X INTERNATIONAL CONFERENCE OF SOCIAL AND TECHNOLOGICAL DEVELOPMENT
X MEĐUNARODNA KONFERENCIJA O DRUŠTVENOM I TEHNOLOŠKOM RAZVOJU

ORIGINALAN NAUČNI RAD - ORIGINAL SCIENTIFIC PAPER 10.7251/ZRPIM2101002B

EARTHQUAKE AS A SOCIO-TECHNOLOGICAL CHALLENGE

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ABSTRACT

The earthquake is one of the most devastating natural disasters which human civilization encounters. Striking suddenly, they can cause huge material damage and casualty in a short time. It is not possible to predict them, but only expect them with some probability, in certain area and time. The consequences of the earthquake are multiple - collapse of buildings, power and water outage, telecommunications fall, fires, as primary causes, which yield secondary ones - lack of grocery, accommodation of home-lost people, overload on the health system, epidemic risk, security aspects, short and long term economic consequences, depending on the damage extent. The effect of earthquakes is most pronounced in urban areas – either direct or indirect (tsunamis, floods, landslides, liquefaction) - where there is a large concentration of buildings, so through their collapse earthquake impacts human society in various forms. Therefore, it is necessary to pay a special attention to the planning and implementation of seismic construction, and organization of public services and other systems in order to reduce the consequences to a socially acceptable measure. In this context, design and construction of such objects is a compromise between design requirements, a sublimation of social needs and adopted design and engineering solutions, while respecting technical standards. The paper presents the results of seismic analyses of infilled frame structures, as typical in the construction of residential and commercial buildings, with design recommendations.

Keywords: earthquake, seismic analysis, theory of structures, frame structures, crisis.

INTRODUCTION

Earthquake is a series of sudden movements in the Earth's crust or in the upper layers of the mantle. They happen without warning, and within a few tens of seconds can cause enormous material damage and casualties. It is not possible to predict an earthquake, but the analysis of all recorded earthquakes in certain region leads to an estimate of the maximum strength of the earthquake that can be expected. Although the seismography began only since the end of the 19th century, earlier earthquakes are included with a certain probability, relying on historical sources. The record of damages, albeit sometimes unreliable, can give an estimate of the earthquake intensity.

Earthquakes are result of tectonic displacements and dynamics, volcanoes, massive collapse of karst rocks in the depth, strong explosions. The most destructive earthquakes are of tectonic origin (including induced earthquakes due to the filling of artificial lakes) and, hence, they are the most important for study, planning and undertaking activities in order to prevent the consequences. The Earth's crust is composed of six main rigid tectonic plates connected by soft seams, and a number of smaller plates that are constantly moving. At the boundaries of large slabs strong shear forces arise. As the plates move, potential energy accumulates and when the critical value is reached, there is a sudden transformation into kinetic energy. The kinetic energy released by the fracture of the material in the focus propagates from the focus in the form of seismic waves that we at the surface experience as earthquake. The largest number of earthquakes occurs in the zone of boundaries between individual plates, but a significant number also occurs inside the plates. The devastating effects of earthquakes stem from vibrations in surface layers of the soil that occur due to seismic waves.

In addition to direct damage and demolition of buildings, there are also induced effects and heavy consequences with material and human losses involved. Some of these indirect effects are changes in soil properties, triggering of landslides, leakage of hazardous substances, tsunamis, fires and the like. Other consequences include outages of power, cut of water supply and telecommunications, as primary effects, which cause secondary ones - lack of food, accommodation of victims, stress on the health system, risk of epidemics, safety, economic consequences, short and long term, in depending on the extent of the damage. The consequences are most pronounced in urban areas - both direct and indirect (fires, tsunamis, floods, landslides, liquidation) - where there is a large concentration of buildings, through the demolition of which all forms of earthquake impact on human society are broken.

The international disaster database ″Emergency events database″ (EM-DAT) is a global database on natural and technological disasters, containing essential core data on the occurrence and effects of more than 22,000 disasters in the world, from 1900 to the present day. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université catholique de Louvain located in Brussels, Belgium. EM-DT provides both information on the human impact of disasters (the number of people killed, injured or affected) and disaster-related economic damage estimates and disaster-specific international aid contributions.

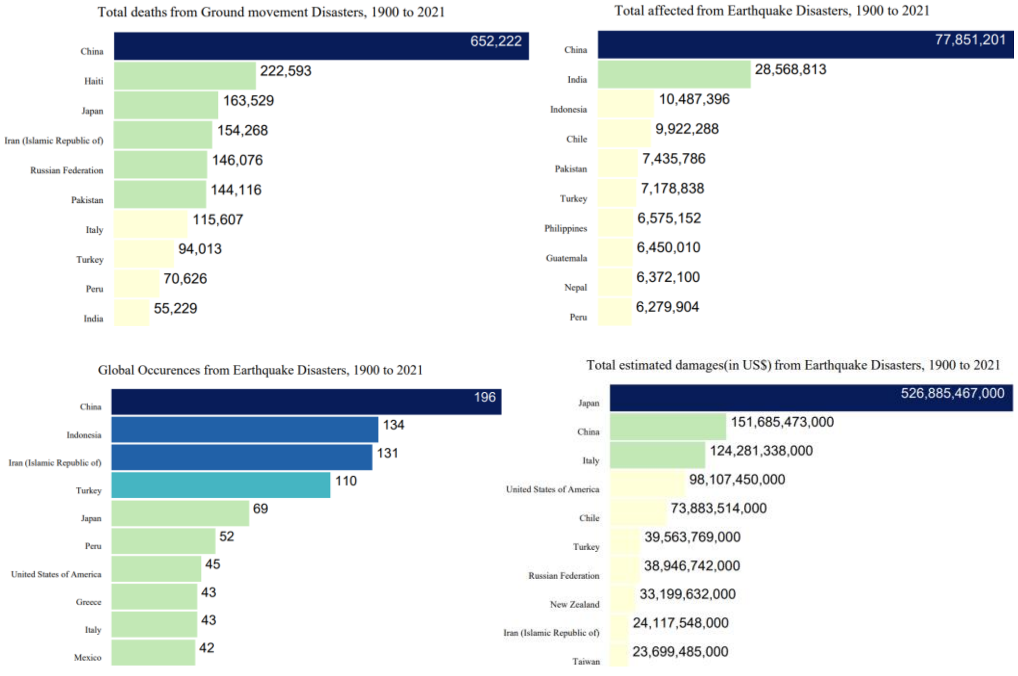


Figure 1. Earthhquake disaster mesure after EM-DAT database 1900-2021.

The criteria for recording data in the database are at least one of the following: 10 or more people dead, 100 or more people affected, the declaration of a state of emergency or a call for international assistance (EM-DAT, 2021). The main aim of EM-DAT is to assist humanitarian action at both national and international levels, to rationalize decision-making for disaster preparedness and to provide an objective basis for vulnerability assessment and priority setting. Systematic collection and analysis of these data helps to identify the disaster types that are most common in a given country and that have had significant historical impacts on human populations, and provides information to governments and agencies in charge of relief and recovery activities.

HISTORICAL REVIEW OF POST EARTHQUAKE CONSEQUENCES

Earthquake engineering has been developed through observation and analysis of failure of structures during earthquakes. The main goal is not to repeat the same mistakes in the event in the future earthquakes Summarizing the consequences of major world catastrophes caused by strong earthquakes shows that a large casualties happened after the earthquake. In modern urban construction, fires which occur during and after earthquakes appear as the greatest danger. Unfortunately, only a few world catastrophes have prompted seismologists, civil engineers and fire experts to develop a joint strategy for passive prevention of post-earthquake fires and their active suppression. In addition to a large number of local arsons that were successfully localized, in some of them the fire reached such proportions that the number of human victims was measured in tens of thousands, and entire cities were levelled to the ground (Folic, & Babic, 2008). In some earthquakes (San Francisco 1906, Kanto 1923, Kobe 1995) the consequences of fires were much more severe than the consequences of seismic actions. Although the fire as a scenario of post-seismic action does not always happen, the possible consequences are catastrophic and require a serious approach in analysing and solving the problem.

Lisbon was hit by a strong earthquake on November 1, 1755, after which a terrible fire spread. More than 100,000 people died in the entire area, 90,000 in Lisbon itself, which until the event had 275,000 inhabitants. In the very fire, which lasted for 5 days, about 60,000 people were killed, a large number were injured, and 85% of the buildings were destroyed. Valuable historical buildings were burned to the ground, including the Royal library building, with 70,000 books, and several hundred works of art, including paintings of Titian and Rubens. The magnitude of the earthquake was estimated at 9 on the Richter scale. After this earthquake, the builders of that time began to develop seismic constructions, and even made wooden test models of objects that were exposed to simulated seismic actions.

Kanto in Japan on September 1, 1923, an earthquake of magnitude 8.3 followed by a large fire that left catastrophic consequences (Bukowski, 1994). The spread of the fire was contributed by the mass use of gas in numerous households and restaurants for food preparation, as well as traditional materials for building and furnishing apartments, wood and paper. There was also an explosion in the ammunition factory, and the horrible scenario was helped by the interruption of the water supply. The death toll is estimated at 143,000. At the World Engineering Congress held in 1929, one of the main topics was the catastrophic earthquake in Japan and its consequences. Here, the first steps in the concept of seismically resistant structures were made, and even the first papers on seismic insulation were published (Scawthorn, & Chen, 2003).

The earthquake that struck San Francisco on April 18, 1906, was also followed by a large fire and disastrous consequences. The number of dead is estimated as 3,000, and the material damage at about 524 million dollars. The water supply was cut off, which made it even more difficult to put out the fire. The earthquake in Japan in 1923, caused the largest fire in the world in a populated area. It is characteristic that the most severe damages and demolitions were not caused by earthquakes but by fires, and that the buildings which had adequate fire protection suffered much less damage. After the earthquake, the damages were analysed and useful data on the behavior of various structures exposed to dynamic and extreme thermal effects were obtained. The earthquake was the immediate cause of only 20% of the losses, and the greatest damage was caused by the three-day fire. The fire destroyed about 500 blocks of the downtown.

The city Napier (Hawke's Bay) in New Zealand was hit by an earthquake of magnitude 7.8 on February 3, 1931, killing 256 people and causing huge material damage. Immediately after the quake, more than ten fires spread to various parts of the city. The biggest fire quickly spread from the business center. Local fires broke out in a couple of chemical stores, so the lack of water for extinguishing made it difficult to fight the fire.

On January 17, 1995, an earthquake measuring 7.2 on the Richter scale struck the city Hanshin (Kobe) in Japan, killing 6,434 people and leaving 316,000 homeless. Damaged gas pipelines, wooden buildings and interrupted water supply made it difficult to put out the fire. Traditional roof coverings weighing up to 2 tons (to resist the frequent typhoons that hit the area), were carried by a light wooden construction, which produced that the floors were literally stacked on top of each other. Experiences from this earthquake have contributed to completely changing the concept of construction, by easing the roof structure and strengthening the walls.

An earthquake measuring 7.8 on the Richter scale occurred on July 12, 1993, hit the small island of Okushiri (Aonae) near Hokkaido, when 240 people were killed. The quake itself did not cause much damage, but it caused liquefaction of the soil and triggered a landslide. Aonae is a fishing town with about 1500 inhabitants. The town is located along the coast, the streets are very narrow and the houses are a short distance from each other. The houses are mostly one-storey and two-storey, mostly wooden. Only a couple of houses were made of steel and concrete. The wooden buildings were covered with a non-flammable cement mixture. Almost every house had unburied warehouses of various fuels for heating, fishing boats or cooking. The fire crews were well organized, with two fire trucks, dimensions adapted to move through narrow streets. Very soon after the quake, local fires broke out on two fishing boats and one house. The fire spread slowly, but the tsunami made it difficult to put it out in time, and overturned the stored fuel. A couple of local fires broke out that merged, and the fire was contained only after 12 p.m. Almost the entire island was destroyed, and one of the causes is poorly stored fuel and the method of construction.

In Coalinga, California, on May 2, 1983, a fire broke out after an earthquake and destroyed quite a number of buildings in the business center, over 800. Poor construction was the cause of the great ruins. Loma Prieta, California was hit by a strong earthquake on October 17, 1989, which was also followed by a fire. The water supply was cut off and that stopped the fight to fire. The fire was extinguished with the help of a special fire boat that came to the rescue. The death toll is 67 dead and 3,757 wounded. The demolition of a two-kilometer-long Cypress Street viaduct killed 42 people. The upper floor of the highway collapsed on the lower part full of vehicles. North Carolina, Gape Mendosino, was hit by earthquakes on April 25 and 26, 1993, which caused fires in the town of Scotia in which the business part of the settlement was destroyed. The water supply was cut off. The earthquake blocked the door of the fire station in Petrolia, so that due to the impossibility of the fire brigade to react in time, the building next to it burned to the ground.

OVERVIEW OF PREVAILING APPROACHES IN THE AREA OF SEISMIC ANALYSIS

Methods for the analysis of structures for seismic effects have been developing rapidly in the last few decades, following the development of technology. A large number of methods open a new question, which method to apply in which situation for particular type of structure and load (Folic, & Cosic, 2016).

There are four types of the seismic analysis of structures: linear static, non-linear static, linear dynamic and non-linear dynamic analysis (Duggal, 2013)

Linear static analysis is highly applicable in conceptual design, and gives acceptable results for low and medium-tall structures in which the first vibration tone is dominant. The linear change of stiffness is adopted and coefficients of ductility and damping that depend on the structural system and applied materials are introduced. Inner forces are computed after the application of pseudo seismic load. In high structures, higher tones are dominant and the use of this method does not give reliable results.

Non-linear static analysis (NSA) is more convenient for models where the effects of higher tones are not significant. There are more variants of NSA in use. Good results are obtained with the pushover analysis. Through the application of this method, the structure is exposed to a gradual increase of horizontal seismic load, till the occurrence of a local or total failure of the structure (Fajfar, 2000). Deformations are also obtained by the analysis, which enables the determination of critical cross-sections of the structure. Linear dynamic analysis includes methods of spectral response (spectral modal analysis) and the method of time history analysis. It is usually used in systems with more degrees of freedom. Non-linear dynamic time history analysis gains greater application with the development of computer hardware capacities. It requires complex mathematical operations, and detailed information on the structure and the excitation. Therefore, it is rarely used in designing of new structures, though it is largely applied in scientific investigations. Introducing of the influence of the structure-soil interaction additionally complicates the analysis on the mathematical model (Sigmund, & Zlatović, 2000). The calculation obtained through the application of equivalent static load gives good results when the first tone dominantly affects the response of the structure, i.e. when the contribution of the higher forms is negligible.

The concept of designing of structures for common exploitation loads and the concept of designing seismically resistant structures are diametrically different. In the first case, protection against reaching the bearing capacity is provided by introducing safety coefficients when dimensioning the cross sections of the bearing elements, while in the second case the limit is exceeded in a targeted manner, striving to achieve sufficient deformation capacity. The classic design concept of seismically resistant structures is based on controlled load reduction. The required load capacity is determined for the design level of seismic influences, which is many times lower in relation to the value of the force in the elastic response. This allows a nonlinear response for the actual seismic action, whereby the structures will be exposed to seismic forces during the earthquake that are approximately equal to its nominal bearing capacity. In this way, the structure is protected from unnecessary overload, but a certain degree of damage will occur because the structure is forced to go into an inelastic phase of work (Ladjinovic, & Folic, 2004).

The design for seismic actions in technical regulations of different countries are presented in different forms, but they all have in common that the calculated seismic action is determined in the function of seismicity of the area, adopted seismic hazard, foundation soil category, dynamic structural characteristics, importance factors and available. Usual procedure of applying linear calculation models for static or dynamic analysis does not provide insight into the real behaviour of buildings exposed to earthquakes, because it does not take into account the occurrence and development of nonlinear deformations in the load-bearing structure. Modern methods for the analysis of structures in the conditions of earthquake action are based on the application of nonlinear behaviour, taking into account the development of both geometric and material nonlinearities.

In contemporary norms (e.g. Eurocode, EN 1998-1, FEMA 273) the reference method for determining seismic influence is the response spectrum method and modal analysis, using a linearly elastic model of construction and reduced spectra. Depending on the characteristics of the load-bearing system of building, a simplified method is applied, for buildings that meet certain conditions, and multi-modal response spectrum for all types of buildings. Nonlinear analyses in the time or frequency domains can be used as alternative. The amplitudes of the accelerogram, for the reference return period, should be multiplied by the building significance factor (Eurocode, EN, 1998; FEMA-273, 1997).

The objectives of seismic design in accordance with Eurocode, EN 1998-1 are explicitly stated. Its purpose is to ensure that in the event of earthquakes: human lives are protected, damage is limited, structures important for civil protection remain operational. In the seismic area, it is necessary to design and build a facility that meets the requirements, within the estimated price.

INFILLED RC FRAME STRUCTURES

Reinforced concrete (RC) frame structures are predominant method of construction in a large number of countries. It is estimated that in Turkey about 75% of the total constructed facilities are of this type, in Mexico 80%, over 30% i Greece etc. Infilled frame structures are typical structures in the construction of residential and commercial buildings (Murty, Brzev, Faison, Comartin, & Irfanoglu, 2006).

In modern construction, when it comes to architectural structures, mostly buildings, a compromise of architectural and functional requirements, on the one hand, and construction, on the other hand, is shaped as a demand for elimination of walls in the first floor of buildings, important for stabilization of the structure in the case of seismic actions. Functional requirements (e.g. planned premises and garage space) on the ground floor of the building are the reason that such constructions are seismically very unfavourable. Design and construction are the result of a compromise between design requirements, as a sublimation of social needs, and adopted design and engineering solutions, with the respect of technical norms.

Two approaches to structural modelling are micro approaches (detailed modelling) and macro modelling through application of simplified models (Tabeshpour, Azad, & Golafshani, 2012).

The micro approach involves the nonlinear behaviour of frames, infills, and their interrelations. It is based on finite element methods. The model takes into account the relationship between the frame and the infill. The infill can be modelled as a homogeneous material, which approximates the characteristics of all the elements of which it is composed. In masonry infill, which is often used in our region, the homogeneous material contains the characteristics of both brick and mortar. It is possible to model the connection between brick and mortar and include it in the analysis, which significantly complicates and slows it down. The micro model, which includes modelling of bricks and mortars, as well as their mutual connections, including sliding of bricks on joints, is very demanding for practical application. Macro modelling is applied to the global analysis of the structure and with acceptable simplification of the calculation gives the results with satisfying accuracy. The research is focused on the development of different models of interchangeable diagonals by which the filling is introduced into the calculation. The stiffness of the RC frame structure with masonry infill cannot be determined by simply summing the lateral stiffness of the frame and the infill (Kose, 2008).

Our national standards do not provide recommendations for the impact of masonry infill on the structure. The masonry infill walls are treated as nonstructural element in structural analysis and only the contribution of its mass is considered (Babic, & Folic, 2010). The structural parameters like strength and stiffness are ignored in practice. Such approach may lead to an unsafe design. As the construction of frame structures with masonry infill is widespread in our environment, short excerpts from some foreign codes have been given that can indicate to our designers the guidelines that regulate this area. Taking into account the interaction of the structure and the masonry infill contributes to making the design model of the structure to be closer to its actual behavior in the event of an earthquake.

Eurocode - EN 1998–1: 2004, strictly states that masonry infill must be taken into account, which significantly contributes to the lateral stiffness and resistance of the structure. The impact of the infill in the seismic analysis is taken into account by reducing fundamental period, and the project spectrum is calculated by giving its ordinates by applying the average values of the period T_1`.

$$T_1^{'} = \left(T_{1b} - T_{1l}\right), \tag{1}$$

where is:

T_{1b} … the period of the first vibration tone of the structure with neglected infill stiffness

T_{1l} … the period of the first tone of the vibrations in which the infill is treated as a structural element

When the stiffness of the infill is not taken into account, all impacts from seismic actions (except in the displacement calculation) are multiplied by the ratio $Sd\left(T_1\right) / Sd\left(T^{'}_{1b}\right)$

Approximate formulas that can give an estimate of the period of the first tone are:

$$T_{1l} = T_{1b} \Big/ \sqrt{1 + \left(T^2{}_{1b} A_w Gg / 16HW\right)}, \tag{2}$$

where is:

A_w … the average area of the horizontal cross-section of the infill walls per floor in the appropriate direction,

G … shear module for infill,

g … gravitational acceleration

H … building height

W … building weight,

$$T_{1l} = \min \begin{cases} 0.065n \\ 0.08\left(H/\sqrt{B}\right)\left(H/\left(H+B\right)\right) \\ 0.075H^{3/4} \end{cases} \tag{3}$$

where is:
n … number of floors,
H … building heigh [m],
B … width of the building in the observed direction [m]

With an evenly distributed infill, the additional effect of the filling is favorable and the infill can be neglected. It has a role in energy dissipation only. The only negative effect with such constructions is the displacement of the lower floor, but these deformations are below those that would lead to the soft floor mechanism (Fardis, 2006). If the ground floor is open, significant damage to the columns can occur (Bell et al., 2001). FEMA 273 prescribes that the masonry infill should be taken as equivalent diagonal strut. The bars can be placed concentrically over the diagonal, or eccentrically to directly calculate the impact of the filling on the columns.

In order to introduce a diagonal into the calculation, the filling must satisfy the condition that 0.50 < h / L < 2.0 (h- infill height, and L-infill span), (Folic, 2004).

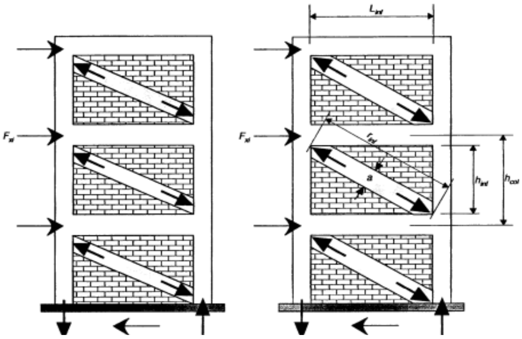


Figure 2. Compression strut analogy – eccentric and concentric struts after FEMA 273.

FEMA takes into account the permissible deformations. It allows the nonlinear behavior of the structure, the application of insulators and dampers to be taken into account.

FEMA 356 prescribes that the equivalent diagonal has the same thickness and modulus of elasticity as the wall infill, but does not recommend which direction the modulus of elasticity is calculated.

The length of the infill is calculated as:

$$\frac{w}{d} = 0.175\left(\lambda' h'\right)^{-0.4} \tag{4}$$

and

$$\lambda' = \sqrt[4]{\frac{E_d t \sin\left(2\theta\right)}{4E_f I_c h}} \tag{5}$$

where is:
t … thickness of infill, h … height of masonry infill,

l … length of the infill,

$\theta = a\tan\left(h/l\right)$,

I_c … moment of inertia of the column.

h' … frame height measured between the middle of the beam.

E_d, E_f … Young's moduli of infill and frame construction material

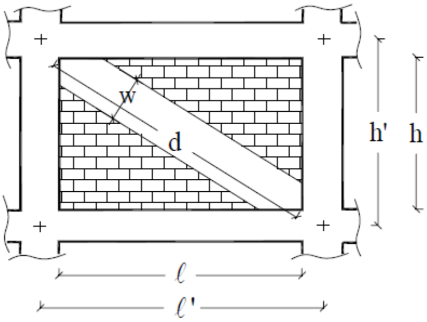


Figure 3. Compression diagonal model for estimation of the infill wall stiffness.

In SAP 2000 software package, a frame element is modelled as a line element with linearly elastic properties (SAP, 2000). Nonlinear force-displacement characteristic of frame elements is modelled as hinges with several straight segments. Inter-storey drifts represent structure behaviour. The expected behaviour of the walls is in the elastic domain up to the value of inter-storey drift of 0.2 ÷ 0.3%. According to the recommendations given by FEMA, cracking of the filling along the diagonal of the wall occurs when the drifts exceed the value of 0.25%. In the software package SAP 2000, by which numerical analyses were performed in this paper, it is possible to predict the places of formation of plastic hinges at the ends of linear elements where the occurrence of nonlinear deformations is expected. As shown in Figure 4, after the unloaded condition at point A, the increase of the deformation leads to the state B, which represents the yielding of the element. When the yield point is exceeded, there is an increase in plastic deformations to the limit capacity represented by point C. The drop from C to D represents the initial failure of the element. The residual resistance from D to E allows the structure elements to sustain gravity loads. Point E correspondents to the maximum deformation capacity, and beyond point E, gravity load can no longer be sustained.

The seismic capacity of the structure is represented by the levels between the initial state and the state of the limit capacity, and they are IO - immediate occupancy, LS - life safety and CP - collapse prevention. FEMA 356 prescribes that the slope of the part between parameters B and C to be less than 10% (FEMA-365, 2005).

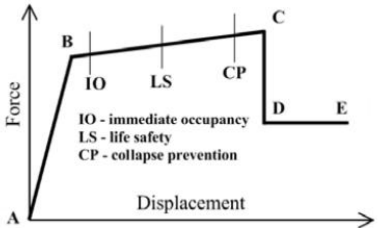


Figure 4. Basic plastic hinge properties.

FEMA 356 regulations define special conditions for beams and especially for columns. In the case of beams, nonlinear deformations are taken to depend on the moments in the plastic hinges, and in the case of columns, on the bending moments and the normal force.

NUMERICAL ANALYSIS OF INFILLED RC FRAMES AND DISCUSSION OF RESULTS

The results of seismic analysis of infilled RC frame structures as typical in the construction of residential and commercial buildings are presented. The 4-story RC frames with 3 bays are analyzed. The cases of bare frames, infilled frames and infilled frames without infill at the first floor are compared. Compared results are obtained from nonlinear static pushover analysis by SAP2000 for infill brick walls. Inter-storey drifts and displacement of the top of the structure were obtained by the nonlinear static analysis. The expected occurrence of significant nonlinear deformations and the formation of plastic hinges were obtained at critical places. The infill was selected according to the recommendations of Turnišek and Šepard (Salatić, Petrović, & Koković, 2009). Brick walls 12x25x6.5cm in flexible mortar of nominal strength M2.5 (1: 3: 10), G = 120000 kN/m^2 and G/E = 0.1 were applied. The thickness of infill walls is 25cm. Calculation was carried out according to EN 1992 and EN 1998-1. AB sections are made of concrete C25/35. The modulus of elasticity is E = 3.1 GPa. S500 armature was used. The dimensions of the beams are 30x40cm, and the dimensions of the columns are 50x50cm. Impacts from seismic action and gravitational load were taken into account.

As a result of nonlinear static analysis, the locations of critical sections were determined for bare frame, infilled frame and infilled frame with open first floor.

Table 1. Inter-storey drifts for 4-storey 3-bay RC frame h_1 = 3m, b = 4.8m (%).

Yield	Bare	Infilled	Empty first floor
19-20	0,27467	0,1303	0,104
18-19	0,39867	0,35	0,29067
17-18	0,4267	0,51467	0,512
16-17	0,233	0,33467	0,424

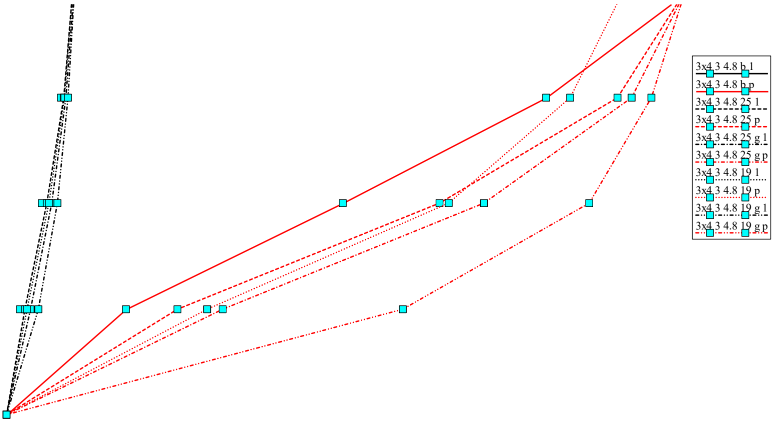
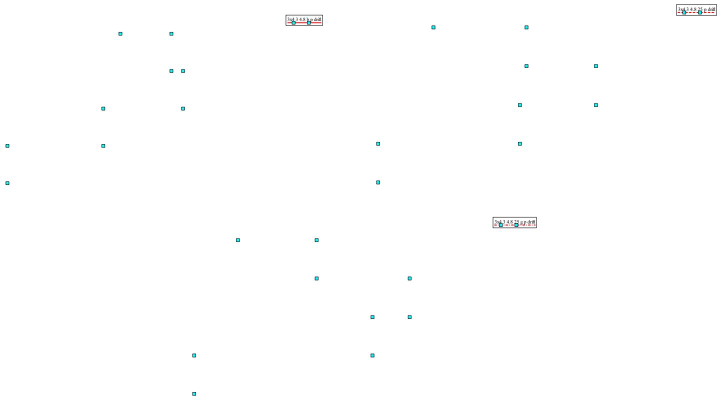


Figure 5. Comparative diagram of displacement.



(a) (a) (c)

Figure 6. Inter-storey drifts for 4-storey 3-bay RC frame $h = 3$m, $b = 4.8$m (a) bare frame, (b) infilled frame, (c) infilled frame with empty 1st floor.

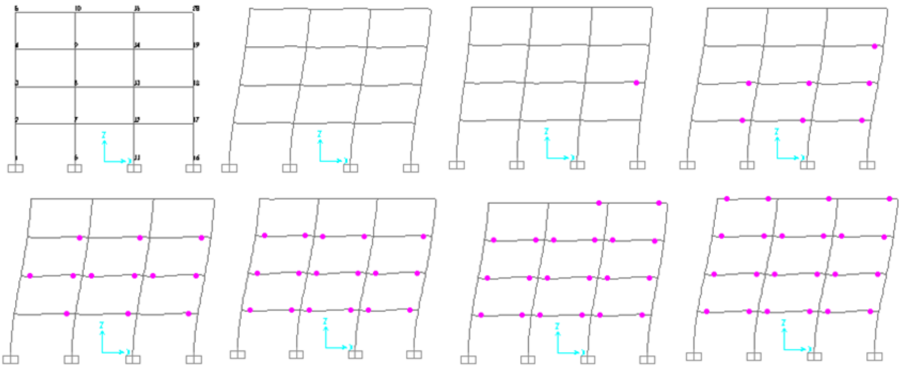


Figure 7. Hierarchy of forming plastic hinges for a 4-storey 3-bay bare frame, $h = 3$m, $b = 4.8$m.

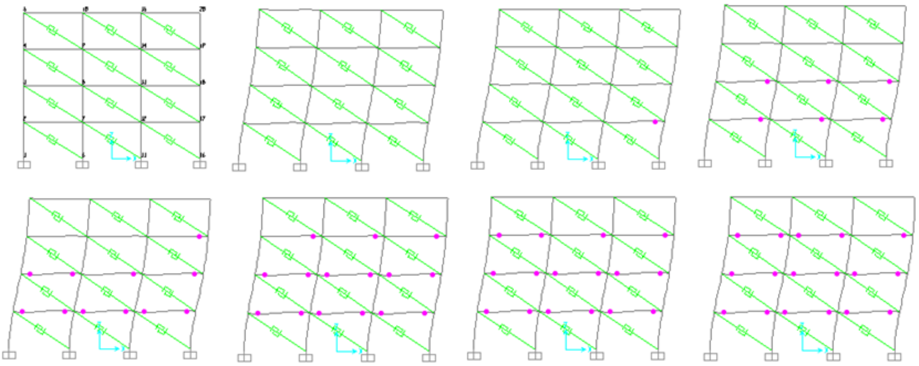


Figure 8. Hierarchy of forming plastic hinges for a 4-storey 3-bay infilled frame, $h = 3$m, $b = 4.8$m.

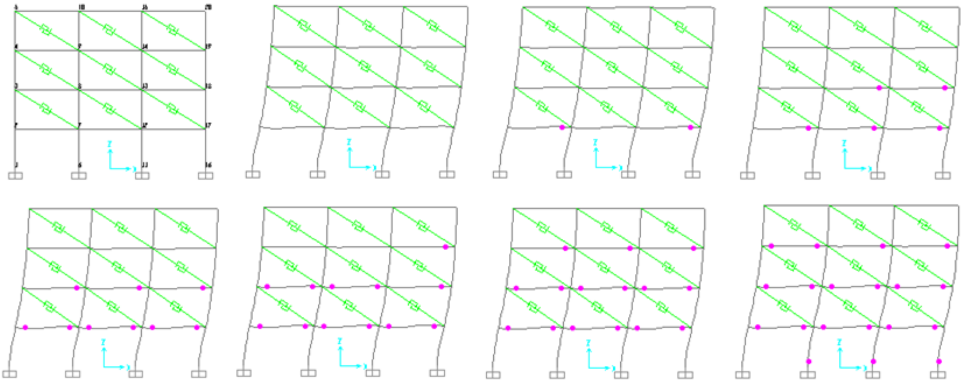


Figure 9. Hierarchy of forming plastic hinges for a 4-storey 3-bay infilled frame with empty first floor h_1 = 3m, *b*=4.8m.

Table 2. Comparison between analysis results of period T and banding moment M for bare and infilled RC frames).

Model	**T_1**	**[%]**	**max My [kNm]**	**[%]**
Bare frames	0,26231		346,29	
Infilled frames	0,19063	□27,33	519,31	+49,96
Empty first floor	0,21604	-17,64	655,00	+89,15

Figures 7, 8 and 9 show the hierarchy of formation of plastic hinges, which indicates a large loss of load-bearing capacity of the structure, which is performed without infill in the ground floor, due to design requirements. The inter-storey drift for the performance levels of reinforced concrete structures indicates the degree of possible damage to the infill, which is caused by damage to the beams, in the case of frames without infill, and in the case of frames with infill that is omitted on the ground floor. The resulting damage to the columns threatens the stability of the entire structure. With the frame without filling, the higher value of drifts is in the upper floors, and the formation of the first plastic hinges took place on higher floors.

The formation of the first plastic joint occurred in the beam on the second floor, then the simultaneous formation of one plastic joint in the beams on the first and second floors, and one joint in the beam on the third floor.

The result is not complete plasticization of the beams, but the two beams on the last floor have a plastic hinge only at one end. In the case of an infilled frame, the values of drifts are the highest on the second and third floors, respectively, and have the lowest value on the last floor. The formation of the first hinge occurs in the beam of the first floor, and further formation of the hinges takes place correctly and proportionally from the lower floors to the top of the structure.

All plastic hinges are in a state below the immediate occupancy. In frames where the infill is omitted on the ground floor, plastic hinges are also formed in the columns. Drift on the first floor is significantly higher than with frames with and without infill. The possible effect of a soft storey and a short column poses a great danger to the stability of the structure during earthquakes.

In the initial phase of seismic action, infill has a positive effect, increasing the global stiffness of the structure. However, as the load increases, plastic hinges are formed in the construction elements, energy is dissipated and the structure is deformed in a controlled manner. The Table 2 shows a comparative analysis of modal period *T* and bending moment for bare and infilled frames. Construction is especially risky in urban areas, where multi-storey buildings are being built that are almost leaning on each other. In the absence of appropriate regulations defining the infill as a structural element that has a significant effect on the seismic response of the structure, results can be obtained which, despite strict compliance with applicable technical regulations, give a wrong insight into the behavior of the structure during earthquakes. By studying earthquakes and analyzing damage to buildings where the infill is designed as a gravitational load and a non-constructive element, recorded collapses, material damage and loss of human lives indicate the need to improve and modernize national norms.

CONCLUDING REMARKS

The first and the basic line of defense against the consequences of earthquakes is seismic construction, but it is necessary to pay special attention to organization of public services and other systems in order to reduce the consequences to a socially acceptable measure. In this context, design and construction are the result of a compromise between design requirements, as a sublimation of social needs, and adopted design and engineering solutions, while respecting technical standards. AB frames with infill are an example of the required compromise that is widely present in modern construction in urban areas.

A particular problem is the existence of a large number of facilities all across the world that had been built before the adoption of advanced technical standards. In the event of strong earthquakes, major consequences can be expected in these areas, both during and after the earthquake.

It is technically feasible to design and build a structure that will withstand earthquake without significant damage and remain in full function after it. However, applying this approach to all facilities under construction is not economically viable option. Even the richest societies cannot afford it. Analyzing catastrophic earthquakes in the past, it is evident that even in the case of destructive earthquakes, representative buildings of historical significance have been preserved to this day in a large number of cases. This indicates the fact that from ancient times, when choosing the method of construction, a selection was made according to the importance of the buildings.

An economically viable approach to modern seismic design is a list of determinants which regard how human lives should be protected, damage should be limited and the usability of structures important for human life should be maintained. The main goal is to prevent buildings from collapsing and endangering people. This is a minimum condition and as such is implied, but the next level is to agree in advance with the user what will happen to his property in the event of an earthquake, whether he will be able to continue using it after event, how much and what kind of repairable damage will be, or will it be unusable after an earthquake. This approach is called Performance based design, where seismic performances are clearly defined and expressed. On the other hand, the structure can pass without significant damage, but the post-earthquake consequences are great, e.g. that expensive equipment in the building is destroyed or unusable, that gas installations are destroyed and the fire devastates the building, that valuable exhibits are damaged or destroyed in museums, etc. All this requires that designers and investors to agree prior the event, harmonize design requirements and their technical feasibility and economic justification, with prior risk assessment. Engineers are able to meet all the requirements of investors, and the result of their mutual agreement is inextricably linked with the economic parameters of the company. As the field of earthquake engineering is in many respects subject to the laws of probability, it poses a constant challenge both technologically and sociologically.

ACKNOWLEDGEMENT

The remarks and suggestions given by professor Ranko Babić were quite helpful, particularly in the preliminary phase of this work.

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