability of the community. It is therefore very important to analyze the bridges in detail as part of an overall analysis of disaster risk.

In this lecture analysis of earthquake hazard and impact on bridges, as a part of transportation infrastructure system in Bosnia and Herzegovina, is presented. Namely, geo-hazards, earthquake and landslides, are dominant hazards in Bosnia and Herzegovina. The territory of Bosnia and Herzegovina is a seismically active area with earthquake intensities of over six degrees in the last hundred years. Also, earthquake is a trigger for additional hazards such as post-quake fires, landslides, tsunamis, etc. Because of this, design codes give special design recommendations for seismically active areas. Also, in this area health monitoring (continuous monitoring) of dynamic parameters is very important.

Procedure for evaluation of bridges safety in Bosnia and Herzegovina is presented through the case study of cable – stayed pedestrian and motorway overpass in Tuzla city urban environment.

2. UNCERTAINTIES OF CIVIL ENGINEERING DESIGN MODELS

The primary function of civil engineering is design of system to accommodate the transfer of energy, apropos to transform the induced applied energy to tolerable levels so as to accomplish an intended purpose. Analysis in civil engineering design means idealization of a system, which admits to simple but logical mathematical solution and still contains the essential elements of the actual system.

Induced loadings to civil engineering systems are never completely known. Among these are uncertainties with respect to the frequency and intensity of earthquakes, the flow of surficial water, groundwater, toxic and hazardous materials, variability of wind, heat and cold, freezing and thawing, chemical and environmental factors, vibration and shock, vehicular and pedestrian traffic etc. Almost all induced loadings are random and all systems may often be subjected to overloads.

All engineering materials contain micro and macro imperfections, which can initiate cracks or permit their propagation.

No two designed objects can be exactly same. To date no general theory exists that relates the strength to the deformation of a body. No single framework accounts for such common phenomena as plastic flow and brittle fracture of metals, fatigue and creep, elastic and inelastic response. In [1] Bourgault quotes S.A. Wenk, who gave definitions that material is collection of defects.

All civil engineering systems are founded in the soil which is composed of complex aggregations of discrete particles with varying shapes, sizes and orientations. Also, voids between the particles are of various orientations and sizes.

The mentioned uncertainties are related to the loads and structure resistance. More generally a range of uncertainties need to be considered, as environmental conditions, workmanship, human error and prediction of future events. The types of uncertainty are classified in [2] (Fig.1).

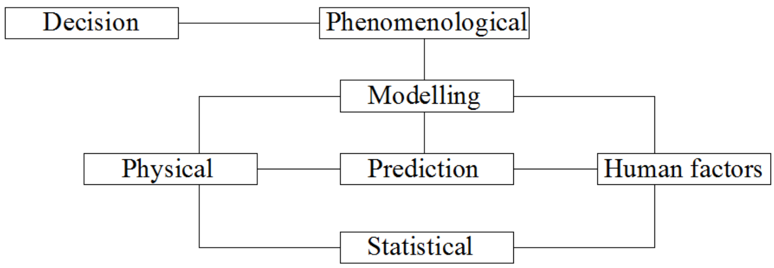


Figure 1. Uncertainty classification after Melchers [2]

Phenomenological uncertainty may be considered to arise whenever the form of construction or the design technique generates uncertainty about any aspect of the possible behavior of the structure under construction, service and extreme conditions.

Decision uncertainty arises in connection with the decision as to whether a particular phenomenon has occurred. For example, if limit states is concerned the decision whether limit state violation has occurred.

Modelling uncertainty is associated with the use of simplified relationship between the basic variables to represent the real relationship or phenomenon of interest. Modelling uncertainty concerns the uncertainty in representation of physical behavior.

Prediction uncertainty involves problems of the prediction of some future state of affairs.

Statistical uncertainty is associated with the amount of available data.

Uncertainties due to human factors may be considered as due to the effects of human errors and human intervention.

However, the ways in which civil engineering systems fail, its economic and social consequences, demonstrate considerable differences between hypothetical and actual systems. Complex interrelationships between loadings, materials defects, structural deficiencies, site characterization and human errors influenced to varying degrees a randomness.

The approaches to the reduction of uncertainties are under umbrella title of quality assurance, which should be based on a detailed risk and hazard scenario analysis. The subject of such analysis should be reduction of consequences through reliable procedure.

In many countries around the world, civil infrastructure systems face increasing service demands while they deteriorate as a result of inadequate maintenance, material degradation and increasing exposure to overloads. In addition, these systems are subject to a variety of natural and man-made hazards. For bridges, as the most critical components of transportation infrastructure systems, with large and expensive structures that are of great importance to our economy and society, proper hazard identification is very important step in process of reducing cosequences. Direct consequences of failure can range from injury to loss of life and property in the case of collapse, and indirect consequences such as disruptions to economic activities and reduced access to emergency facilities in the event of collapse or closure. If lifelines are not operational after an extreme event, such as an earthquake, entire communities may have to be displaced. With limited resources available to address these deficiencies, there is need for infrastructure-specific decision support tools that will help facility owners allocate scarce funds. Unfortunately, for many years, research has focused primarily on improving the performance and reliability of individual structures or components, and relatively little effort has been dedicated to examining infrastructure systems as a whole.

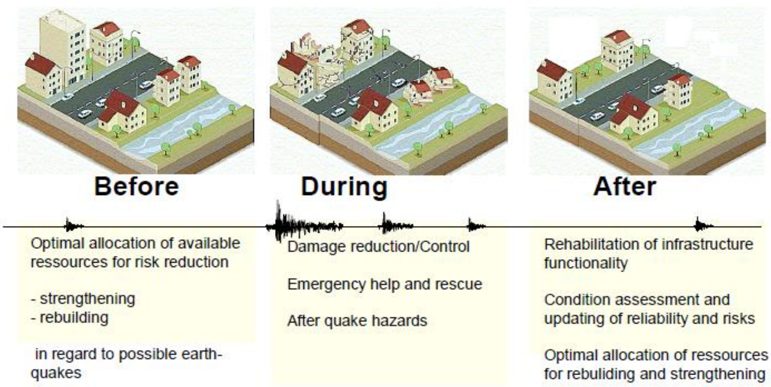


Figure 2. Decision situations for management of earthquake risks after [4]

Earthquake engineering is a sector of civil engineering that deals with the mitigation of earthquake-induced damage on structures and the minimization of loss of life. The earthquake resistant design of structures requires that structures should sustain, safely, any ground motions of an intensity that might occur during their construction or in their normal use. From the structural engineers point of view two questions are of major interest: the estimation of the possible damage before and the assessment of the existing damage after the event. Numerous methods are in use to handle especially the former. But since risk is not only defined by the probability of occurrence of an event, but also by the consequences, the decision problems needs to be formulated in a broader sense [3]. The decision problems can be categorized in three different situations, before – during - after (see Fig. 2) [4].

Before an earthquake the main questions are to identify the probability of the occurrence of the earthquake event and to estimate its effect on the building stock. This information may be rendered by the decision maker in order to allocate the available resources optimally for the risk reduction. Decisions regarding e.g. retrofitting or rebuilding of the buildings indicated as vulnerable may be made based on these. During the event of a hazard the issue is to limit consequences by containing damages and by means of rescue, evacuation and aid actions. After a hazard event, the situation is to some degree comparable to the situation before the event, however, the issue here is to decide on the rehabilitation of the losses and functionalities and to reconsider strategies for prevention measures.

Engineering facilities such as bridges, power plants, dams, offshore platforms, water supply infrastructure are all intended to benefit the quality of life of the society. Therefore it is prerequisite that the benefit of the facility can be proven considering all phases of the life (design, manufacture, construction, operation and eventually demolition). The ultimate task for the engineer is to establish decision basis that it may be ensured that facilities provide the largest possible benefit.

3. EARTHQUAKE HAZARD IN BOSNIA AND HERZEGOVINA

Seismic risk analysis includes assessment and mapping of seismic risk. Some examples were presented in the papers [5] - [10]. The principal elements of seismic risk assessment were outlined in the papers [11] and [12].

Assessing the seismic hazard at regional or local levels and for specific sites with critical facilities is the first step of the strategy of prevention. In fact this is, at the moment, the only way to prepare for earthquakes. An adequate strategy of prevention should include three main principles:

- acknowledgement of the seismic phenomenon and its consequences in the built environment;
- assessment of the risk in both the seismic hazard and vulnerability of all components of the built environment;
- awareness of the importance of these assessments and putting in practice different actions in order to mitigate the estimated risks.

The first two are of scientific and technical nature and the third one has an important political component.

The territory of Bosnia and Herzegovina is located northeast of active tectonic collision between Adriatic mass, as a part of African plate and Dinaric Alps as a part of Eurasian plate. Bosnia and Herzegovina is located on the Dinarides plateau, with some paleogeographic and structural units, which lie one over the other, with the outer parts of Dinaric Alps at the bottom and the Sava-Vardar thrust at the top.

As you can see on figure 3 southern part of Bosnia and Herzegovina has intensive tectonic activities. Earthquakes, which occures on Dinaric plateau, were caused by the release of energy induced by sliding the African plate beneath the European continent. The earthquake measuring magnitude of 5 to 6.5 M indicates the indigenous earthquakes as well as the existence of seismic zones and tectonic structures in the territory of Bosnia and Herzegovina. In the paper [13], overview of seismotectonics of Bosnia region was presented.

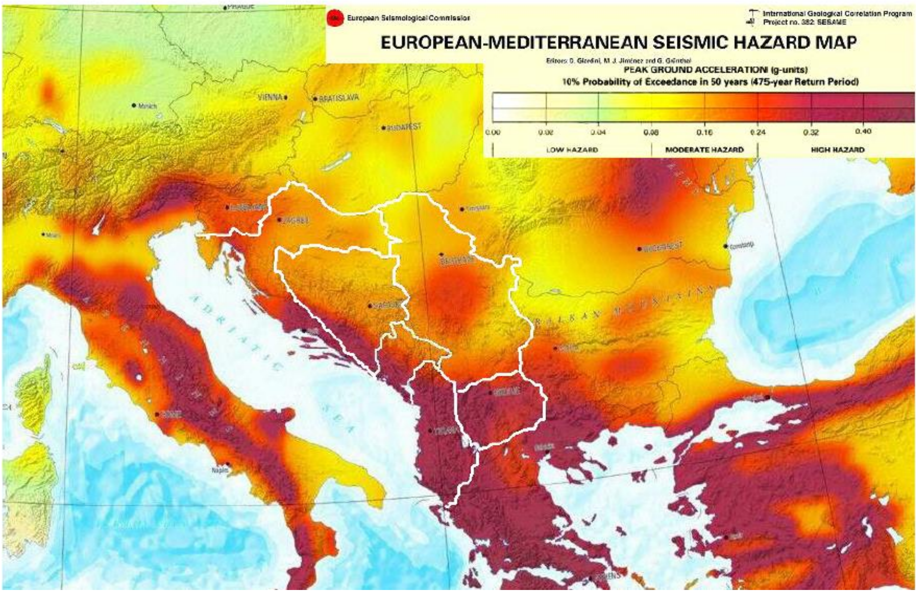


Figure 3 – Southeastern Europe's Hazard Map

On figure 4 you can see disposition of thrust and faults. The main deep faults were presented. The main direction of faults is northwest-southeast, with some faults with direction northeast-southwest. Surface geology and recent seismic activity point to their pronounced neotectonic activity.

Of all the deep faults in Bosnia, the Banja Luka-Tuzla-Zvornik fault (fig.4, no.2 and 3), which is part of the large regional tectonics fault of Zagreb-Skopje, the Vrbas fault (fig.4, no.9) and the Banja Luka-Zenica fault, coupled with the Busovaca deep fault (fig.4, no.8), are particularly interesting for research. The Una fault (fig.4, no.1) is significant, in geological terms, because it is relatively deep and generaly reflects on the geological-tectonic material of this area. The fault has horizontal movement of regional character, starting from Zagreb, via Karlovac, to Split. Also,one of the most important fault is the

Vrbas fault (fig.4, no.9), stretched from the Jajce through Vrbas valley to Gornji Vakuf, then extends across the Jablanica lake, Neretva valley, Gatac field to Montenegro. The Busovaca fault (fig.4, no.8) is geomorphologically very pronounced and can be clearly observed on satellite and airplanes. Start from Jajce, where it reaches Vrbas fault, via Travnik, Vitez, Busovaca, Kiseljak, Ilidza, along the slopes of Jahorina and close to Foca crosses into Montenegro. The Busovaca fault has vertical and horizontal movements. The amount of vertical movements at the perimeter of the Sarajevo-Zenica basin is 1500 to 2000m. These vertical movements were periodically followed by significant right horizontal displacements in the pliocene. The zone of the fault is characterized by the appearance of thermomineral and mineral waters, and the neotectonic rise of Vlasic and Igman. The Spreca-Kozara fault can be distinguished, which passes directly to Tuzla city. The fault is a part of the northeastern border of the Ofiolit zone, or the southern edge of the Pannonian basin. It start from Bosanska Dubica, on the southern slopes of Prosara and goes to the southeast, via Prnjavor and Doboj, to Ozren, than continue via Zivinice to Zvornik. In the part of the fault, between Doboj and Zivinice, is a system of parallel faults, which form together with the main fault regional fault zone. In the zone vertical movements are over 2000 m. The position of the other faults is shown on figure 4.

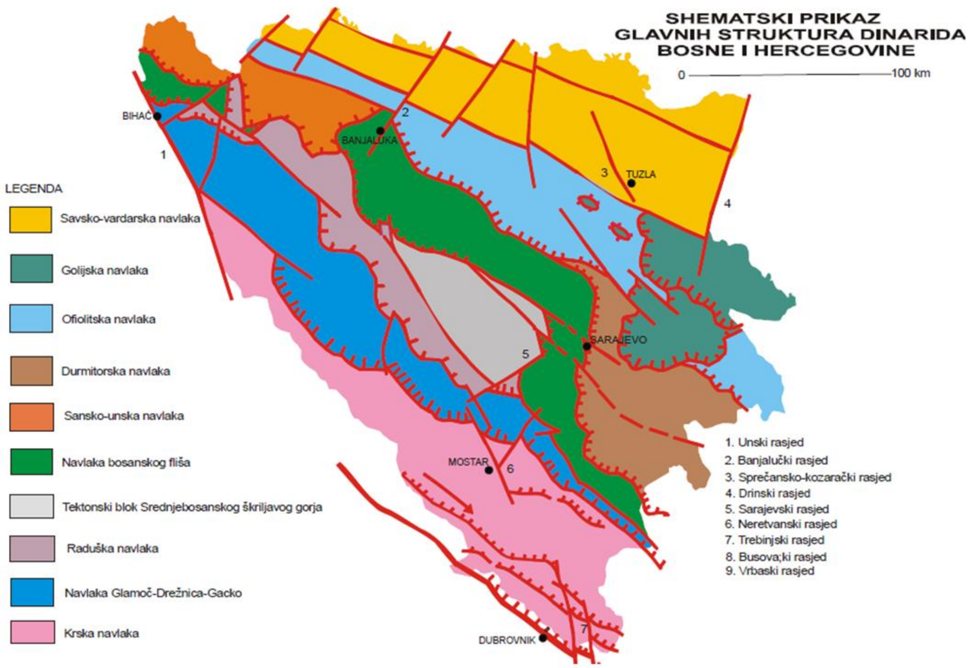


Figure 4 –Map of fault systems in Bosnia and Herzegovina

Table 1 – The epicenters of earthquakes in Bosnia and Herzegovina

The epicenters of earthquakes in period 1901 - 2004 (according to Federal Hydrometeorological Institute)					
		Depth to hypocenter (km)			
Number of events	Magnitude	0-10	11-20	21-30	> 30
2	> 6,0		1	1	
10	5,6 – 6,0	3	4	2	2
14	5,1 – 5,5	6	4	2	2
78	4,6 – 5,0	48	16	10	2
162	4,1 – 4,5	125	29	13	3
406	3,6 – 4,0	363	38	4	1
118	3,1 – 3,5	108	6	2	2
790		653	92	34	11

Table 2 – List of earthquakes in period 1905 - 2003

Time	Place	Magnitude (M)	Intensity at the epicenter (Io) MCS scale
07.04.1905.	Petrovac	M = 5,0	Io = 7^0
01.08.1907.	Počitelj	M = 5,7	Io = $7\text{-}8^0$
25.12.1908.	Vlasenica	M = 5,3	Io = $6\text{-}7^0$
12.03.1916.	Bihać	M = 5,0	Io = 7^0
06.02.1923.	Jajce	M = 5,0	Io = 7^0
14.02.1927.	Ljubinje	M = 6,0	Io = 8^0
17.12.1940.	Derventa	M = 5,1	Io = 7^0
31.12.1950.	Drugovići	M = 5,7	Io = 8^0
11.06.1962.	Treskavica	M = 6,0	Io = 8^0
07.03.1967.	Srebrenica	M = 5,1	Io = 7^0
27.10.1969.	Banja Luka	M = 6,6	Io = 9^0
25.08.1970.	Gacko	M = 5,0	Io = 7^0
29.10.1974.	Lukavac	M = 5,0	Io = 7^0
10.09.2003.	Stolac – Hutovo blato	M = 3,6	Io = 5^0

The territory of Bosnia and Herzegovina is one of the most seismically active parts of the Balkan Peninsula. According to available data, on the territory of Bosnia and Herzegovina several devastating earthquakes have occurred with magnitude $M \geq 5.0$ and intensity in the epicenter Io ≥ 7 ° MCS scale. In the last hundred years, over thousands earthquakes were occurred in Bosnia, out of which thirty earthquakes had a magnitude M > 5.0 (table 1 and table 2). The last 35 years of the 20th century was characterized by increased seismic activity at the area of Banja Luka, Tuzla, Zenica and Herzegovina. Complete Adriatic Zone can be distinguished as a seismically highly active area, with many epicenter of earthquakes. The location of this zone coincides with the most important faults on the surface of the terrain, stretching along the Adriatic Sea. This is the area of the coastal part of Croatia and Montenegro, where occurred very strong earthquakes ranging from M 5.5 to M 7.2 (Dubrovnik, Kotor, Split). Strong seismic activity is along the fault Ploce-Dubrovnik-Bar.

In the report [14] harmonized seismic hazard maps for the Western Balkan Countries were presented. On figure 5 seismic zones in Bosnia and Herzegovina is presented. From the enclosed drawing it is evident that most of the territory is in zones 7, 8 and 9^0 MCS. The description of seismic zones is given in Table 3.

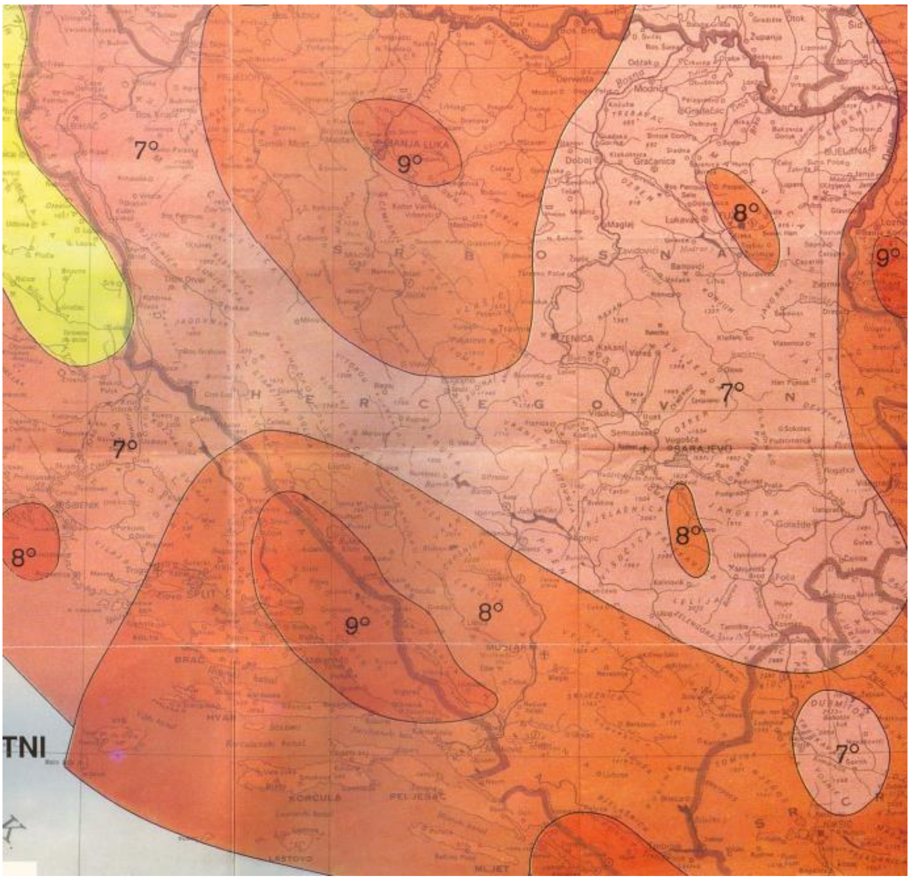


Figure 5 – Seismic zones in Bosnia and Herzegovina

Table 3 – Seismic zone classification

Degree (MCS)	Description of oscillation effect and damages caused by earthquake	Acceleration (m/s^2)
1	Oscillations register only by equipment	< 0.0025
2	Oscillations are felt only in quiet environment	0.0025-0.005
3	Some people feel oscillation	0.005-0.010
4	Oscillation are felt by many people, glasses shouting	0.010-0.025
5	Cracks appear in the mortar	0.025-0.050
6	Cracks in the mortar and damages of weaker buildings	0.050-0.10
7	Damages of the buildings in normal condition, cracks in the mortar, dissipation of the mortar, cracks in wall joints (connections)	0.10-0.25
8	Significant damages of the buildings, cracks in structural walls, wide cracks in non-structural walls	0.25-0.50
9	Wide cracks in structural walls, demolition	0.50-1.00

4. BRIDGES IN BOSNIA AND HERZEGOVINA

Bosnia and Herzegovina has about 22.5 thousand km of roads categorized. The total length of railways is 1031 km, which should be added and industrial tracks to every significant manufacturing capacity. Through Bosnia and Herzegovina strecth part of the European route E 73 or Corridor Vc (Corridor 5c), a branch of the fifth Pan-European corridor, 340 km in length. E73 connects three countries, stretching from Budapest, Hungary, via eastern Croatia, bisecting Bosnia and Herzegovina, ending in the Croatian port of Ploce.

Today there are about 3000 bridges in Bosnia and Herzegovina, of which on the Federal Roads about 1000, and the rest to regional and local roads. Approximate value of all bridges is 1 billion EUR. Bridges are of different ages, shapes, and structural systems, mostly built of concrete, stone and steel. About 70% of the bridges were built in the period from 1955 to 1985, and 90% of bridges were constructed mainly of reinforced concrete and prestressed reinforced concrete (fig.6a, 6b and 6c). Other bridges are mostly composite steel-concrete (fig. 6d).

Bridges in Bosnia and Herzegovina are designed in accordance with the regulations of the former state of Yugoslavia, which means the use of elastic linear analysis of the structures. Ultimate limit state (strength method) and serviceability limit state was adopted in 1971, for concrete structure. For ultimate limit state, both linear and non-linear methods are used, and for serviceability limit state usually the linear method. Further advancement was the Rule for Concrete Structure in 1987 (Regulation for CS and RCS, 1987). Both the documents from 1971 and 1987 were based on the Model Code CEB-FIP. In recent years it was introduced the design methodology from EN 1990: 2002 to EN 1998: 2005.

(a)

(b)

(c)

(d)

Figure 6 – Bridges in Bosnia and Herzegovina: (a) Prestressed concrete bridge "Aleksin han", (b)Prestressed concrete bridge over river Bosnia, (c)Reinforced concrete bridge "Bijela" Salakovac; (d)Composite bridge over lake Jablanica

The bridges in Bosnia are inspected regularly to ensure that bridges perform properly. If a discord appears, it is carefully studied since it could influence the future actions. There is an incpection check list (fig.7), which includes: number of the road, chain age, name of the obstacle, name of the bridge, data about the designer and the contractor, technical data on the bridge, photos, sketches,description of structure, condition of structure, nature of loading and detrimental elements, original condition of structure, materials of construction, construction practices, and initial physical properties of hardened concrete. Inspection check list includes detailed data about croos section of bridge superstructure, deck, abutments, piers, bearings, special equipments, railings, footpath, pavement, drainage, expansion joints, waterproofing.

At the end of the inspection form, the condition of the bridge is evaluated. Each structural part of the bridge is evaluated (fig.8).

For the observation of technical condition of structures on regional and main roads, the following types of inspections are performed:

- Control inspections,
- Regular inspections,

- Detailed inspections,
- Special inspections, and
- Extraordinary inspections.

INSPECTION FORM:

NV = 187 m						Pictures n° :	to
Date : /	Inspector : J T	Entity : F RS	Canton/Region :	Road n° :		Section :	3
KM :	GPS coordinates :	X = 44 ° 32 ' 39,8 ''	Y = 18 ° 30 ' 09,7 ''			Bridge length:	96,8 m
Name of bridge :	-	Type of obstacle : RI R0 RA CA BR		Name of obstacle :	Rijeka Spreča		
Loading limitation : - T	By-pass on site : E D I	Diversion road :	Izradom provizorija na lijevo ili desno				
Envrionment : R U S	Pedestrian traffic : N I V	Comments :	U blizini mosta nalazi se autobusko stajalište				
Skew : 62 °	H. aligment : S C	V. alignment : H S C	Position/road : C D	Comments :			
Osovina mosta je u prelaznici krivine 1400 i u pravcu. Uzdužni nagib je 0%. Poprečni nagib je 2%.							
Hydraulic capacity : S U C	Position/river : S U	Comments :					

CROSS SECTION

Left side					Central	Right side					Vertical
Footpath	Kerb	Height	Shoulder	Carriageway	Reserve	Carriageway	Shoulder	Height	Kerb	Footpath	clearance
0,95 m	Y N O	18 cm	- m	3,5 m	- m	3,5 m	- m	18 cm	Y N O	0,95 m	- m

Comments : Kolovoz na mostu je asfalt betonski. Pješačke staze su izdignute,betonske su, bez završnog sloja asfalt betona. Vijenac je monolitni, u sastavu konzola. Ivičnjaci su betonski.

Railings	Type	Material	Length	Heigth	Comments :
Y N	ČSO sa R	Čelik	193,6 m	0,95 m	L_L=36 m; L_D=36 m.

Utilities : 1Φ80 sa desne strane

Figure 7 – Bridges Inspection Form in Bosnia and Herzegovina

BRIDGE CONDITION ASSESSMENT

	1	2	3	4	5	URG. S
APPROACHES		x				
FITTINGS			x			
SUPERSTRUCTURE		x				
SUBSTRUCTURES		x				
FOUNDATIONS		x				

Conclusion :

1 : No work is needed except routine maintenance 2 : Specialised works are needed in a long term 3 : Specialised works are needed in a short term
4 : Emergency works are needed, 5 : To rebuild

Figure 8 – Part of Inspection Form: Rating of a bridge

The aim of regular inspections is to control the state of structure directly and keep the traffic safety on a satisfactory level. It begins with an initial visual inspection which is meant to obtain data concerning scope and way of detailed inspection. In the first place it is necessary to provide a safe access to the damaged structure. Therefore, during this inspection the structural condition category is determined, depending on damage properties and seriousness. On the basis of the visual inspection the scope of detailed inspection and testing methods are determined. A detailed inspection is aimed to obtain information on optimal scope in order to assess the condition of structure and possibility of further use with necessary interventions. Detailed inspections of bridges should be done at last once in two years. During the inspection all elements of the bridge are included. For bridges with a 15 m span or larger permanent control is conducted according to the regulations and the regulations system. During special inspections, special equipment and measuring instruments are used in order to check the actual degree of damage, especially at structures for which it has been established, by the regular or occasional inspection, if it is endangered from falling down or ruining, which requires urgent repairs. A special inspection is conducted according to a previously planned program. Extraordinary inspections are conducted according to the regular inspection rules after an unexpected event, as well as before and after the transportation of an extraordinary load which might endanger the capacity or function of the structure. In the case of damage, equipment for the inspection is the same as during the special inspection.

Major threats to bridges primarily consist of the aging of the structural elements, earthquake-induced shaking, and standing waves generated by windstorms. In order to ensure their reliability, and especially their stability and serviceability, it is important to analyze the bridge structure loaded by dynamic excitation. For both, newly constructed bridges and older existing bridges, it is desirable to measure the dynamic properties, resonant frequencies, mode shapes, and modal damping of the bridges to understand better their dynamic behaviour under normal traffic loads as well as extreme loads such as those caused by seismic events or high winds. According to existing regulations, compliance of structures performance in real with the design structure performance defines with bridge test load (static and dynamic test load). However, loading of the bridge is often expensive. It is necessary to consider that traffic interruption during bridge test, even occasionally, can have significant consequences because the bridges are often the vital point in the transport network. Therefore, the trend is the application of continuous monitoring of bridges by measuring of bridge structure kinematic parameters under ambient action. Current nondestructive testing methods for the monitoring and the diagnosis of structures, such as acoustic, ultrasonic, electromagnetic, and radiographic methods, are very useful for the evaluation of the state of condition of structures but sometimes are unsuited for continuous monitoring.They are considered as being local methods since they require detailed inspection of small parts of the structure and assume that the damaged zones are a priori known.The need for more global methods of damage diagnosis led to the development of dynamic evaluation methods based on vibration measurements. In recent years, techniques based on ambient vibration recordings have become a popular tool for characterizing the seismic response and state-of-health of strategic civil infrastructure. In ambient vibration testing, it does not require a external excitation of the structure. The structures response to ambient excitation records in large number of points. The system identification technologies were applied to determine and analyse the frequency response functions from measured signal data. The loading could be from environmental, vehicular or pedestrian traffic or any other service loading. More about measurements of ambient vibrations, performed in Tuzla, is presented in papers [15] - [20].

Here is presented one specific case study of evaluation of cable-stayed bridge, which is located in urban environment, in the center of Tuzla city.

5. CASE STUDY – THE CABLE STAYED PEDESTRIAN AND MOTORWAY OVERPASS

This case study is interesting because it is designed with short tower in order to urban conditions, which resulting in a small angle of the first and second cable. The result is that during construction increased deflections were appeared in the part of the structure supported by mentioned two cables. In order to determine the behavior of cable-stayed overpass for exploitation conditions bridge testing and ambient testing were performed. Also, comparative numerical analysis was performed. This part of presentation summarizes the results of performed research with the assessment of structural behavior of the bridge.

Figure 9 - View of the bridge

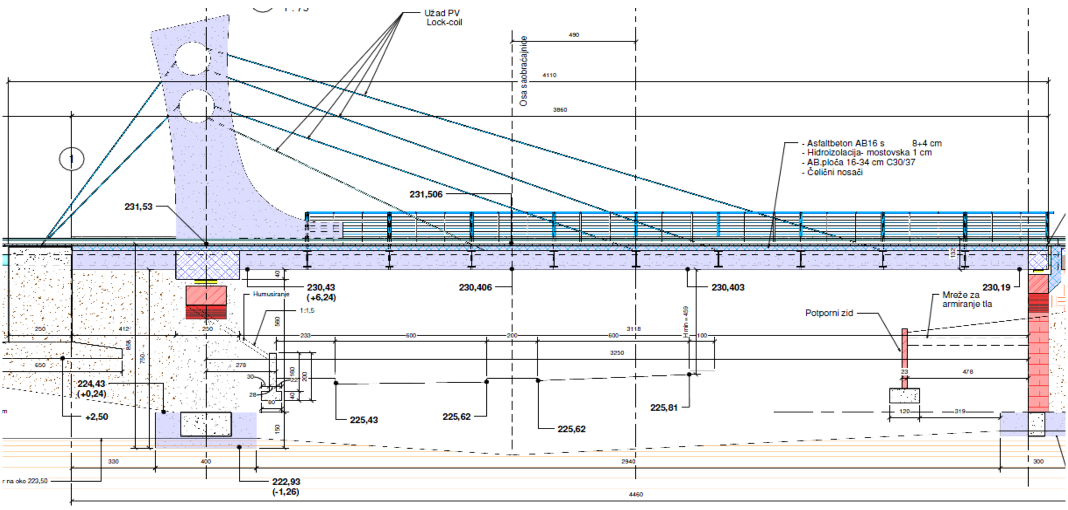


Figure 10 - Longitudinal cross-section

5.1 Structure description

The overpass is used for crossing pedestrians and vehicles over the city streets in Tuzla. It was designed and constructed as the cable-stayed bridge. The cross section of the bridge consists of two traffic lanes 6.0m width and pedestrian lane. The total width of the bridge is 14.6m. The bridge span is 32.0m.

Superstructure consists of two main prestressed beams and composite bridge deck. Composite bridge deck consists of concrete slab with variable thickness 16-36 cm, which is coupled with steel I beams with 3.25m grid. Steel beams are profiles HEB700, steel S355. Complete superstructure was designed with concrete C30/37, reinforcement B500, and prestressed cables 1570/1770 N/mm2. Main prestressed beams were stayed on four cables (fig. 9 and fig. 10).

The primary load-bearing structure consists of a reinforced concrete tower, cables and steel ties. Reinforced concrete tower is 9.5m height. Cables for supporting of main prestressed beams are PV360 Lock Coil St 1570/1760, with diameter 60mm (first and second cable) and PV640 Lock Coil St 1570/1760 with diameter 80mm (third and fourth cable). Steel ties with counter weight concrete block consist of 20 rebar with diameter 32mm on one tower. Quality of rebar steel is B500.

Tower, the main prestressed beams and lateral beams are integral structure supported on neoprene bearings and substructure. Substructure consists of reinforced concrete abutments and reinforced concrete counter weight blocks. Abutments were founded with foundation footings.

5.2 In situ test program

Testing of the bridge was performed for several loading regimes, namely:

Load 1 – Vehicle speed 15km/h

Load 2 – Vehicles on the pavement (Fig. 11a)

Load 3 – Two vehicles one behind the other with stopping (Fig. 11b)

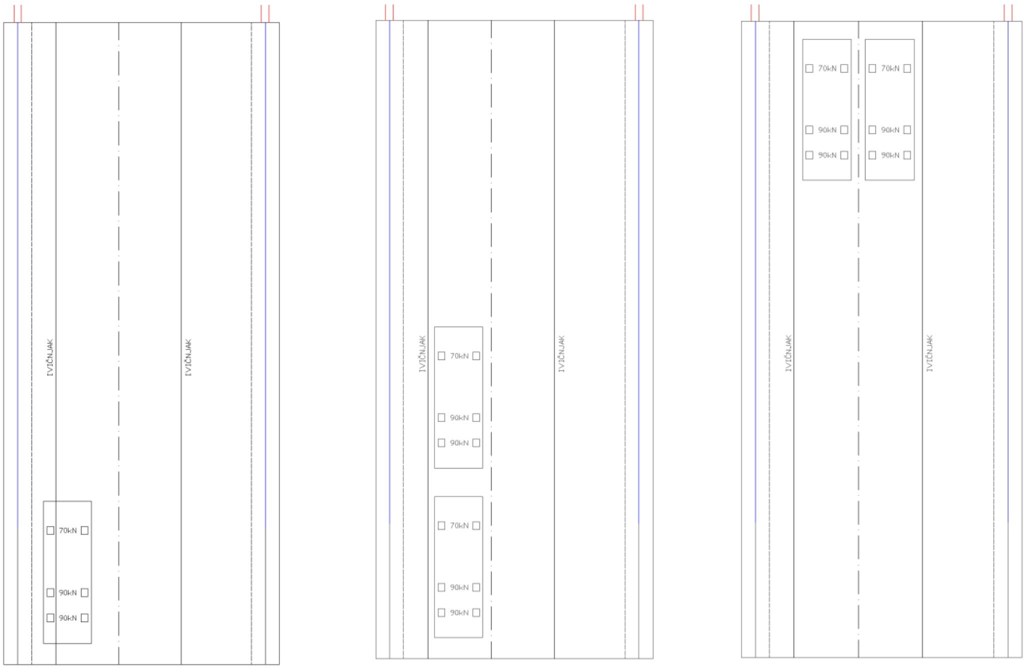
Load 4 – Two vehicles side by side with stopping (Fig. 11c)

Load 5 – Vehicle speed 25km/h

Load 6 – Ambient load (Ambient vibration)

During the tests strain state of the ties (bars), cables, main prestressed beams, secondary steel beams and slab were measured. Measurements were performed using:

- Strain Gauges (Tie bars and Secondary Steel Beam) (Fig. 12a),
- Inductive Displacement Transducer IDT (Cables (Fig. 12b), Main beams (Fig. 12c), Secondary beams, Slab),
- Accelerometer.



(a) (b) (c)

Figure 11- (a) Load 2; (b) Load 3; (c) Load 4

(a) (b) (c)

Figure 12 - (a) Strain gauges on tie bars; (b) IDT on cables; (c) IDT under main beam

In figure 13 arrangement of measurement points are shown. Continuous monitoring was performed during the loading of the bridge. In Figures 14 and 15 were presented the measurements of one regime (Load 3). In Figure 16 the measurement using accelerometers for load 1 is presented and in Figure 17 frequency spectrum of ambient vibration measurements is presented.

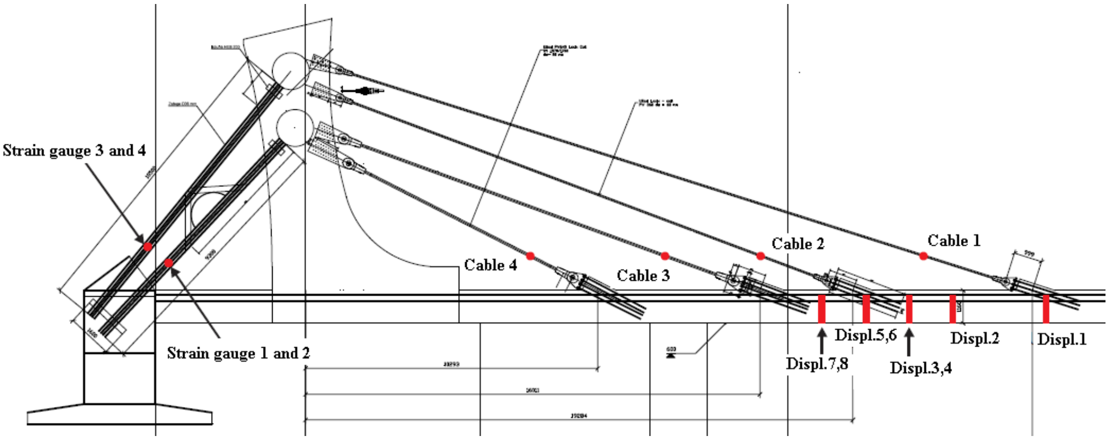


Figure 13 - Arrangement of measurement points

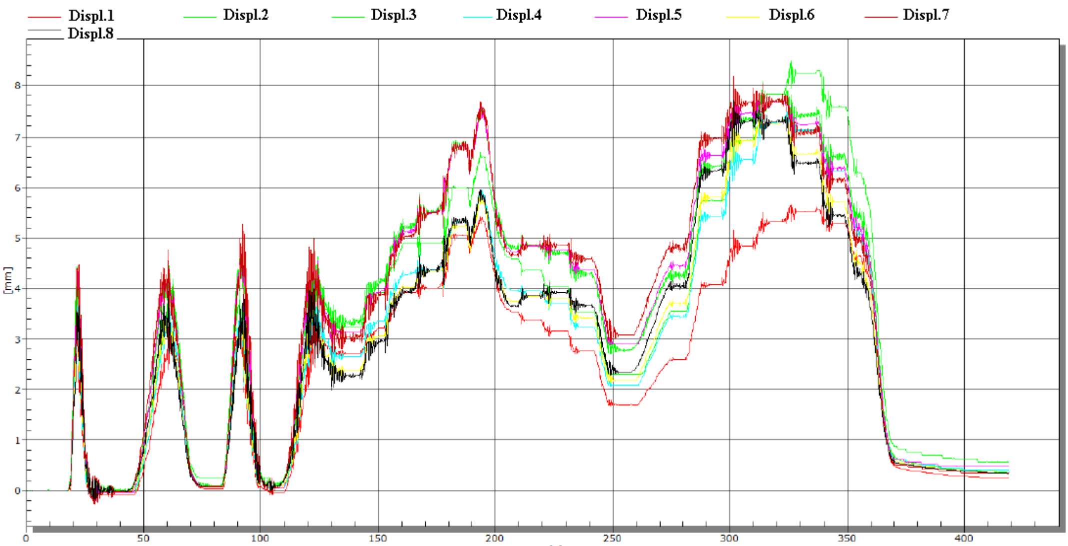


Figure 14 - Main prestressed beams and secondary steel beams, IDT measurements, Load 3

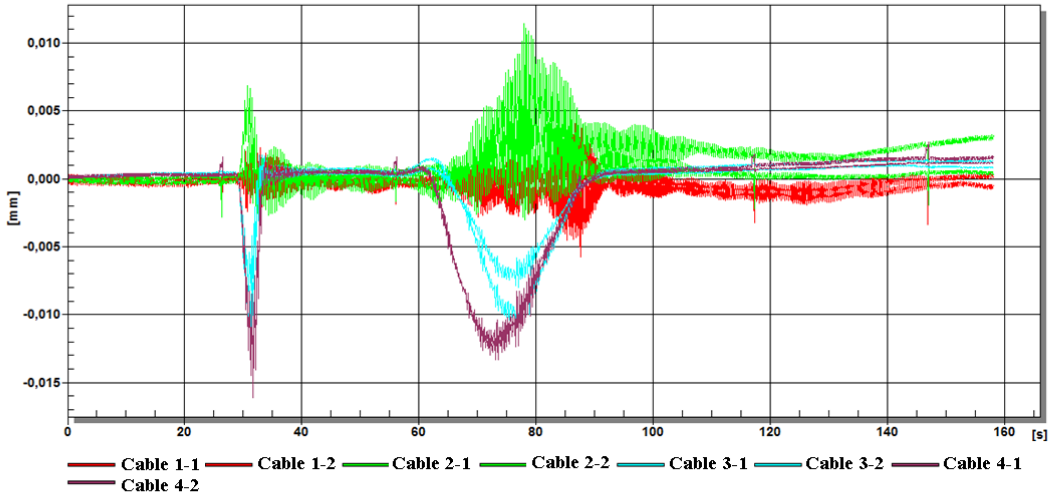


Figure 15 - Cables, IDT measurements, Load 3

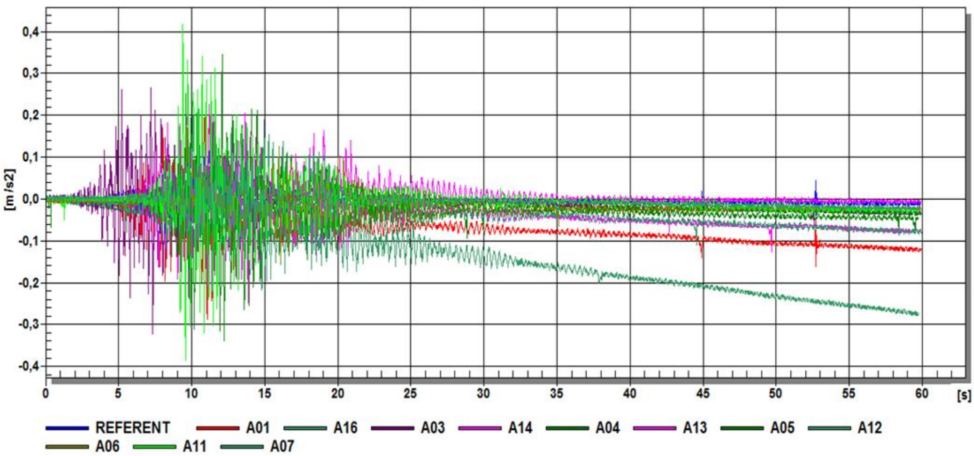


Figure 16 - Tie bars, Strain gauges measurements, Load 3

From the presented illustration law of deformation states for load 3 is obvious. It is important to indicate that the research detected problem with first cable, which is not activated during the application of the load (Fig. 13, cable 1). Cable 2 is activated. The reason for better activation of cable 2 could be due to the fact that close to cable 2 supporting place displacement of the main beam, realized during construction, have maximum so that the cable is thus activated. By measuring the ambient vibration was determined first three vertical vibration modes (Fig. 18).

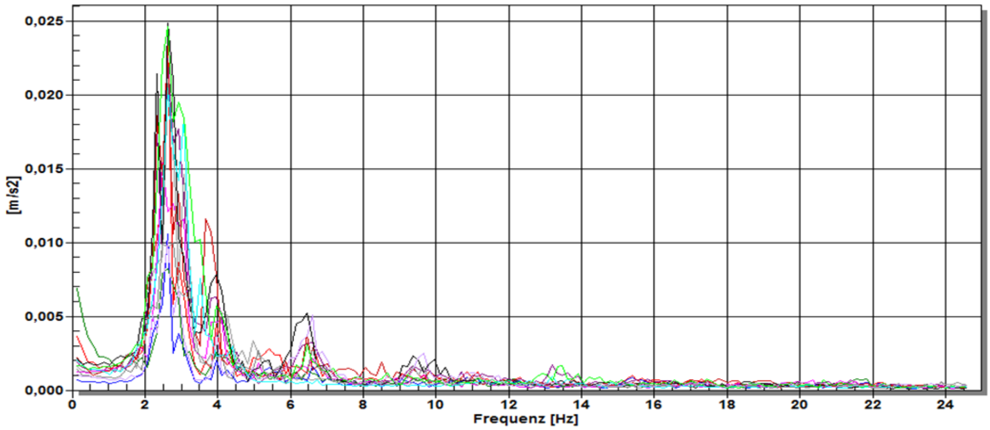
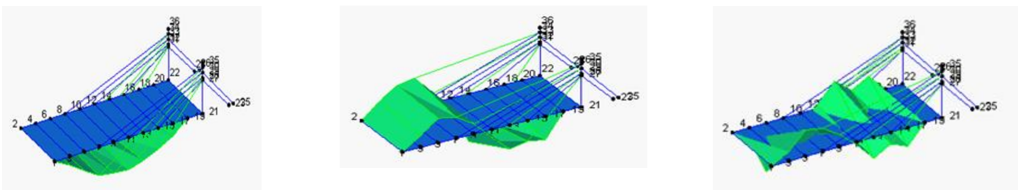


Figure 17 - Frequency spectrum, Ambient Vibration

Modes presented in Figure 18 were obtained using Enhanced Frequency Domain Decomposition techniques (frequency domain).



(a) (b) (c)

Figure 18 - (a) Mode 1 – 2.719Hz; (b) Mode 2 – 6.79Hz; (c) Mode 3 – 9.609Hz

6. CONCLUSIONS

The procedure for determining the dynamic behavior parameters of a civil engineering structure has been presented previously.

A disadvantage of the engineering approach to bridge analysis is that it is focused on bridge structures and the environmental impact on the bridge rather than the the bridge impact on the environment. This approach changes through the development of procedures for the analysis of vulnerability, ie robustness of the bridge structure, which implies the analysis of the likelihood of certain hazardous situations, which indicates that the need to analyze the bridge structure from the aspect of hazard assessment, risk analysis and analysis of impact on community resilience.

The future of infrastructure object analysis is a multidisciplinary integral approach to analysis of object as an integral part of the community.

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REVIEW QUESTIONS

1. Possibilities of applying risk analysis in Civil Engineering?
2. What are the influential parameters of seismic hazard in the Balkans?
3. Why bridges are backbone of any country's economy?
4. Types of bridges inspection?
5. Example for multidisciplinary integral approach to bridge analysis?