



OBNOVA GRADA ZAGREBA NAKON POTRESA
Ciklus predavanja: Znanjem za Zagreb (i Hrvatsku) - Zagrebu od Rijeke

Dinamika blokovskih sustava: što smo naučili iz eksperimentalnih ispitivanja

Nina Čeh

Građevinski fakultet u Rijeci



Uvod

Ponašanje povijesnih građevina i suhozidanih sustava prilikom dinamičkog opterećenja



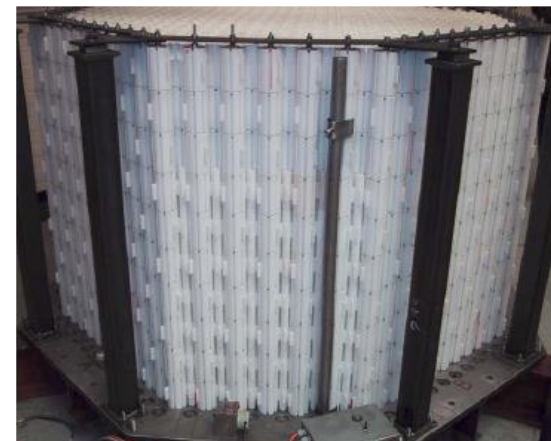
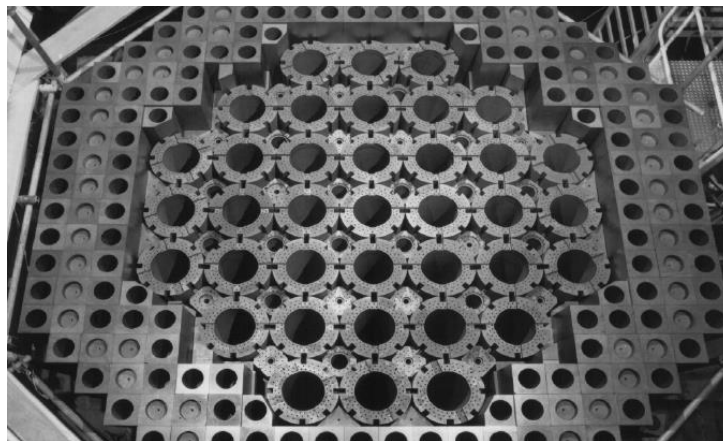
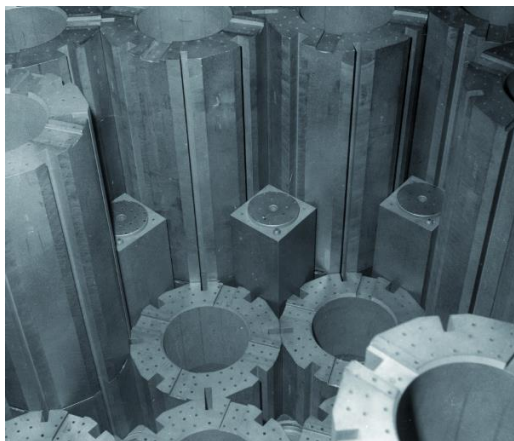
Ponašanje zidanih konstruktivnih elemenata nakon popuštanja veziva



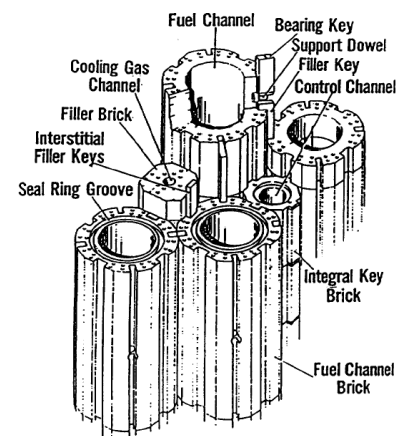


Uvod

Industrija: dinamički odziv grafitne jezgre u nuklearnim elektranama (veliki broj krutih nepovezanih blokova u nekoliko slojeva)



Ljuljanje kao mjera disipacije energije potresa?
(Makris, 2014)





Uvod

Istraživanje se provodi(lo) u sklopu projekata:



• **“Evidence Based Characterisation of Dynamic Sensitivity for Multiblock Structures – Computational Simulation and Experimental Validation” (2013-2015):**

- Tim: **Nenad Bićanić**, Nina Čeh, **Gordan Jelenić**, Jean-Francois Camenen, Tomasz Koziara, Nik Petrinić



• **“Collisions in rocking multi-body systems – experimental and numerical investigation” (2019):**

- Tim: **Nina Čeh**, Nik Petrinić



• **“Ljuljanje krutog bloka na elastičnoj konstrukciji – pristup metodom neglatke kontaktne dinamike i eksperimentalna provjera” (2019-2020) :**

- Tim: **Gordan Jelenić**, Teo Mudrić, Nina Čeh, Miran Tuhtan, Martin Arnold, Stefan Hante, Marina Paschowski



MARTIN-LUTHER-UNIVERSITÄT
HALLE-WITTENBERG

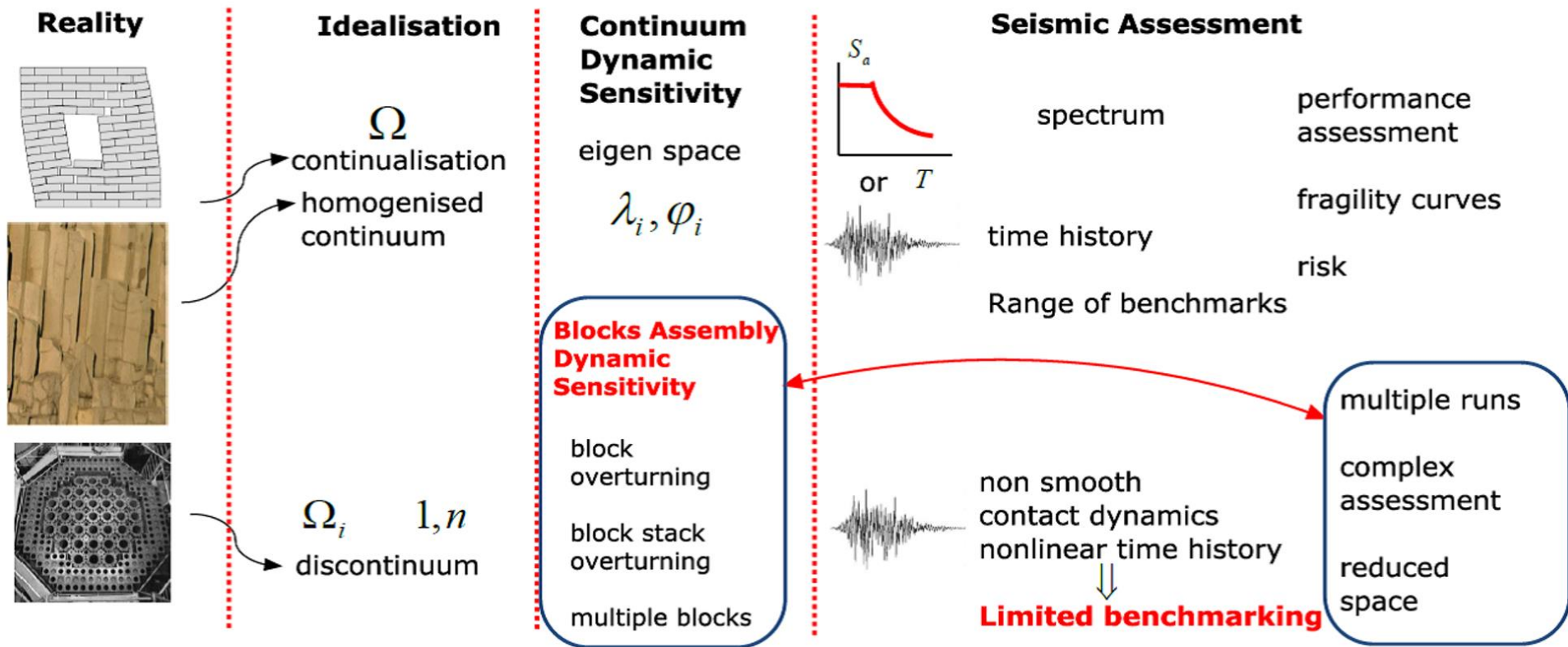
Dio prikazanih rezultata je napravljen u sklopu radova slijedećih studenata:

- Paula Babić (završni rad, 2019.)
- Lidija Rendulić (završni rad, 2019.)
- Dorian Brnić (završni rad, 2020.)
- Emina Smlatić (završni rad, 2020.)
- Nikola Trbović (završni rad, 2020.)



Uvod

Možemo li karakterizirati dinamički odgovor blokovskih konstrukcija?

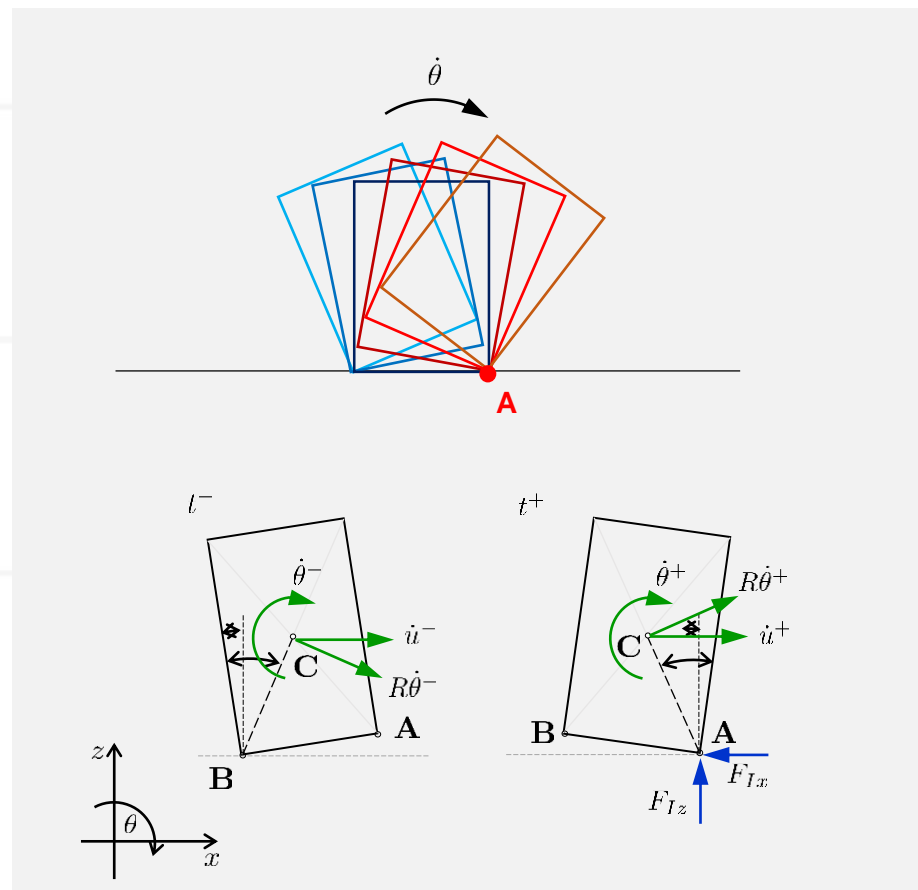
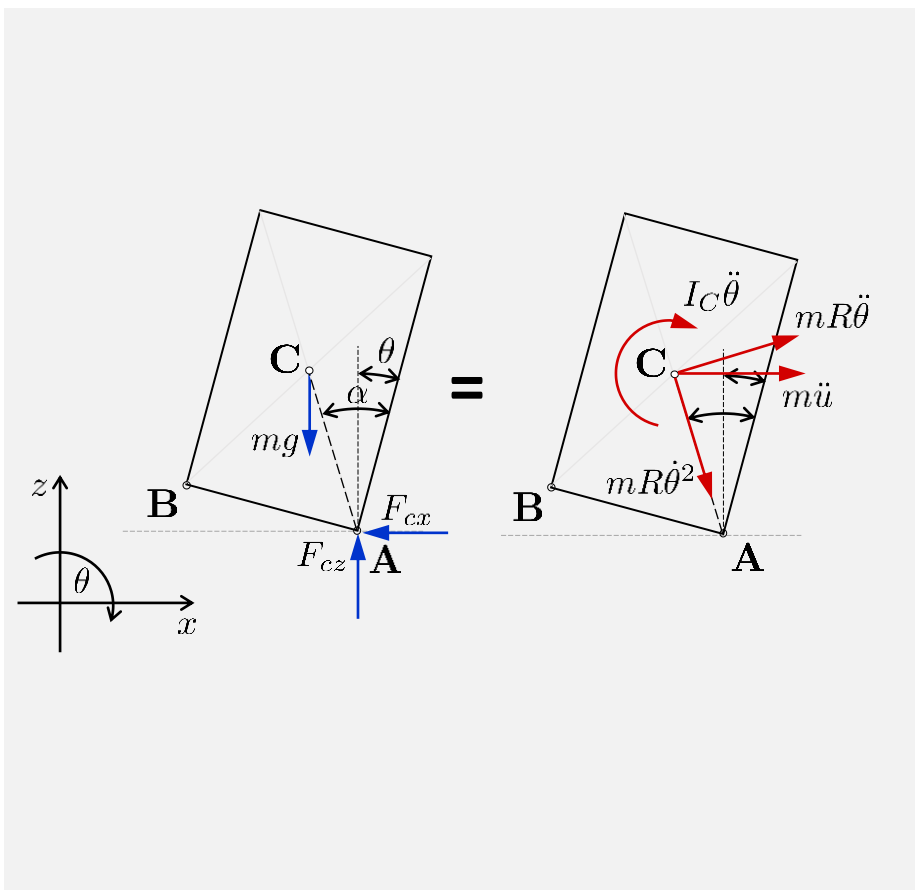


Continuous or Discontinuous Simulation Routes to Dynamic Assessment of Multi Block Structures



Mehanika ljuljanja

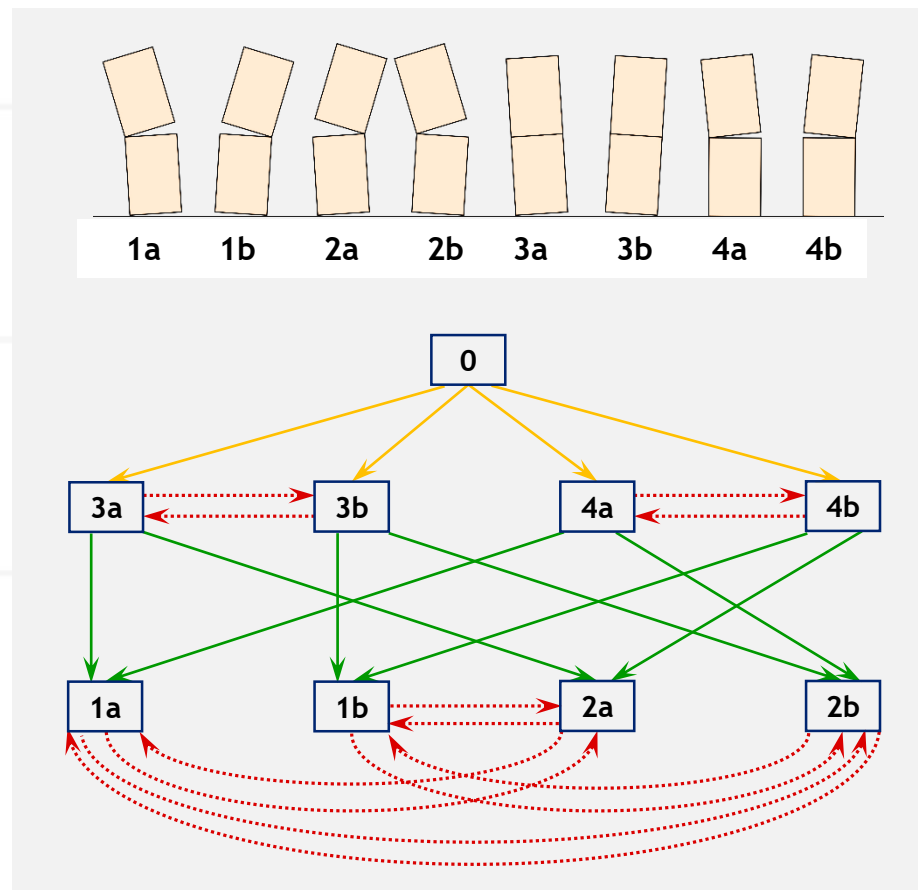
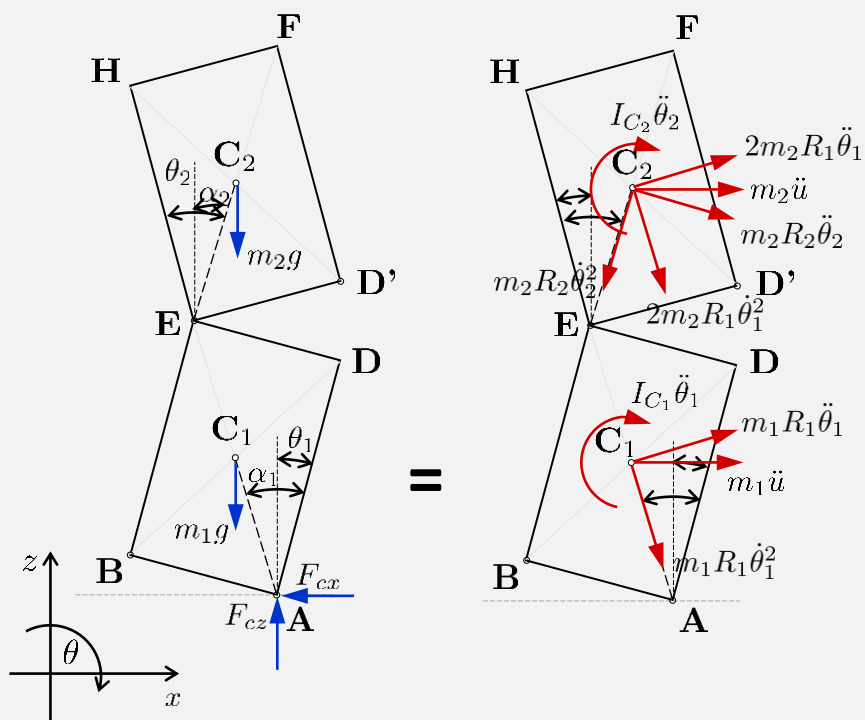
Ljuljanje jednog krutog pravokutnog bloka na krutoj podlozi bez proklizavanja:





Mehanika ljuljanja

Ljuljanje stupca od dva bloka na krutoj podlozi bez proklizavanja:





Eksperimentalni postav

Tlocrt:

Kontrolna jedinica

SUSTAV ZA
POBUĐIVANJE

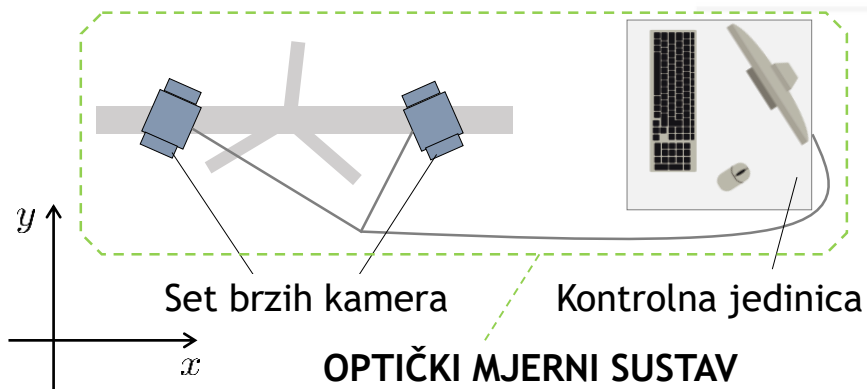
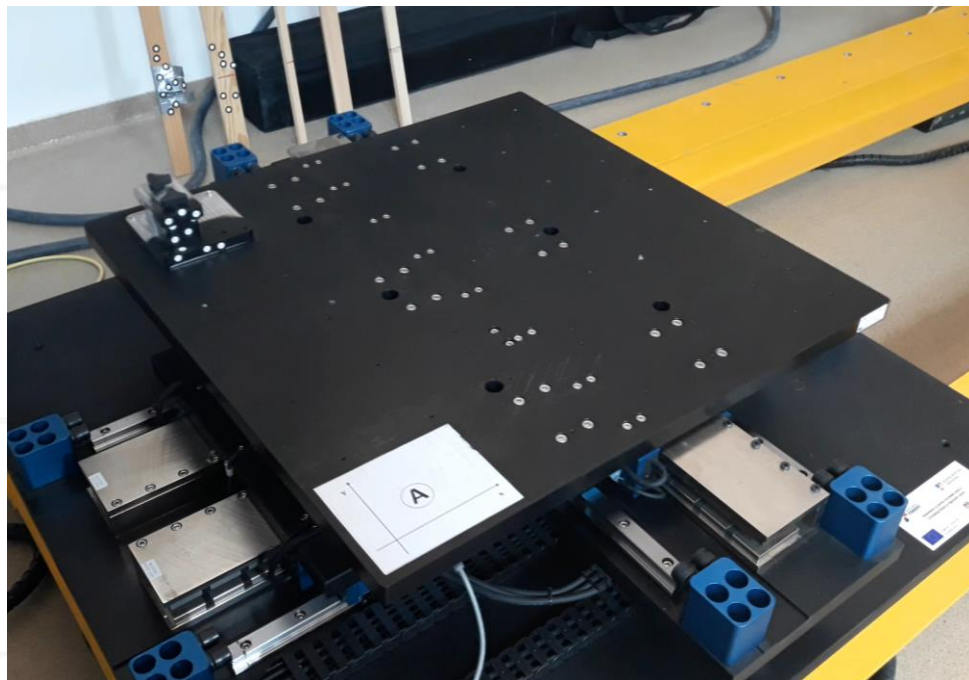
Potresna
platforma

MJERNI VOLUMEN
(uzorci)

Set brzih kamera

Kontrolna jedinica

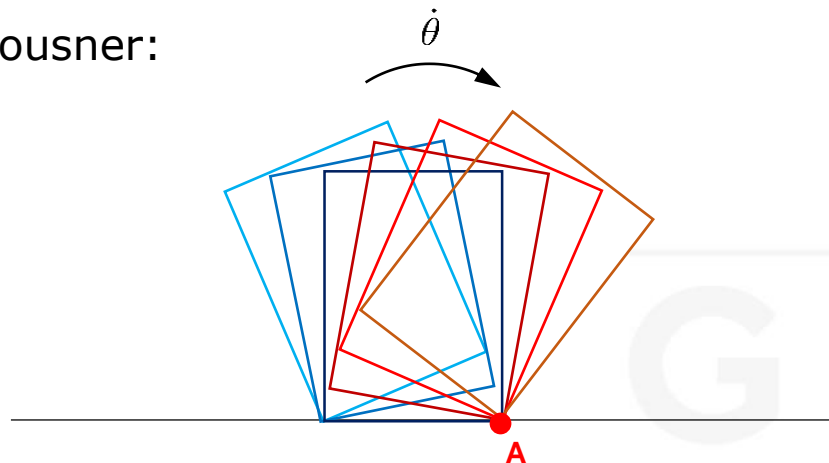
OPTIČKI MJERNI SUSTAV





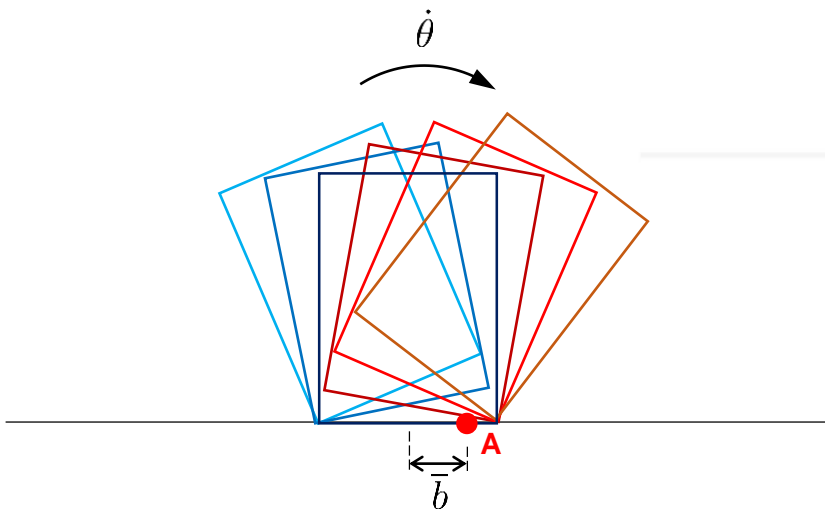
Koeficijent restitucije

Housner:



$$\Delta J_A = 0 \longrightarrow \eta_H = 1 - \frac{3}{2} \sin^2 \alpha$$

Kalliontzis i dr., Chatzis i dr.:

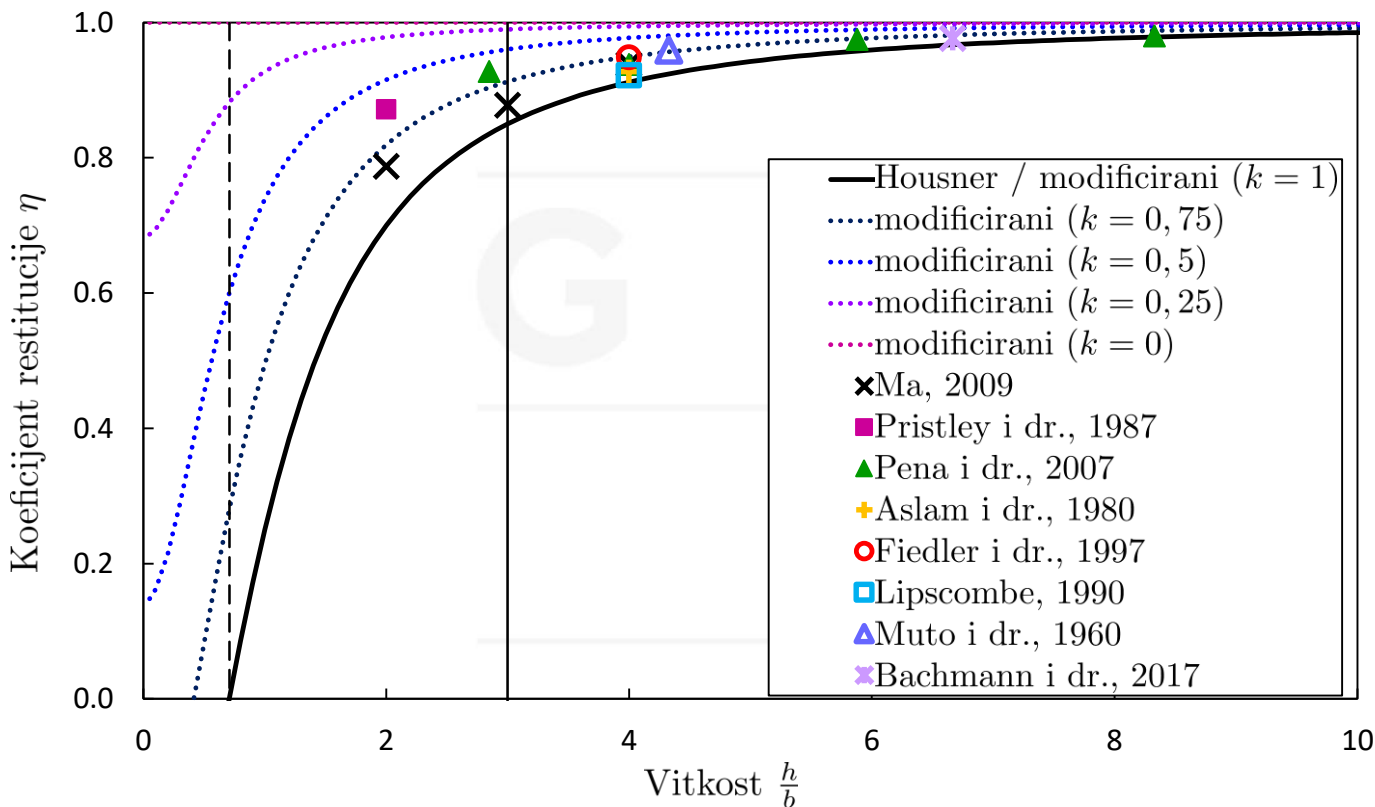


$$\Delta J_A = 0 \longrightarrow \eta_M = \frac{4 - 3 \sin^2 \alpha (1 + k^2)}{4 - 3 \sin^2 \alpha (1 - k^2)}$$

$$k = \frac{2\bar{b}}{b}$$

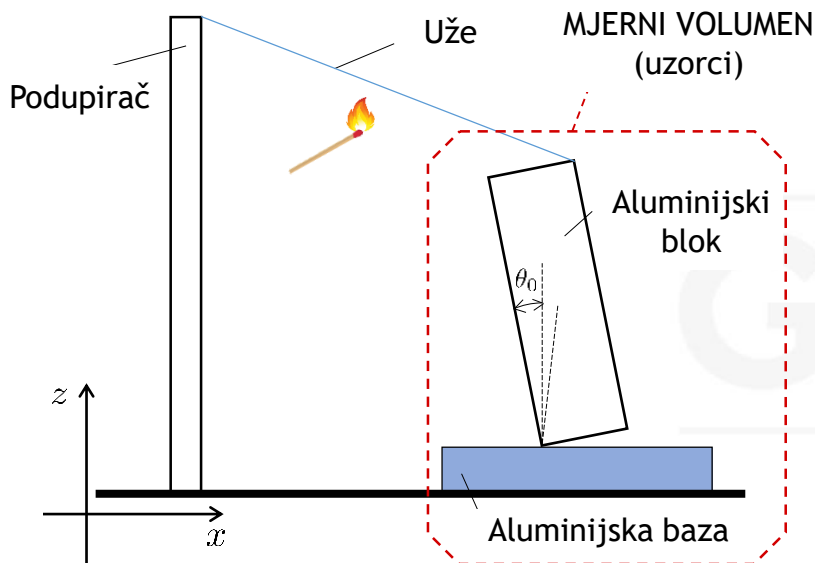


Koeficijent restitucije

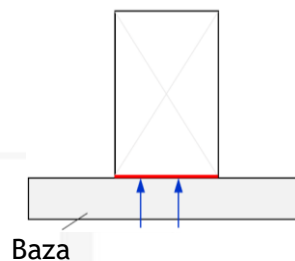




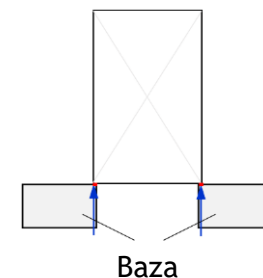
Koeficijent restitucije



Dopušten potpuni kontakt



Kontakt na rubovima
 $l = 1,5 \text{ mm}$

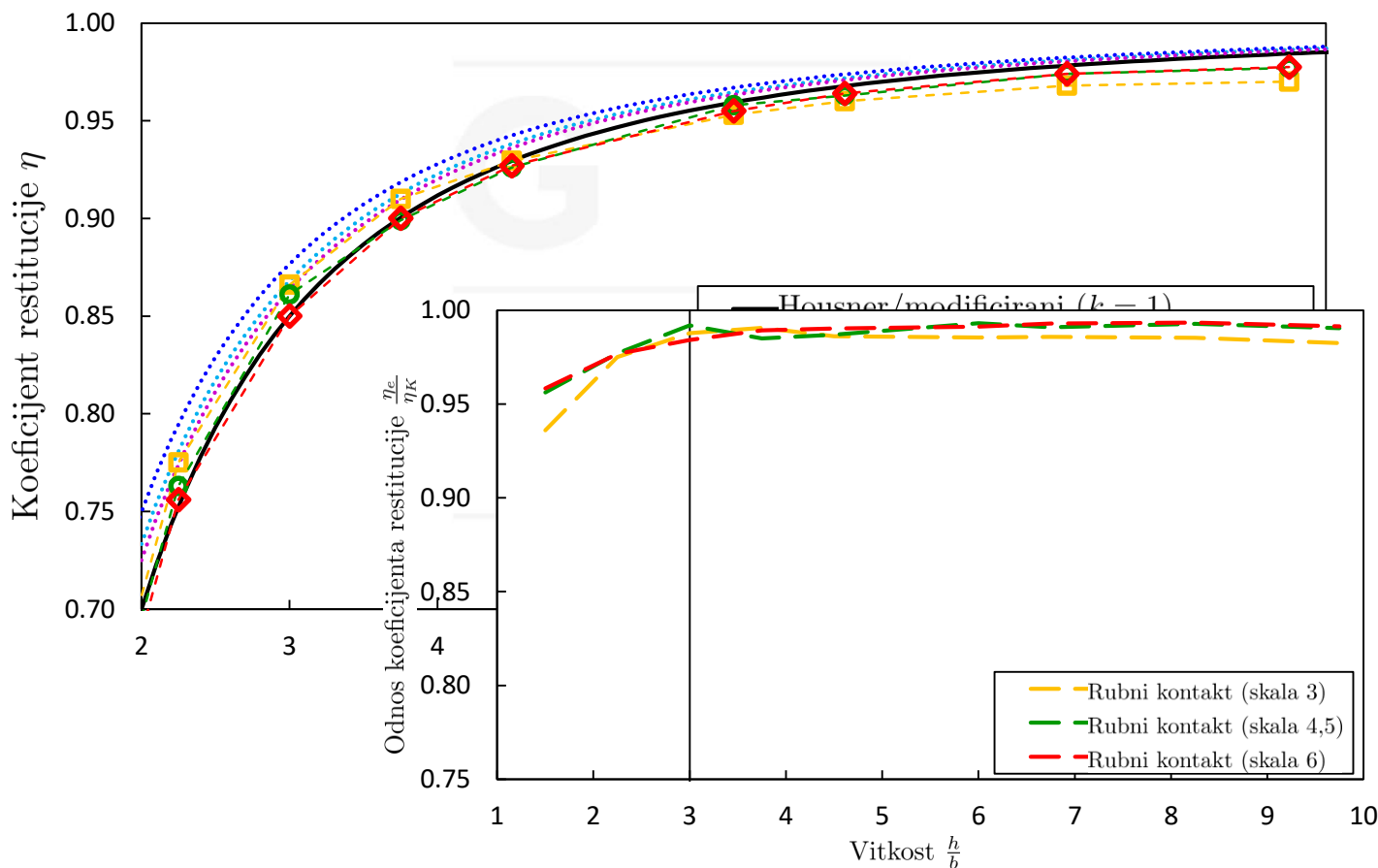
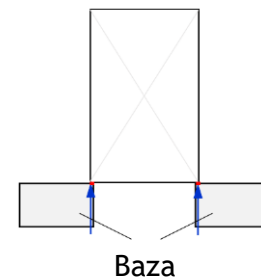


Skala	\bar{b} [mm]	k
3	13,5	0,9
4,5	21	0,93
6	28,5	0,95



Koeficijent restitucije

Kontakt na rubovima
 $l = 1,5 \text{ mm}$

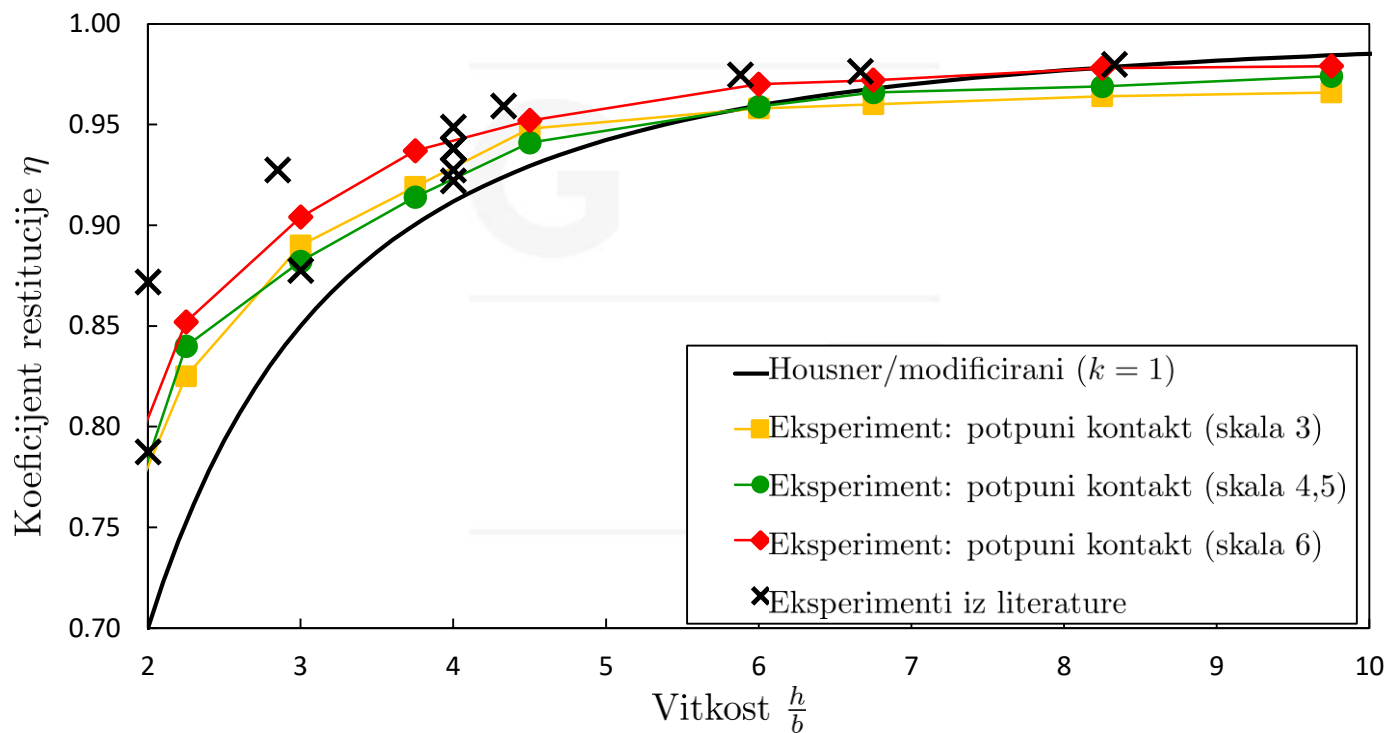
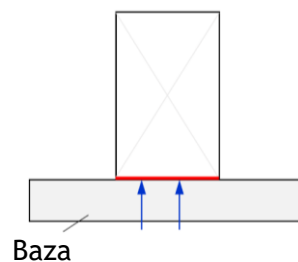


$$\eta_{mat} = \frac{\eta_e}{\eta_K} \approx 0,989$$



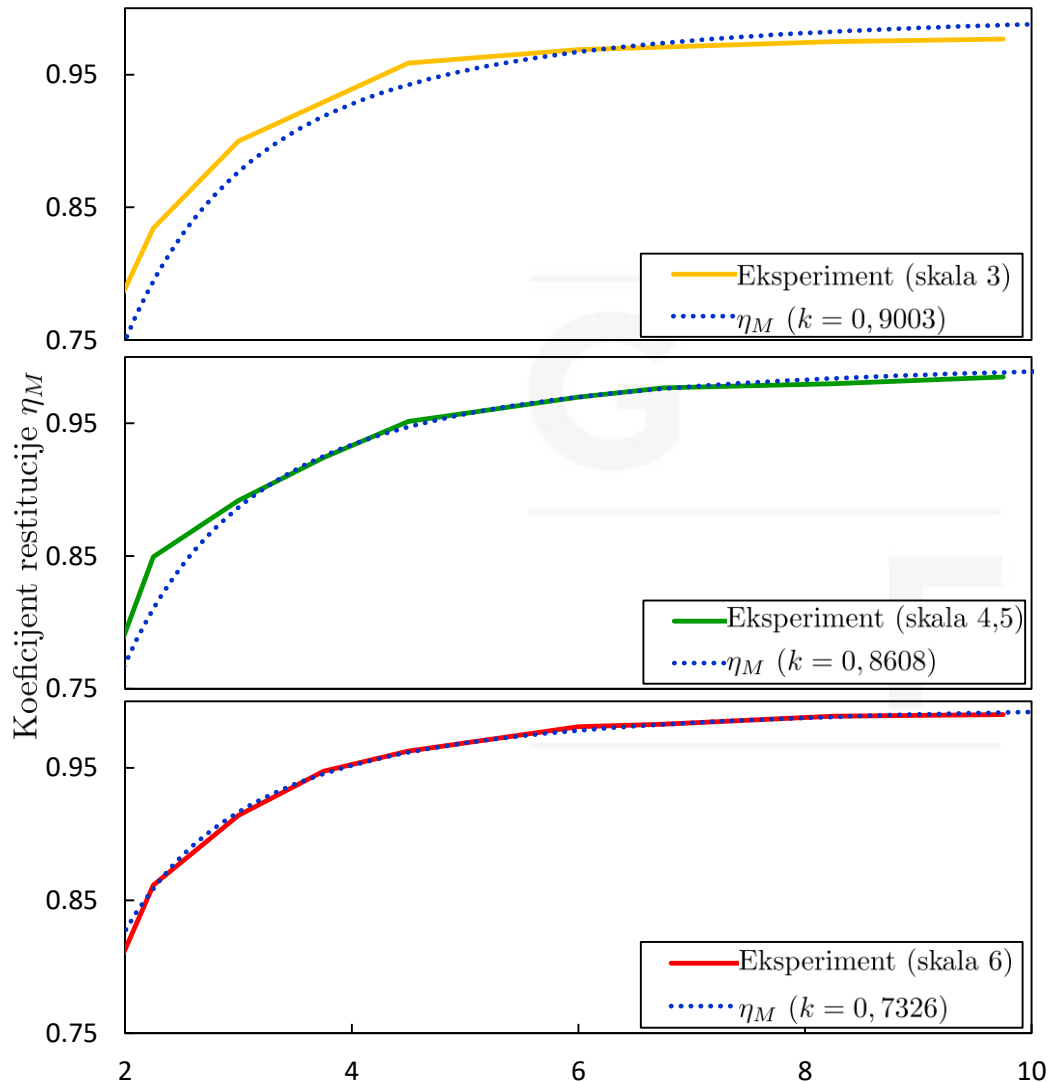
Koeficijent restitucije

Dopušten potpuni kontakt





Koeficijent restitucije



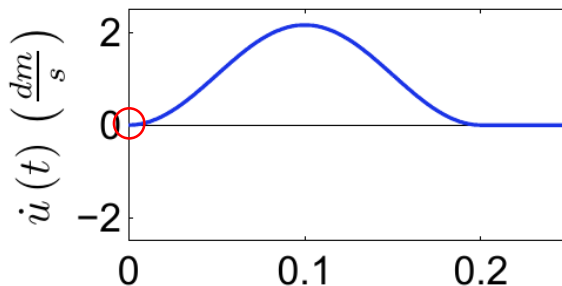
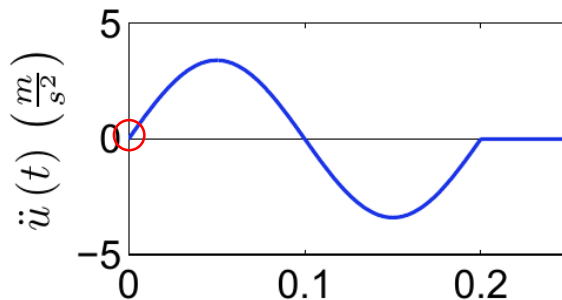
↓
Veličina

↓
Koeficijent restitucije

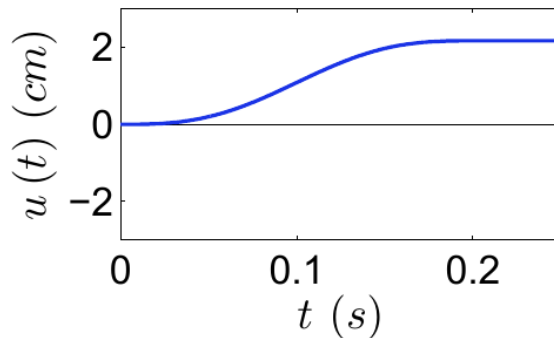
↑
Zavisnost koeficijenta restitucije o vitkosti



Harmonijsko opterećenje

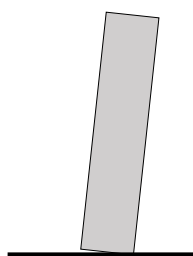


Eksperimentalna validacija:

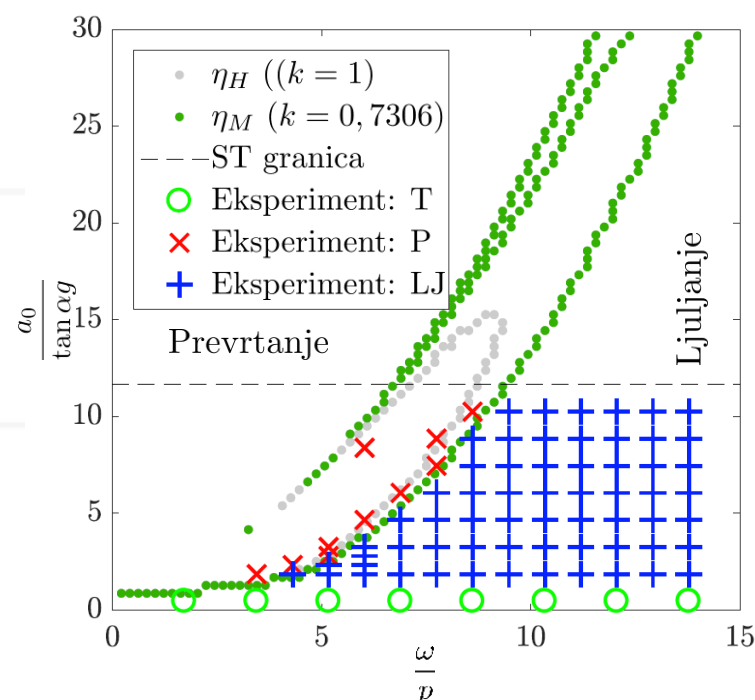
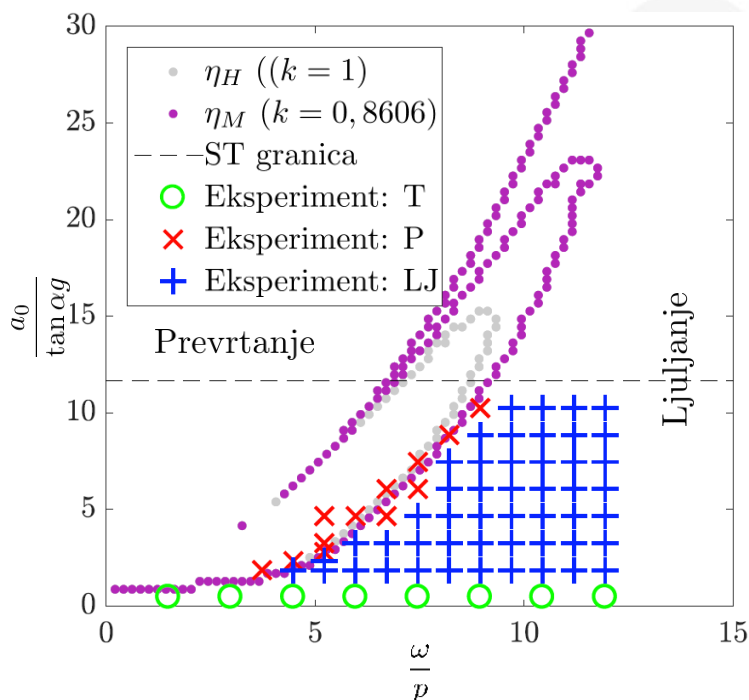




Harmonijsko opterećenje

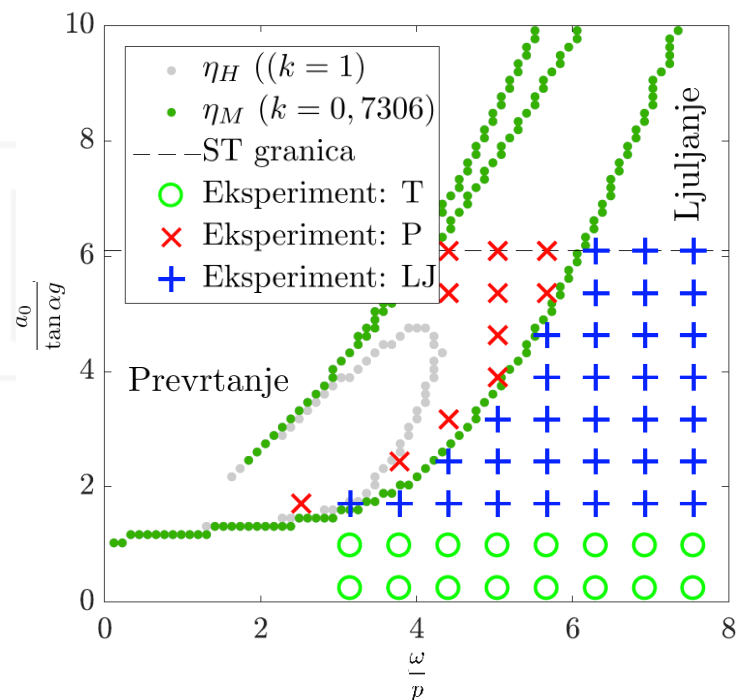
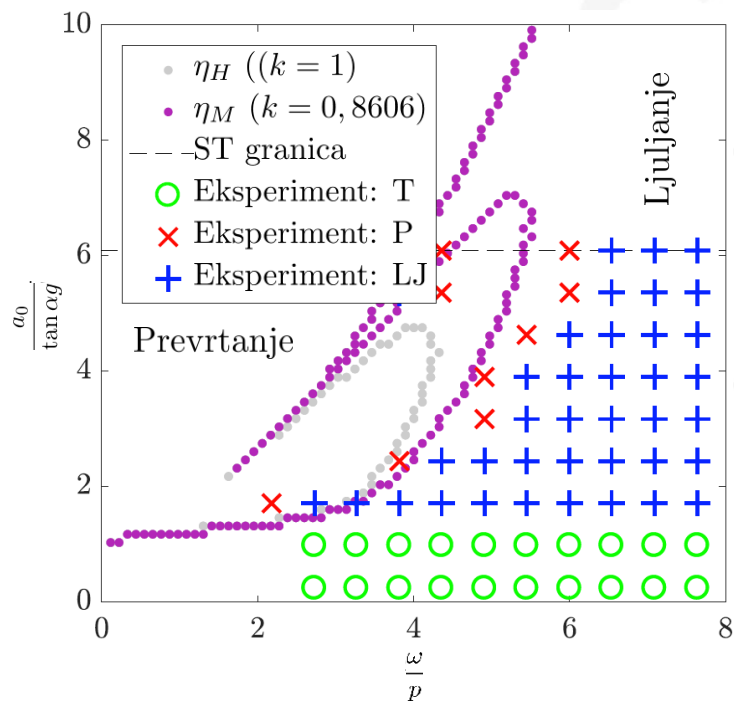
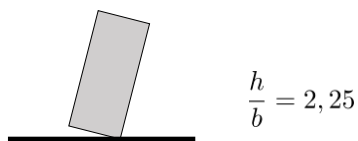


$$\frac{h}{b} = 4,5$$



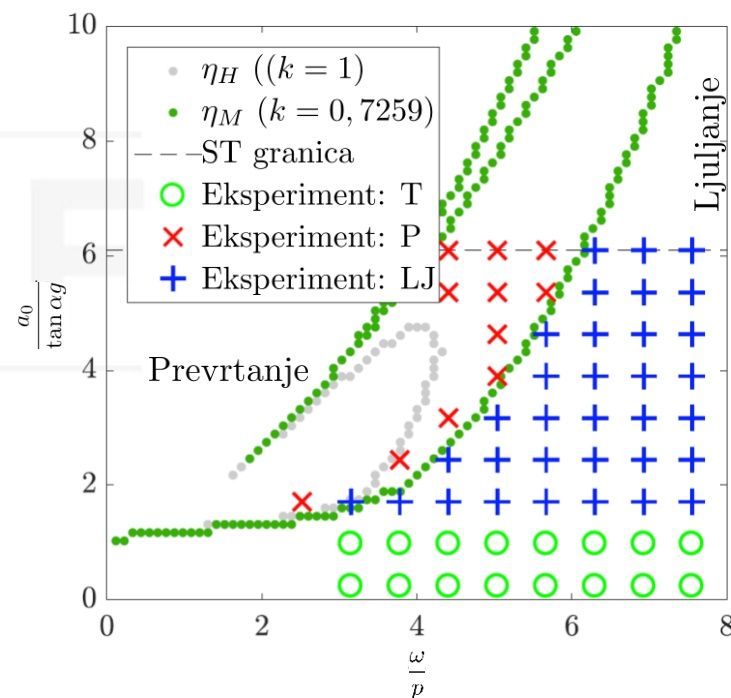
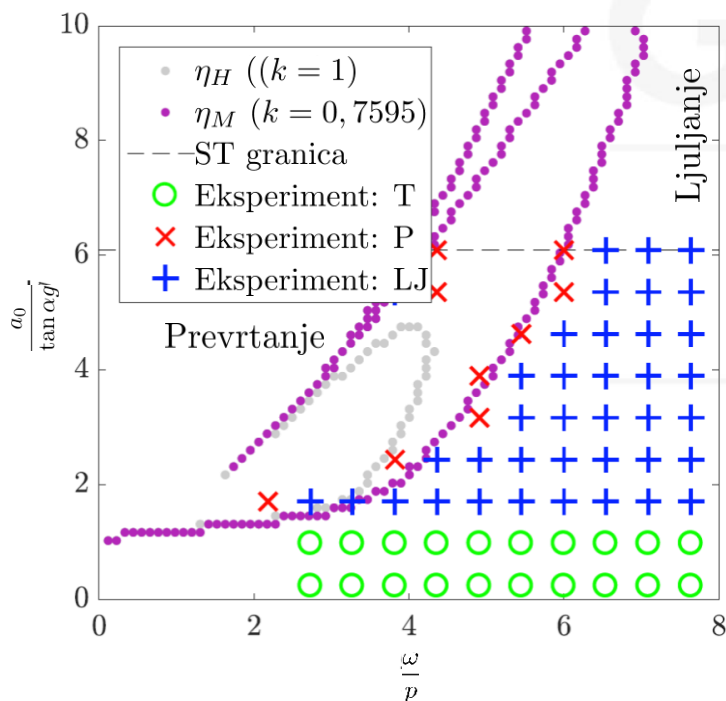
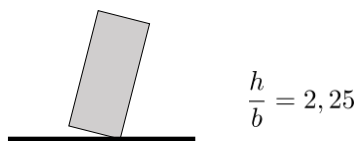


Harmonijsko opterećenje



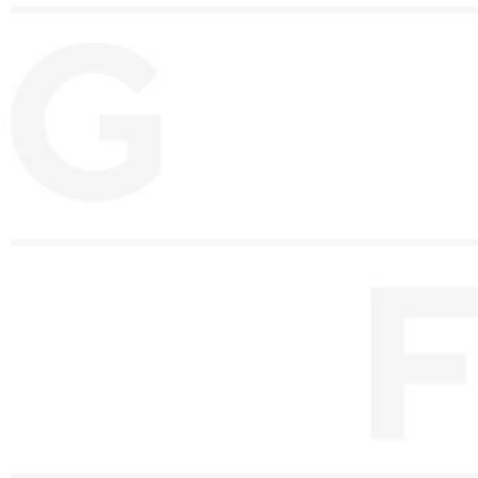


Harmonijsko opterećenje





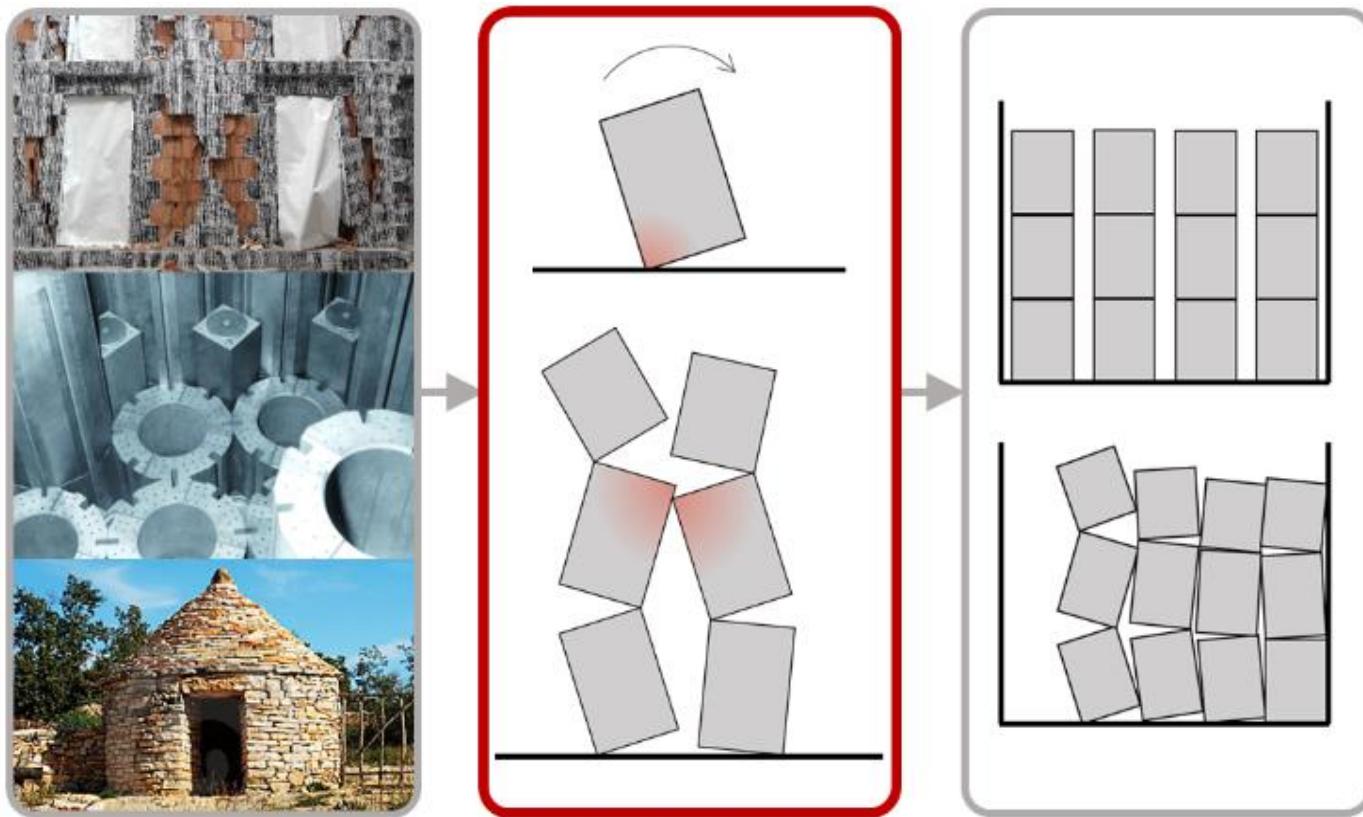
Što dalje?





Horizontalni sudar blokova

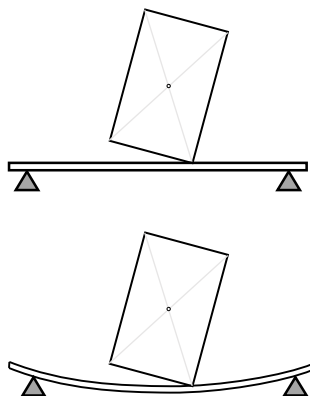
- **Collisions in rocking multi-body systems – experimental and numerical investigation** (2019)
- **Horizontalno sudaranje susjednih konstrukcija uslijed dinamičke pobude podloge** (2021)





Blok na gredi

- Ljuljanje krutog bloka na elastičnoj konstrukciji – pristup metodom neglatke kontaktne dinamike i eksperimentalna provjera (2019-2020)



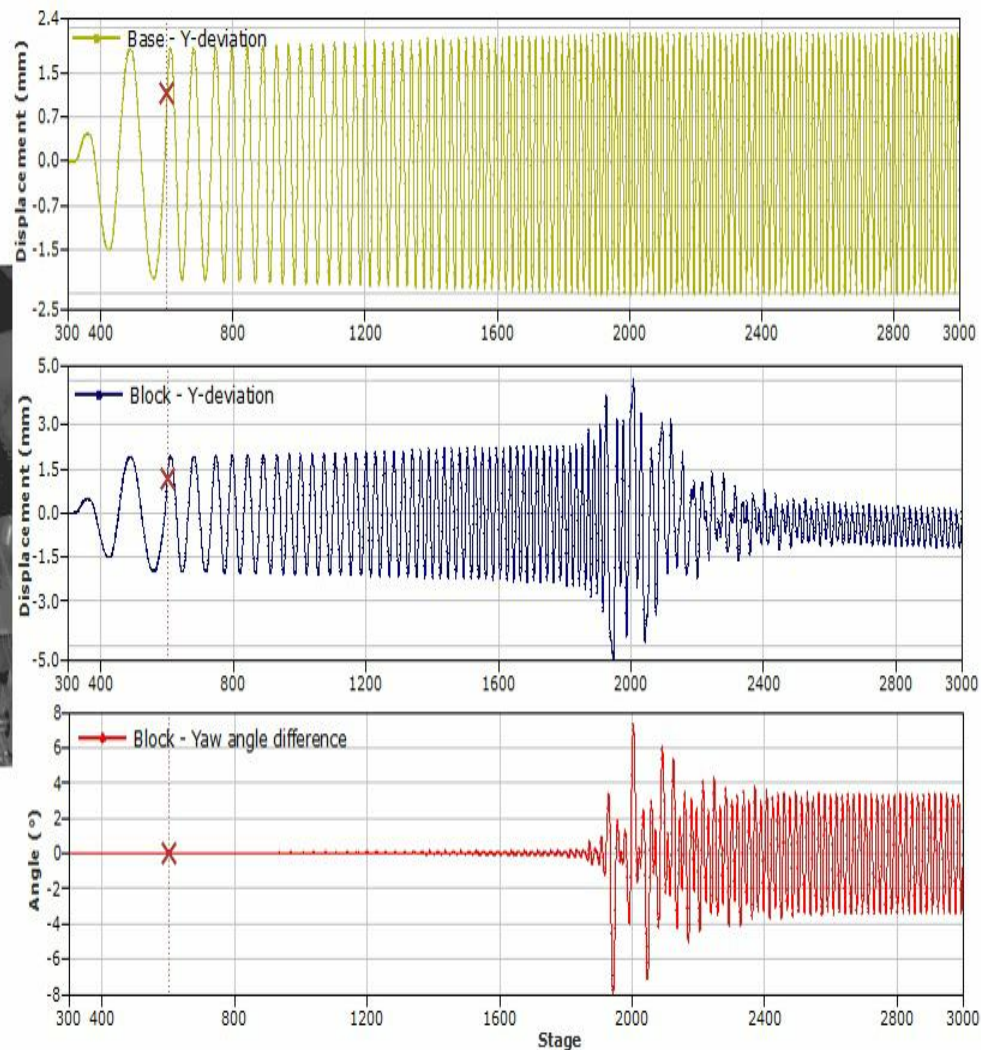
Stage 601
TK-DE bilateral project: test2

11/3/2020

70 fps



Left camera image





Za kraj

Stupac od tri bloka na potresnoj platformi podvrgnut harmonijskoj pobudi
Kvazi-periodično ljuljanje donjeg bloka između 14 s i 22,5 s:

