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Hospital safety in spatial and urban planning and design–seismic zone in the Kolubara region in Serbia

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Abstract

Natural and technological disasters in the European countries have caused significant loss of life and damage to structures and infrastructure, which has led to the ratification of conventions at world level in the field of disaster preparedness (Hyogo Framework for Action and Sendai Framework for Disaster Risk Management).These strategies were also adopted at the lower levels of national decision-making in order to establish risk reduction and control on acceptable level. Since disasters can cause severe hazards on social infrastructure (healthcare facilities, schools etc.), these objects should be specifically treated in urban and spatial plans in terms of resilience-improvement.

This paper presents methodology of Hospital Safety Index (HSI) adapted for the territory of Western Balkan countries, on the case study of seismic risk zone in the Kolubara Region in Serbia. This zone has history of seismic hazards, which have led to implementation of numerous spatial and urban plans for renovation and application of new measures in risk reduction.

Main goal of the paper is to implement HSI as new methodology in spatial and urban planning, not only on healthcare facilities, but also on the wider network of social infrastructure that were and still are jeopardized by seismic risk. Also, the paper proposes measures and potential interventions for improvement of healthcare facilities in seismically vulnerable region of Kolubara, based on HSI.

Keywords: seismic risk, urban planning and design, Hospital Safety Index, healthcare facilities, Kolubara region, Serbia

1. Introduction

Resilience in terms of cities generally refers to the ability to absorb, adapt and respond to changes in an urban system [1], [2], [3]. The resilience and preservation of the social infrastructure, within which healthcare facilities and schools are of special importance, is an integral part of the city resilience [4], [5], [6]. Hazards can be natural or anthropogenic with a high probability of causing the socioeconomic consequences (possible human losses, damage to property and economy including the destruction of infrastructure), and can have harmful effects on the environment [2]. The World Disasters Report 2010 [6] warns that 2.6 billion people in urban areas in low- and middle-income nations are susceptible to high

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levels of risk generated by rapid urbanization, inadequate local governance, unprecedented population growth, and poor health services [7].

The Sendai Framework for Disaster Risk Reduction 2015- 2030 was adopted in 2015 [8], and set the long-term goals in which the effects of the previous Hyogo Framework were assessed [9]. It was concluded that the Hyogo Framework has contributed to raising awareness about the importance of disaster risk management, as well as reduced human losses due to disasters and created common forms of action amongst the member countries (168 signatories, including Serbia). In spite of the realized contribution, primarily the contribution to the institutional disaster risk reduction measures, it was concluded that the large-scale disasters have occurred. Disasters, many of which are exacerbated by climate change and which are increasing in frequency and intensity, significantly impede progress towards sustainable development [8].

The Sendai Framework together with the Action Plan sets high targets within the four priority fields: understanding disaster risk; strengthening disaster risk governance to manage disaster risk; investing in the disaster risk reduction for resilience; enhancing the disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction [8]. The activities are divided into activities at global level and activities at national level, while the mechanisms of additional support to the less developed member countries in order to achieve common, global goals are pointed out. The updated databases on threats to cities and their vulnerability, as well as the risk assessment performed based on them, should be used as a basis for drawing up spatial and urban plans and for decision making. The involvement of the educated public is an important prerequisite for reducing the vulnerability of cities to risks. A special importance of healthcare facilities in emergency situations requires their safety assessment and then possible improvements if necessary.

Population healthcare in special conditions caused by hazards is addressed thought the issue of critical infrastructure. The Directive 2008/114/EC defines critical infrastructure as an asset, system or part thereof located in Member States that is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact on a Member State as a result of the failure to maintain those functions. Healthcare facilities play an important role during disasters as they provide "lifeline" services to reduce disaster associated mortality and mobility, and thus minimize the impact of disasters on the community [6], [10], [11], [12], [13]. Efficient healthcare facility disaster management is considered an essential way for healthcare facilities to supply continuous health services during disasters, even if these facilities are directly affected by the disaster [14], [15].

The paper presents a methodology developed in the field of the healthcare facility safety assessment for earthquake prone areas. The methodology implies the safety assessment for seismic activities. Hence, starting from the methodologies described in the paper, a specific methodology was developed in accordance with Hospital Safety Index (further on referred as HSI) for the healthcare facility resilience to hazards in the earthquake-prone Kolubara region (for calculating the multi-hazard index of alignment with safety criteria). The documentation of the Regional Spatial Plan of the earthquake-prone Kolubara District [16] and the Regional Spatial Plan of the Kolubara and Mačva Administrative District [17], realized by the Institute of Architecture and Urban & Spatial Planning of Serbia, served as a basis for the analysis. The mentioned results can serve as a model example for determining the preparedness for seismic hazards in other regions in Serbia and wider.

2. Materials and methods

2.1. Hospital Safety Index –evaluation criteria

Healthcare facilities represent more than 70% of public spending on health in countries. Most of this spending is for specialized health personnel and sophisticated and costly equipment. It is critical that healthcare facilities continue to work during emergencies and disasters since people immediately go to the nearest healthcare facility for medical assistance when emergencies occur, without considering whether the facilities might not be functional. Consequently, it is vital to identify the level of safety and functionality that healthcare facility will have if an emergency or disaster occurs. These evaluations aim to determine elements that need improvement in a specific or network of healthcare facilities and to prioritize interventions in healthcare facilities. Their type or location (depending of the surrounding context) are essential for reducing the mortality, morbidity, disability and other social and economic costs associated with emergencies and disasters [18].

Because of importance of safe healthcare capacities in normal, and particularly in emergency situations, a method for checking their safety has been developed by the World Health Organization (WHO) [18]. The check is carried out by determining the HSI, which represents a methodology for fast and relatively economical evaluation of functional capacity of a healthcare facility.

2.2. Case study – Kolubara region

The Kolubara region is one of eight administrative districts of Šumadija and Western Serbia. It occupies the central part of western Serbia. According to the 2011 Census results, it has a population of 174,513 inhabitants (Figure 1).

Fig. 1. Location of the Kolubara region within the Republic of Serbia
Source: Authors

The area covered by the mentioned plans [16], [17] is exposed to the earthquake, flood, atmospheric, earth fall and landslide hazards, as well as fire, explosion and other hazards. Large-scale occurrences of such events are those which can endanger human health and life or cause large-scale damage. Natural disasters can cause significant destruction of natural resources and their depletion, as well as damage to

Source: Seismological Survey of Serbia

technical systems (water supply, electricity and other types of energy, wastewater drainage, solid waste disposal, transport of people and goods, information exchange etc.). On the other hand, vulnerability to natural hazards (primarily to earthquakes) can be considered an important criterion for selecting the locations for settlements, and particularly for the healthcare facilities.

The intensity of seismic hazard in the Kolubara region, for a 50-year return period, increases from northwest to southeast, with values of 6°MCS to 7,5°MCS. The intensity of seismic hazard will increase in the coming period, particularly in the southern part of the area, approaching to the value of 8°MCS.

Permanent danger of disastrous earthquakes, which occur relatively frequently in the subject region (and particularly the manifestation of earthquake with main shock in 1998 which stuck the area of the Kolubara district) indicates the need for preventive action already in the stage of planning. For this reason, it is necessary to anticipate specific measures for remediation of damages caused by earthquake. Through the planning and design activities, it is possible to prevent possible greater and more frequent harmful consequences of disasters, and particularly of earthquakes [16]. Seismic risk mitigation is achieved by anticipating the earthquake-related requirements for the area and by using the engineering seismic-related data in planning and design of healthcare facilities.

Therefore, the issues related to the earthquake protection measures can be solved through planning and design only if considered as a part of complex structure of technical, economic and functional criteria. For this reason, it is more rational to take the precautionary measures in the stage of planning than in later stages of construction and exploitation. Thus, it is necessary to take into account two main requirements in planning and design of earthquake resilient buildings and earthquake resistant equipment. Firstly, it is necessary to define measures that would contribute to reducing the loss of human life and injury, as well as to reducing the material damages. On the other hand, it is necessary to ensure that the earthquake damage remediation costs do not exceed the increased costs of planning, construction and financial investments, which represent an additional prevention in case of disasters. Hence, for the purpose of preventing a greater loss of life or damage, all stages of planning must be aligned with the higher-level development plans, and in all stages of spatial and urban planning and design. The seismological hazard map for the Republic of Serbia was used in assessing the seismic hazard (Figure 2), as well as the seismological hazard map created for the needs of the Regional Spatial Plan of the earthquake-prone Kolubara District and the Regional Spatial Plan of the Kolubara and Mačva Administrative District (Figure 3) [16], [17].

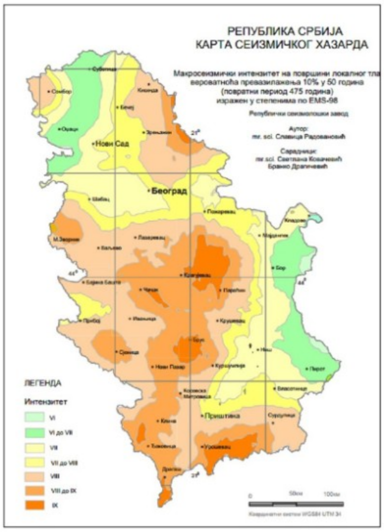

Fig. 2. The Seismological hazard map for Serbia for a return period of 475 years

Source: Seismological Survey of Serbia

Fig. 3. The Seismological hazard map for the Kolubara region for a return period of 500 years
Source: Seismological Survey of Serbia

2.3. Hospital safety for the Kolubara region

The Hospital Safety Index not only estimates the functional capacity of a healthcare facility during and after an emergency, but it provides ranges that help authorities determine which healthcare facilities most urgently need actions to improve their safety and functionality. Priority might be given to a healthcare facility which has a poor level of safety which would put the lives of occupants at risk during an emergency or disaster. The check is carried out for basic group of criteria that are diversified into 2 forms: 1) general information on a healthcare facility, and 2) safe healthcare facility checklist, divided into 4 modules: Module 1: Hazards affecting the safety of the healthcare facility and the role of the healthcare facility in emergency and disaster management; Module 2: Structural safety; Module 3: Non-structural safety; and Module 4: Emergency and disaster management. Each of the mentioned modules contains a set of questions for evaluation, whereby the risk is quantified based on the magnitude of impact on the safety of capacity of healthcare facilities and probability of risk occurrence. Structural safety of the healthcare facility involves assessment of the type of structure and materials, and previous exposure to natural and other hazards. Non-structural Safety considers architectural safety, Infrastructural Protection, Access and Physical Security, Critical Systems and Equipment and Supplies. Emergency and disaster management (functional capacity) considers the level of preparedness of a healthcare facility's organization, personnel and essential operations to provide patient services in response to an emergency or disaster.

Evaluation of the building safety for earthquake hazard in HSI was conducted through Module 2. The results show necessity for use of assessing methods which correlate with the above shown damage of the buildings:

- most earthquake building codes consider a minimum separation of 10 cm when the shorter of two adjacent buildings is 10m high, which is 1.0% of the height of the building. (Low = Separation is less than 0.5% of the height of the shorter of two adjacent buildings; Average = Separation is between 0.5% and 1.5% of the height of the shorter of two adjacent buildings; High = Separation is more than 1.5% of the height of the shorter of two adjacent buildings)
- determine the type of foundations (e.g. shallow, deep, isolated and, if a combination, whether they are united or isolated). The level of groundwater and type of soil at the building site play a critical role in determining the facility's vulnerability to floods and differential settlement of the

foundations, and the associated effects on vertical structural elements. (Low = No evidence that foundations were designed according to standards (foundation size, soil survey) and/or there is evidence of damage; no plans are available; Average = Little evidence (drawings, soil survey) that foundations were designed according to standards; and/or there is evidence for moderate damage; High = Strong evidence that foundations were designed according to standards with strong evidence of no damage)

- irregularities in building structure plan (rigidity, mass, resistance) - irregular structures can be expressed in terms of shape, configuration and torsional eccentricity (i.e. the distance between the centre of mass and the centre of rigidity (Low = Shapes are irregular and structure is not uniform; Average = Shapes on plan are irregular but structure is uniform; High = Shapes on plan are regular and structure has uniform plan, and there are no elements that would cause significant torsion)
- irregularities in height of storeys - differences in height between the floors (often the case in the lobby and lower floors of hospitals) which can cause concentrations of tension in changes of level. A so-called “soft floor”, an undesirable feature in earthquake-prone zones, can be present owing to significant changes in rigidity due to variations in height. Evaluators should be aware that an in-fill wall can convert a column designed for support along its entire height into a “short” column (Low = Height of storeys differs by more than 20%; Average = Storeys have similar heights -less than 20% but more than 5%); High = Storeys are of similar height, less than 5%).

3. Results and discussion

Within the HSI methodology, earthquake risk is particularly emphasized in modules 1 and 2. In the first module, the earthquake is defined as a natural hazard, or more precisely, as a geological hazard (point 1.1.1). Earthquake prone areas must be accessed by referring to regional and local hazard maps or other hazard information, and rate the level of earthquake hazard for the healthcare facility location (including catchment area) in terms of geotechnical soil analyses. In this way, it can be determined whether the healthcare facility should be prepared to respond to an emergency or disaster due to earthquakes (based on exposure of the catchment population or the specialized role of the healthcare facility for the treatment of injured patients). In case of Kolubara region in Serbia, it is very important to state that this is an area which has high risk for earthquakes, so part of the module 1 and 2 concerning seismic hazard (and whole HSI checklist) should be evaluated with greater significance (more important than wind or similar hazard in this area). In that case, where there is a higher risk of earthquake and/or cyclones, like in the Kolubara region, model for evaluating HSI is presented as following: structural safety has a weighted value of 50% of the index; the non-structural module has a weighted value of 30%; and emergency and disaster management is weighted at 20%. Structural system design is recommended to be the most valued part of HSI. Model 2 does not evaluate structural safety as most significant and all three modules are weighted equally: i.e. each module contributes 33.3% to the calculation of the safety index. This model is proposed for countries or regions where earthquakes and high winds are not considered to be likely hazards.

Taking into account the application of HSI in the Kolubara region, it is necessary to primarily introduce the assessment of the existing healthcare facilities for earthquake risk and then secondarily also introduce the assessment of damage in buildings, as well as assessment of the types of damages after earthquake. The healthcare facility should be inspected visually and through engineering seismic-related data (as-built design). According to this, it is possible to consider the structural system design of a building and its resilience to seismic hazard. In that respect, the assessment of the existing buildings is more important because such healthcare facilities can and must be in compliance with certain seismic regulations, depending on where and when the buildings were designed and built. The process should include the assessment of the overall quality of the structural system design of the healthcare facilities, as there is wide variance in the performance of buildings due to the designs and standards to which they have been built. Poor structural design can indicate that damage from hazards to the structure of the building may cause building failure and collapse. For instance, if no evidence of reinforcement is found for concrete or masonry systems, HSI suggests that then the structural system design should be rated as "low". Moderate structural design provides partial protection and would cover situations where the effect of hazards may cause damage, but this damage is not expected to cause building collapse. A good rating would indicate that the building should not collapse when affected by hazards. In the case of an earthquake, buildings that are too closely spaced, depending on their height and proximity, can pound against each other until damage is sustained. The exterior of a healthcare facility should be inspected to determine whether such problems might arise.

On the other hand, in addition to the assessment of potential risk for the existing buildings, it is also necessary to assess damage and further risks after earthquake through two analyses: the analysis of two conditions of building (damaged building and undamaged building) and in case of registered damage – to carry out the analysis for six grades of damages. In this case, the evaluation can also be carried out in a different way, whereby it is necessary to extend the way of determining the risk to more than three levels (low, average, high).

A general risk is a combined effect conditioned by the analytically determined different seismic events for the selected scenarios. Several types of scenarios were considered for assessing individual risks. Different approaches to the response analysis were used for each type of system relative to the determined scenario from the assessed seismic hazard and level of the existing information about response and behaviour of the systems and their characteristics in the given area. Obvious advantage of such analysis over other procedures lies in the fact that it provides information about response of a building to hazard. In this way, the direct assessment of the probability of reaching or exceeding critical response level is made possible. The solution has a simple analytical form which facilitates its application in general seismic safety analysis.

Two types of analyses were used in the planning practice in Serbia: general risk analysis for the systems with two types of damages and the general risk analysis for the systems with several types of damages. In the first case, the building after earthquake can be: undamaged (grade 0) and damaged (grade 1). It is possible to express a risk that meets the needs of planning and design through limitation on two conditions of building, on condition that the probability is defined as the expectancy with a limit value less than 10% for the building damage that occurred in the period of its service life. In the other case, it is about the degree of damage given in the seismic scale and damage coefficient which in itself contains factors such as remediation costs, level of structural damage (damage in load-bearing structure), non-structural damage, etc. Six building damage grades are determined according to that.

Table 1. Correlation between stages of buildings with damage of earthquakes and safety levels from HSI

Grade of damage and symbol	Description of damage	Damage coefficient (%)		HSI index and classification according to WHO methodology	Description of intervention
		Interval	Middle value		
No damage (0)	No damage or irrelevant non-structural damage	0 - 0,05	0	A (0.66-1)	Hospital resilience is on very high level. Healthcare facilities will function independent in emergencies and disasters
Slightly damaged (S)	Slight localised non-structural damage	0,05 - 1,25	0,3	B (0.36-0.65)	Hospital resilience could be improved with small-scale measures in the short term. Current condition of the hospital safety level is jeopardized without endangering lives of people
Moderately damaged (M)	Significant non-structural damage, structural damage that can be easily remediated	1,25 - 20	5		
Severely damaged (SD)	Severe structural damage, possible complete non-structural damage	20 - 65	30	C (0-0.35)	Hospital resilience needs urgent intervention measures. Function of the hospital is threatened and current safety levels are very low.
Completely damaged (CD)	Building to be remediated along with reinforcement or replacement	65 - 100	100		
Collapse (C)	Collapse of whole building or parts of the building	100	100		

Source: [16], [18] and authors

4. Conclusions

The aim of HSI is to identify and evaluate the building condition, but it is possible to modify it for the use at all levels of planning and design which do not assess the healthcare facilities in a sufficiently detailed way. The adjustments of the HSI methodology was achieved in accordance with the specific characteristics and conditions obtained in the process of drawing up the plan for the Kolubara district in Serbia. Based on this, the additional aspects that help better determine the exposure to risk of healthcare facilities to seismic hazards can be determined.

It is recommended to add within the HSI methodology a segment related to the macroseismic investigations which examine two scenarios. The first scenario refers to the evaluation of the existing condition of the building for which it is necessary to obtain technical documentation of the as-built design (soil characteristics, groundwater level, design documentation (plans and sections) with dimensions of openings and position of load bearing elements – columns and beams, wall thickness, characteristics of materials of all load bearing structures, short description of simple structure buildings (fences, roofs and chimneys, etc.) in immediate vicinity of the subject building, distance from the nearest seismological station, etc.). In this segment, there is a problem of the existence of appropriate regulations. The second scenario refers to the inspection of the building condition after earthquake for which the following parameters are defined: the evaluation of the technical condition of the building before and after earthquake, observed deformations on the building, condition of the load bearing and other elements of the building, detailed description of structural elements and evaluation of its condition relative to the current seismic regulations. This scenario recognizes the level of damage and potential further risks for functioning of the building.

By introducing the additional indicators, the HSI methodology can be used for a more precise evaluation of condition of healthcare facilities in the Kolubara district and, given that the seismic activities in this area are frequent, it is necessary to carry out a detailed assessment of potential risks for the buildings of this type. Supplementing the HSI methodology contributes to its adequate application in a specific area which is highly vulnerable to seismic hazards. Thus, the mentioned research can also serve as a guideline for the implementation in other seismic vulnerable areas, whereby more clear indicators of structural, functional and similar parameters for adequate consideration of risk from seismic hazard are obtained.

Also, paper has shown direct link between six stages of buildings with damage of earthquakes and safety levels from HSI. This leads to better understanding of risk zones and levels of risks on the observed territory.

Further recommendation for methodology improvement could be implementation of GIS technology in defining all types of seismic hazards and threatened structures in potentially endangered seismic zones.

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