DIREKTNA DINAMIČKA ANALIZA ČELIČNIH RAMOVSKIH KONSTRUKCIJA UKRUĆENIH SPREGOVIMA

DIRECT DYNAMIC ANALYSIS OF STEEL BRACED FRAME CONSTRUCTIONS

Mirsad TARIĆ
Enis SADOVIĆ
Emir MASLAK

PRETHODNO SAOPŠTENJE
UDK: 006.77:624.04.001.23:699.841(497.11+1) = 861

1 UVOD

Poslednjih desetak godina aseizmičko projektovanje napredovalo zahvaljujući permanentnom razvoju nauke. Međutim, potrebe za praktičnim i relativno grubim konceptima projektovanja rezultirale su različitim simplifikacijama i idealizacijama. Ovakve pretpostavke mogu imati u nekim slučajevima suprotne implikacije kod očekivanog seizmičkog ponašanja i racionalnosti i pouzdanosti principa projektovanja [5]. Zbog toga je neophodno principe i primenjena pravila konstantno usavršavati i ispitivati kako bi se unapredilo shvatanje seizmičkog ponašanja.

Metode predviđanja predstavljaju uvek kompromis između tačnosti i složenosti metode, prema [8]. Najpoželjniji je onaj metod koji je ujedno i najprostiji i koji omogućava dobijanje informacija dovoljne tačnosti (obično je to i najbolji metod). Ovakav pristup najviše odgovara inženjerima u praktične svrhe čija se metoda zasniva na korišćenju numeričkih aparata tj. programa u kojima je moguće modelirati konstrukciju, seizmičke uticaje i dobiti na kraju realan rezultat primenjiv u projektovanju. Pretpostavka je da objektivnu analizu odgovora čini proces modeliranja svih parametara za određivanje performansi ramovskih sistema sa posebnim naglaskom na silama i neelastičnim deformacijama u okolini veza greda-stub i na sprečavanju prekoračenja dozvoljenog opterećenja stubova [8]. Postoji takođe još potencijalnih zahteva za posebnim naglašavanjem kao što je formiranje plastičnih mesta u gredama.

Doc. dr Mirsad Tarić, dipl.inž.građ., Univerzitet u Prištini, Fakultet tehničkih nauka, Kneza Miloša 7, Kosovska Mitrovica, mirsadtaric@hotmail.com
Enis Sadović, dipl.inž.građ., Ambijent doo, 37 Sandžačke divizije 18, 36300 Novi Pazar
Ass. Emir Maslak, dipl.inž.građ., Univerzitet u Novom Pazaru, Departman za građevinarstvo, Vuka Karadžića bb, 36300 Novi Pazar

1 INTRODUCTION

Even though the aseismic design progressed thanks to the continuous development of science in recent years, the need for practical and relatively rough design concepts have resulted in a variety of simplifications and idealizations. In some cases these assumptions may have opposite implications at the expected seismic behavior and the rationality and reliability of design principles [5]. It is therefore essential to constantly improve and test the principles and applied rules in order to improve understanding of seismic behavior.

Prediction methods are always a compromise between accuracy and complexity of the method according to [8]. The preferred method is the one which is also the simplest and which allows obtaining information of sufficient accuracy (usually the best method). This approach best suits to engineers for practical purpose, whose method is based on the use of numerical devices i.e. programs where it is possible to model the structure, seismic effects and get a realistic result in the end, that is applicable in the design. Therefore, the assumption is that an objective analysis of response is made of the modeling of all the parameters for determining the performance of frame system, with special emphasis on the forces and inelastic deformations in the vicinity of beam-column connection and to prevent exceeding the allowable load pillars [8]. There is also another potential application for special emphasis such as the formation of plastic seats in the rafters.

Doc. dr Mirsad Tarić, dipl.inž.građ., Univerzitet u Prištini, Fakultet tehničkih nauka, Kneza Miloša 7, Kosovska Mitrovica, mirsadtaric@hotmail.com
Enis Sadović, dipl.inž.građ., Ambijent doo, 37 Sandžačke divizije 18, 36300 Novi Pazar
Ass. Emir Maslak, dipl.inž.građ., Univerzitet u Novom Pazaru, Departman za građevinarstvo, Vuka Karadžića bb, 36300 Novi Pazar

Raniji standardi, koji su zastupali stav o elastičnom odgovoru konstrukcije, bili su ograničeni u smislu primene u područjima sa niskom seizmičnošću ili sa primenom na specijalnim objektima posebne važnosti. Zato se konstrukcije ne mogu projektovati prema svom disipacijskom ponašanju prema [2]. Cilj standarda je da omogući ekonomičan dizajn upošljavajući disipativno ponašanje u kojem značajne neelastične deformacije mogu biti smeštene u toku velikih seizmičkih aktivnosti [5]. U ovom slučaju neregularne ili kompleksne konstrukcije je neophodno tretirati detaljnim nelinearnim dinamičkim analizama.

Uticaj zemljotresa na konstrukciju u praksi se simulira horizontalnim seizmičkim silama čiji intenzitet zavisi od ukupne spratne mase, koeficijenta seizmičnosti, vrste tla i kategorije objekta. Ovaj pristup se naziva metoda ekvivalentnog statičkog opterećenja koja je još uvek u upotrebi i prisutna je u standardima [16], [2], a u praksi se koristi kao preliminarna metoda proračuna. Ona predstavlja linearno statičku metodu koja zbog osnovnih postulata mora davati jedan grublji prikaz seizmičkog dejstva u odnosu na stvarni. Samim tim su i sile veće i posledično veći uticaji u konstrukciji, a korišćenje takve proizvoljne raspodele sila po visini konstrukcije ne može voditi ka optimalnom iskorišćenju materijala [10]. Razlog ovome jeste i nepoznavanje stvarnih podrhtavanja tla koja se prenose na konstrukciju. Da bi se otklonili nedostaci ove metode razvijene su dinamičke linearne i nelinearne metode na osnovu kojih se konstrukcija projektuje kao seizmički otporna, ali sa kontrolisanim smanjenjem nosivosti [12] čime se dozvoljavaju konstrolisana oštećenja konstrukcije bezopasna po stabilnost sistema. U tom slučaju je konstrukciji omogućeno nelinarno ponašanje u toku dejstva zemljotresa u kojem se seizmičke sile približavaju nosivosti elemenata konstrukcije. Bitnu ulogu u analizi odgovora konstrukcije ima i njen kapacitet deformabilnosti izražen duktilnošću.

Veliki broj ekspirimenata i analitičkih istraživanja sprovedeno je u cilju ispitivanja validnosti pristupa distribucije horizontalnih sila prema standardima, ali je i nelinearnoj analizi posvećen veliki broj radova [15].

Oštećenja izazvana zemljotresima Northridge u Kaliforniji (1994) i Kobe u Japanu (1995) pokazala su nedostatke trenutnih ograničenja dizajna zasnovanog na silama (force-based seismic design). Tokom ovih zemljotresa više od 150 čeličnih ramovskih konstrukcija je oštećeno iako su ispunjavali zahteve tadašnjih standarda. Posle ovakvih dešavanja postaje imperativ određivanje performansi konstrukcija pri seizmičkoj analizi [19].

Ovaj rad predstavlja uvod u dinamičku analizu ramovskih čeličnih konstrukcija sa elementima za ukrućenje, čiji je osnovna uloga u konstrukciji navlačenje seizmičke energije. Predstavljeni su rezultati direktne dinamičke analize, uz pretpostavku nelinearog ponašanja ramova, za različite vrste spregova postavljenih centrično i ekscentrično. Aktuelnim problemom uticaja ovih delova na odgovor konstrukcije su se bavili različiti autori. Postoje rezultati evropskih projekata autora Elghazouli, Broderick, Goggins i ostalih prema [6] koji su prodrli u osnovu ponašanja kako glavnih tako i sekundarnih elemenata konstrukcije pri cikličnom opterećenju.

The older standards, which were argued on the elastic response of the structure, were limited in terms of application in areas with low seismic activity or the implementation on the special objects of great importance. Therefore, the structures can be designed according to their dissipation behavior toward [2]. The objective standard is to provide cost-effective design employing dissipative behavior in which significant inelastic deformation can be stored during high seismic activity [5]. In the case the irregular or complex structures have to be treated with the detailed nonlinear dynamic analysis.

Impact of earthquakes on the form is simulated, in practice, with horizontal seismic forces, whose intensity depends on the total storey mass, coefficient of seismicity, soil type and category of object. This approach is called the method of the equivalent static load that is still in use and is present in the standards [16], [2], and it is used as a preliminary method of analysis in practice. It is a linear static method which on account of the basic postulates must provide a coarse view of the seismic action in relation to the actual. Thus the forces are stronger and consequently there is bigger influence in the construction and use of such arbitrary power distribution by the amount of construction cannot lead to optimal utilization of the material [10]. The reason for this is the ignorance of the actual tremors, which are transmitted to the structure. In order to eliminate the disadvantages of these methods dynamic linear and nonlinear methods have been developed. On the basis of these models the construction is projected as the seismic-resistant, but with controlled reducing capacity [12] which allow controlled structural damage, harmless to the stability of the system. In that case, the design is enabled with nonlinear behavior during the earthquake in which the seismic forces approach the carrying capacity of structural components. Important role in the analysis of the structure responses has the capacity of deformability expressed by ductility.

Many experimental and analytical researches were conducted to examine the validity of the approach to the distribution of horizontal forces to the standards, and likewise, a great number of analysis are devoted to the nonlinear analysis [15].

The damage caused by earthquakes in Northridge California (1994) and Kobe in Japan (1995) have shown the shortcomings of current limitations of force-based seismic design. During these earthquakes, more than 150 steel frame structures were damaged, although they fulfilled the requirements of that time actual standards. After these events it becomes imperative to assess the performance of structures during seismic analysis [19].

This paper presents an introduction to dynamic analysis of frame steel construction with stiffening elements, whose primary role in construction is to contract the seismic energy. The results of direct dynamic analysis, assuming nonlinear behavior of frames, for various types of centric and eccentric bracings are presented. Current problem of the impact of these parts on the response of the structure are dealt with by different authors. There are results of European projects by Elghazouli, Broderick, Goggins and and others, according to [6] that have penetrated into the behavior of both the main and secondary structural elements of a structure under cyclic loading.

2 DUKTILNOST ČELIČNIH RAMOVSKIH KONSTRUKCIJA

Odgovor i ponašanje čelične konstrukcije usled seizmičkog opterećenja zavisi od mehaničkih karakteristika čelika. Za aseizmičku otpornost objekata od čelika najvažniji su:

- granica popuštanja i zatežuća čvrstoća
- duktilnost
- žilavost

Granica popuštanja i zatezna čvrstoća su u direktnoj sprezi zavisno od vrednosti opterećenja i karakteristika čelika koje se mogu sagledati sa radnog dijagrama [14]. Granica popuštanja predstavlja prelaz (prag) između elastičnog i neelastičnog ponašanja, a zatežuća čvrstoća najveće stvarno naprezanje pri aksijalnom zatezanju prema istom radu.

Na osnovu radnog dijagrama čelika izloženog naponima zatezanja i pritiska može se zaključiti da se čelik ponaša isto za navedena naprezanja. Dakle, radni dijagrami zatezanja i pritiska su identični. Osim navedenog može se zaključiti i to da čelik ima veliki napon tečenja, veliki napon loma i veliki modul elastičnosti (njihove vrednosti zavise od vrste odnosno kvaliteta čelika, osim modula elastičnosti koji je za sve vrste čelika konstantan) u odnosu na druge materijale koje koristimo u građevinarstvu. Bitno je napomenuti da se konstruktivni elementi sistema retko nalaze u jednoaksijalnom stanju naprezanja osim elemenata za ukrućenje. Ovde je pre svega reč o zgradama.

Nelinearno ponašanje konstrukcije u toku zemljotresa je jedno od centralnih problema u zemljotresnom inženjerstvu. Pošto je takav odgovor u kauzalnom odnosu sa karakteristikama materijala, u literaturi su materijali podeljeni na duktilne i krte [9]. Upravo duktilni materijali mogu trpeti značajne nelinearne deformacije pre nastanka loma. Ovakve konstrukcije svojim radom mogu uspešnije disipirati energiju unešenu pobudom (zemljotresom) ili prema [14] imaju mogućnost održavanja nosivosti u nelinearnom području .

Pri definisanju duktilnosti obično se pretpostavlja elasto-plastični radni dijagram materijala dat u standardima [1],[3]. Pauley i Prestley navode da je kod konstrukcija koje imaju veliku obezbeđenu duktilnost moguće u većoj meri smanjiti nosivost nego kod zgrada sa manjom raspoloživom duktilnošću prema [13]. To znači da treba iskoristiti nelinearno ponašanje konstrukcije, a da pri tome ipak ne dođe do rušenja objekta. U zavisnosti od postignutog balansa između nosivosti i duktilnosti pri određenoj krutosti, može se očekivati i različit odgovor konstrukcije pri dejstvu jakih zemljotresa.

Konstrukcija poseduje zadovoljavajuću seizmičku otpornost samo pod uslovom da njen granični kapacitet deformisanja, uz određenu rezervu kao meru sigurnosti, prevazilazi zahtevane maksimalne deformacije koje se dostižu za vreme jakih zemljotresa.

- Duktilnost se može analizirati sa više aspekata tj. postoje različite vrste duktilnosti, a najvažnije su prema [14].
- duktilnost na nivou konstruktivnih materijala
- duktilnost na nivou cele konstrukcije

Prema ovim pristupima poračun duktilnosti je opisan u više radova [7],[9], [14]. Na osnovu klase duktilnosti i vrednosti faktora ponašanja postoje dva osnovna pristupa konceptu projektovanja [2].

2 DUCTILITY OF STEEL FRAME STRUCTURES

Response and behavior of steel structure due to seismic loads depend on the mechanical properties of steel. For aseismic resistance of steel structures are the most important:

- yield point and the tightening strength
- ductility
- toughness

Yield point and tensile strength are directly tied, depending on the load values and characteristics of steel which can be seen in the work diagram [14]. Yield point represents a transition (threshold) between the elastic and inelastic behavior, and the tightening strength represents the largest real strain in axial tension to the same work.

Based on the working diagram of steel exposed to tensile and compressive stresses it can be concluded that steel has the same behavior for mentioned strains.

So, working diagrams of tension and pressure are identical. Except the mentioned, it can be concluded that the steel has high level of lapse stress, stress fracture and high modulus of elasticity (their values depend on the type and quality of steel, except the elastic modulus, which is constant for all kinds of steel) compared to other materials used in a construction. It is noteworthy that the structural elements of the system are rarely found in the uniaxial state of stress beside stiffening elements. Buildings are primarily concerned here.

Nonlinear behavior of structure during earthquakes is one of the central problems in earthquake engineering. Since such a response in a causal relationship with the characteristics of the material in the literature materials are divided on the ductile and brittle [9]. Exactly ductile materials can suffer significant inelastic deformation prior to the fracture. Through their work, such structures can successfully dissipate energy entered by inducement (earthquake) or by [14] are allowed to maintain the load in the nonlinear region.

Nonlinear behavior of structure during earthquakes is one of the central problems in earthquake engineering. Since such a response in a causal relationship with the characteristics of the material in the literature materials are divided on the ductile and brittle [9]. Exactly ductile materials can suffer significant inelastic deformation prior to the fracture. Through their work, such structures can successfully dissipate energy entered by inducement (earthquake) or by [14] are allowed to maintain the load in the nonlinear region.

When defining the ductility it is generally assumed the elastic-plastic working diagram of materials given in standards [1], [3]. Pauley and Prestley indicate that the load in the structures which have high secured ductility, can be reduced to a greater extent than with buildings with less available ductility toward [13]. That means that we need to use non-linear behavior of structure, and in doing so, be sure that it won't come to demolition. Depending on the balance achieved between strength and ductility at a given stiffness, it can be expected a different response of the structure during the effect of strong earthquakes.

A construction has sufficient seismic resistance only if its limit capacity strain, with a reservation as a measure of security, is beyond the required maximum strain that is reached during strong earthquakes.

Pored numeričkog pristupa, nekoliko autora se bavilo eksperimentalnim istraživanjem ovog problema. Lee i Goel su analizirali seriju od 2 do 20-spratnih ramovskih modela, Chopra je analizirao zahteve duktilnosti nekoliko modela i zaključeno je da horizontalna distribucija ne zahteva istu duktilnost na svim spratovima već je najveća na prvoj etaži citirano u [10].

3 RAMOVSKE KONSTRUKCIJE SA SPREGOVIMA

Elastičnom teorijom i statičkim metodama se objekat opterećuje silama velikog intenziteta i dimenzionisanje često prelazi u domen neracionalnog. Iz tog razloga je puno racionalnije uspostavljanje i modeliranje disipacijskih područja u konstrukciji koja seizmičku energiju troši preko histerezisnog ponašanja. Osnovni načini trošenja energije kod čelika, opisani u radu [10] su:

- plastični zglobovi pri savijanju
- smičuća rebra
- elementi pod uticajem plastičnog zatezanja

U istom radu je opisana razlika u elastičnom i neelastičnom konceptu preko histerezisnih dijagrama. U toku zemljotresnih dejstava konstrukcija više puta menja kvadrante koordinatnog sistema i pri prelasku u nelinearno područje odgovora obrazuju se krivolinijski ograničene površi. Površi su ograničene histerezisnim petljama (krivim), a predstavljaju utrošenu energiju na deformacije.

Zavisno od ponašanja primarnih konstruktivnih elemenata pri dejstvu seizmičkih sila postoje različiti sistemi čeličnih konstrukcija. Predmet ovog rada su ramovske konstrukcije sa centričnim i ekscentričnim spregovima (ukrućenjima) koje zavisno od vrste ukrute imaju različitu disipaciju energije. Kod visokih zgrada postavljenih na malom rastojanju postoji problem od velikih hrizontalnih pomeranja i eventualnog sudara usled delovanja seizmičkog opterećenja kao što je to kod armirano betonskih zgrada. Takav problem je detaljnije opisan u radu [20],, ali je težnja da se kod čeličnih konstrukcija otkloni upravo primenom određene vrste spregova.

Pojedinosti i konstruktivni predlozi za štapove ukrućenja su dati u standardima [1],[2], a ovde je pažnja usmerena na značaj izbora oblika ispune (X, V, /) na odgovor konstrukcije i trošenje energije. Rezultati su predstavljeni histerizisnim petljama za momente savijanja i ukupne smičuće sile u dnu rama. Bitno je napomenuti da se najveći deo energije troši preko zatezanjem napregnutih štapova, a ponašanje veza zavisi od izbora poprečnih preseka štapova. Manje vitki elementi mogu apsorbovati mnogo više energije nego vrlo vitki [14] i ako su ovi drugi popustljivi u području pritisaka.

Ideja o primeni escentrično postavljenih spregova (veza) leži u namernom izazivanju momenata savijanja i smičućih sila u gredama kako bi se smanjilo izvijanje štapova ispuna. Ovim načinom ukrućenja se postižu dve korisne stvari: troši se velika energija zbog ekscentriciteta i omogućava se plastifikacija čvora u gredama što odgovara povoljnom mehanizmu loma konstrukcije. Elementi koji se formiraju na mestu spoja ispuna-greda se nazivaju seizmičke veze (spone) i kao u [1] mogu se oblikovati kao na slici 1.

Ductility can be analyzed from several aspects, i.e. There are different types of ductility, and most important, according to [14] are:

- ductility at the level of material
- ductility at the level of construction materials
- ductility in the whole structure

According to these approaches, estimation of ductility is described in several papers [7], [9], [14]. On the basis of ductility class and behavior factor values, there are two basic approaches to the concept of design [2].

Besides the numerical approach several authors were occupied by experimental investigation of this problem. Lee and Goel have analyzed a series of 2 to 20-storey frame models, Chopra has analyzed the requirements of ductility for several models and it is concluded that the horizontal distribution does not require the same ductility on all floors but the highest at the first level cited in [10].

3 PANEL STRUCTURES WITH BRACINGS

With the elastic theory and static methods, an object is loaded with forces of great intensity and dimensioning often exceeds the domain of the irrational. For this reason, it is much more efficient establishing and modeling of dissipative areas in the construction which consume the seismic energy by hysteresis behavior. The basic ways of spending energy in steel, as described in [14] are:

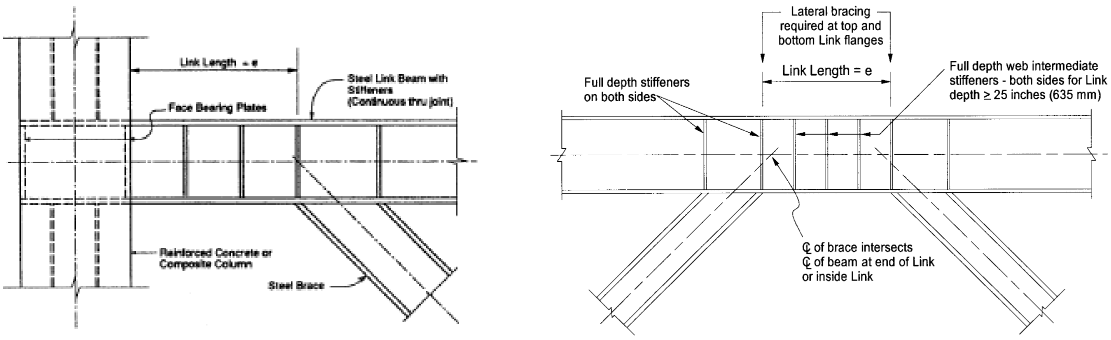
- plastic hinges in bending
- shear rib
- elements under the influence of plastic strain

There is the difference in the elastic and inelastic concept through hysteresis diagram in the same study. During earthquakes a construction repeatedly change quadrants of the coordinate system and in the transition to non-linear field response, the curvilinear limited surfaces are formed. Surfaces are limited by hysteresis loops (curves), and represent the spent energy on deformation.

Depending on the behavior of primary structural elements during the effect of seismic forces, there are different systems of steel structures. The paper focuses on frame structure with centric and eccentric bracings (stiffeners) that depending on the type of bracing have different energy dissipation. Multistory building, placed with small distance, have a problem of great horizontal displacements and possibility of crash due to seismic action as it is case of concrete constrution. This kind of problem is in detail described in paper [20]**Error! Reference source not found.**, and ambition at steel constructions is remove this problem with application of adequate kind of braces.

Details and constructive proposals for stiffening rods are given in standards [1], [2], and here, attention is focused on the importance of the shape fill (X, V, /) on the response of the structure and energy consumption. The results are presented by hysteresis loops for bending moments and the total shear force at the bottom of the frame. It is noteworthy that most of the energy is consumed by tension exerted sticks, and the behavior of the connections depends on the choice of cross sections of rods. Less slender elements can absorb much more energy than a very slender ones [14] though the latter are permissive in the area of pressure.

The idea of applying the eccentrically set bracings (links) lies in intentional causing of bending moments and shear forces in beams, in order to reduce buckling of diagonal bars. This way of stiffening run down to two useful things: the great energy is consume due to eccentricity and beam nodes plasticization is enabled, which corresponds to a favorable mechanism of fracture of the structure. Elements that are formed in the area of filling-beams joint are called seismic ties (bonds) as in [1] and can be formulated as in figure 1.



Slika 1. Detalji konstruisanja seizmičkih veza prema [1]
Figure 1. Details of the constructing of seismic links according to (AISC)

Spregovi

U literaturi **Error! Reference source not found.** su dati razlozi za slabo ponašanje ramova sa spregovima od kojih su najvažniji ograničena duktilnost i disipacija energije u trenucima cikličnog opterećenja i sklonost krtom ponašanju njihovih veza u konstrukciji. Histerezisno ponašanje spregova je takođe kompleksno. Misli se na ispoljavanje asimetričnih karakteristika pri zatezanju i pritisku i tipičan gubitak čvrstoće pri monotono pritiskajućem ili cikličnom naprezanju u neelastičnom području. Kompleksno ponašanje je rezultanta značajnih razlika u distribuciji unutrašnjih sila i deformacija predviđenih nekom od konvencionalnih metoda baziranih na elastičnom ponašanju materijala prema [17]. To može dovesti do posledica da su izabrani preseci štapova spregova predimenzionisani na nekim spratovima dok su na drugim na granicama nosivosti. Isto tako distribucija sila na grede i stubove je drugačija nego što se u stvarnosti očekuje. Tako postoje realni izgledi da se formiraju „meki“ spratovi. Prevelika izvijanja spregova dovode do oštećenja nekonstruktivnih elemenata.

Za razvoj novih metoda projektovanja čeličnih ramova, poučena zemljotresom NorthRidge, američka agencija FEMA je usvojila metodološki pristup baziran na performansama [7]. U ovoj metodologiji cilj pristupa je predvideti performanse u vidu stepena oštećenja i nivoa seizmičkog hazarda koji očekuje konstrukciju. Prednost ovog pristupa leži u eksplicitnom opisu neodređenosti i proizvoljnosti seizmičkog hazarda, odgovora konstrukcije, analitičkom modeliranja i nosivosti sistema i njegovih elemenata. Kod novih konstrukcija naglasak je stavljen na obezbeđenje veka konstrukcije i prevenciju kolapsa [17].

Bracings

Reason for poor behavior of frames with bracings, are given in the literature [17], whereof the most important are limited ductility and energy dissipation in times of cyclic loading and the tendency to brittle behavior of their interactions in the structure. Hysteresis behavior of bracings is also complex. This refers to the manifestation of asymmetrical characteristics of tensile and compressive strength and typical loss of the thickness in monotonous pressure or cyclic strain in the inelastic region. Complex behavior is the result of significant differences in the distribution of internal forces and deformations provided by some of the conventional methods that are based on elastic material behavior according to [17]. This can lead to consequences that selected sections of sticks are too excessive on some floors, while they are at the limits of carrying capacity on other floors. Also distribution of power in the beams and studs is different than it is expected in reality. So there is realistic prospect of forming a "soft" floors. Excessive buckling of bracings cause damage to non-structural elements.

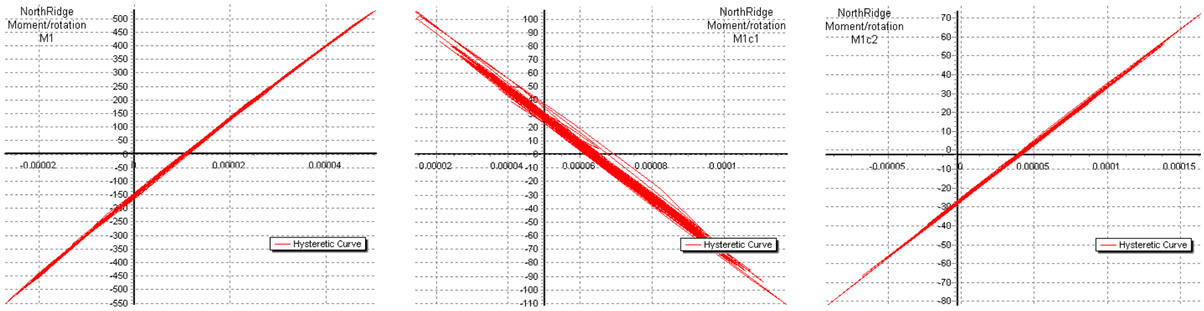
For the development of new methods of steel frames design, after the earthquake in Northridge, U.S. agency FEMA has adopted a methodological approach based on the performances [7]. The goal approach of this methodology is to predict performances in mind of degree of damage and the level of seismic hazard that structure is expected to endure. The advantage of this approach lies in its explicit description of the vagueness and arbitrariness of seismic hazard, structure response, analytical modeling and capacity of the system and its elements. At new construction the emphasis is placed on providing endurance of the construction and prevention of collapse [17].

Grede

Pod značajnim seizmičkim opterećenjima nastaju delimično ili potpuno plastificirana mesta čija lokacija, dužina i raspodela dilatacija zavise od geometrijskih karakteristika, graničnih uslova, efekta stalnog opterećenja [8]. Iskustvo je pokazalo da su plastični zglobovi smešteni uglavnom (ne u svim slučajevima) u blizini stubova što je u neku ruku poželjno, ali je opasno zbog prenošenja energije na veze i očekivanja njihovog dobrog odgovora. Ako je lokalno i horizontalno izvijanje sprečeno naponska slika usled momenata savijanja u poprečnim presecima dalje od plastičnih zglobova je zadovoljavajuća [8]. Kod zemljotresa koji izazivaju proizvoljne cikluse, odgovor grede može biti ilustrovan kao na slici 2.

Beams

Under significant seismic loads that are part of frame steel system there are elastic parts and partially or completely coated places whose location, size and distribution depend on the geometric characteristics, boundary conditions and the effects of constant stress [8]. Experience has shown that the plastic hinges located mainly (not in all cases) near the poles, which is in some ways preferable, but is dangerous due to the transfer of energy and expectations of their good response. If the local and the horizontal deflection is prevented the voltage image, due to of bending moments in cross sections away from the plastic hinge, is satisfactory [8]. At earthquake that cause arbitrary cycles, the response beam can be illustrated as in figure 2.



Slika 2. Histerezisne krive greda rama
Figure 2. Hysteresis curves of beam frame

Grede pokazuju stabilne i dosta velike histerezisne putanje. Na slici su prikazani odgovori iste grede rama sa i bez spregova. Oznake: M1, M1c1 i M1c2 predstavljaju: ram bez spregova, ram sa centričnim „V“ spregom i ram sa ekscentričnim „V“ spregovima respektivno. Očigledna razlika u vrednostima momenata savijanja u gredama govori kolika se energija troši u štapovima spregova, a na poslednja dva grafika se vidi razlika i između centričnih i ekscentričnih ukruta. Karakteristike modela su date u sledećem poglavlju na slici 7.

Beams show a stable and great hysteresis path. The picture shows the same beam frame responses with and without bracings. Tags: M1, M1c1 and M1c2 are: frame without bracings, the frame with centric "V" bracing and frame with an eccentric "V" bracings respectively. The obvious difference in the values of bending moments in beams tells how much energy is spent in the bracing sticks, while in the last two graphs we can see the difference between centric and eccentric bracing. Characteristics of the models are given in the next chapter in the picture.

Stubovi

Prisustvo velikih normalnih sila, koje razlikuje stubove od greda, znatno komplikuje ponašanje stubova generalno ako se uporedi sa gredama i delimično ako se pojave neelastične deformacije u stubovima. Veza distribucije neelastičnih dilatacija i momenata savijanja u poprečnoim preseku postaje komplikovana i zavisi od istorije aksijalne sile praćene momentima. Ako je normalna sila velika, plastična mesta se povećavaju u značajnoj meri u odnosu na dužinu stuba i aproksimacija sa plastičnim zglobovima postaje beznačajna. Kapacitet plastičnih deformacija zavisi od mnogo parametara prema Nakashima, citirano u [8] koji opet mogu značajno varirati. Mogućnost pojave P-Δ efektata, koje je teško odrediti za svaki neelastično deformisani stub, prati svaki stub izložen momentima savijanja [8]. Zbog pomenutih P-Δ efektata maksimalni momenti ne moraju biti kod

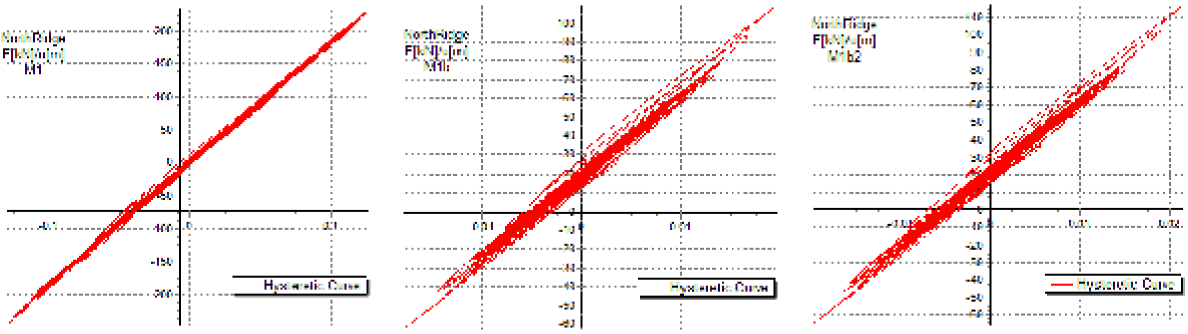
Pillars

The presence of large normal forces, which differ pillars from beams, significantly complicate behavior of pillars in general when compared to beams and partially if there are non-elastic deformation in the pillars. The link between inelastic dilatations and moments of bending in the cross section, become complicated and depends on the history of the axial force followed by moments. If the normal force is great, plastic seats are increased significantly, compared to the length of the pillars, the approximation with plastic joints becomes insignificant. The capacity of plastic deformation depends on many parameters by Nakashima, cited in [8], which again can vary significantly. The potential for P-Δ effects, which are difficult to determine for each inelastic deformed pillar, can appear in each pillar exposed to bending moments [8]. Because of the P-Δ effects, maximal moments may oslonaca. Pored toga stubovi su izloženi izvijanju u odnosu na obe ose pa superpozicija momenata savijanja u jednoj ravni i izvijanja u drugoj predstavlja poseban problem.

Za razliku od greda stubovi su podložniji značajnijim neelastičnim deformacijama pa su površine okvirene histerezisnim petljama veće (slika 3). Posebno su razmatrani slučajevi ramova sa ukrućenjima kod kojih su manje i sile i pomeranja u pravcu delovanja zemljotresa.

not be located in pillars. Furthermore pillars are exposed to buckling with respect to both axes, so the superposition of bending moments in one and buckling in the second plane presents a special problem.

Unlike the beams, pillars are prone to significant non-elastic deformation so the areas bordered by hysteresis loops become larger (fig.3). Cases of stiff frames are discussed in particular where both forces and displacements in the direction of earthquake activity are smaller.



Slika 3. Histerezisne krive vertikalnih elemenata za model bez ukrućenja i model sa ukrućenjima
Figure 3. Hysteresis curves of the vertical elements for the model without stiffeners and the model with stiffeners

U radu [15] je sprovedena analiza jednog rama trospratne zgrade kako bi se istražili efekti seizmičkih sila (akcelerograma) i odredili odgovarajući profili stubova i greda i ispunila ograničenja koncepta dizajniranja. Dokazano je da se određenim rasporedom krutosti elemenata može obezbediti ujednačena deformacija i olakšati konstrukcija uz potpuno iskorišćenje nosivosti.

4 NUMERIČKI PRIMER

U saglasnosti sa trenutno važećim aseizmičkim principima projektovanja, koji su u Evropi zastupljeni i uvedeni preko Evrokoda 8 [2], konstrukcije se mogu projektovati prema svom disipacijskom ponašanju. Prethodni standardi, koji su zastupali stav o elastičnom odgovoru konstrukcije, su bili ograničeni u smislu primene u područjima sa niskom seizmičnošću ili primenom na specijalnim objektima posebne važnosti. Cilj standarda je da omogući ekonomičan dizajn upošljavajući disipativno ponašanje u kojem značajne neelastične deformacije mogu biti smeštene u toku velikih seizmičkih aktivnosti [5]. U ovom slučaju neregularne ili kompleksne konstrukcije je neophodno tretirati detaljnim nelinearnim dinamičkim analizama. Suprotno njima, regularne konstrukcije se projektuju dodeljivanjem faktora ponašanja koji se koristi da bi redukovao standardom određene seizmičke sile dobijene na osnovu idealizovanog elastičnog spektra odgovora (slika 6). Ovi principi projektovanja disipativnih konstrukcija su u sprezi sa konceptom projektovanja nosivosti koji zahteva određivanje nosivosti sistema baziranog na pomenutom namernom obezbeđivanju plastifikacije zona u konstrukciji (mehanizmi loma).

Direktna dinamička metoda-vremenska analiza odgovora (time history) podrazumeva proračun uz pretpostavku nelinearnog ponašanja materijala. Zemljotres (pobuda) je predstavljena vremenskim zapisom istog (akcelerogramom) ili vremenskim tokom ubrzanja koje je

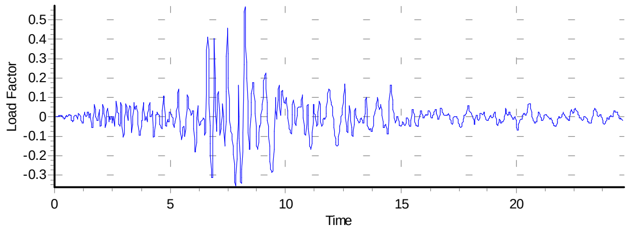
In [15] a three-story frame building analysis is conducted in order to investigate the effects of seismic forces (acceleration) and to determine the appropriate sections of pillars and beams to meet the limitations of the concept design. It is proven that the particular arrangement of stiffness can provide uniform strain and facilitate the construction with the full utilization of capacity.

4 NUMERICAL EXAMPLE

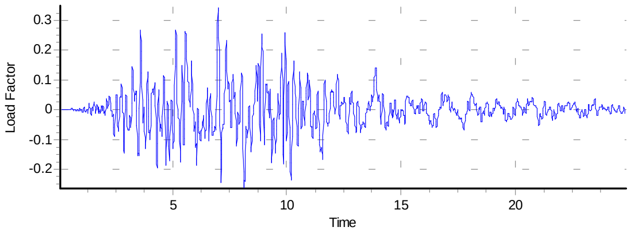
In accordance with current applicable seismic design principles, which are presented and introduced by Euro code 8 in Europe [2], structures can be designed according to their dissipation behavior. Previous standards, which argued the elastic response of the structure, were limited in terms of application in areas with low seismic activity or the implementation on the objects of special importance. The standard objective is to provide cost-effective design employing dissipative behavior where significant inelastic deformation can be stored during high seismic activity [5]. In this case irregular or complex structures have to be treated with the detailed nonlinear dynamic analysis. In contrast, regular structures are designed by assigning factors of behavior that is used to reduced the standard specified seismic forces obtained from an idealized elastic spectrum of response (fig.6). These design principles of dissipative structures are in conjunction with the concept of capacity design, which requires the determination of carrying capacity of the system, based on mentioned purposed provision of coating zone within structure (fracture mechanisms).

Direct dynamic method- time response analysis (time history) means a budget with the assumption of nonlinear material behavior. An eearthquake (excitation) is presented with time record of the same (accelerograms) or acceleration running time divided by podeljeno inkrementima Δt=0.01sec. Prednost ove metode je uvid u odgovor konstrukcije u bilo kom vremenskom intervalu delovanja zemljotresa ili njenom deformisanom obliku. S obzirom da su Northirge i Kobe izazvali velika oštećenja u čeličnim konstrukcijama u ovoj analizi biće korišćeni njihovi akcelerogrami kao opterećenja (slika 4 i 5).

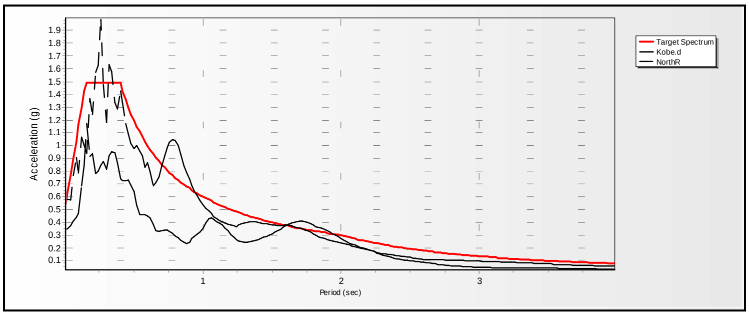
the increments Δt=0.01sec. The advantage of this method is an insight into the response of the structure at any time interval of an earthquake activity or its deformed shape. Since Northirge and Kobe caused severe damage in steel structures, this analysis will use their accelerograms as loadings (figures 4 and 5).



Slika 4. Akcelerogram za zemljotres NorthRidge
Figure 4. Accelerogram of an NorthRidge earthquake



Slika 5. Akcelerogram za zemljotres Kobe
Figure 5. Kobe earthquake accelerogram



Slika 6. Elastični spektar odgovora prema EC8 i za analizirane zemljotrese
Figure 6. Elastic spectrum response to EC8 and for the examined earthquakes

Pomenuti događaji u Kaliforniji i Japanu su dokazali da obuhvatajući stalna opterećenja i vetar kao merodavnu kombinaciju za dimenzionisanje, nismo obuhvatili sve parametre kako bi sačuvali konstrukciju od loma. Vetar jeste merodavan povremeni uticaj na čeličnu konstrukciju kod hala, visokih čeličnih zgrada sa velikom fasadnom površinom i sl, ali su zemljotresi nepredvidivi i teško ih je analitički obuhvatiti. Posebno su seizmičkim uticajima izloženi čelični sistemi sa spregnutom međuspratnom konstrukcijom od čelika i armiranog betona. Uobičajena debljina betonskih ploča je od 10 cm pa naviše, zavisno od raspona, i ona predstavlja ozbiljno opterećenje koje povećava seizmičke sile. Ovakvi sistemi se sreću kod višespratnih parkirališta, mostova, nekih zgrada itd. Kod numeričkog primera koji je predstavljen u ovom radu za sve modele je usvojena ista debljina ploče od 10cm sa određenim slojevima podova i usvojeno je korisno opterećenje od 2.0kN/m2. Ukupno opterećenje je naneto u vidu koncentrisanih sila u

The mentioned events in California and Japan have shown that we did not include all the parameters, including constant loads and wind as reliable combination of sizing, in order to preserve the structure of the fracture. Wind is the authoritative occasional impact on the steel structure of a hall, high steel building facade with a large surface area, etc, but earthquakes are unpredictable and difficult to capture analytically. Steel systems with composite floor structures of steel and reinforced concrete are particularly exposed to seismic effects. Regular thickness of concrete goes from 10 cm and up, depending on the range, and it is a serious burden that increases the seismic force. Such systems are usually associated with multistory parking lots, bridges, some buildings and so on. In the numerical examples presented in this paper the same plate thickness of 10 cm is adopted for all the models, with certain layers of floors, a payload of 2.0kN/m2 is also adopted. Total load was applied in the form of concentrated forces in pillars, in stubovima u nivou spratova. Dimenzije glavnih i sekundarnih elemenata svih modela (slika 7) su :

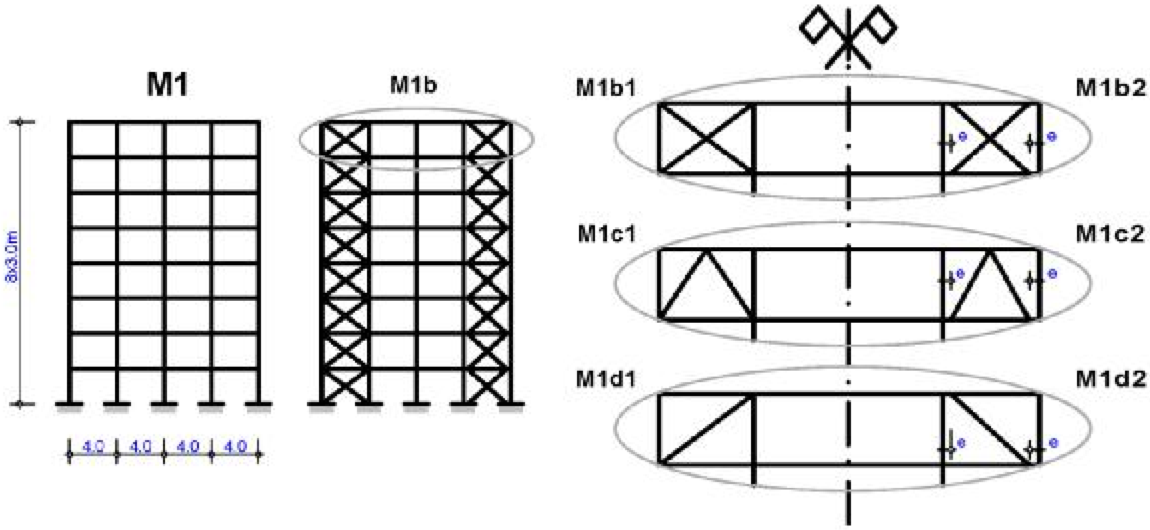
- Stubovi: pravougaone cevi 420x220x10mm
- Grede : I nosač I300
- Spregovi (ispune) : HOP 100x60x4mm.

Prvi model je ram bez spregova dok su ostali ukrućeni simetrično u zadnjim rasterima. Jedna grupa modela sa zadnjim indeksom 1 je sa centrično postavljenim spregovima, a grupa modela sa zadnjim indeksom 2 imaju ekscentricitet od izabranih 0.6m.

the level of floors. Dimensions of main and secondary elements of the model (figure 7) are:

- Pillars: rectangular pipe 420x220x10mm
- Beams: I mount I300
- Bracings (fill): HOP 100x60x4mm.

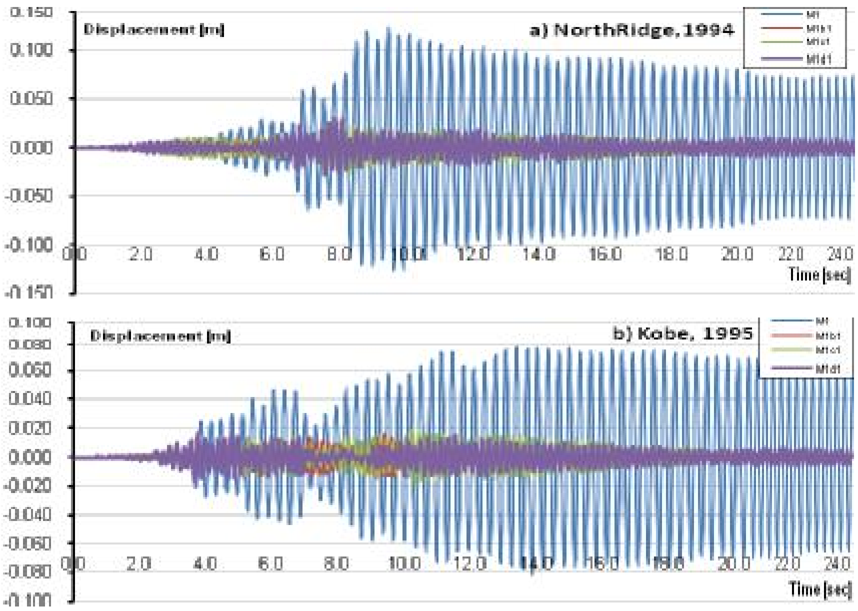
The first model is a frame without bracings while others remain stiff in the hindquarters symmetrical grids. One group of models with the last index 1 is with centrally placed bracings, and a group of models with the last 2 have the eccentricity index of the selected 0.6m.



Slika 7. Modeli čeličnog rama usvojeni za analizu
Figure 7. Steel frame models adopted for analysis

Prvi deo dinamičke analize čini proračun odgovora konstrukcije tačnije pomeranja vrha rama usled seizmičkog opterećenja zadatog preko akcelerograma zemljotresa NorthRidge.

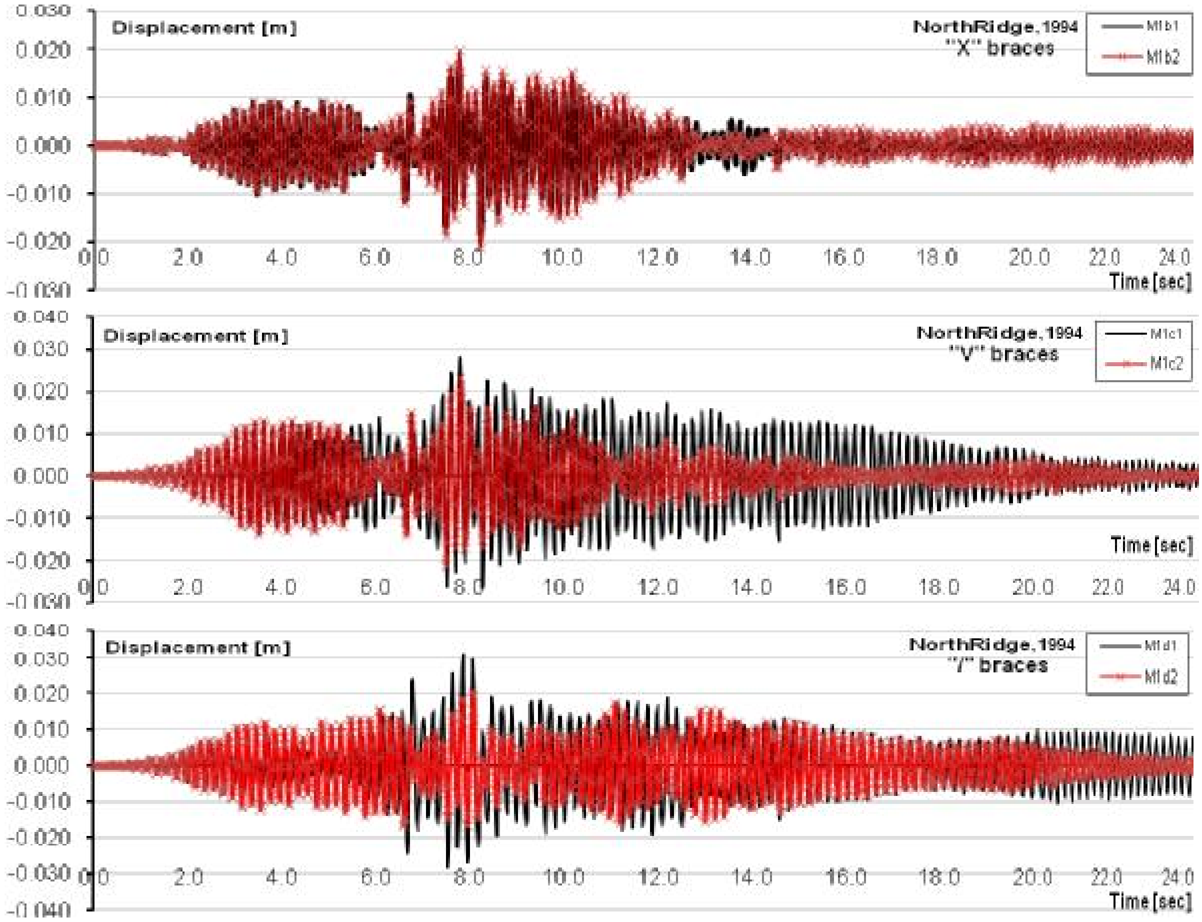
The first part of the dynamic analysis is the calculation of structures response, more accurately the top frame displacement due to seismic load specified by the earthquake accelerograms in NorthRidge.



Slika 8. Poređenje odgovora rama bez ukrućenja i sa ukrućenjima za: a)Northridge i b)Kobe
Figure 8. Comparison of responses of frames with or without stiffening for: a) Northridge b) Kobe

Ukoliko uporedimo odgovor konstrukcije (rama) bez ukrućenja (slika 8) koji je predstavljen plavom bojom dobićemo očekivane rezultate. Evidentna razlika u vrednostima pomeranja vrha srednjeg stuba pri prigušenju od ξ=2%=0.02 pokazuje koliku energiju seizmičkih sila troše štapovi spregova i to u ovom slučaju centrično postavljeni. U nastavku su upoređeni odgovori modela rama sa istim vrstama spregova, ali je razlika u zadatom ekscenticitetu kod modela sa brojem 2 u indeksu. Razmatrana su samo pomeranja jer se slični odnosi u rezultatima dobijaju i za brzine i ubrzanja.

If we compare the response of the structure (frame) without stiffeners (fig. 8) that is presented in blue, we will get the expected results. Evident difference in the values of the central pillar top displacements during damping period of ξ = 2% = 0.02 demonstrates the amount of seismic forces power that is used by bracings sticks, in this case centrally placed. The following are compared responses with the same model frame, with similar types of bracings, the difference is in a given eccentricity on models with number 2 in the index. Only movements have been considered because of the similar proportions in the results obtained for speed and acceleration.



Slika 9. Odgovor modela sa centričnim i ekscentričnim spregovima, M1b-M1d za NorthRidge zapis
Figure 9. Response of the model with centric and eccentric bracings, M1b-M1d for NorthRidge record

Rezultati drugog dela analize nisu prikazani zbog sličnosti sa rezultatima sa slike 9. U ovom slučaju korišćen je zapis zemljotresa Kobe dat na slici 5.

5 ZAKLJUČAK

Odgovor i ponašanje konstrukcija je jako složeno u toku dejstva zemljotresa pre svega zbog same prirode pobude. Seizmičko dejstvo je stohastičkog tipa. Za izučavanje njegovog dejstva potrebna je teorija vibracija, a za proračun konstrukcija postoje različite metode koje se mogu upotrebljavati shodno svojstvima konstrukcije. Čelične konstrukcije su veoma duktilne, imaju malu

Results of the second part of the analysis are not presented due to similarities with the results in the figure 9. In this case we used the Kobe earthquake record given in figure 5

5 CONCLUSION

Response and behavior of structures is very complicated during an earthquake, primarily due to the nature of excitation. Seismic activity is of stochastic type. To study its effect the theory of vibration is required, and for estimation of structures there are different methods that can be used in accordance to the properties of the težinu i kod njih postoji više varijanti za prijem seizmičkih sila. Ove konstrukcije se dele prema načinu disipacije energije proizvedene zemljotresom, a standardi i mnogi autori su predstavili širok spekatar metoda kojima se može konstrukcija seizmički pojačati. U ovom radu je sprovedena paralelna dinamička analiza poznata kao „time history“ kojom se model tj. konstrukcija izlaže zemljotresnom dejstvu u vidu akcelerograma. Za modele su izabrani čelični ramovi sa jednakim rasterima i spratnim visinama i čine ih jedan ram bez spregova i tri rama sa različitim oblicima spregova, centrično i ekscentrično postavljeni. Iako su prema karakteristikama ovi modeli predstavnici regularnih konstrukcija, izabrana je nelinearna analiza i očekivani odgovor konstrukcije u vidu neelastičnih deformacija. Na osnovu upoređenih rezultata odgovora dokazala se opravdanom upotreba spregova kod ovakvih konstrukcija jer se najveći deo seizmičke energije potroši na štapove ispuna i u plastičnim zglobovima formiranim na krajevima greda. Tako su vertikalni noseći elementi izloženi manjim silama zbog programirane distribucije sila. Svrha ove metode i ostalih nelinearnih metoda jeste da se konstrukcija izloži nelinearnom ponašanju u toku dejstva zemljotresa zbog smanjene nosivosti, ali da se sačuva njena globalna stabilnost.

Pored ove analize upoređivani su i odgovori (pomeranje vrha rama) ramova sa centričnim i ekscentričnim spregovima. Na osnovu dejstva zemljotresa NorthRidge i Kobe može se zaključiti da se energija bolje disipira kod ovih drugih jer je na taj način veštački izaziva plastifikacija u gredama pa su pomeranja i sile u stubovima manje.

Ovaj vid projektovanja konstrukcija je svakako bliži realnoj predstavi zemljotresa i njegovom dejstvu na konstrukcije. Tako se dobijaju lakše konstrukcije koje su istovremeno otpornije na seizmičke aktivnosti. Ostaje samo pitanje njihove praktične primene u toku projektovanja.

structure. Steel structures are very ductile, they are light weighted, and there are several options for the seismic force reception with them. These structures are classified according to the dissipation of energy produced by the earthquake, yet standards and many authors have presented a wide spectrum of methods which can strengthen structures seismically. This paper presents a parallel dynamic analysis known as "time history" by which a model, thus a structure is exposed to seismic effects in the form of acceleration. Steel frames with the same grids and the storey heights were selected for the models. They consist of one frame without bracings and three frames with different types of bracings, set centric and eccentric. Although, according to characteristics, these models are representatives of regular structures, the nonlinear analysis and expected response of the structure in the form of non-elastic deformation were chosen for. According to compared results of responses, the use of bracings proved to be justified, because most of the seismic energy is spent on the filler bars, as well as in plastic hinges formed at the ends of the beams. Thus, the vertical supporting elements are exposed to weaker forces due to the programmed power distribution. The purpose of this method and other nonlinear methods is to expose a structure to nonlinear behavior during the earthquake due to reduced capacity, but to preserve its global stability.

In addition to this analysis, the responses (scroll the frame top) of frames with centric and eccentric bracings were compared, too. On the basis of NorthRidge and Kobe earthquakes, it can be concluded that the energy better dissipates in the latter, because thereby plastification of beams is caused artificially, so displacements and forces in pillars are smaller.

This type of design is certainly closer to the real performance of earthquakes and their effects on structures. Accordingly, we get lighter structures that are also more resistant to seismic activity . However, the question of their practical application in the design still remains.

6 LITERATURA
REFERENCES

[1] ANSI/AISC 341-02, An American National Standard, Seismic Provisions for Structural Steel Buildings, AMERICAN INSTITUTE OF STEEL CONSTRUCTION, 2002

[2] CEN-EN 1998-1, Eurocode 8, Deo 1, Opšta pravila, seizmička dejstva i pravila za zgrade - prevod, Građevinsko arhitektonski fakultet Univerziteta u Beogradu, Beograd, 2009

[3] CEN/ EN 1993-1-1, Eurocode 3: Design of steel structures, Part 1-1: General rules and rules for buildings, 2005.

[4] Chopra A., Dynamic of Structures -Theory and Applications to Earthquake Engineering, Prentice Hall, Upper Sadder River, New Jersy, 1995, pp. 763

[5] Elghazouli A. Y., Assessment of European seismic design procedures for steel framed structures, Bull Earthquake Eng., Vol. 8, 2010, pp. 65–89

[6] Elghazouli A.Y., Castro J.M., Izzuddin B.A., Seismic performance of composite moment-resisting frames, Engineering Structures 30,2008,

[7] FEMA, Recommended Seismic Design Provisions for New Moment Frame Buildings Report FEMA 350, Federal Emergency Management Agency, Washington DC, 2000.

[8] FEMA, State of the Art Report on Systems Performance of Steel Moment Frames Subject to Earthquake Ground Shaking Report FEMA 355C, Federal Emergency Management Agency, Washington DC, 2000.

[9] Hrasnica M., Seizmička analiza zgrada, Građevinski fakultet Univerziteta u Sarajevu, Sarajevo, 2005, str. 282

[10] J´armai K., Farkas J., Kurobane Y., Optimum seismic design of a multi-storey steel frame, Engineering Structures 28 (2006), pp. 1038–1048

[11] Lađinović Đ., Nelinearna dinamička analiza konstrukcija izloženih dejstvu impulsnih zemljotresa, Materijali i konstrukcije 45, Vol. 3-4, 2002, str. 73-77

[12] Lađinović Đ., Savremene metode seizmičke analize konstrukcija zgrada, Materijali i konstrukcije

pp. 1802–1819

[13] Lađinović Đ., Folić R., Analiza konstrukcija zgrada na zemljotresna dejstva, Materijali i konstrukcije 47, Vol. 3-4, 2004, str. 31-64

[14] Markulak D., Posebna poglavlja čeličnih konstrukcija, Građevinski fakultet, Sveučilište Josipa Jurja Strossmayera u Osijeku, 2010, str. 388

[15] Moghaddam H., Hajirasouliha I., Doostan A., Optimum seismic design of concentrically braced steel frames: concepts and design procedures, Journal of Constructional Steel Research 61, 2005, pp. 151–166

[16] Pravilnik o tehničkim normativima za izgradnju objekata visokogradnje u seizmičkim područjima, Sl. List SFRJ br. 52/90

51, Volume 2, 2008, str. 25-40

[17] Sabelli R., Mahin S., Chang C., Seismic demands on steel braced frame buildings with buckling restrained braces, Engineering Structures 25, 2003, pp. 655–666.

[18] Uang C.H, et al, Seismic design of steel structures, The seismic design handbook, second edition, eitor. F. Naim, Kluwer Academis Publishers, 2001, pp. 409-462.

[19] Yousuf M.D., Bagchi A., Seismic performance of a 20-story steel-frame building in Canada, The structural design of tall and special buildings, Struct. Design Tall Spec. Build. 19, 2010, pp. 901–921

[20] Žugić LJ., Brčić S., Vremenski odgovor nesimetrične zgrade u zavisnosti od dominantnog pravca djelovanja zemljotresa, Materijali i konstrukcije 53, Vol. 1, 2010, str. 14-32.

REZIME

DIREKTNA DINAMIČKA ANALIZA ČELIČNIH RAMOVSKIH KONSTRUKCIJA UKRUĆENIH

Mirsad TARIĆ
Enis SADOVIĆ
Emir MASLAK

Aseizmičko projektovanje čeličnih ramovskih konstrukcija podrazumeva iskorišćenje raspoloživih mehaničkih i geometrijskih karakteristika materijala pri seizmičkom dejstvu uz dirigovanu disipaciju energije. U radu je opisana dinamička nelinearna analize vremenskog odgovora nekoliko modela čeličnog rama sa komparacijom rezultata. Akcenat je stavljen na upotrebu ukrućenja tj. spregova različitog oblika koji su postavljeni centrično i ekscentrično sa namerom da se ispita odgovor konstrukcije i donese zaključak o boljoj disipaciji energije paralelnih modela. Pri analizi su korišćeni zapisi zemljotresa NorthRidge i Kobe koji su prouzrokovali velika oštečenja u čeličnim konstrukcijama.

Ključne reči: ramovske konstrukcije, spregovi, nelinarna analiza, duktilnost, disipacija energije

SUMMARY

DIRECT DYNAMIC ANALYSIS OF STEEL BRACED FRAME CONSTRUCTIONS

Mirsad TARIĆ
Enis SADOVIĆ
Emir MASLAK

Aseismic design of steel frame constructions defines usage of capable mechanical and geometrical material characteristics during the seismic action with controlled energy dissipation. This paper presents dynamic nonlinear time history analysis of several steel frame models with comparison of results. The accent is pointed on brace application with different shape which are placed concentrically and eccentrically wit aim to investigate construction response and make conclusions about better energy dissipation of models. In this analysis accelerograms of two earthquakes NorthRidge and Kobe were used, which caused great damages in steel constructions.

Ključne reči: steel frames, braces, nonlinear analysis, ductility, energy dissipation