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# SEISMIC VULNERABILITY OF KINDERGARTEN BUILDINGS IN THE CITY OF OSIJEK

# POTRESNA OŠTETLJIVOST OSJEČKIH DJEČJIH VRTIĆA

***ABSTRACT***

*The territory of Croatia is located in a highly prone earthquake area with the threat from earthquakes producing ground accelerations ranging from 0.10g to 0.38g. More than half of the Croatian territory (56.22%) with more than one third (1,633,529) of the total Croatian population is characterized as a zone with a high risk of occurrence of earthquakes. In order to reduce primary catastrophic consequences of earthquakes, certain preparedness and emergency procedures have to be organized in the event of and prior to an earthquake. Earthquake risk refers to the expected losses to a given element at risk, over a specified future time period. Risk may be measured in terms of expected economic loss, or in terms of number of lives lost or the extent of physical damage to property.*
*Kindergartens in Osijek have an important role in the educational process. For each of the 21 kindergarten buildings, the properties related to the year of construction, height, type of structure, total area, etc., are given. Since they mostly have only a base floor and are built as reinforced concrete buildings, they may serve as emergency shelters after earthquake events. Therefore, a complete strategy for evaluating their capability to face probable earthquakes has to be provided. The aim of the article is to determine seismic vulnerability of kindergarten buildings - the degree of loss to a given element at risk resulting from a given level of hazard, defined as a ratio of the expected loss to the maximum possible loss on a scale from 0 to 1, where 0 means without damage and 1 means collapse of building.*

***Key words***: *Seismic risk, seismic vulnerability, kindergarten buildings*

**_SAŽETAK_**

*Područje Republike Hrvatske odlikuje se izraženom potresnom aktivnošću kojima prijete potresi s vršnim ubrznjima tla u granicama od 0.1g do 0.38g. Više od polovice teritorija Republike Hrvatske (56.22 %) s više od trećine ukupnog broja stanovnika (1,633,529)koji živi u Republici Hrvatskoj označene su kao zone s vrlo visokim rizikom pojavljivanja potresa. Kako bi se smanjile primarne katastrofalne posljedice potresa, određene pripravnosti i hitni postupci moraju biti definirani u trenutku i poslije potresa.*
*Potresni rizik se odnosi na očekivane gubitke za dani element izloženosti riziku, tijekom određenog budućeg razdoblja. Rizik se može mjeriti očekivanim gospodarskim gubitkom ili brojem izgubljenih života ili veličinom fizičke štete na imovini.*
*Dječji vrtići u Osijeku predstavljaju bitnu ulogu u obrazovnom procesu. Za svaki od 24 zgrade dječjih vrtića, prikazane su značajke vezane uz godinu izgradnje, visinu, vrstu konstrukcije (konstrukcijkog sustava), ukupnu površinu itd. Budući da se uglavnom radi o zgradama samo s prizemljem, a koje su većinom izgrađene od armiranog betona, smatra se da bi mogle poslužiti kao prihvatilišta za unesrećene nakon dogođenog potresa. Zbog toga, mora se provesti potpuna strategija s ciljem evaluacije njihove sposobnosti da bez oštećenja pretrpe mogući potres. To će se učiniti određivanjem njihove oštetljivosti , što je i cilj ovoga rada - stupnja gubitka danoga elementa rizika koji je posljedica dane razine opasnosti - definirana kao omjer očekivanoga gubitka i najvećega mogućeg gubitka na ljestvici od 0 do 1, znači bez oštećenja, a 1 što znači slom konstrukcije.*

***Key words***: *Potresni rizik, potresna oštetljivost, zgrade dječjih vrtića*

## 1. Introduction

Amongst the strongest and most destructive forces in nature are earthquakes. The seismic phenomenon has existed since time immemorial but only in the last century have earthquakes been researched leading to knowledge of what earthquakes are and what causes them. There is no possibility to predict where and when the next destructive earthquake will happen, but awareness that the continuous growth of the population is related to a continuous growth of the size and number towns and cities in seismic areas can lead to a reduction of potential catastrophic consequences. For this reason, the effort in reducing losses due to possible earthquakes is one of the key points in terms of risk evaluation.

Seismic risk, determined by the combination of hazard, vulnerability and exposure, is the measurement of the damage expected in a given interval of time, based on the type of seismicity, the resistance of buildings and anthropization (nature, quality and quantity of assets exposed). Seismicity indicates the frequency and force of earthquakes and represents a physical characteristic of an area. If the frequency and the energy of the earthquakes that characterise a certain area are known with a value to the probability of a seismic event of a given magnitude occurring in a certain interval of time, seismic hazard can be calculated. The greater the seismic hazard is, the greater the probability there is of an earthquake occurring of great magnitude in the same interval of time (Protezione Civile Presidenza del Consiglio dei Ministri Dipartimento della Protezione Civile).

The consequences of an earthquake also depend on the resistance of buildings to the effects of a seismic tremor. A building's potential for damage is called vulnerability. The more vulnerable a building is (due to its type, inadequate design, poor quality materials and construction methods, lack of maintenance), the greater the consequences will be.

Seismic risk is the probability that humans will incur loss or damage to their built environment if they are exposed to a seismic hazard. In other words, seismic risk is an interaction between seismic hazard and vulnerability (humans or their built environment). In general, seismic risk can be expressed qualitatively as:

$$R = H \cdot V \tag{1}$$

As shown in Equation 1, a high seismic hazard (*H*) does not necessarily mean high seismic risk (*R*) and vice versa. There is no risk if there is no vulnerability (*V*), even though there is a high seismic hazard. Equation (1) also shows that engineering design or a policy for seismic hazard mitigation may differ from design and policy decisions related to seismic risk reduction.

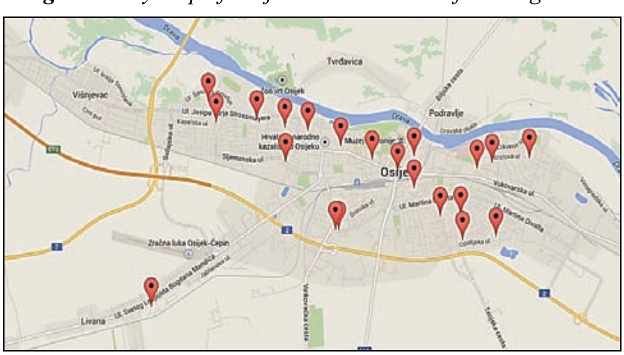
A fourth parameter may then be added through which the seismic risk can be related to a social or economic loss – for example, the damage of buildings may be related to the direct economic loss for their repair or replacement, or the collapse of the buildings may be related to the number of injured or dead.

In this paper, the assessment of seismic vulnerability of kindergarten buildings is presented. The paper is organized as follows: in Chapter 2, the study area with the arrangement of located kindergartens is presented; in Chapter 3 the main characteristics of the kindergarten buildings important for the seismic vulnerability estimation, such as construction type and materials, the number of storeys, the year of construction etc is presented. Then a concept for seismic vulnerability based on a calculation of Damage Ratio is presented in Chapter 4, while results of the seismic vulnerability are given in the Chapter 5.

## 2. Study area

Osijek is the fourth largest city in Croatia with a population of 107 784 in 2011. It is the largest city and the economic, cultural, governmental and industrial centre of the eastern Croatian region of Slavonia, as well as the administrative centre of Osijek-Baranja County. Osijek is located on the right bank of the river Drava, at an elevation of 94 metres comprising an area of 171 km$^2$ [1]. In the area of the city are located 24 kindergartens, of which 21 kindergartens are located in Osijek, one in Josipovac, one in Tenja and one kindergarten in the area of Čepin District (Figure 1).

***Figure 1*** *City map of Osijek with locations of kindergartens*




*Source: Google map edited by authors*

## 3. Data collection on kindergartens

The kindergarten buildings in Osijek were built between 1900 and 1980 with most of them, about 71%, built in the 70-s of the last century (Table 1). Almost all kindergarten buildings suffered war damage, and apart from necessary repairs after the war there were no serious construction interventions until 2005 when the reconstruction of most kindergartens began. Kindergarten buildings mostly have only a base floor appropriate to activities that are performed within them, only some of them have a second floor as well. Around 62% of the buildings have only a base floor, and the remaining 38% also have a second floor. The buildings are composed of living rooms for children, ancillary rooms (toilets, dressing rooms, storage, etc.), halls, hall for physical education and manifestations, dining room, kitchen and staff room.

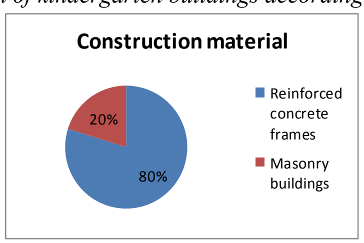
***Table 1*** *Distribution of construction year for the evaluated kindergarten buildings*

| Construction Year | Percentage of Buildings |
|---|---|
| before 1910. | 9% |
| od 1910. – 1950. | 5% |
| od 1950. – 1960. | 5% |
| od 1960. – 1970. | 5% |
| od 1970. – 1980. | 71% |
| after 1980. | 5% |

*Source: Authors´ analysis*

As shown in Figure 2, the majority of kindergarten buildings were built of reinforced concrete (RC) as an RC frame with unreinforced masonry infill walls, and a small number of them were built as an unreinforced masonry structure. The foundation is mainly done on the system of RC footings and foundation beams with reinforced concrete supporting slab, and the floor structures are performed as RC slabs or as clay blocks "FERT" system.

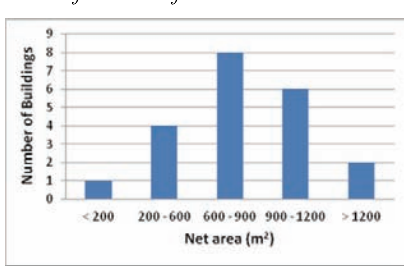
***Figure 2*** *Classification of kindergarten buildings according to type of construction*




*Source: Authors´ analysis*

Floor plans are generally regular, some are irregular, and the floor areas are between 200 $m^2$ and 1300 $m^2$. Majority of these buildings have a net area of 600 $m^2$ - 1200 $m^2$, as is shown in Figure 3. The heights of the buildings vary depending on the number of floors and ranges between 3 and 9 m.

***Figure 3*** *Distribution of net area for the evaluated kindergarten buildings*




*Source: Authors´ analysis*

## 4. Seismic vulnerability of kindergarten buildings

Each vulnerability assessment method models the damage on a discrete damage scale; a frequently used example is the EMS98 scale (Grünthal, 1998). The damage scale is used in reconnaissance efforts to produce post-earthquake damage statistics (in empirical vulnerability procedure) or is related to limit-state mechanical properties of the buildings, for example interstorey drift capacity (in analytical procedures). Simplified methodologies for seismic vulnerability assessment of building stocks are of fundamental importance for the development of earthquake loss models. These models are needed to support the decision process in disaster prevention and emergency management, as far as seismic risk is concerned (Ricci, 2010).
A relatively simple and fast analysis of potential seismic vulnerability was proposed by Morić et al. (2002). The research starts with a detailed analysis of the concept on which seismic vulnerability analysis of structures is based, especially the notion of damage ratio (DR) coefficient as a numerical value indicating the level of structural damage. Morić et al. (2002) proposed that the seismic response analysis of regular structures is acceptable if it is done as a simplified non-linear dynamic analysis with the time history function of ground motion as input load, and an SDOF model with known weight, elastic stiffness, damping, elastic base shear capacity and post-elastic stiffness representing the structure. A new deterministic formula of the DR coefficient is presented, where the DR coefficient is defined as a linear combination of plastic deformations, stiffness degradation and energy dissipation of a structure during an earthquake.

### 4.2 Damage Ratio (DR) Coefficient

Usually, in literature, the problem of structural damage is solved by calculating the DR coefficient. DR coefficients can generally be considered as either local (performed on the structural elements) or global coefficients (performed for the whole structure). Depending on their definition, they can be categorized as deterministic or probabilistic coefficients (Banon and Veneziano 1982, DiPasquale and Cakmak 1989), structural or economic coefficients (Gunturi and Shah 1992, Park and Ang 1985), structural or non-structural coefficients (e.g. Gunturi and Shah 1992). Other categorizations include coefficients based on deformation, stiffness, or energy, or even a combination of two or more of them, noncumulative (i.e. peak response values) or cumulative coefficients, low-cycle versus high-cycle fatigue coefficients, global coefficients as a weighted average of local indicators or modal coefficients, etc. (Comité Euro-International du Béton 1998).

In Morić et al. (2002), the seismic damage ratio model of regular structures is analysed and a valorised new original formula for DR is given. The seismic damage ratio model is based on following assumptions:

- Seismic response of regular structures (symmetric plans and constant vertical stiffness) can be interpreted by using an SDOF system as a mathematical model of the structures,
- The structure response parameters: ductility, stiffness change, energy balance and number of plastic excursions can describe the real level of structural damage.
- The level of structural damage (Damage Ratio (DR)) can be described as a function of the following calculated structure response parameters:
    - Displacement ductility (D) which defines the measure of post-elastic region in which a structure was during an earthquake;
    - Maximum base shear force, $BS_{max}$, and maximum top displacement ($u_{max}$) which define the residual stiffness (K') of the structure at the end of the earthquake;
    - Number of yield excursions ($N_Y$) and hysteresis energy ($E_H$) which define the post-elastic cyclic nature of DR developing.

The first two parameters define damage mechanism under monotonic load while the third parameter takes into account the cyclic failure. The DR coefficient is defined as the linear combination of plastic deformations, stiffness degradation and energy dissipation of a structure during an earthquake:

$$DR = \frac{1}{30}\left[D + \Delta K + \sqrt[3]{\left(N_Y E_H / W\right)}\right] \quad (1)$$

where:

| | | |
|---|---|---|
| $D = u_{max}/u_y$ | - | the displacement ductility demand; |
| $\Delta K = Ke/K'$ | - | the relative degradation of stiffness at the end of the earthquake; |
| $Ke = BS_y/u_y$ | - | the initial structure stiffness; |
| $K' = BS_{max}/u_{max}$ | - | the residual secant stiffness of a structure after an earthquake; |
| $N_y$ | - | the number of yield excursions reached during the earthquake; |
| $E_H/W$ | - | the hysteresis energy per unit of structure mass, dissipated during an earthquake. |

The simplest way of categorization of damage indices is to correlate them and observed damage. Park and Ang (1985) and Park et al. (1987) classified the structural damage as: None, Minor, Moderate, Severe and Collapse. Bracci et al. (1989) classified the structural damage as: Undamaged or minor damage, Repairable, Irreparable and Collapsed. Morić et al. (2003) implemented the DR values in pre and post-earthquake damage analysis by relating the DR values with the values of damage level identification (S), defined in the Croatian codes for post disasters damage assessment and with the values of damage level identification according to the European Macroseismic Scale (EMS 98) (Table 2).

***Table 2*** *Physical interpretation of damage ratio (DR)*

| Damage Ratio (DR) | Structural damage description | Possibilities of technical and economic reparation | Code damage level (S) ($1^O$ to $6^O$) | Code damage level (MSE 98) **($1^O$ to $5^O$)** |
|---|---|---|---|---|
| $0 \leq DR \leq 0.3$ | insignificant | repairable | $1^O$ - $2^O$ | $1^O$ |
| $0.3 < DR \leq 0.5$ | moderate | repairable | $3^O$ | $2^O$ |
| $0.5 < DR \leq 0.8$ | severe | repairable | $4^O$ | $3^O$ |
| $0.8 < DR \leq 1.0$ | heavy | repairable | $5^O$ | 4 |
| $1.0 < DR$ | extremely high level or collapse | non-repairable | $6^O$ | **$5^O$** |

*Source: Morić et al. (2003)*

Based upon this, Hadzima-Nyarko (2011a) performed a detailed analysis of the dynamic properties of RC frame structures and RC structures with walls, as well as post elastic parameters of vertical and horizontal structural elements using a large number of available databases of experiments carried out, thus relating the parameters of real buildings, seismic loads defined by peak ground acceleration and DR coefficients of structures. By applying neural networks, the impact of certain structural response parameters on the degree of damage depending on seismic load was determined, thereby obtaining information about the importance of the individual parameters as well as their values (Hadzima-Nyarko et al., 2011b). With this knowledge, a more precise estimate of the damage level was obtained (Hadzima-Nyarko, 2011). Finally, using the results and database obtained during the research, a program that relates structural dimensions with the dynamic properties of structures and global damage ratio coefficient of different seismic areas was created for RC frame and wall structures (Hadzima-Nyarko et al., 2012).

A computer program or application specifically designed for fast Earthquake Damage Analysis of Building Structures (EDABS) was developed. This application determines the DR coefficient using only the structural dimensions of buildings, structure type and the peak earthquake ground acceleration as input. The software EDABS is expanded with the research of Morić (1998) considering seismic vulnerability of masonry buildings (Hadzima-Nyarko et al., 2015). A graphical user interface (GUI) for the application is shown in Figure 4.

*Figure 4* *Graphical user interface of EDABS*

*Source: Hadzima-Nyarko et al. (2012)*

## 5. Results

For Croatia, the hazard, presented with two maps, is expressed in terms of the peak horizontal ground acceleration during an earthquake, which is exceeded on average once in 95 or 475 years. The maps are accepted as a part of the National Annex to EN 1998-1 (Herak, 2012). On the map, which is used in the design of earthquake resistance of buildings, the reference peak ground acceleration (PGA) on type A for the return period of 475 years with a probability of exceedance of 10% in 50 years is shown. According to that seismic hazard map for Croatia0, the peak horizontal ground acceleration for the city of Osijek is 0.11*g*. We decided to describe hazard in terms of PGA from 0.1g to 0.3g. Thus, with regard to the selection of reference earthquakes, three deterministic events have been considered, having intensity $I_{\mathrm{MSK}}$ equal to VI, VII and VIII.
A relatively fast seismic analysis of all kindergarten buildings in Osijek was performed using the Software for Earthquake Damage Analysis of Building Structures (EDABS). The software performs analysis and provides estimated DR values in the x- and y- directions i.e., in the longitudinal (length) and transversal (width) directions of the building. The results of the analysis of one RC frame building built in 1976 are presented in Table 3. According to the obtained results, one can expect negligible to slight damage when the peak ground accelerations are 0.1g and 0.15 g. For the peak ground acceleration of 0.2g, which corresponds to VIII intensity, moderate structural damage could be expected, and for the PGA of 0.3g, heavy structural damage and very heavy non-structural damage of the considered building could be expected.

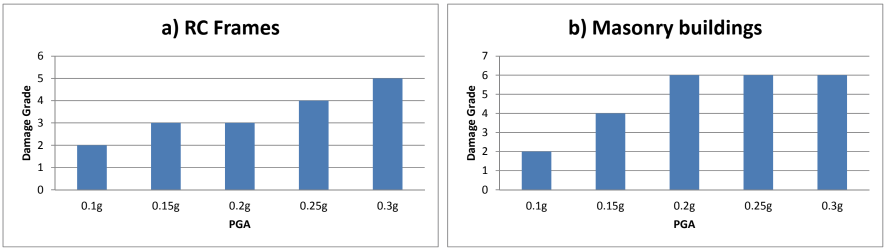
***Table 3*** *Damage analysis and assessment for the selected kindergarten RC frame building*

| | Dimensions [m] | Storey height [m] | No. of storeys | Building vulnerability | Peak earthquake ground acceleration 0.1$g$ | 0.15$g$ | 0.2$g$ | 0.25$g$ | 0.3$g$ |
|---|---|---|---|---|---|---|---|---|---|
| RC frame built 1976. | 29.80 x 8.00 | 2.90 | 1 | $DR_x$ | 0.128 | 0.268 | 0.400 | 0.583 | 0.814 |
| | | | | Damage Level Code | 1° - 2° | 1° - 2° | 3° | 4° | 5° |
| | | | | $DR_y$ | 0.086 | 0.286 | 0.351 | 0.594 | 0,830 |
| | | | | Damage Level Code | 1° - 2° | 1° - 2° | 3° | 4° | 5° |

*Source: Authors' results*

The overall results of all 20 kindergarten buildings are presented in the form of the graph considering the structural system of the buildings, as it is shown in Figure 5.

***Figure 5*** *Average values of damage levels for the: a) RC Frames, b) Masonry buildings*




*Source: Authors' results*

The RC frame buildings show lower average values of damage grades than masonry buildings, as it was expected. Thus, both structural types indicate that the level of structural damage for the earthquakes having PGA 0.1g is negligible to slight damage. This state of damage level implies fine cracks in plaster in walls at the base or fine cracks in partitions and infills. In the case of earthquakes having PGA 0.15g and 0.2g, substantial to heavy damage (moderate structural damage, heavy non-structural damage) for RC frames could be expected. For that damage state, cracks in columns and beams of frames and in structural walls could occur, cracks in partition and infill walls; fall of brittle cladding and plaster or falling mortar from the joints of wall panels. In the case of earthquakes having PGA 0.25g and 0.3g, RC frame structures will suffer heavy structural damage and very heavy structural damage. For these damage states, the following descriptions are given: cracks in columns and beam column joints of frames at the base and at joints of coupled walls; spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
Masonry buildings show much worse seismic performance, which can be seen from Figure 5. In the case of earthquakes having PGA 0.15g, very heavy damage (heavy structural damage, very heavy non-structural damage) could be expected. It means that large cracks in structural elements could appear with compression failure of concrete. In the case of earthquakes having PGA 0.25g or higher, destruction (very heavy structural damage) or collapse of ground floor or parts (e.g. wings) of buildings can be expected.

## 6. Conclusion

Seismic risk analyses of large urban regions should be fast and simple in order to gain insight into the level of physical deterioration (degradation) of structure and perform analyses of the damage level before and after an earthquake. Damage coefficient is usually normalized such that a value of 0 indicates an undamaged state while a value of 1 indicates complete failure. It interprets the level of structure damage by relating its values to the values of damage level identification, defined in the codes for post disasters damage assessment. Using kindergarten buildings as examples, the level of structural damage using DR coefficient for various earthquakes with different peak ground accelerations defined with time histories are predicted and DR values are related with the values of damage level identification.
According to the results of the analysis provided using the software EDABS, the buildings will suffer insignificant damage only in the case of the earthquake with a PGA of 0.1g for both RC frames and masonry buildings. RC frames show lower values of damage grades, indicating much better seismic performance. In the cases of earthquake having PGA 0.2g or higher, it is likely that the masonry buildings will collapse. The reason of such insufficient seismic resistance is due to year of construction, material properties and the absence of the rigid floors.

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