*Filip Miljević i Nikola Ružić **

Numerička simulacija, optimizacija i realizacija seizmičkog amortizera

U radu je posmatran problem ublažavanja uticaja zemljotresa na zgrade upotrebom različitih vrsta seizmičkih amortizera (Tunned Mass Damper, u daljem tekstu TMD) (Constantinou *et al*. 1998; Liu i Coppola 2010; Connor 2002). Numeričke simulacije vršene su u softveru Comsol. Ispitivana su tri različita modela zgrade, u dve varijante, sa i bez seizmičkog amortizera. Ispitivan je uticaj amortizera u formi opruge (slika 1a) i amortizera u formi fizičkog klatna (slika 1b) na modelu zgrade u centimetarskim dimenzijama i na modelu zgrade u metarskim dimenzijama. Treći ispitivani model je model zgrade u realnim dimenzijama, sa TMD-om u formi fizičkog klatna (slika 1c). U trećem slučaju vršeno je variranje mase i dužine klatna, čime su pronađeni optimalni parametri za prigušenje oscilacija zgrade.

Model simulirane zgrade u realnim dimenzijama se sastoji od 8 spratova. Temelj je oblika kvadra dimenzija 21 × 21 × 1 m i nepokretan je tokom simulacije. Svaki sprat se sastoji od poda dimenzija 20 × 20 × 1 m i osam stubova koji predstavljaju zidove, dimenzija 1 × 1 × 3 m. Masa zgrade iynosi $m = 9.8 \cdot 10^6$ kg, a TMD-a $m_a = 5.567 \cdot 10^3$ kg. Početni impuls je zadat vrhu zgrade i položaj vrha zgrade je praćen tokom vremena. Na slici 2a je prikazan grafik zavisnosti položaja vrha zgrade od vremena kada se na zgradi ne nalazi TMD, dok je na slici 2b prikazan slučaj kada se na zgradi nalazi fizičko klatno. Sa grafika možemo da zaključimo da prisustvo seizmičkog amortizera značajno prigušuje oscilacije zgrade, što pokazuje efikasnost klatna pri apsorbovanju energije oscilovanja zgrade (Vagelis *et al*. 2012; Chen 2010).

Koristeći Comsol izdvojene su sopstvene mode zgrade i uočena je najveća frekvencija. U simulaciji je frekvencija oscilacije podloge na kojoj se nalazi zgrada podešena blizu sopstvene frekvencije, jer je prenos energije na zgradu u tom slučaju najveći. Varirane su dužina i masa klatna i ispitivano vreme potrebno da se oscilovanje zgrade zaustavi. Na slici 3 prikazana je zavisnost vremena potpunog zaustavljanja zgrade od dužine klatna, za različite mase klatna izraženih u procentima mase cele zgrade. Minimalno vreme zaustavljanja zgrade se dobija za dužinu klatna od 7 metara i masu klatna koja iznosi 0.7% mase zgrade. Primećujemo da zgrada brzo ulazi u ravnotežno stanje, što potvrđuje uspešnost merenja.

Drugi deo projekta je uspešna implementacija seizmičkog amortizera. Realizovan je model zgrade kod koje je dodatkom seizmičkog amortizera vreme do zaustavljanja smanjeno sa 8 sekundi na 5 sekundi. Nizom empirijskih merenja eksperimentalno je potvrđen princip rada TMD-a pri prigušivanju oscilacija zgrade.

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Filip Miljević (2001), Beograd, učenik 3. razreda Matematičke gimnazije u Beogradu

Nikola Ružić (2000), Beograd, učenik 3. razreda Devete gimnazije u Beogradu

MENTOR: Stefan Graovac, Fizički fakultet Univerziteta u Beogradu

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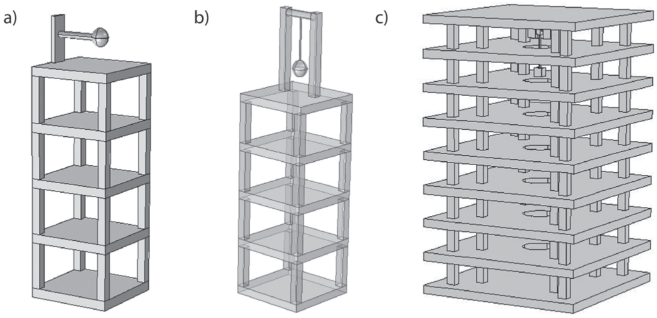


Slika 1. a) Simulirani model zgrade sa TMD-om u formi opruge;

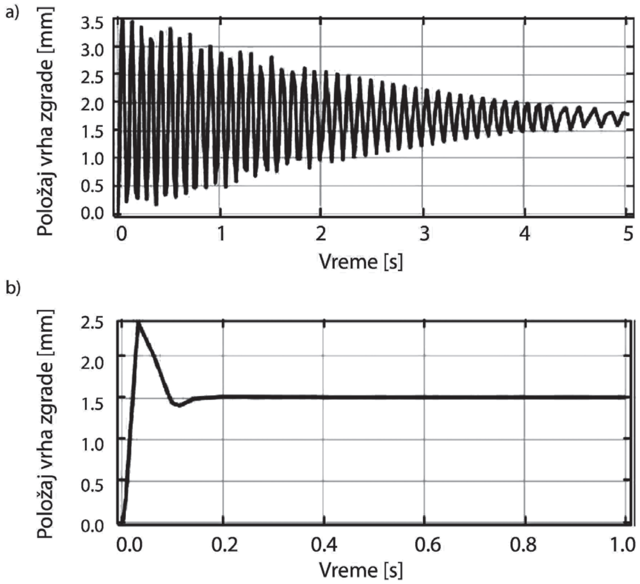
b) Simulirani model zgrade sa TMD-om u formi fizičkog klatna;

c) Simulirana zgrada sa TMD-om u formi fizičkog klatna. Zgrada je realnih dimenzija.

Figure 1. a) Simulated model of a building with the spring TMD;

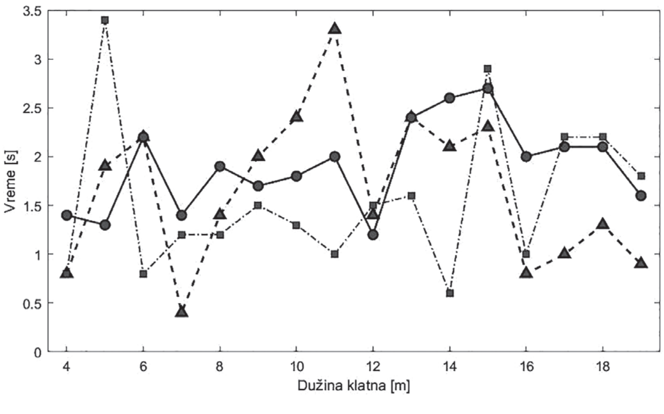
b) Simulated model of a building with the pendulum TMD;

c) Simulated model of a building with the pendulum TMD in real dimensions.



Slika 2. Grafik zavisnosti položaja vrha zgrade od vremena: a) bez TMD-a; b) sa TMD-om. Na y-osi je prikazan položaj vrha zgrade, dok je na x-osi prikazano vreme proteklo od zadavanja impulsa vrhu zgrade.

Figure 2. Graph representing the dependence of the position of the top of the building as a function of time: a) without the TMD; b) with TMD. On the y-axis the position of the top of the building is shown, and on the x-axis the time since the initial momentum is given.



Slika 3. Zavisnost vremena potrebnog zgradi da se umiri od dužine klatna. Trouglovi označavaju rezultate kada je masa TMD-a jednaka $\eta = 0.7\%$ mase cele zgrade, plusevi označavaju rezultate za $\eta = 0.9\%$, a krugovi $\eta = 5\%$ mase cele zgrade.

Figure 3. Dependence of the time needed for the building to stop the motion as a function fo the length of the pendulum. The triangles represent the results when the mass of the TMD is equal to $\eta = 0.7\%$ of the mass of the building, pluses for $\eta = 0.9\%$, and the circles for $\eta = 5\%$ of the mass of the building.

Vagelis P., Chara C. M., Nikos D. L. 2012. *Structural seismic design optimization and earthquake engineering: formulations and applications*. Hershey: IGI Global

Numerical Simulation, Optimization and Realization of Tuned Mass Dampers

In this paper we considered ways of mitigating the effects of earthquakes on buildings using different kinds of seismic dampers called Tuned Mass Dampers (TMD) (Constantinou *et al*. 1998; Liu i Coppola 2010; Connor 2002). Numerical simulations were done in the Comsol software. Simulations were made for three different models of buildings, of which every model had two cases: with and without TMDs. TMDs were modeled in two forms, in a form of a spring (Figure 1a) and as a physical pendulum (Figure 1b), mounted on the building models which were in centimeter and meter dimensions. The third model depicted a building with realistic dimensions and a pendulum TMD (Figure 1c). Optimization was done on the third model, where the optimal parameters for oscillation damping were found, by varying the mass and length of the pendulum.

The model of the simulated building in real dimensions consists of 8 levels. The foundation is in a shape of a cuboid, dimensions 21 × 21 × ×1 m, and is fixed and unmovable. Every level is of the dimensions 20 × 20 × 1 m, and contains 8 pillars that represent walls of the dimensions 1 × 1 ×3 m. The mass of the building is $m = 9.8 \cdot 10^6$ kg, of the TMD is $m_a = 5.567 \cdot 10^3$ kg. Initial momentum was applied on the top of the building and the position of the top of the building was plotted as a function of time. The graph of the position of the top of the building versus time with the TMD is shown in Figure 2a, whereas the case without the TMD is shown in Figure 2b. If we take a look at these graphs we can conclude that the TMD greatly muffles the oscillations of the building, which shows the effectiveness of the pendulum TMD in absorbing the energy of the oscillating building (Vagelis *et al*. 2012; Chen 2010).

Using Comsol we distinguished the eigenmodes of the building and detected the biggest frequency. In the simulation the frequency of the oscillation of the foundation is set to be near to the natural frequency, because the flow of the energy onto the building is the biggest in this case. The length and the mass of the pendulum were varied and the time needed for the oscillations of the building to stop was examined. In Figure 3 the dependence of the time needed for the building to completely stop as a function of the length of the pendulum is shown. Different lines represent the different masses of the pendulum. The minimum time found appears for the length of the pendulum of 7 meters and mass of the pendulum equal to the 0.7% of the mass of the whole building. We notice the building quickly stops, which confirms the success of the measurements.

The second part of the project is the successful implementation of the TMD. The model of the building was constructed, where the stop time was reduced from 8 to 5 seconds by adding the TMD onto the building. The series of experiments has confirmed the principle that the TMD works while absorbing the oscillations of the building.