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REGIONAL INFRASTRUCTURE INVENTORY TOWARD SEISMIC NETWORK SAFETY

Bridges represent a critical facet when determining a community’s resilience to a disaster and its ability to resume normal activities. The accurate prediction of the future condition of bridges is an important part of any bridge management system. Past bridges inspection data along with information on any repair and/or retrofit can provide a baseline for predicting their future conditions. To develop a reasonable estimate for future bridge safety, this paper describes a creation of the information system that get insight into the critical infrastructure elements and can identify the losses that can be caused by earthwuake. This system includes bridge infrastructure network elements from the N. Macedonian region. An extended database of bridge population (created for the Infra-NAT project www.infra-nat.eu) is developed through a data collection form and allows for a detailed exposure model of the bridge network to be compiled. The database is upgraded with retaining walls that are important parts of the regional transportation network. By considering the general characteristics of the bridge, a representative sample of bridges is chosen to develop fragility functions for bridges exposed to seismic hazard. To estimate the physical vulnerability and potential economic losses due to seismic hazards to all transportation network, seismic risk assessment toll is developed. The results enable a better understanding of the relevance of the vulnerability level of critical infrastructure in the analyzed region, correlating it to the corresponding levels of development, as well as other socio-economic variables.

Keywords: bridge inventory, seismic hazard, exposure, fragility curves.

1. INTRODUCTION

The resistance of the transportation infrastructure systems is of a primer importance, particularly in the period after occurrence of any natural or man-made disaster. In an environment exposed to frequent natural disasters (earthquakes, floods, landslides and alike) as is the case with N. Macedonian region, it is of a particular importance to monitor the conditions of the transportation infrastructure and all its elements for the purpose of obtaining timely information about their current conditions, conceiving and evaluating possible risks and their mitigation.

Although the occurrence of natural disasters is inevitable in numerous cases, considering their consequences, we are increasingly becoming aware of the importance of fulfillment of serious obligations of all entities within the system of action in conditions of crisis, related to establishment and development of systems and standards for prevention and mitigation of consequences for the purpose of proactive management of the risk through adequate prioritization and taking preventive measures. Pursuant to item 6.9 of the National Platform for Mitigation of Disaster Risks announced by the Government of RNM in September 2019, IZIIS is involved in the activities for prevention and early warning, performing: research of earthquake phenomena and their manifestation upon ground and consequences upon engineering structures; exploration of risks pertaining to natural disasters; development and improvement of methods of management of natural disasters and alike.

This paper presents part of the research activities in the framework of two projects "Upgrading and Improvement of Information System on Transportation Infrastructure and Seismic Risk Assessment for New Infrastructure Structure" [1] and international project Infra-NAT (783298 – INFRA-NAT – UCPM-2017-PP-AG, http://www.infra-nat.eu/). [2]. The projects are oriented towards particular contribution in definition of the regional infrastructure inventory and amendment of the already defined comprehensive frame for monitoring of the vulnerability of the bridge infrastructure in our country.
For the purpose of the analyzed inventory database, the analytically developed type of fragility curves were developed. The mathematical description facilitates their incorporation in computational environments for regional risk and resilience assessment of transportation networks such as introduced in MAEviz (Mid-America Earthquake Center 2006) [3], Hazus (Hazus-MH 2011) [4]. These analytical fragility models have received increased attention in the literature in the past decade given their ability to overcome limitations of subjective expert-based fragilities or empirical ones that are constrained by the lack of adequate data, as stated in Gidaris et al. (2017) [5].

2. INFRASTRUCTURE INVENTORY

Different countries have different institutions that maintains bridge inventory data systems. Illinois Highway Information System has data for 2,601 bridge [6]. In Serbia, predecessor of the 'Roads of Serbia' public enterprise, the Road Directorate of Serbia, began recording bridge inspection data in a database named BPM (in Serbian **B**aza **P**odataka o **M**ostovima) in 1990 [7].

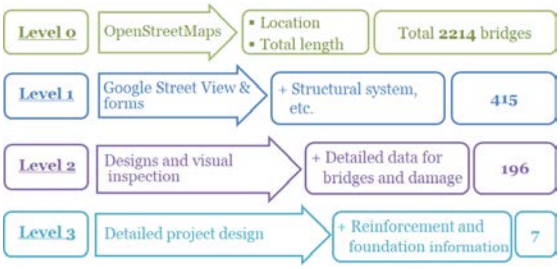

Figure 1. Schematic presentation of levels of data on the bridges

For the territory of N. Macedonia, an information system was created including data on a total of 679 bridge structures that are part of the existing motorways and main roads in our country, selected due to their extraordinary importance for the country and the region. A most up-to-date model of seismic hazard and the most reliable time histories for analysis of bridge structures, were also defined. For each of these bridge structures, different number and type of data are available. The information entered into the information system is divided into three sets: 1) Level 0, involving data on the location of the structure and its total length; 2) Level 1, data of level 0 + involve material, structural system and alike; 3) Level 2, level 1 + involves complete geometry and damage data; and 4) Level 3, level 2 + includes data on the reinforcement and foundation (Fig. 1).

Locations of the bridges with Level 0 and 1 data are given on Fig. 2 [2].

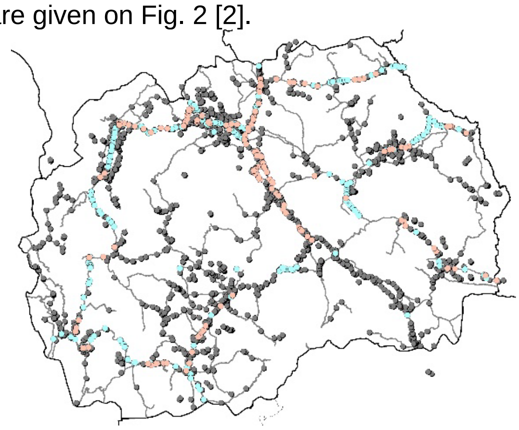

Figure 2. Bridge locations with Level 0 data (grey), Level 1 (blue) and Level 2 (pink)

Based on the data from the created information platform, a typological classification of the bridges was made as the basis for formulation of analytical models for definition of the vulnerability of different bridge typologies. For each typology, there were developed numerical models per 50 bridge structures with different geometrical parameters, including span length, height of central piers and width of superstructure. For each of these bridges, nonlinear dynamic analyses were performed using 30 time histories with 7 hazard levels, or more specifically, over 10000 analyses were done for each type. The used methodology is published in the literature [8]. The obtained results were used for development of vulnerability curves for each of the different typologies and these were entered into the web-based platform that has the possibility of identifying the critical parts of the infrastructure network (http://www.infra-nat.eu/web-based-platform/). For 2 span bridges results are given on Fig. 3, for 3 span on Fig. 4 and for 4 spans on Fig. 5.

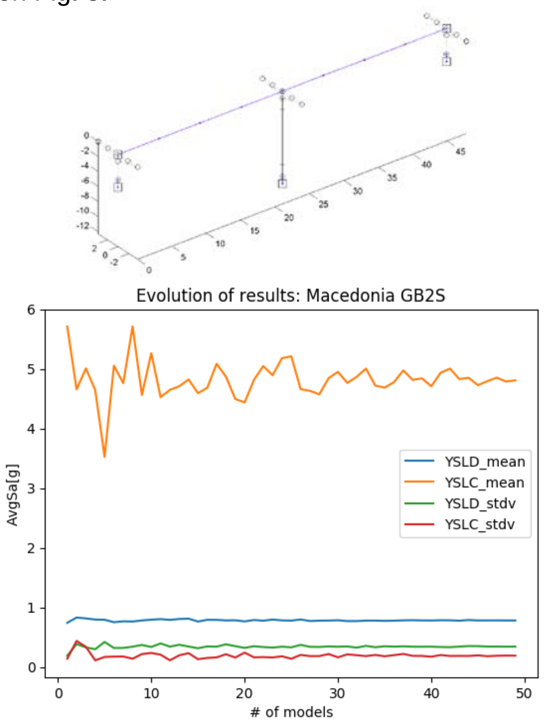

Figure 3. Numerical model and results from the vulnerability analyses for 2 span girder bridges (mean and standard deviation of damage and colapse limit state of risk indicator (Y) for whole system).

After the definition of the vulnerability curves, the infrastructure inventory is upgraded with information of other structures that are part of the transportation system and assessing the risk. The main activities involved three phases 1) acquisition, processing of data on structures and definition of vulnerability; 2) analysis and integration of the seismic conditions and site soil conditions; 3) risk assessment which are explained below.

2.1 PHASE 1

The first phase of the research was upgrading the information system with data on new structures that are part of the Miladinovci-Shtip motorway, part of the Deve Bair – Kafasan motorway as well as part of the state roads A4 Shtip – Radovish and A1 Prilep-Gradsko. That includes bridge structures and retaining wallsThe system is upgraded with 20 such structures. For all of these structures design documentation was provided, mainly bridges that are situated along the roads in the part bordering on Greece and Albania for the purpose of preparations for the international project financed by EU, namely, CRISIS (Comprehensive Risk Assessment of Basic Services and Transport Infrastructure) that just started and will be coordinated by IZIIS (www.crisis-project.org).

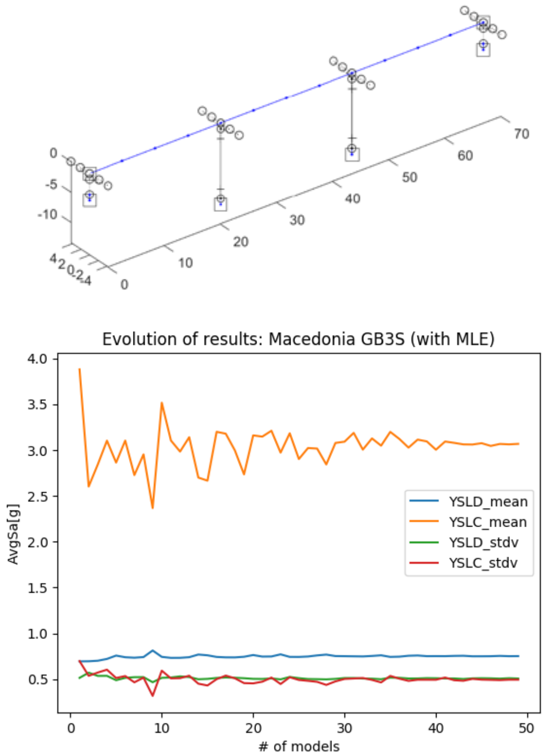

Figure 4. Numerical model and results from the vulnerability analyses for 3 span girder bridges (mean and standard deviation of damage and colapse limit state of risk indicator (Y) for whole system)

This first phase started with first part which included definition, i.e., selection of roads, i.e., railway corridors that have to be encompassed, selection of structures whose data have to be included in the information system, and finally, providing safety to these structures. For all types of structures, a certain number of data are entered into the system. These data will refer to structures that are part of the new motorways, state roads. For most of these structures detailed data were available, encompassing level 3, meaning that, in addition to location and total length of the structure, these include data on the structural system complete geometry, data on the foundation and the reinforcement. Integrated in the system will be also data on the type of soil. In this phase data affecting the stability of the structures that are of a temporary character were included. Inspection of the conditions of the greater number of structures was done in 2007, while regular inspection on some of the structures was done in 2017.

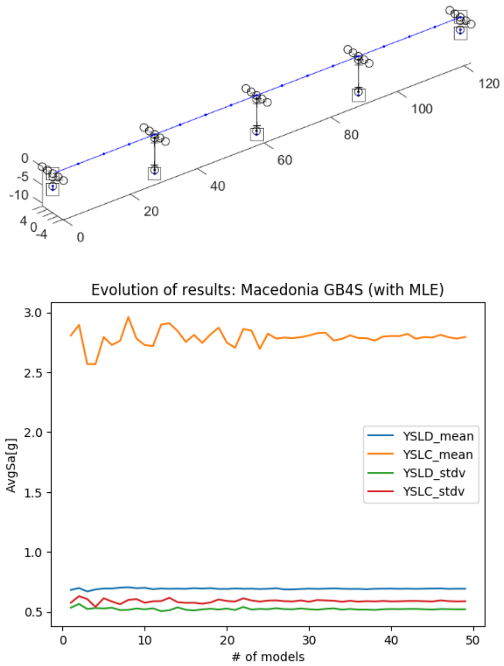

Figure 5. Numerical model and results from the vulnerability analyses for 4 span girder bridges (mean and standard deviation of damage and collapse limit state of risk indicator (Y) for whole system)

These data are the subject of inspection by institutions that manage the road and railway network and are of a particular importance for the stability of the structures as they affect their vulnerability and risk. With these information, the already existing information system was considerably upgraded and improved. In addition to the main geometrical data and data on damages, the information system integrates data referring to vulnerability of each of the structures that is the basis for definition of the seismic risk for each structure taken separately. Most of the structures that are part of the information system belong to one of the different structural typologies for which two levels of vulnerability were already defined within the frames of the Infra-NAT project [9].

2.2 PHASE 2

With the completion of the first phase, the activities envisaged in the second were started within which the hazard conditions were defined for each structure, depending on the site soil conditions and the seismic hazard on the site. The hazard was defined through three parameters of expected seismic events: 1) location (where), 2) genesis and evolution (how much) and 3) intensity (degree). Mapping of the hazard consists of consistent and uniform discretization of the territory of Macedonia into smaller territorial units of a size suitable for reasonable monitoring of changes of all parameters referring to distribution and concentration of the hazard. These data were basic for the realization of the last phase of the project.

2.3 PHASE 3

The final, third phase, involved activities related to risk assessment. It represents a factor that is not constant, but changes in the course of time. The frame for risk management assessment provides the static current state of the risk at a certain time and place that is changed by following the dynamics of the hazard and the dynamics of the parameters affecting the vulnerability of structures. In this phase, assessment of the current risk was made for the structures included in the information system that also includes the newly built structures that are part of the Miladinovci – Shtip motorway and part of the Deve Bair Kafasan motorway as well as state roads A4 Shtip – Radovish and A1 Prilep – Gradsko. In the first part of this phase, the parameters to be used for risk assessment were defined. A methodology for monitoring and consideration of vulnerability by following the characteristic indicators or a group of indicators was applied, that recognized and indicated the conditions that are with a great probability of causing the occurrence of a certain hazard and realization of the corresponding risk. The information system offers the possibility of a multiple risk assessment, namely, when change of some characteristic indicators or a group of indicators affecting the vulnerability or definition of risk takes place, it will be possible to re-assess the risk. This system provides the possibility for temporary definition of the risk pertaining to the transportation network, which considerably contributes to high quality fulfilment of the obligations of the Institute as part of the National Frame, creating tools that can be used by the institutions in charge of management of the transportation infrastructure and effectuation of the necessary controls for the purpose of mitigation of the consequences of possible risks and bringing the exposure to risk to an acceptable level. Fragility curves for the typical bridge structures in R.N. Macedonia, obtained from the analyses are given on Fig. 7, 8 and 9 [10].

3. TOWARD SEISMIC NETWORK SAFETY

The created system gives a great contribution to getting a better insight into the risk related to natural hazards pertaining to the critical infrastructure by development and refinement of a comprehensive frame for evaluation of vulnerability, with a special focus on the seismic hazard and the effects of ageing/deterioration of the transportation infrastructure network that can be used independently by a number of countries. The results of this research are double: greater knowledge and increased awareness.

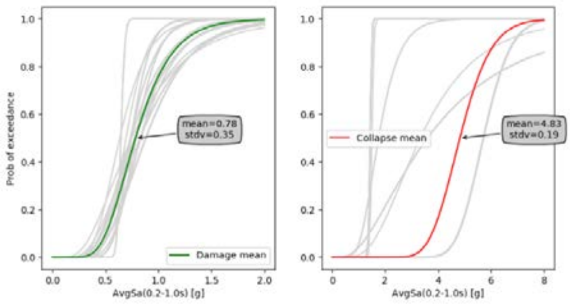

Figure 7. Fragility curves for the 2 spans girder bridges

By synthesis of the data on the exposure and the vulnerability of the critical infrastructure in the territory of a country, one can obtain new knowledge and better insight into the current number, location and conditions of existing elements of the considered critical infrastructure.

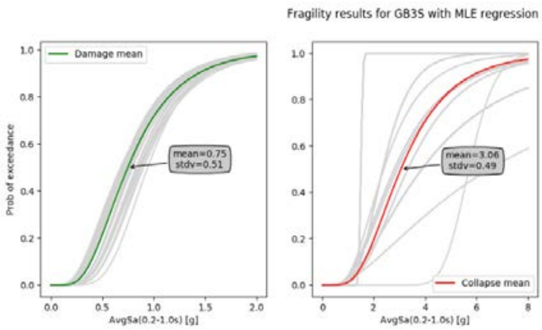

Figure 8. Fragility curves for the 3 spans girder bridges

Increased awareness about natural hazards and changes of existing critical infrastructure facilities is necessary for the success of the strategies of response to emergency situations and definition of the level of resistance of the European (and neighboring) societies.

By realization of all the activities realized in this research, the following is achieved:

- Integration and harmonization of data in the information system with data on the entire
- Exposure of the structures that are part of the main roads and motorways in our country, including bridges, retaining walls and alike. These data will provide all relevant information about the structures at regional level;
- Combination of existing seismic hazard models and their including into the information system;
- Characterization of the direct physical vulnerability and indirect losses through existing methods from former studies of seismic risk and through an innovative approach to fast consideration of reduced capacity due to deterioration of structures;
- Monitoring of the risk will be enabled through relevant factors of monitoring, parameters and data for identification of the efficiency of the existing frames of risk management;
- The application of the information system in using prevention measures, effective management of resources and prioritization, with a focus on seismic hazard and effects of ageing of bridges, will contribute to the increase of resistance of the critical infrastructure;
- For the local and regional bodies, there will be provided the necessary tool for risk assessment through definition of the vulnerability of the critical infrastructure, providing thus instructions for optimal distribution of available resources. This tool can also be used in other European countries.

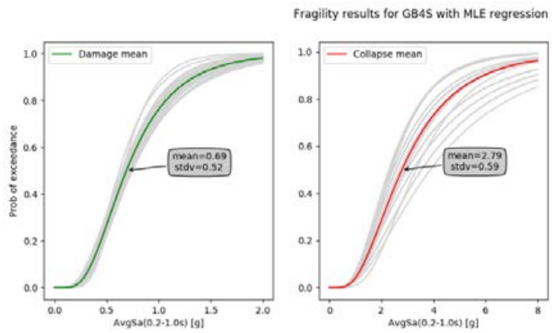

Figure 9. Fragility curves for the 4 spans girder bridges

4. CONCLUSIONS

This paper deals with research which anticipated to enable upgrading and improvement of the information system that was created within the international project Infra-NAT (783298 – INFRA-NAT – UCPM-2017-PP-AG, http://www.infra-nat.eu/) with structures that are part of the infrastructure network on the territory of N. Macedonia. In addition to bridges, the system includes newly built retaining walls that are part of the state roads and motorways that are under construction. Presented here are the results from the performed nonlinear analyses of bridge samples and calculation of the fragility curves.

To estimate transport network vulnerability, seismic assessment toll is developed based on bridge inventory system. Of particular importance is the including of parameters that are of a temporary nature and refer to the conditions of the structural and non-structural elements that directly affect the stability and vulnerability of the structures. These data can be collected in a certain time period and then integrated into the system and processed. As a result of their analysis, one can get an insight into the critical infrastructure elements and identify losses to be caused by an earthquake event. These could contribute to the process of optimization of the distribution of resources by public and private stakeholders.

The creation of this tool was based on systematic approach through integration of national and international practice and theoretical and methodological soundness whereby practical usability of the offered system solution was achieved. In this sense, this system can be used as a referent model for a consistent approach to prevention, early warning and management of a large number of risks and possible seismic disasters. The main advantage of this system is that it can easily be upgraded and adapted in order that it could also be used beyond the boundaries of our country. By application of this tool, the process of management of infrastructure elements can be systematized and made practical and simple by which it can significantly contribute to the improvement of the conditions for its use for the purpose of development of the country and improvement of the lives of its citizens.

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