**Izlaganje na seminaru “Integritet građevinskih konstrukcija” održanom u okviru**
**Druge godišnje konferencije Društva za integritet i vek konstrukcija, Beograd, 27-28. oktobar 2005.**

**Presented at the seminar “Integrity of Civil Engineering Structures” held in the scope of**
**The Second Annual Conference of the Society for Structural Integrity and Life, Belgrade, 27-28 October 2005**

*Zoran Petrašković [1], Dragoslav Šumarac [2], Miloš Anđelković [2], Svetlana Miladinović [3], Marina Trajković [4]*

# SANACIJA OŠTEĆENIH ZIDANIH KONSTRUKCIJA TEHNOLOGIJOM DC 90

# RETROFITTING DAMAGED MASONRY STRUCTURES BY TECHNOLOGY DC 90

Originalni naučni rad / Original scientific paper
UDK /UDC: 699.841.059
Rad primljen / Paper received 7.9.2005.

Adresa autora / Author's address:
[1)] Sistem DC 90, Beograd
[2)] Građevinski fakultet, Beograd
[3)] Sistem DC 90-Savetnik, Beograd
[4)] Građevinsko-arhitektonski fakultet, Niš

**Ključne reči**
- oštećenje
- zemljotres
- ojačanje
- absorberi
- eksperimenti

**Keywords**
- damage
- earthquake
- retrofitting
- dampers
- testing

*Izvod*

*U radu se daje numerička analiza oštećenja zidanih konstrukcija korišćenjem metode konačnih elemenata. Prikazan je postupak sanacije oštećenih konstrukcija korišćenjem tehnologije DC 90. Pokazani su rezultati ispitivanja dampera dobijeni u relevantnim institutima. Opisani su i eksperimenti na raznim modelima zidanih konstrukcija izvedeni na vibroplatformi. Detaljno su pokazani primeri sanacije zidanih konstrukcija u Kolubarskom okrugu.*

*Abstract*

*In the present paper numerical analysis of damaged masonry structures using finite element method is presented. Retrofitting of those structures using technology DC90 is outlined to. Experimental results of testing of dampers in relevant institutes are described. Besides that, tests on vibroplatform for various masonry structures are presented. Examples of retrofitting of damaged structures in Kolubara region are explained in detail.*

## UVOD

Zemljotresi predstavljaju najopasnije uticaje na građevinske konstrukcije. To se posebno odnosi na zidane konstrukcije. U ovom radu analiziraju se oštećenje i nastanak prslina u zidanim konstrukcijama korišćenjem metode konačnih elemenata. Poznato je da ove konstrukcije imaju veliku masu i zbog toga i slabe veze između cigle (kamena) i maltera one prskaju i oštećuju se usled zemljotresa. U radu je takođe pokazano kako se primenom tehnologije DC 90 mogu uspešno sanirati ove vrste konstrukcija. Pokazana su i ispitivanja dampera u laboratoriji, kao i ispitivanja različitih modela zidanih konstrukcija na vibro-platformi.

## NUMERIČKA ANALIZA OŠTEĆENJA ZIDANIH KONSTRUKCIJA USLED ZEMLJOTRESA

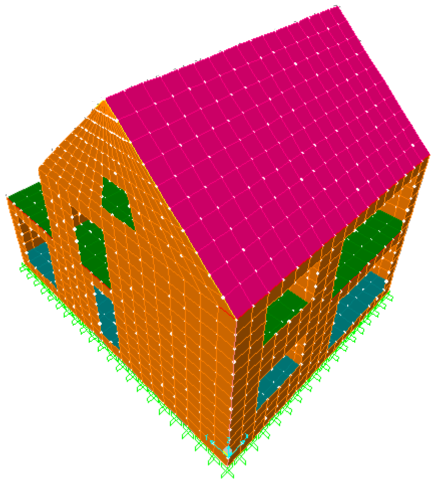
Tipična zidana dvospratnica izgrađena od cigle i maltera je pokazana na sl. 1. Modelirana je sa elementima ljuske. Zemljotres je simuliran sa El Centro zapisom. Analiza je urađena za dejstvo zemljotresa u dva pravca. Proračun pokazuje da se najveći naponi zatezanja, koji su odgovorni za pojavu prslina, javljaju između otvora (prozori, vrata) i da se prsline razvijaju u pravcu dijagonala (sl.2, sl.3).

## INTRODUCTION

Earthquakes are more dangerous influences on civil engineering structures. Especially masonry structures are sensitive to them. In this paper damage and cracking of masonry structures is analyzed using FEM. It is well known that those structures have large mass, and consequently because of very bad cohesion between bricks (stones) and mortar they crack and suffer damage due to earthquakes. Also in the paper it is shown how technology DC 90 can be successfully applied for retrofitting of damaged masonry structures. Also testing of dampers and on vibro platform for various types of masonry structures is presented.

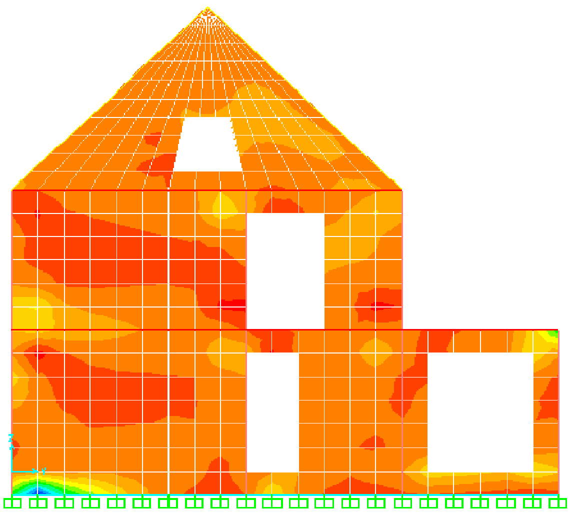
## NUMERICAL ANALYSIS OF DAMAGE OF MASONRY STRUCTURES DUE TO EARTQUAKES

Typical two store building made from bricks and mortar is shown in Fig. 1. It is modeled by shell finite elements. The earthquake is represented by El Centro response. The analysis is performed with two directions of earthquake effect. Analysis shows that the largest tensile stresses, responsible for crack initiation, occur between holes (windows, doors) and cracks grow in direction of cross diagonals (Fig. 2, Fig. 3).

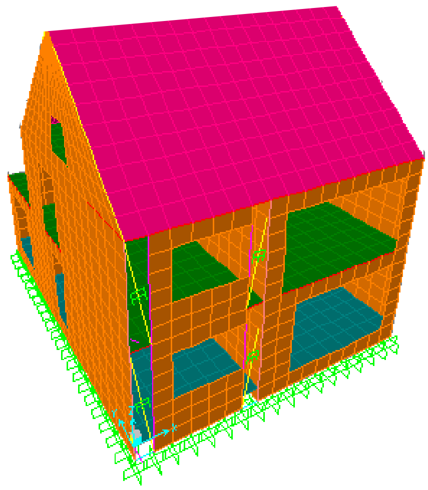


Slika 1. Model konačnih elemenata za dvospratnu zgradu
Figure 1. Finite element model of two store masonry structure.

Slika 2. Tipičan oblik i raspored prslina kod zidanih konstrukcija
Figure 2. Typical crack pattern of masonry structures.



Slika 3. Maksimalni naponi dobijeni konačnim elementima
Figure 3. Finite element results of maximum stresses.



Slika 4. Model konačnih elemenata ojačane konstrukcije
Figure 4. Finite Elements model of retrofitted structure.

## SANACIJA OŠTEĆENIH OBJEKATA PRIMENOM TEHNOLOGIJE DC 90

Sistem DC 90 čini nekoliko konstrukcijskih elemenata koji ojačavaju krte zidove i čine ih duktilnim i žilavim. Pored toga omogućavaju podnim pločama i tavanicama da postanu krute u svojoj ravni i integrišu čitav sistem konstrukcije zgrade sa temeljnim kragnama. Ovi elementi čine objekt jačim da primi značajna horizontalna i vertikalna opterećenja.

*Vertikalni elementi - zidovi*

Zidovi se ojačavaju vertikalnim ukrućenjima koja povezuju sve horizontalne ploče i temelj. Vertikalna ukrućenja - rešetke čine vertikalne utege koje se prednaprežu, a ostali elementi rešetke su sami kosnici sa apsorberom seizmičke energije i horizontale kao delovi krutih međuspratnih ploča. Ovako ojačani zidovi postaju duktilni (žilavi) i sposobni da prime alternativna horizontalna dinamička pomeranja.

## RETROFITING OF DAMAGED STRUCTURES BY APPLYING TECHNOLOGY DC 90

System DC 90 comprises a number of structural elements which strengthen brittle walls and make them ductile and tough. They make floor slabs and ceilings stiff and capable to transmit the load in their own plane, and connect them by foundation collars. These elements make structure stronger to accept the horizontal and vertical loads.

*Vertical elements – walls*

Walls are strengthened by vertical stiffeners that connect all horizontal slabs and the foundation. Vertical stiffeneers – trussess consist of the vertical ties, which are pre-stressed, and the other elements are diagonals with the seismic energy absorber and horizontals as a part of stiff floor slabs. Walls strengthened in this way become ductile (tough) and capable to accept the alternative horizontal dynamic displacements.

*Horizontalni elementi*

Ukoliko nisu krute u svojoj ravni, međuspratne i tavanske ploče se ojačavaju na jedan od sledeća dva načina:
– sprezanjem lakoarmiranom tankom betonskom pločom ili
– izradom horizontalnih spregova, koji su povezani sa vertikalnim ukrućenjima.

*Temelji*

Temeljna konstrukcija se obuhvata temeljnom kragnom, povezanom ankerima, u kojoj su usidrena vertikalna ukrućenja.

ISPITIVANJE DAMPERA

Ispitivanja, obavljena u Vojnotehničkom institutu (VTI), Žarkovo, Beograd (sl. 5.) i (sl. 6.), ukazuju na sledeće:

Analizom dobijenih dijagrama zavisnosti sila–pomeranje može se zaključiti da se radi o klasičnom niskocikličnom zamoru. Prilikom rada, u kontroli pomeranja dolazi do pojave trajnih plastičnih deformacija, ili drugim rečima, sa povećanjem broja ciklusa rada dolazi do slabljenja materijala i do smanjenja maksimalne sile (dolazi do pada sile pri istom pomeranju, materijal slabi). Što je pomeranje manje, to će broj ciklusa do loma biti veći.

Međutim, ovde se ne radi o klasičnom lomu uzoraka, ovde se pre svega radi o slabljenju uzoraka.

EKSPERIMENTALNA ISPITIVANJA NA SANIRANIM I NESANIRANIM OBJEKTIMA U MIONICI

Eksperimentalna ispitivanja na saniranim objektima u Mionici, prikazana na sl. 7. je izveo Institut za zemljotresno inženjerstvo i inženjersku seizmologiju (IZIIS) iz Skoplja, metodama ambijentnih i prinudnih vibracija pokazala su da dominantne frekvence izgrađenih objekata nalaze se u opsegu 6-8 Hz, a nakon sanacije se krutost objekata povećava za oko 35%.

ISPITIVANJE ZIDA OD ŠUPLJIH BLOKOVA 19X19X25, UOKVIRENOG SERKLAŽIMA, NA KVAZIDINAMIČKO OPTEREĆENJE

Na sl. 8. je prikazan eksperimentalni dvospratni zid izveden na tri načina: (1) od šupljih blokova, (2) u vidu klasičnog rešenja, (3) kao ojačan po sistemu DC 90 i u fazi ispitivanja. Posle nekoliko ciklusa, za pomeranje vrha konzole od 10 mm pojavile su se velike pukotine, 8-10 mm, u pravcu glavnih napona zatezanja u prvom polju do unošenja sile. U polju do uklještenja zida pojavile su se prsline karakteristične za naprezanje sa dominantnim savijanjem.

Početna krutost na smicanje je iznosila $E_{s\text{-poč}}$ = 60 kN/ 6 mm = 10 kN/mm, da bi posle nekoliko ciklusa za pomeranje od oko 30 mm, pala na Es-kraj= 90 kN/60 mm = 1,5 kN/mm. Ovaj višestruki pad krutosti zida može se nazvati kolapsom zida i smatrati kolapsom cele zgrade.

*Ispitivanje ojačanog zida*

Početna krutost na smicanje je $E_s$ = 20/3,5 = 5,7 kN/mm, da bi kasnije blago padala, najviše zbog popuštanja sidrenja donje utege, a posle ponovo ojačala. To navodi na zaključak da se sidrenje mora kvalitetno uraditi i kvalitet izvedenih radova kontrolisati.

*Horizontal elements*

If they are not stiff in their own plane, floor slabs and ceilings are being strengthened in one of following two ways:
– impregnation with a thin, lightly reinforced, concrete slab or
– incorporation of the horizontal bracings that are connected with the vertical stiffening elements.

*Foundations*

The foundation structure is confined with the foundation collar, connected by anchors and in which the vertical stiffening elements are anchored.

TESTING OF DAMPERS

Testing done in Military Ttechnical Institute (VTI), Zarkovo, Beograd (Fig. 5) and (Fig. 6), show the following:

Analysing of diagrams force-displacement, one can conclude that clasic low cycle fatigue is in question. During work, in displacement control, permanent plastic deformations appear, or in another words, with increasing number of work cycles material weakens and maximum force drops down (force decreases for the same deflection, material is weaker). With smaller displacement, number of cycles needed for failure is greater.

This is not classical failure of the sample, this is above all weakening of the sample.

EXPERIMENTAL TESTING ON RETROFIT AND NON-RETROFIT OBJECTS IN MIONICA

Experimental testing on retrofit objects in Mionica, presented in Fig. 7, had been performed by Institute for earthquake engineering and engineering seismology (IZIIS) from Skopje, by methods of ambient and forced vibrations have shown that dominant frequencies of built objects are within the range of 6-8 Hz while after retrofit stiffness raises up to approximately 35%.

TESTING OF WALL MADE OF HOLLOW BLOCKS 19X19X25, FRAMED BY GIRDERS, UNDER QUASIDYNAMIC LOADING

Figure 8 presents experimental two store wall made in three forms: (1) from hollow blocks, (2) as classical solution, (3) as strengthened according to DC 90 System and during testing. After few cycles, for displacement of console top point of 10 mm, extended cracks of 8-10 mm appeared in the first area from the point of force application. In the area to the wall constraint, cracks typical for dominant bending stresses appeared.

Initial shear stiffness was $E_{s\text{-start}}$ = 60 kN/6 mm = 10 kN/mm, and after few cycles for deflection of approximately 30 mm, it was decreased to the $E_{s\text{-end}}$= 90 kN/60 mm = 1.5 kN/mm. This multiple decrease of wall stiffness can be considered as a collapse of the wall and whole building.

*Testing of strengthened - retrofitted wall*

Initial shear stiffness was $E_s$ = 20/3.5 = 5.7 kN/mm, and later it slightly decreased, mostly due to anchorage yield of lower tie, and then it rises up again. That leads to the conclusion that anchorage must be done properly, and that quality control of performed works must be done.

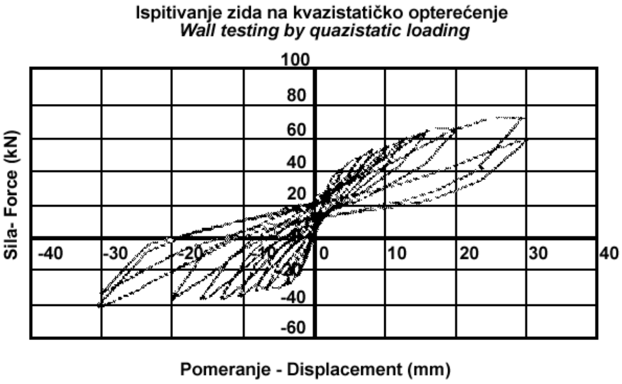
Zid se tokom cikličnog opterećenja ponaša daleko žilavije. Za opterećenje od 60 kN, a pomeranje vrha za 25 mm javile su se mnogo manje prsline širine otvora 2-3 mm.

Ispitano ukrućenje ima nosivost i za veće deformacije, iskazuje dovoljnu žilavost i verovatno da može kao sklop vertikalnih ukrućenja zadržati zgradu od kolapsa i za veća pomeranja, za razliku od zgrade koja je ukrućena samo serklažima, a pogotovu od zgrade koja nema vertikalne serklaže i gde je kolaps i za manje potrese neizbežan. Opisana ispitivanja dvospratnog zida sprovedena su u Institutu za ispitivanje materijala IMS, Beograd.

Wall behaves much tougher during cyclic loading. For loading of 60 kN, with displacement of the top for 25 mm far less cracks occurred with openings 2–3 mm.

Tested stiffener has carrying capacity for bigger deformation, shows sufficient durability and probably can, as part of the vertical stiffening frame, preserve the building during larger deflections and keep it from collapse, making the building safer during influences of earthquake, especially if building is built without girders. Described testing was performed in the IMS Institute for material testing, Beograd.

Slika 5. Tipični damperi sistema DC 90 i njihovo testiranje
Figure 5. Typical dampers of the system DC 90 and their testing




Slika 6. Histerezisni dijagram dobijen testiranjem dampera
Figure 6. Hysteretic diagram obtained by testing of dampers.

Slika 7. Eksperimentalno ispitivanje objekata
Figure 7: Experimental testing of objects.

Slika 8. Model dvospratnog zida pre sanacije, posle sanacije i u fazi ispitivanja
Figure 8. Two-store wall model, before retrofit, after retrofit and during testing.

## MODELSKO ISPITIVANJE NA VIBRO PLATFORMI ZIDA OJAČANOG SISTEMOM DC 90 U RAZMERI 1/10

Navedeno ispitivanje je urađeno početkom februara 2004 u Laboratoriji za dinamičko ispitivanje u Institutu za Seizmologiju i zemljotresno inženjerstvo u Skopju. Predmet eksperimentalnog istraživanja bilo je ispitivanje na vibracionoj platformi modela zidova od cigala ojačanih po sistemu DC 90 u razmeri 1/10.

*Opis modela*

Modeli su napravljeni u razmeri 1/10, dimenzija: dužina 30 cm, visina 25 cm i debljina 3,5 cm. Prvi tip modela bio je od giter blokova, drugi od obične pečene cigle, a treći od obične sušene cigle (sl. 9). Svaki tip modela je napravljen u dve varijante: kao običan model zidanog zida i kao model ojačanog zida, primenom ojačanja po sistemu DC90. Cilj je bio poređenje ponašanja zidova koji su zidani klasično i onih koji su ojačani po Sistemu DC90, pod dinamičkim opterećenjem, kao i poređenje uticaja tipa cigle na dinamičko ponašanje zida.

*Opis opreme za ispitivanje*

Vibro platforma je jedinstvena jedinica opreme za ispitivanje modela pod harmonijskom pobudom, u opsegu frekvencija od (1,0 - 100) Hz i sa opsegom amplitude od (0-10) g.

*Program ispitivanja*

Program ispitivanja se sastojao od sledećih faza:
- Definisanje rezonantnih frekvencija
- Definisanje elastičnog odgovora modela, uporedno za neojačan i ojačan model
- Definisanje graničnog stanja i mehanizma loma

Rezultati ispitivanja su prikazani u tab. 1. Proračunata krutost treba da bude pomnožena korekcionim faktorom 1/10 kako bi se dobila krutost elemenata realnih zidova. Iz rezultata je jasno vidljiv uticaj elemenata sistema DC 90 na povećanje krutosti zidova.

## SHAKING TABLE TEST OF A WALL MODEL IN SCALE 1/10, STRENGTHENED BY DC 90 SYSTEM

Testing was performed at the beginning of February 2004, in the Dynamic Testing Laboratory of the Institute of Earthquake Engineering and Engineering Seismology at Skopje. The subject of experimental investigation was shaking table test of a reduced scale models 1/10 of masonry walls strengthened by DC 90 system.

*Description of models*

The models have been constructed in scale 1/10 having the dimensions: length: 30 cm, height: 25 cm and thickness 3.5 cm. The first type of model was made by so-called giter blocks, the second one by plane burned bricks and third model by plane dried bricks (Fig. 9). Each type of model was made in two ways: as conventional and as strengthened by DC 90 System. The idea is to compare dynamic behavior of traditional and strengthening method of construction for the same type of bricks, as well as to compare the influence of brick type to dynamic behavior of the models.

*Description of testing equipment*

The single component shaking table has been used to test the models under harmonic excitation within the frequency range of 1.0-100 Hz and amplitude range (0-10) g.

*Testing program*

The testing program consists of several phases:
- Definition of resonant frequencies
- Definition of elastic response of the models (comparatively non-strengthened and strengthened)
- Definition of limit state and fracture mechanism

Result of testing are presented in Table 1. The calculated stiffness should be related to the scale factor 1/10 to obtain the actual stiffness of the real wall element. From results it can be seen clearly the contribution of the elements of System DC 90 to increasing of stiffnesss of walls.

Model 1. Šuplji giter blok - Hollow brick

Model 2 – Pečena cigla - Burned brick.

Model 3 – Sušena cigla - Dried brick

Slika 9. Modelsko ispitivanje zida na vibroplatformi
Figure 9. Shaking table test of a wall model.

Tabela 1. Izračunata krutost na smicanje modela, kN/cm
Table 1. Calculated lateral stiffness of the models, kN/cm.

| Tip modela/ Type of the model | Ojačan model/ Strengthened model | Neojačan model/ Non - strengthened.model |
|---|---|---|
| Model 1- giter blok/ hollow block | 35.53 | 24.75 |
| Model 2- pečena cigla/ burned brick | 19.95 | 10.49 |
| Model 3- sušena cigla/ dried brick | 6.48 | 4.40 |

## ZAKLJUČAK

Iz numeričke analize tokom ovog istraživanja i iz eksperimentalnih rezultata može se zaključiti da je Sistem DC 90 vrlo sofisticiarno sredstvo u rukama inženjera da reše problem sanacije oštećenih objekata. Kako se sistem primenjuje spolja, kako je jeftin i brz to je posebno pogodan za primenu u zonama velike seizmičke aktivnosti. Do sada je uspešno primenjen u Kolubarskom kraju i u Alžiru.

## CONCLUSION

From numerical analysis performed during this study and from experimental results it can be concluded that System DC 90 is powerful equipment for engineers to solve problems of retrofitting of damaged structures. Since this system is applicable outside, chip and fast can be applied properly for earthquake regions. So far it has been successfully applied in Kolubara region and Algeria.

## LITERATURA-REFERENCES


1. Petrovic, B.: Neki problemi seizmickog gradjenja, Monografija,-Stanje i pravci razvoja gradjevinske tehnike, *Materijali i konstrukcije* Beograd, 1993.,str 9-12.
2. Popov, E.P.: Bond and Achorage of Reinforcing Bars under Cyclic Loading, *ACI Structural Journal,* July-August 1984., pp 340-349
3. Petrašković, Z., Miladinović, S., Šumarac, D., Technology of seismic strengthening of masonry structures by applying vertical ties and diagonals with seismic energy absorber “System dc 90”, International conference on earthquake engineering, Parallell Session, Topic: Retrofit of structures, p T6-9, August-september 2005.
4. Taškov Lj, Manić M, Shaking table test of a brick-masonry models in scale 1/10, strengthened by DC 90 System, Institute of Earthquake Engineering and Engineering Seismology, University" Ss. Cyril and Methodius", Skopje, Republic of Macedonia, Skopje, May 2004