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COMPARISON OF SEISMIC IMPACTS THROUGH DIFFERENT REGULATIONS

Abstract:

This paper presents the basic principles of seismic analysis of structures according to the YU81 and European norm EN 1998-1: 2004. The aim of the paper is a critical review of comparative analysis of seismic impacts in the design of building structures according to these standards. EC8 involves several innovative approaches for the design and construction of structures, such as no structural failure, limiting the degree of structural damage, important public use facilities must remain usable. Purpose of this research is to compare the value of seismic force according to YU81 and EC8, for the same type of structure, depending on the parameters variation, such as different soil categories, different seismicity class, different building structural systems.

Keywords: seismic analysis, ductility, linear analysis, EC8, YU81

ПОРЕЂЕЊЕ СЕИЗМИЧКИХ УТИЦАЈА КРОЗ РАЗЛИЧИТЕ ПРОПИСЕ

Сажетак:

У овом раду представљени су основни принципи асеизмичког пројектовања према YU81 и Еврокоду EN 1998-1:2004. Циљ је критичко поређење анализа сеизмичких утицаја при пројектовању грађевинских конструкција. EC8 укључује неколико темељних приступа за пројектовање и изградњу објеката, од критеријума спрјечавања отказа конструкције, ограничавања степена оштећења конструкције, одржавања употребљивости важнијих јавних објеката. Сврха овог истраживања је упоређивање вриједности сеизмичке силе према YU81 и EC8, за исти тип конструкција, са варирањем одређених параметара, као што су различите категорије тла, различите класе сеизмичности, различити конструктивни системи.

Кључне ријечи: асеизмичко пројектовање, дуктилност, линеарна анализа, EC8, YU81

1. INTRODUCTION

The area of Bosnia and Herzegovina belongs to the seismically active regions, which means that in the process of designing and building the structure, special attention must be paid to the resistance of the structures to the effects of the earthquake. In the process of implementation of European codes, as has been done in other fields, it is necessary to consider and analyze in detail what are the novelties and differences in this field in relation to the currently valid regulations. The aim of this paper is to identify and compare the difference in design of seismically resistant structures between reinforced concrete structures designed under current regulations (YU81) and current European regulations (Eurocode) that are under implementation in BiH.

First of all, European codes provide a more detailed analysis of seismic effect and pay special attention to the design of structural details, introducing different values of the behavior factor (q) for different types of reinforced concrete structures. Unlike the YU81, different ductility classes are introduced: LD-low ductility, MD-medium ductility, and HD-high ductility, [1], [2]. Seismic load decreases with increasing of ductility, but the calculations are more complex in terms of shaping details, cross section reinforcement, minimum reinforcement coefficients, and length of anchoring and continuation of reinforcement.

The analysis covers different systems (wall systems and frame systems) in different ground types and with different degrees of seismic activity, in order to draw conclusions and a comprehensive comparison of structures depending on which of the mentioned regulations is used for calculation.

2. BRIEF REVIEW OF YU81 AND EC8 STANDARDS

This chapter gives a brief review of the basic principles of European standards and valid YU81 regulations. EC8, considering its detail, as the basic requirements defines the need for designing structures by engineers with extensive experience and knowledge, proper checking of project design documentation, building structures by the person with the necessary knowledge and licenses, using the materials with certificate that meet the requirements defined by European codes. In addition, special attention is paid to the durability and proper maintenance of the structures, and the user-defined construction to the intended purpose. Due to their comprehensiveness and breadth, the specific values given by European codes are given only as recommended, the closer ones will be defined by the national annexes that each country adopts, such as certain coefficients, intensity maps of certain parameters related to snow, wind, temperature and seismics, [3].

In the general provisions of YU81, aseismic design implies that high-rise structures are designed so that earthquakes of the highest intensity may cause damage to load-bearing structures, but no destruction of the structures shall occur. In contrast to the above, EC8 implies several approaches to the design and construction of structures, with the following conditions being met with certain statistical reliability: a) no structural failure; b) limiting the degree of structural damage; c) that important public use facilities remain usable.

In chapter IV YU81 classifies structures into five categories and defines the coefficient of the object category (K_o) as follows: non-category objects, category I (K_o=1.5), II. category (K_o=1.0), III. category (K_o=0.75), IV category. That chapter also describes what types of objects belong to which category, and category II was selected for the research in this paper. Which includes residential buildings, hotels, restaurants, public buildings not classified in the first category and industrial buildings not classified in the first category, [2]. EC8 gives the classes of significance of the object and the corresponding coefficients of significance depending on the consequences of the destruction on human lives, also their importance for public safety and the protection of people in the immediately after earthquake, and on the social and economic consequences of the destruction. The objects are classified into four categories (I, II, III and IV) With coefficients of significance γ_I that are 0.8, 1.0, 1.2, 1.4, respectively, and which correspond approximately to the classes of consequences CC1, CC2 and CC3 that are defined in EN 1990: 2004, Annex V, [1].

Seismic parameters are defined by the degree of seismicity of individual regions based on detailed seismic regionalization and seismic micro-regionalization. According to YU81, a design earthquake is the strongest expected earthquake that can hit an object during its service life, and represent an earthquake that occurs once every 500 years. The regions are represented with a certain coefficient of seismicity (K_s). According to earthquake intensity, the magnitude of the Mercalli-Cancani-Sieberg (MCS) scale, we have zones VII (K_s=0.025), VIII (K_s=0.050) and IX (K_s=0.100). The EC8 for load-bearing capacity states of the aforementioned category of objects also uses the probability of occurrence once every 500 years, and defines seismic parameters through the reference values of maximum ground acceleration (a_g) with values 0.1g to 0.4g.

According to the parameters of soil on which building is based, YU81 in chapter 9. divide three soil categories, depending on its characteristics, from rock-like formations, through compacted and dense or medium-dense soil, to the third category of loose to medium-cohesionless soil. Chapter 25. defines for each soil category formula for dynamic coefficient (K_d), and its limit values, as a function of the period of oscillation of structure. That coefficient is also included in the formula for seismic force calculation. EC8 standards, considering the impact of local soil conditions on seismic loading through five soil types: A, B, C, D, E and two types of liquefaction soils S1 and S2. EN 1998-1: 2004, in chapter 3.2.2.2 gives a horizontal elastic response spectrum that manifests movement due to an earthquake at a point on the ground surface. Horizontal movement due earthquake is described by two orthogonal, mutually independent components that are represented by the same response spectrum. According to [4], the relationship between acceleration and earthquake intensity can be represented as:

$$a_g = 10^{-2.4+0.34I}. \tag{1}$$

Here I is the intensity and according to [6], it can be given as:

$$I = 1.5M - 0.5, \tag{2}$$

where M is the magnitude of the earthquake.

A magnitude of 5.5 corresponds to an acceleration of 0.175g, so for accelerations greater than this, the region in which the object is located is classified as a high seismicity region, and the recommended Type 1 of the elastic response spectrum shown in Figure 1a is adopted, while for smaller ground accelerations it is used Type 2, shown in Figure 1b.

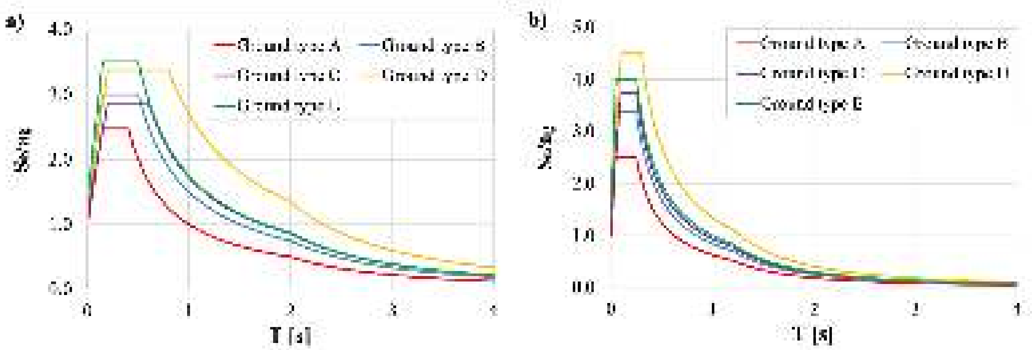

Figure 1 *Recommended types of elastic response spectra for ground types A to E (5% damping): a) Type 1 for magnitude greater than 5.5, b) Type 2 for magnitude not greater than 5.5*

By analyzing the velocity of seismic waves propagating through the soil and by descriptive comparison of different soil categories, it was concluded that the five basic types according to European standard can be identified with three categories according to YU81 so that the soil of category I corresponds to the soil of category A, while the soil of category II corresponds to classes B and C. Bad soil category III corresponds to D and E soil type according to EC8. Liquid soils S1 and S2 were not treated by the YU81 regulations and were therefore omitted from the analyzes in this paper.

When it comes to calculation methods, YU81 provides the equivalent static load method or dynamic analysis method. Structures are calculated as linear-elastic structures by ultimate limit state theory, with coefficients of safety 1.30 for reinforced concrete, 1.15 for steel and 1.50 masonry structures, or by elasticity theory (with 50% increase in permissible stresses). Maximum horizontal deflection of structure for prescribed seismic loads f_{dop}=H/600, where H is the height of the building.

According to EC8, structures are designed by one of four methods: linear analysis, equivalent lateral force method (subject to certain conditions of object regularity), multimodal spectral analysis (which can be applied to all types of buildings), as well as non-linear pushover analysis methods and nonlinear (dynamic) time response analysis. Due to complexity and detail calculation according to EC8, it is especially necessary to fulfill requirements that define the parameters of ductility, stability, serviceability limit states... All structural elements as well as entire structure must have sufficient ductility to ensure a capacity design method for stability loss. Then, the structure must have sufficient stability for all possible load combinations and the required load-bearing capacity of foundations. According to the serviceability limit states, there is a limited interfloors movement due the structural damage ($d_r/v \leq$ h/250 for structures with non-structural elements attached to structural, and $d_r/v \leq$ h/167 for structures with non-structural elements separated from structural ones). It is also important to mention the behavior factor (q), which is also a novelty of EC8, used in design to reduce the forces obtained by linear analysis, in order to take into account the nonlinear response of the structure, with regard to material, structural system and design procedures. This factor takes values up to 8, but not less than 1.5.

Structural design for seismic load according to YU81 is an analysis of the effect of horizontal seismic forces in two orthogonal directions, without their interaction. Design combination take into consideration dead load (g), 50% of liveload (p), snow load (s), horizontal seismic force defined by the standard as:

$$S = K \cdot G, \qquad K = K_0 \cdot K_s \cdot K_d \cdot K_p, \tag{3}$$

where K_o is object category coefficient, K_s is seismic intensity coefficient, K_d is dynamic coefficient and K_p is ductility and damping coefficient. Safety factor for the loads is γ=1.3.

According to EC8, regular structures are analyzed for the dominant seismic directions as two in plane models, but also with the coefficient of interaction, as well as the calculation of torsion (accidental torsion) effects. The load taken into calculations are dead load (g), a live load (p) with a combination coefficient (Ψ=0.3-1.0). The total horizontal seismic force for regular reinforced concrete structures is:

$$F_b = S_d(T_1) \cdot m \cdot \lambda. \tag{4}$$

In this paper, due to its purpose of research, it is not go into details of the distribution of seismic force to structural elements, as well as a design and detailing of individual elements of structure. The aim is to compare the value of seismic force according to YU81 and EC8, on the same type of structure, depending on the parameters variation, such as different soil categories, different degree of seismicity (acceleration), different structural systems (wall systems and frame systems).

3. COMPARATIVE ANALYSIS

The structures chosen for the analysis satisfy the requirements given by provisions of EC8 for lateral force method of analysis. Two types of constructions of importance class II by EC8 and II by YU81 were tested, for which the Base Shear coefficients (B.S.) were determined for the adopted acceleration value. Base Shear coefficient represents the ratio of the total horizontal seismic force and the weight of the structure, that is:

$$B.S. = \frac{F_b}{W} = \frac{S_d(T_1) \cdot \lambda}{g}. \tag{5}$$

According to Yugoslav regulations, the Base Shear coefficient corresponds to the coefficient K, the total seismic coefficient for the horizontal direction.

The following figures (Figure 2 - Figure 4) show the results of the analysis of frame structures and structures with concrete shear walls, with Base Shear coefficients calculated for different vibration periods of the structure for the acceleration of 0.17g. According to YU81, this acceleration corresponds to the VIII zone of seismic activity, so the coefficient of seismicity K_s=0.05 was used for the calculation. Analysis by the method of lateral forces was performed by following provisions of EC8, whereby the recommended elastic response spectra Type 2 for magnitudes less than 5.5 was adopted in the analysis.

The calculation also takes into account different ground types from A to E, which are compared with the corresponding soil categories I, II and III according to YU81. The values of the behavior factor, which is also a measure of the energy dissipation of the structure, have higher values for frame structures. In the case of lower vibration periods, the Base Shear coefficient obtained using the method of analysis given EC8 is higher than in the case of analysis by following the provisions of regulation YU81, which is particularly pronounced for soils with poorer quality. Also, the obtained function of the Base Shear coefficient for the middle class ductility (DCM) for ground type A, the area covered by ground types B and C, as well as the area covered by ground types D and E, gives lower values than the high ductility class and therefore seismic forces, which is expected since the difference in the values of the factors of behavior.

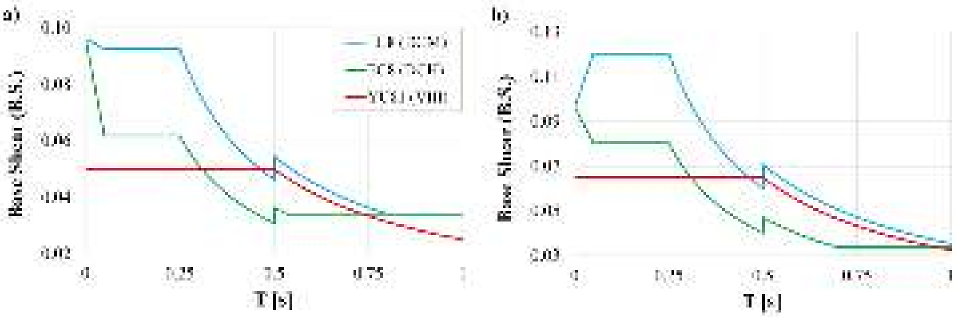

Figure 2 *Base Shear coefficient for ground type A (a_g=0.17g): a) frame systems b) wall systems*

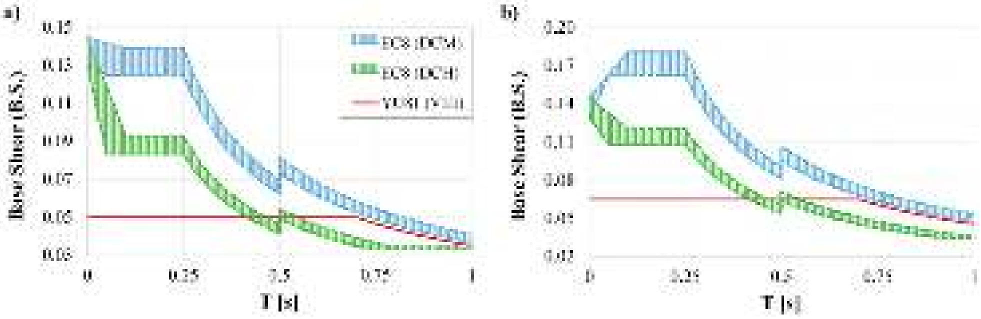

Figure 3 *Base Shear coefficient for ground types B and C (a_g=0.17g): a) frame systems b) wall systems*

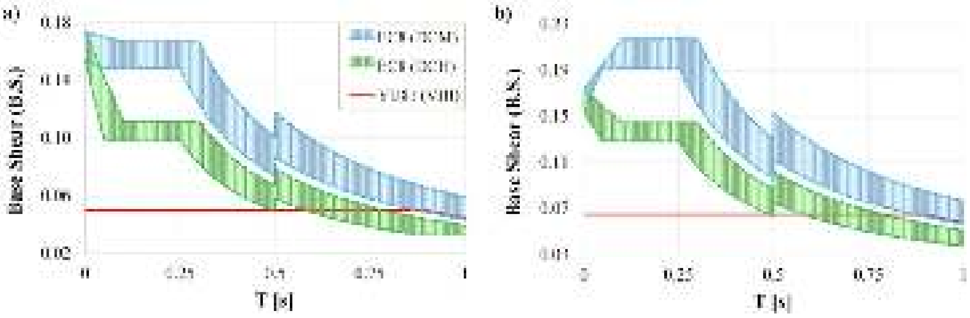

Figure 4 *Base Shear coefficient for ground types D and E (a_g=0.17g): a) frame systems b) wall systems*

The same analysis was performed for the acceleration value of 0.25g, with the adoption of the recommended elastic spectrum Type 1. The results were compared with those obtained for the IX zone according to YU81 and it can be observed that at higher vibration periods smaller differences in the Base Shear coefficient values were obtained for high class ductility (DCH), Figure 5 - Figure 7. Also, it can be observed that EC8 offers a wide range of coefficient values unlike the YU81 which offers only the total seismicity coefficient for different values of vibration periods.

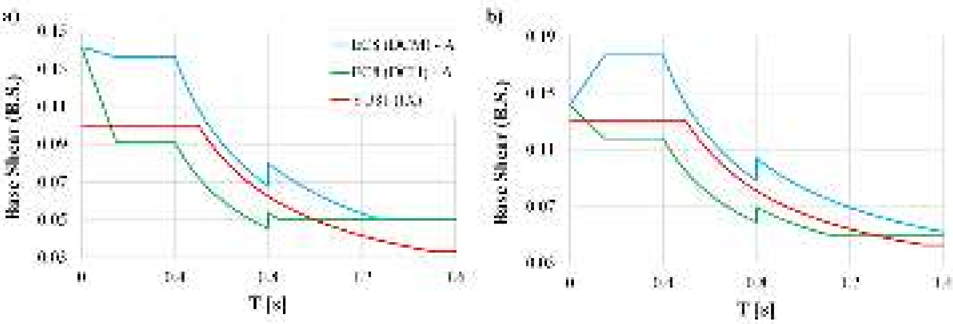

Figure 5 *Base Shear coefficient for ground type A (a_g=0.25g): a) frame systems b) wall systems*

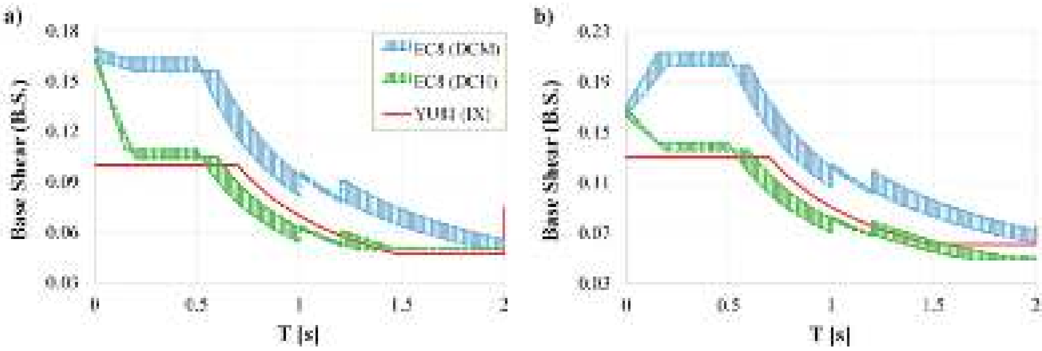

Figure 6 *Base Shear coefficient for ground types B and C (a_g=0.25g): a) frame systems b) wall systems*

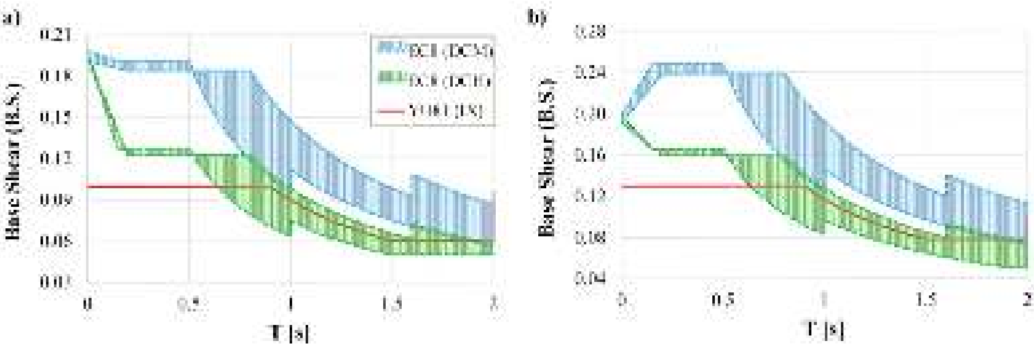

Figure 7 *Base Shear coefficient for ground types D and E (a_g=0.25g): a) frame systems b) wall systems*

In the further analysis, the Base Shear coefficient values were obtained for different values of acceleration and ground types A-E. The results were obtained by calculating the frame structure with the vibration period T=0.9 s and the structure with concrete shear walls with the vibration period T=0.6 s. The following figures show that the values of Base Shear coefficients obtained by applying EC8 greatly deviate from those obtained by applying the provisions of YU81 for accelerations corresponding to the IX zone of seismicity (0.2g-0.4g).

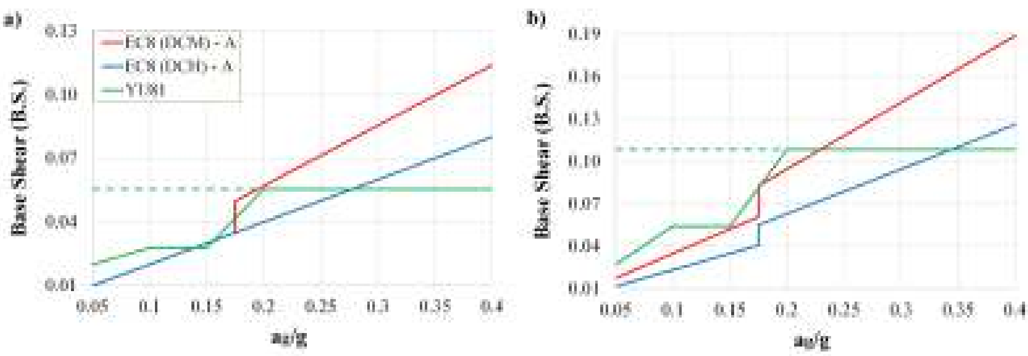

Figure 8 *Base Shear coefficient for ground type A : a) frame system (T=0.9 s) b) wall system (T=0.6 s)*

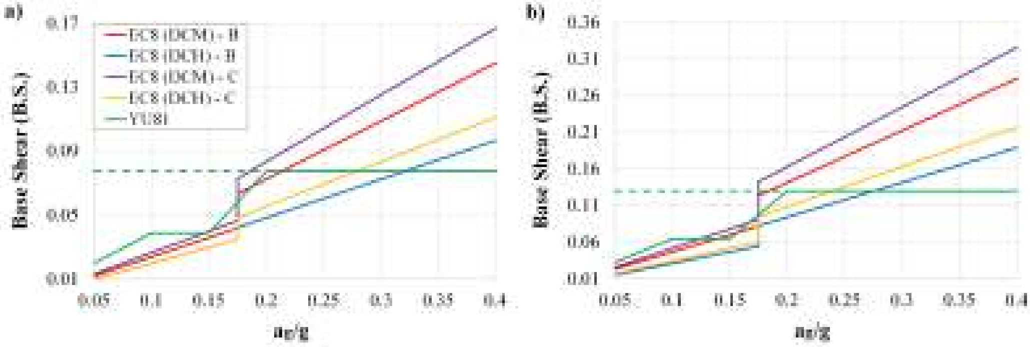

Figure 9 Base Shear coefficient for ground types B and C : a) frame system (T=0.9 s) b) wall system (T=0.6 s)

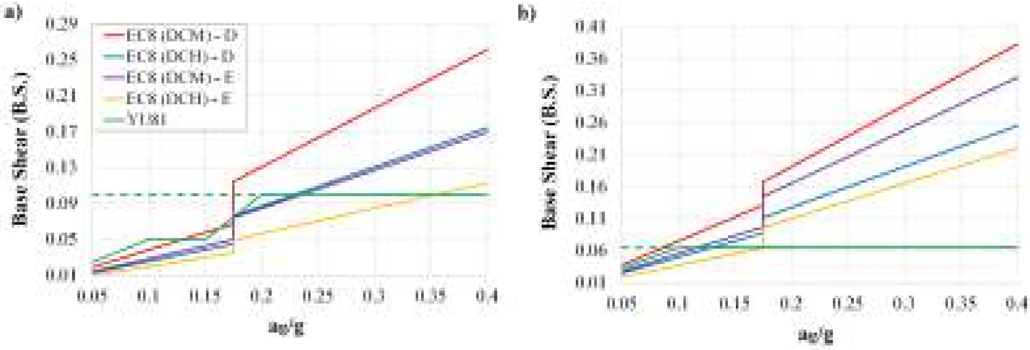

Figure 10. Base Shear coefficient for ground types D and E : a) frame system (T=0.9 s) b) wall system (T=0.6 s)

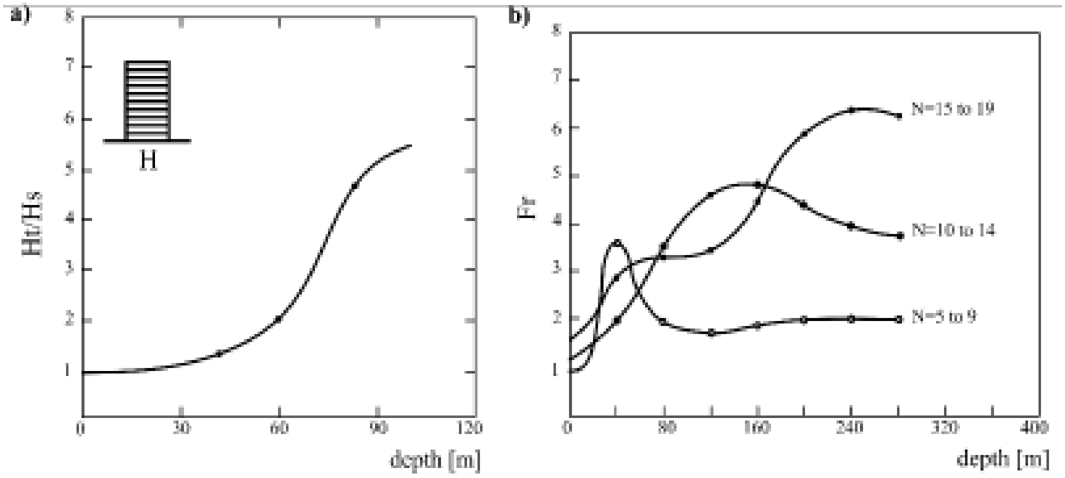

Figure 11. a) Influence of soil depth on the maximum value of the total shear force at the foundation level for a building, as shown in the earthquake in San Fernando, California b) Index of possible structural damage, [5]

Figure 11a shows the functional dependence of the increasing force at the base of a building constructed on soil of different thicknesses relative to the seismic force for a rock-based building. The results are for the building with 10 floors, with weight of 63 600 *kN* and vibration period T=1.2 *s*. The significance of the thickness of the soil above the base of the rock is also evident from Figure 11b, where the damage index function is given as:

$$F_r = \frac{(B.S.)_{\max} T}{W \cdot C}, \tag{6}$$

Here T is the vibration period, W is the weight of the building and C is the coefficient of design lateral load. The values are given as a function of the thickness of the soil above the base rock for different values of number of floors N.

In aseismic designing, the proper choice of the method by which the analysis will be performed is of great importance. In the selected example [6], an eight floor frame structure with vibration period T=0.93 s and importance of class II was tested for three acceleration values. The differences in seismic load level are given in Table 1. For structures where there is no significant contribution of higher oscillation modes to response, according to the provisions of EC8, two static analyzes were introduced: the method of equivalent lateral forces and the nonlinear static pushover method (N2 method). The nonlinear static method N2 gives a better insight into the resistance and ductility of the structure, monitoring of structural behavior and estimate of damage. It applies two mathematical models and combines the Pushover analysis of the multi-degree model with spectrum analysis of an equivalent system with one degree of freedom. According to YU81, the analysis is performed using an equivalent static load based on spectrum analysis.

Table 1 *Comparison of different methods of analysis*

a_g	Base Shear coefficient [%]						
	EN 1998-1:2004				YU81		
	Latheral force method of analysis		Modal response spectrum analysis	Non-linear static (pushower) analysis			
	DCM	DCH			VII	VIII	IX
0.3g	10.5	7.0	10.0	13.6			
0.2g	7	4.7	6.7	13.6	2	3.8	7.5
0.1g	2.3	2.0	3.3	7.7			

4. CONCLUSIONS

The aim of this paper is to critically review the application of individual regulations in analyzing seismic impacts in the design of building structures. From the results of comparative analyzes it can be concluded:

- Proper seismic design of objects requires the development of seismic micro-rayonization of the actual area on which the realization of the object is planned, made by probabilistic analysis of the causes of seismic activity in the analyzed area
- Very important approach in aseismic design is to define the seismic activity of the site as accurately as possible, as well as the geological composition of the soil profile planned for construction. Properly considering the composition and behavior of the soil in response to the seismic activity will direct the designer to the correct selection of the type of structure,
- Proper selection of the type of structure, in response to the seismic activities of the site, is more important than the mere calculation of seismic forces by (once) questionable methodologies.
- The paper clearly emphasizes, through diagrams and tables, the importance of determining the reliable composition (characteristics) of the ground in defining the seismic force, and thus the proper design of the structure,
- It is clearly shown that the defining the seismic force in the analysis of the structure depends on many factors, not just the degree of seismic activity in simplified analyzes.

The performed analyzes provide some of the reasons why to prioritize structural calculations for seismic activity according to EC8 over the procedures defined in YU81 regulations:

- More detailed analysis of the seismic effect where special attention is directed to the design of structural details,
- Different values of behavior factors (q) are introduced for different types of reinforced concrete structures, which more properly considers (describes) the response of the structure to seismic action. Different ductility classes are also introduced: LD-low ductility, MD-medium ductility and HD-high ductility. The seismic load decreases with increasing ductility, but the calculations are more complex in terms of shaping details, designing cross sections of the shear reinforcement (minimum reinforcement coefficients and length of anchoring and continuing the reinforcement),

- Seismic parameters are defined by the degree of seismic activity of individual regions, based on detailed seismic regionalization and seismic micro- regionalization,
- EC8 involves several approaches for the design and construction of structures, with the following conditions being met with certain statistical certainty: a) no structural failure; b) limiting the degree of structural damage; c) that important public use facilities remain usable,
- The effect of local soil conditions on seismic load is taken into account through five ground types; A, B, C, D, E and two categories of liquidation soil S1 and S2,
- According to EC8, the regular structures are analyzed as two plane models for the dominant seismic directions, but also with the correlation coefficient for different direction, as well as the calculation of torsion effects (accidental torsion effects),
- According to EC8, structures are calculated by one of four methods: linear analysis, lateral force method of analysis (subject to certain conditions of regularity of the object), modal response spectrum analysis (which can be applied to all types of buildings), as well as non-linear static (pushover) analysis and nonlinear time history (dynamic) analysis,
- And of course, statistically, the reliability of structures in terms of reducing the risk to human lives is certainly measured by the progress of technical regulations in this area. In this regard, EC8 is the norm on more than 600 edited pages provides more reliable analysis compared to YU81 regulations from about 30 pages.

LITERATURE

[1] EN 1998-1:2004: Proračun seizmički otpornih konstrukcija, Deo 1: Opšta pravila, seizmička dejstva i pravila za zgrade, Beograd, 2009.

[2] Pravilnik o tehničkim normativima za izgradnju objekata visokogradnje u seiymičkim područjima, Službeni list SFRJ, br.31/81 i dopune, Beograd, 1981.

[3] D. Aničić, P. Fajfar, B. Petrović, A. Szavits-Nossan, M. Tomažević, Zemljotresno inženjerstvo – visokogradnja, Građevinska knjiga, Beograd, 1990.

[4] V. Sigmund, M. Bošnjak-Klečina, I. Guljaš, A. Stanić, Usporedba primjene hrvatskih propisa i Eurokoda 8, Građevinar, Zagreb, 2000.

[5] Idriss, I. M. and Seed, H. Bolton (1968b), “An Analysis of Ground Motions During the 1957 San Francisco Earthquake,” Bulletin of the Seismological Society of America, Vol. 58, No. 6, pp. 2013-2032, 1968.

[6] Čaušević M., Dinamika konstrukcija, potresno inženjerstvo, aerodinamika, konstrukcijske euronorme, Tehnička knjiga, Zagreb, 2010.