



**Българска академия на науките
Национален институт по Геофизика, Геодезия и География
Департамент „Сеизмология и Сеизмично инженерство“**

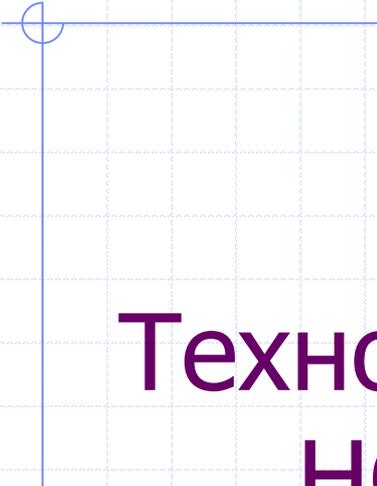
Технологично надграждане на НССЗД и интегриране с НОТССИ. Паралелни научни изследвания

**проф. Радан Иванов, гл. ас. Тодор Желязов,
доц. Емил Ойнаков, доц. Лилия Димитрова**

Съдържание:

- ◆ Технологично надграждане на НССЗД и интегриране с НОТССИ.

- ◆ Съпътстващи изследвания:
 - Моделиране на анизотропни повреди в циментови композити;
 - Приложение на алгоритми за машинно обучение в изследването на динамичното поведение на рамки;
 - Числено изследване на земетръсни характеристики;
 - Числено изследване на напрегнатото и деформирано състояние земната кора вследствие на геодинамични събития;
 - Анализ на люлеенето на сгради при земетръс чрез Метода на дискретните елементи.



Технологично надграждане на НССЗД и интегриране с НОТССИ

Текущо състояние на НССЗД

- ◆ 14 инструмента Etna, инсталирани предимно на станции на НИГГГ-БАН след 2005 г.;
- ◆ Запис чрез тригериране;
- ◆ Връзка чрез GSM модем.

Акселерограф ЕТНА



Акселерограф ETNA

Data Acquisition

Type:	Over sampled delta sigma system with 24-bit digital signal processor
Number of channels:	Three channels (standard)
Dynamic range:	108 dB @ 200 sps
Frequency response:	DC to 80 Hz @ 200 sps
Resolution:	18-bit resolution @ 200 sps
Noise:	< 8 μ V RMS
Sampling rate:	100, 200, 250 sps
Input range:	+/- 2.5V
Chan/chan skew:	None – simultaneous sampling of all channels
Anti-alias filter:	Brickwall FIR filter. Cut-off at 80% of output Nyquist. 120 dB down at output Nyquist.
Real time digital output:	RS-232 output of digital stream

Sensor

Type:	Triaxial EpiSensor force balance accelerometer, orthogonally oriented, internal (standard), external (optional)
Full scale range:	2g (standard); 4g, 1g, 0.5g (optional)
Bandwidth:	DC to 200 Hz
Dynamic Range:	155 dB+

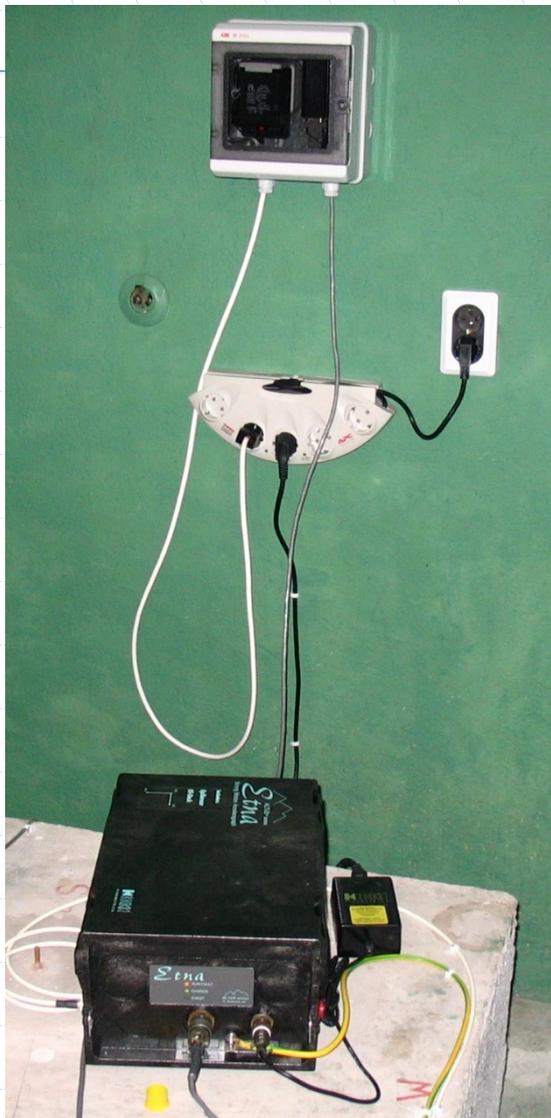
Типична станция



Инсталирана Etna



Комунікація – GSM модем



Концепция за надграждане и интегриране с НОТССИ

- ◆ Използване на съвместими инструменти в двете мрежи;
- ◆ Използване на единна комуникационна платформа;
- ◆ Единно непрекъснато записване и архивиране на данните.

Реализация:

- ◆ Закупване и инсталиране на нови записващи устройства;
- ◆ Закупване и инсталиране на нови сензори.

Нови записващи устройства



Wrangler-HDR

- » Earthquake Early Warning
- » Local and regional broadband seismic networks
- » Induced seismicity monitoring
- » Aftershock and portable deployments
- » Microzonation surveys
- » Site noise surveys

Спецификации

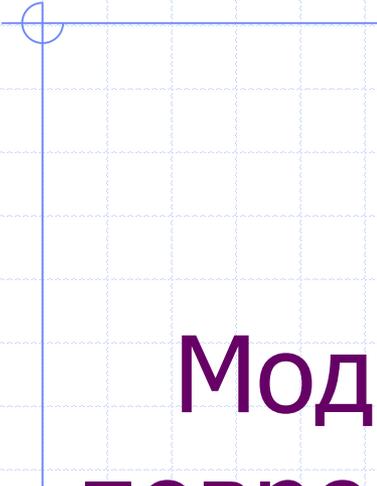
A/D CONVERTER	
Type	32-bit SAR A/D converters Configurable 24 and 30 bit output resolutions
Dynamic Range	~143 dB typical (wideband) @100 sps
Input Channels	3 or 6
Gain Selection	x1, x4, x16 and x64 (Optional x1, x2, x16 and x32)
Input Full Scale	40 Vpp @ x1 gain, 0.625 Vpp @ x64 gain
Input Impedance	26 Kohms, 0.002 uFd, differential @ x1 2 Mohms, 0.002 uFd, differential @ x64
Sample Rates	4000, 1000, 500, 250, 200, 125, 100, 50, 40, 20, 10, 5, 1, 0.1 sps
Multiple Sample Rates	Supported for rates in the group 1000, 200, 100, 50, 40, 20, 10, 5, 1, 0.1
Sampling	Simultaneous on all channels
FIR Filter	~140 dB down in the stopband

Нови сензори



Спецификации

MODEL	147A
ELECTRICAL	
Full-scale Range	4 g
Full-scale Output	10 V differential, 20 VPP
Sensitivity	2.5 V/g
PERFORMANCE	
Self-Noise	<1 $\mu\text{m/s/s}$
Dynamic Range	>155 dB (DC to 10 Hz)
Linearity	<0.1 %
Frequency Response	Flat DC-100 Hz +/- 0.05 dB ; DC-250 Hz +/- 3 dB
Damping	0.7
Self-test Response	Logic level input will produce consistent g level output
Lightning Protection	Built-in surge protection
Cross Axis Sensitivity	<1%
Hysteresis	<0.1% of full-scale
Thermal Drift	$\leq 600 \mu\text{g}/^\circ\text{C}$



Моделиране на анизотропни повреди в циментови композити

гл. ас. Тодор Желязов

1. Introduction
2. Specimens loaded in compression
3. Specimens loaded in compression: healing
4. Specimens loaded in tension-by-flexure
5. Specimens loaded in tension-by-flexure: healing
6. Damage-induced anisotropy
7. Concluding remarks

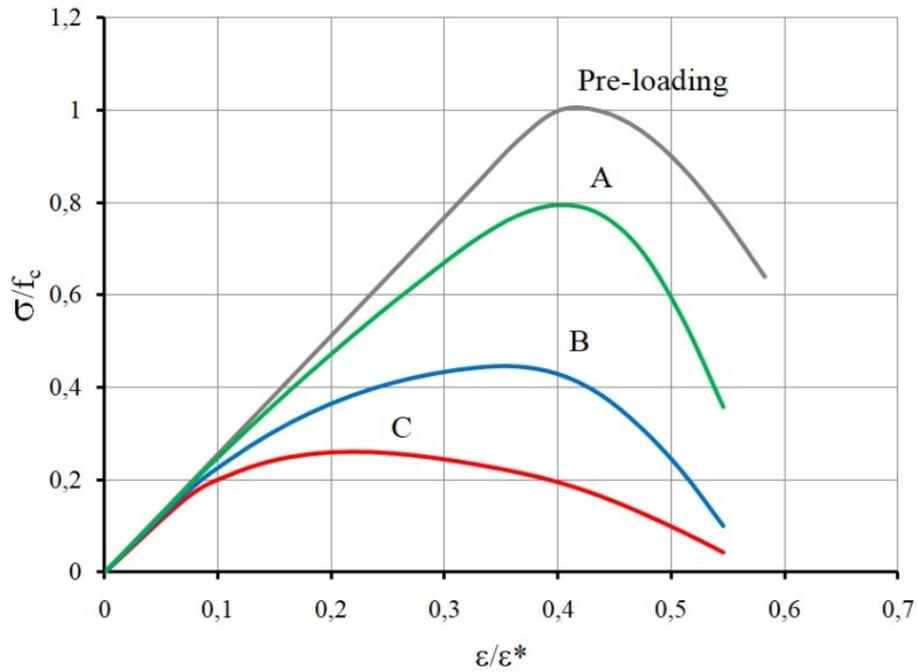
Continuum damage mechanics (Lemaitre, 1996): a damage variable (scalar or tensor) is incorporated into the material constitutive relationship. The classical interpretation implies modifying the material properties dependent on the progressive damage accumulation.

Some models can be regarded as an extension of continuum damage mechanics aimed at also capturing **self-healing** effects, besides degradation.

Scalar damage variable (Granger et al., 2007): a damage variable acting on the material elasticity modulus and another variable to evaluate healing with the option to incorporate a second damage variable to account for damage in the already-healed material; Mergheim and Steinmann (2013): comparable approach involving a time-dependent function to quantify the relative portion of cured material

Independent variables for different principal directions (Barbero et al. 2005): three independent healing variables for the three principal material directions within the assumption that the principal directions of damage and healing coincide (for a self-healing composite)

Tensorial variable (Voyiadjis et al., 2011): damage tensors to capture the overall degradation, the isotropic hardening and the kinematic hardening

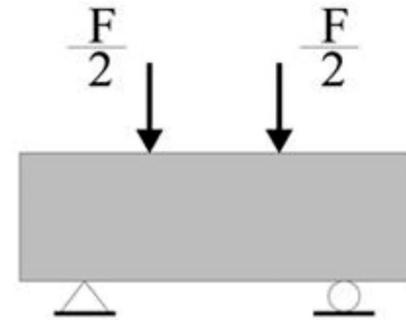
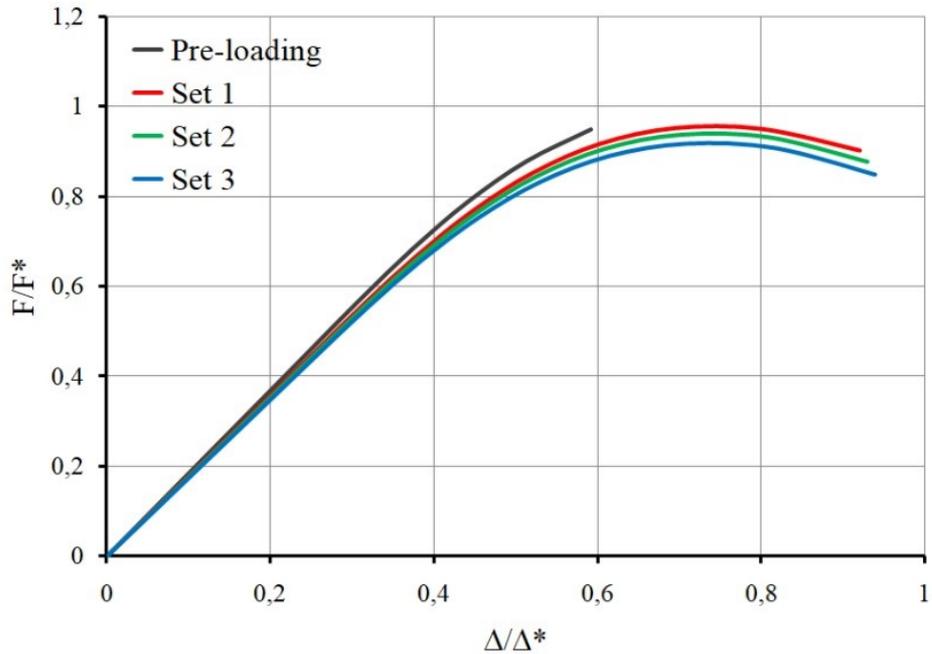


A \rightarrow 0.7 D_{\max}

B \rightarrow 0.5 D_{\max}

C \rightarrow 0.3 D_{\max}

Tension by flexure: healing

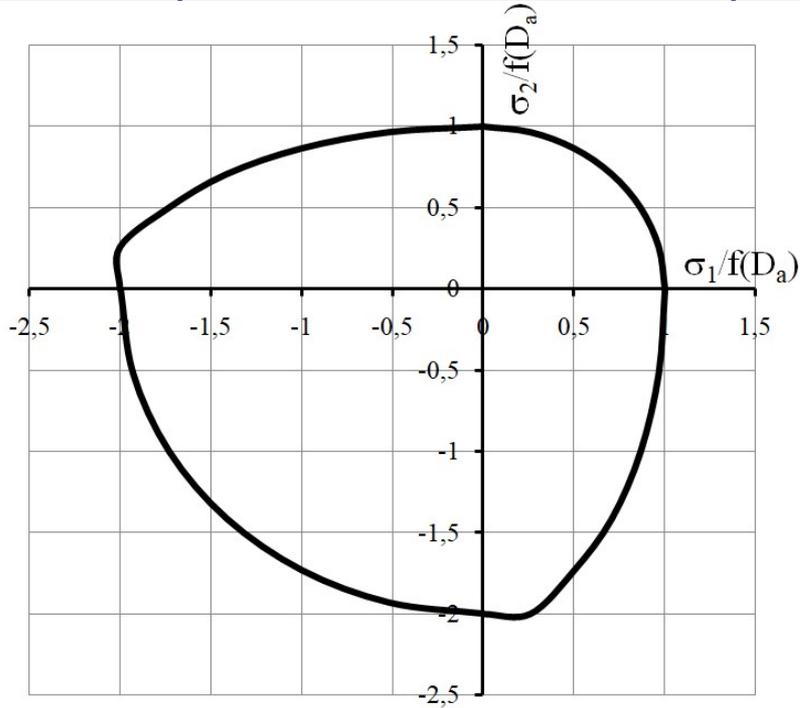


Set 1 $\rightarrow 0.5 D_{\max}$

Set 2 $\rightarrow 0.4 D_{\max}$

Set 3 $\rightarrow 0.3 D_{\max}$

Elasticity domain in a 2-D stress space



Damage function:

$$\Omega = \frac{1}{2} \sigma^+ : \sigma^+ + \frac{1}{2} \sigma^- : \sigma^- - \frac{1}{2} f^2(D_a)$$

$\Omega < 0$

Elastic domain

$\Omega = 0$

Damage initiation

$$\frac{\partial \Omega}{\partial \sigma} : \dot{c}$$

D_a accumulated damage

$$\sigma^+ = \sum_i \sigma^{(i)} \mathbf{e}^{(i)} \otimes \mathbf{e}^{(i)}$$

$\sigma^{(i)}$

eigenvalue of σ

$$\sigma^- = \sigma - \sigma^+$$

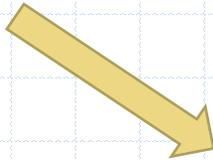
$\mathbf{e}^{(i)}$

corresponding eigenvector

Change in material symmetries

Isotropy

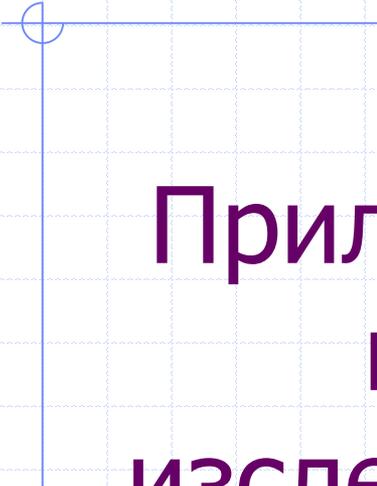
$$\begin{pmatrix} 1/E & -\nu/E & -\nu/E & 0 & 0 & 0 \\ -\nu/E & 1/E & -\nu/E & 0 & 0 & 0 \\ -\nu/E & -\nu/E & 1/E & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/G & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G \end{pmatrix}$$



Transverse isotropy

$$\begin{pmatrix} 1/E_1 & -\nu_{12}/E_1 & -\nu_{13}/E_3 & 0 & 0 & 0 \\ -\nu_{12}/E_1 & 1/E_1 & -\nu_{13}/E_3 & 0 & 0 & 0 \\ -\nu_{13}/E_3 & -\nu_{13}/E_3 & 1/E_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/G_{13} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G_{13} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G_{12} \end{pmatrix}$$





Приложение на алгоритми за машинно обучение в изследването на динамичното поведение на рамки

Presentation outline

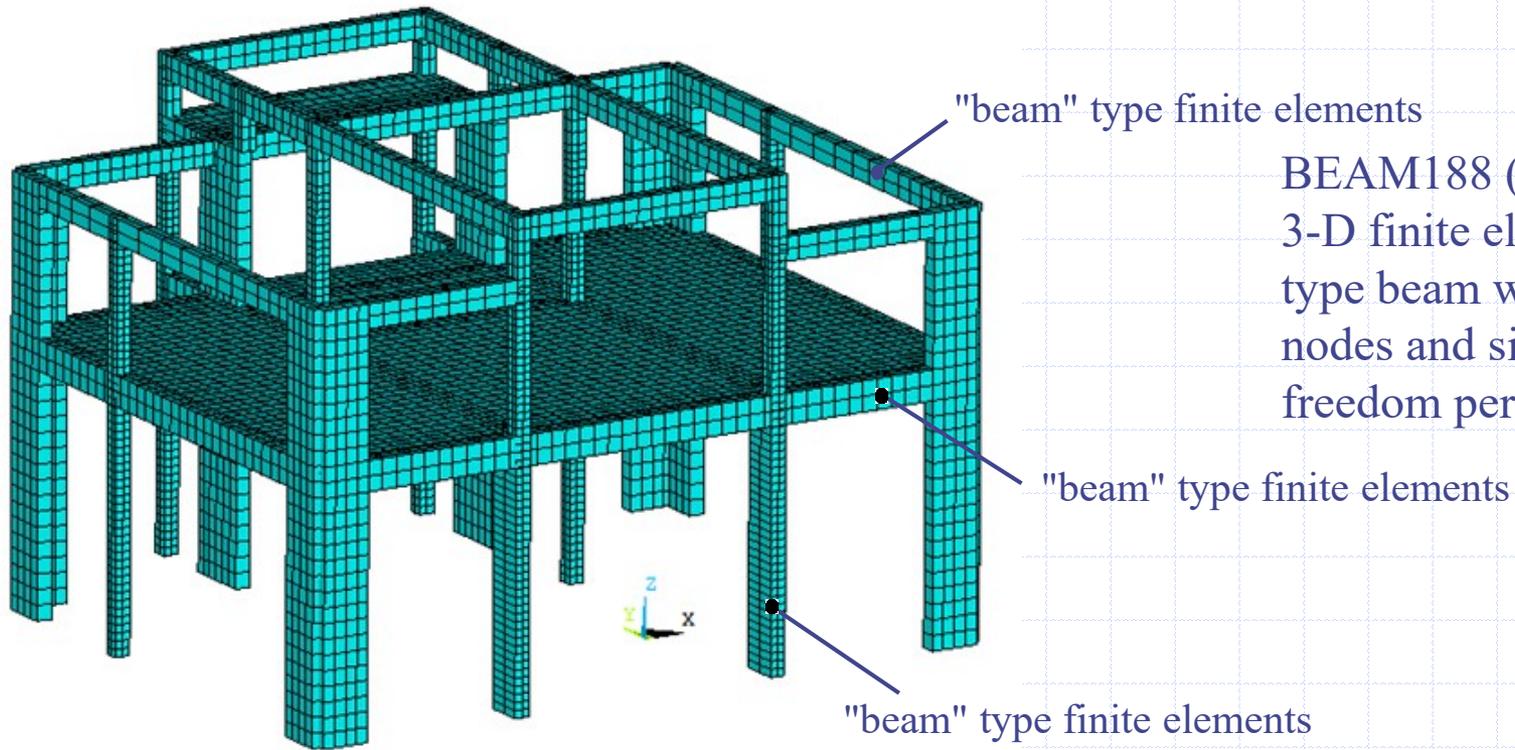
1. Introduction
2. The case studied: finite-element model
3. The case studied: generating the synthetic data
4. The machine learning algorithm
5. Transient response of the structure equipped with base isolation
6. Concluding remarks

Solutions based on machine-learning (ML) algorithms are increasingly gaining popularity in daily life and various fields of industry, including construction and structural design.

A number of recent studies demonstrate the application of ML algorithms as predictors in various cases, such as (i) Damage assessment of prestressed concrete beams [1]; (ii) Strength of steel CHS X-joints [2]; (iii) Shear strength of steel fiber reinforced concrete beams [3]; (iv) Compressive and flexural strength of steel fiber-reinforced concrete [4]; (v) Effective stiffness of precast concrete columns [5]; (vi) Drift capacity of reinforced concrete walls [6, 7]; (vii) Punching shear resistance of concrete slabs [8], (viii) Shear strength of concrete connections [9]; and (ix) Load-bearing capabilities of concrete columns [10]. Generally, the data-driven models reveal interdependencies between the input parameters and the output variables with-out being biased by specific models.

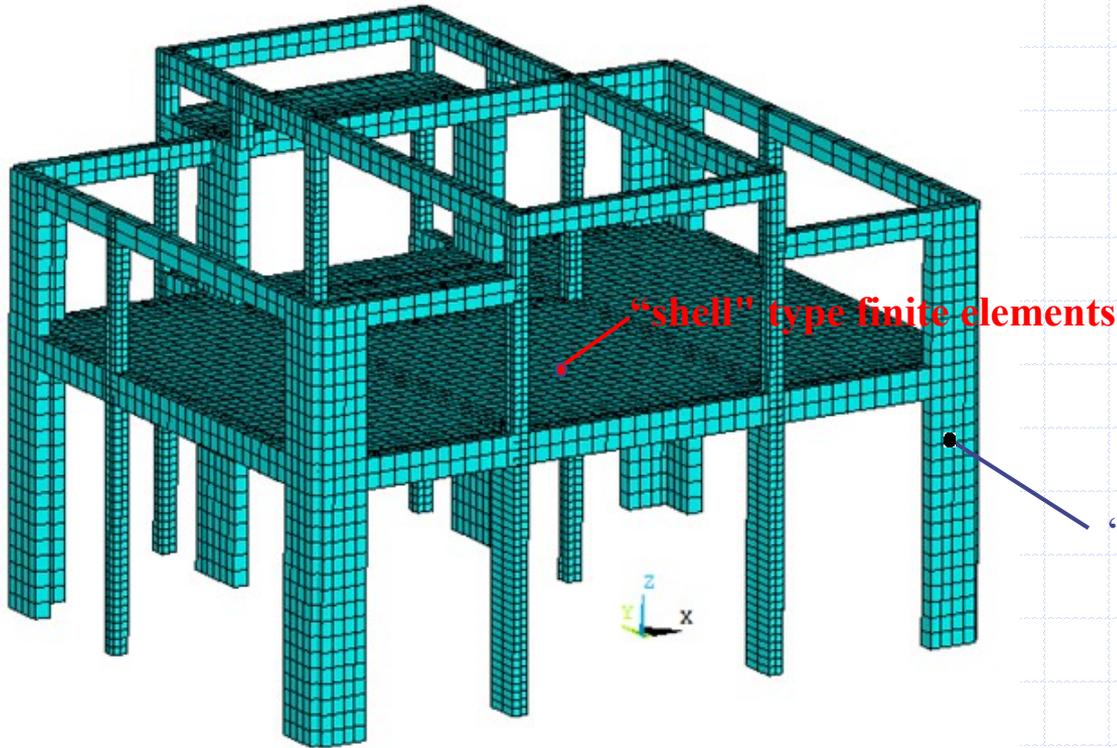
Within the study presented herein, a synthetic database is compiled based on a preliminary defined layout of the vertical elements in the moment resisting frames. The inputs include the relevant cross-sectional geometrical dimensions and the design values of the shear force, the normal force, the bending moment, and the parameters of the seismic excitation. The required database is populated by running a series of response-spectrum analyses. The ML algorithm is applied at this stage. After that, the structural response is studied using time-history analysis with and without base isolation.

The case studied: finite-element model



BEAM188 (ANSYS) is a 3-D finite element of type beam with two nodes and six degrees of freedom per node.

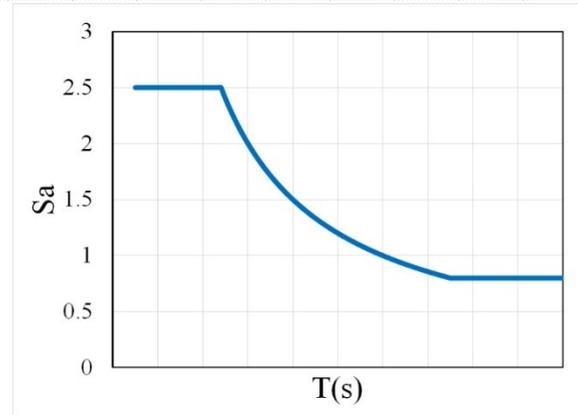
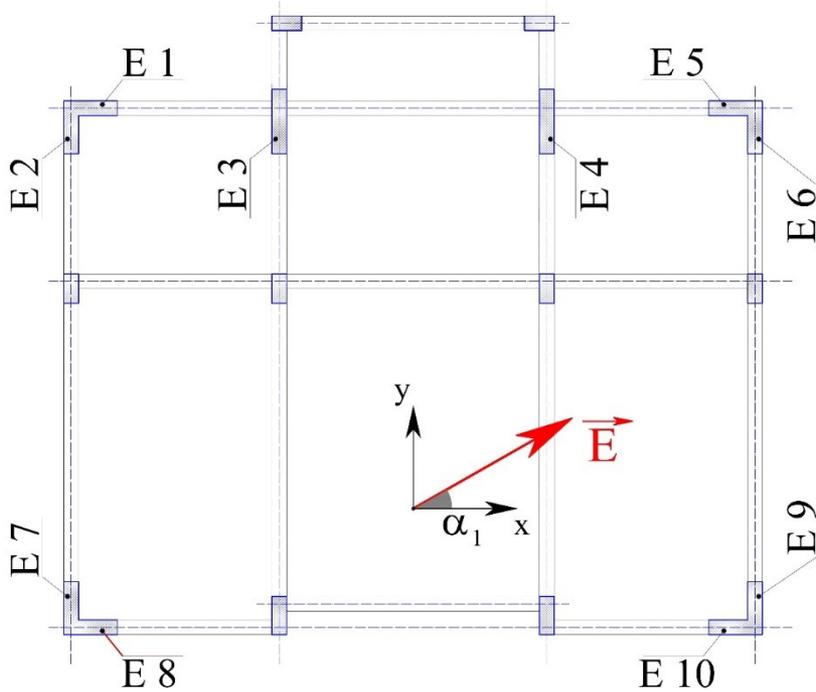
The case studied: finite-element model



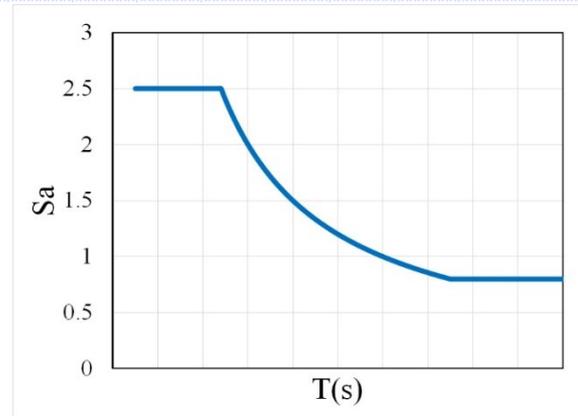
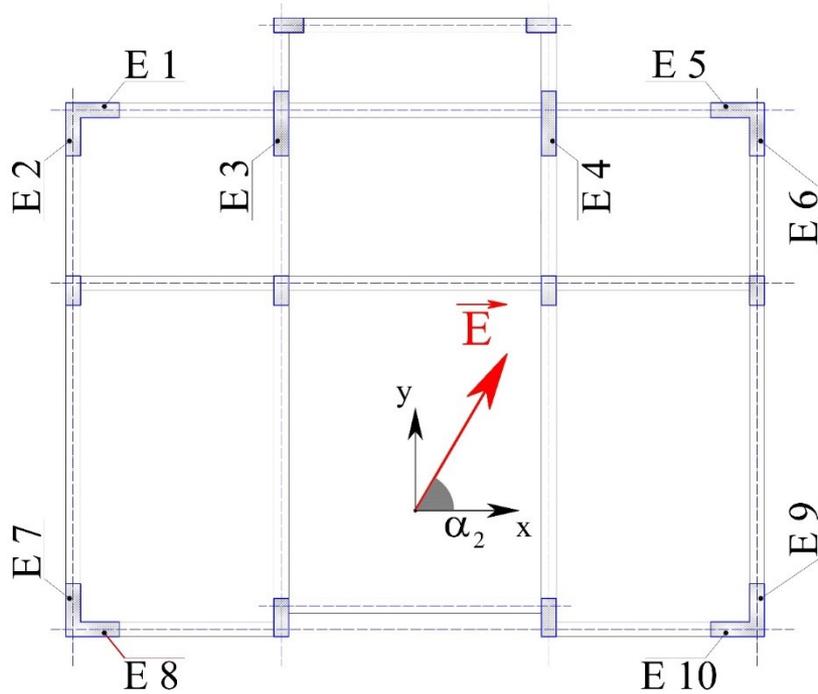
SHELL181 (ANSYS) is a 3-D finite element of type structural shell with four nodes and six degrees of freedom at each node.

"shell" type finite elements

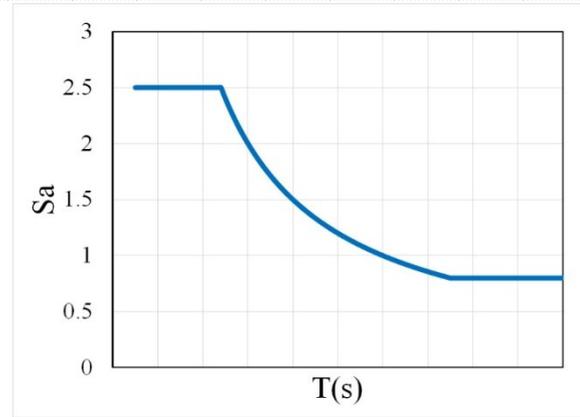
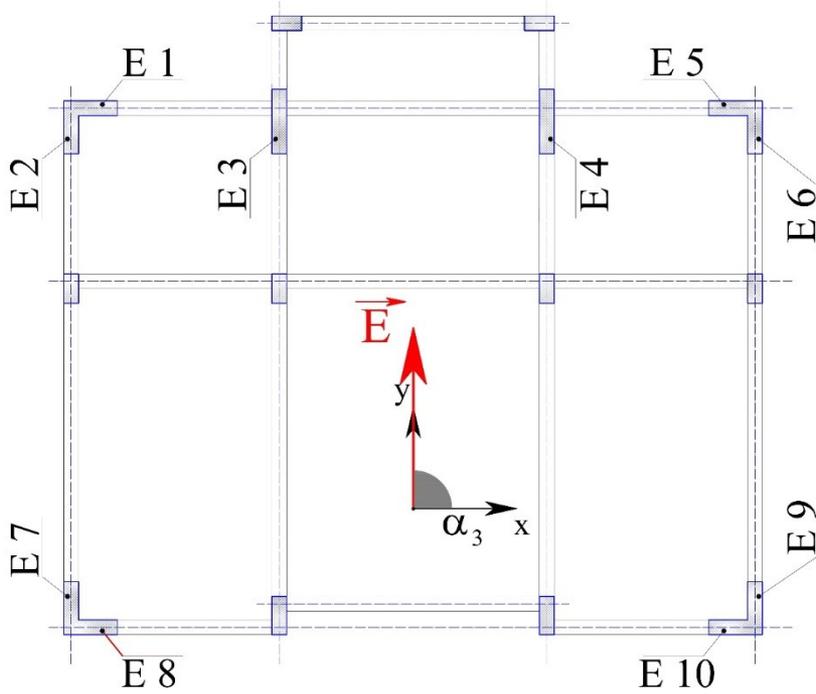
The case studied: generating the synthetic data



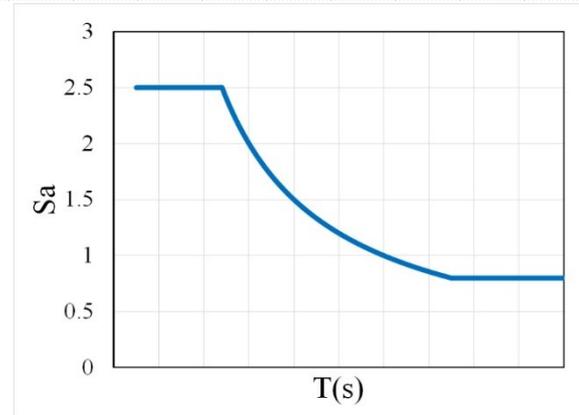
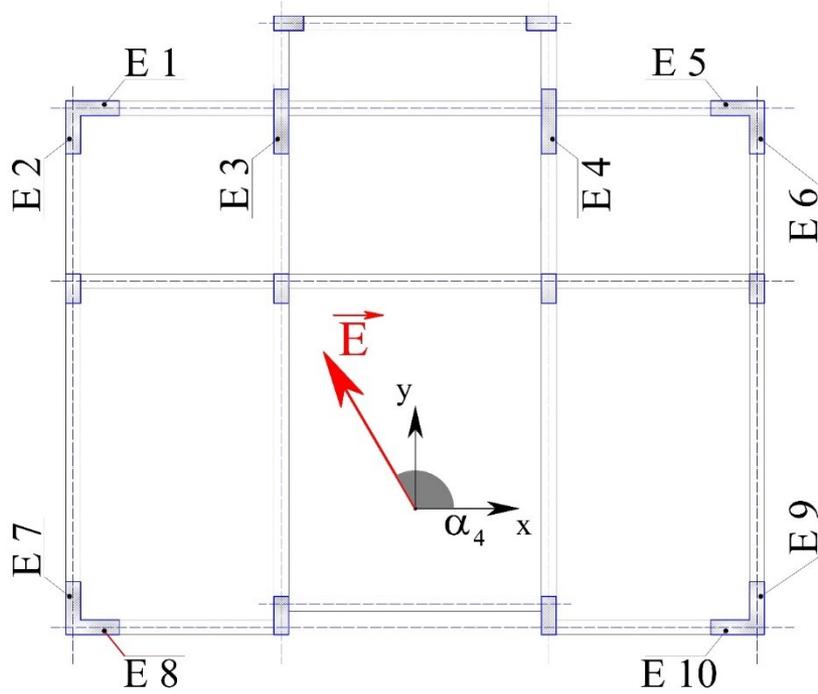
The case studied: generating the synthetic data



The case studied: generating the synthetic data



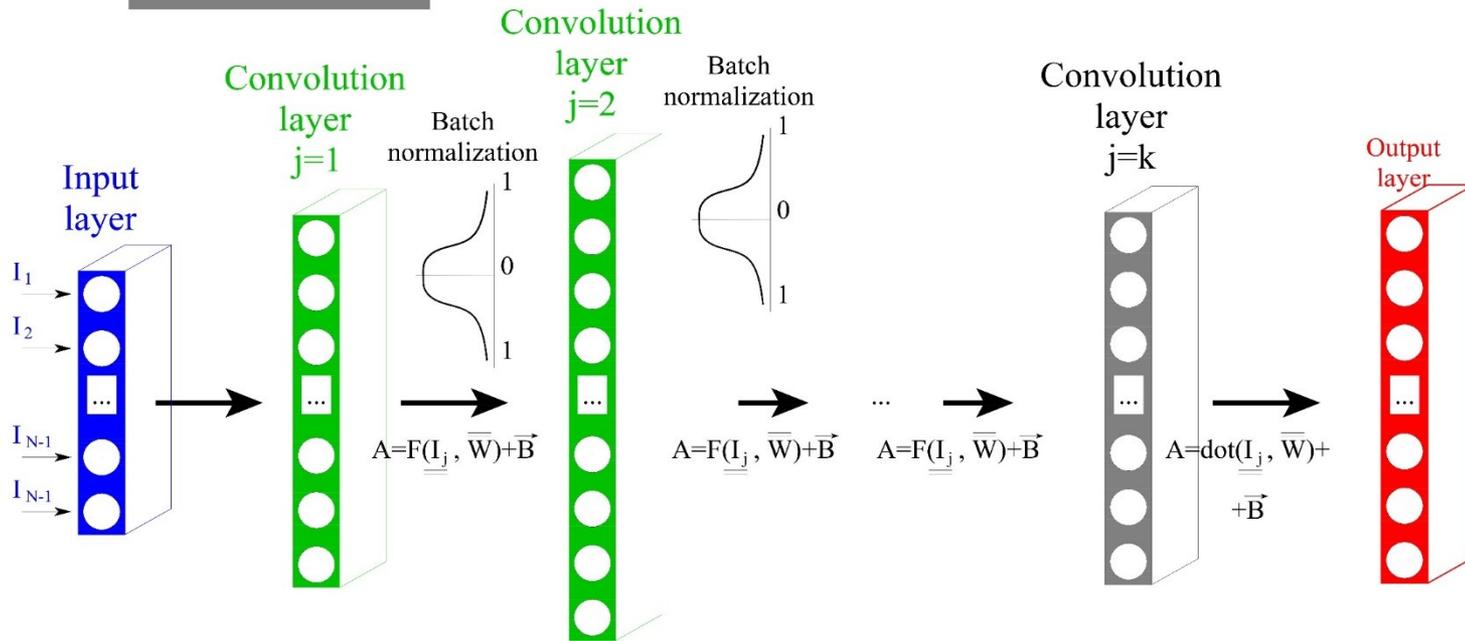
The case studied: generating the synthetic data



The machine learning algorithm

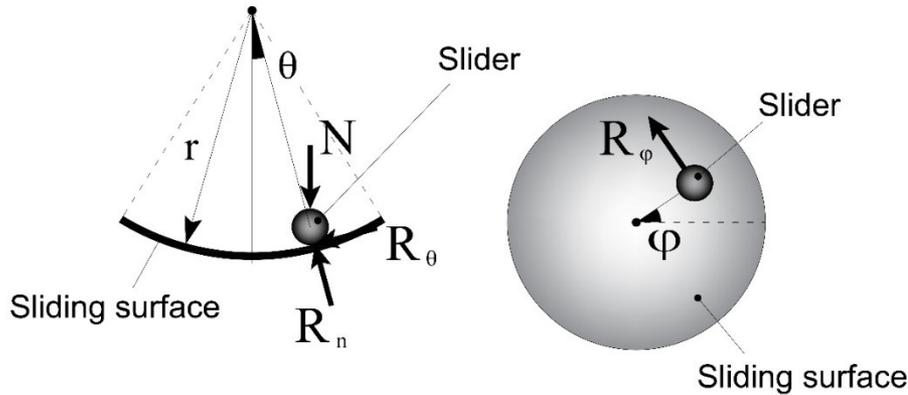
A - activatin function

A = ReLU

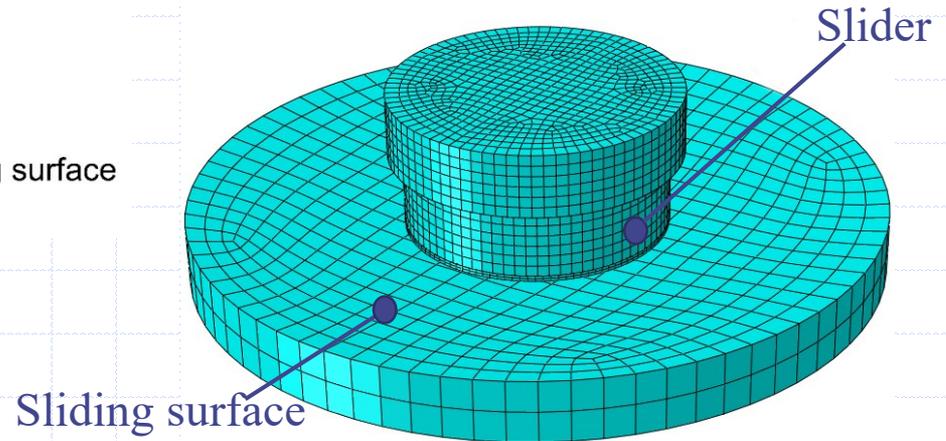


The machine learning algorithm

A convolutional network is built for the purposes of the study using the TensorFlow framework. It consists of input and output layers and several hidden layers. Train and test data are normalized before implementation to enhance ANN functioning. The hidden layers conventionally employ the rectified linear unit (ReLU) activation function and batch normalization. Among the hidden layers, some are defined as “flatten” and “dense.” The Adam optimizer is used, and an appropriate loss function is chosen, along with suitable metrics. Model size and hyperparameters (e.g., the learning rate) are finally set based on the convolutional network’s performance evaluation as a function of their variation.

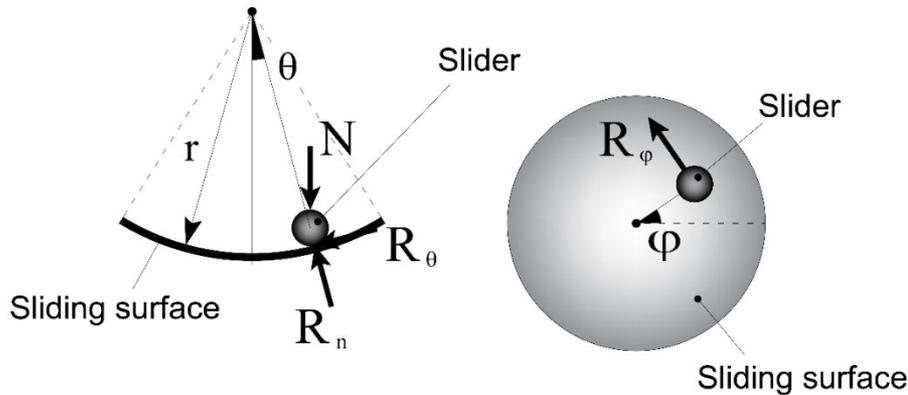


Schematic representation of the friction-pendulum bearing



Finite-element model of a friction-pendulum bearing

Transient analysis of the structure equipped with base isolation

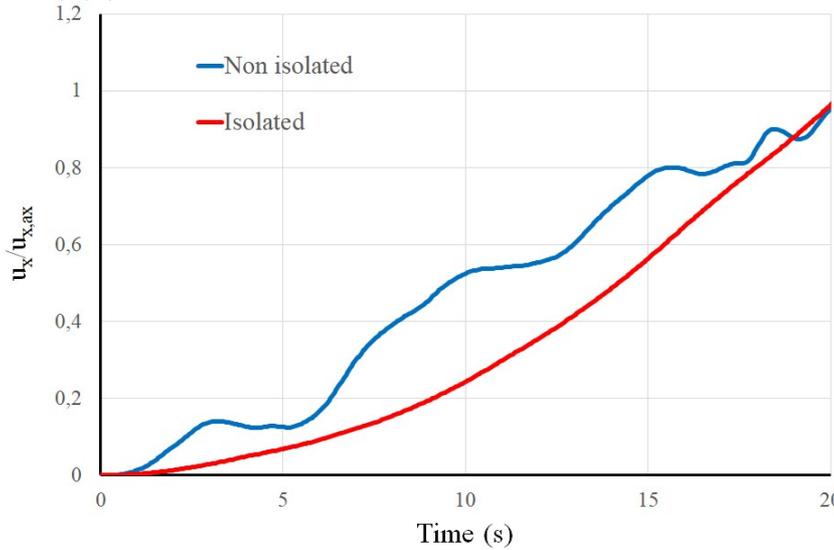


Schematic representation of the friction-pendulum bearing

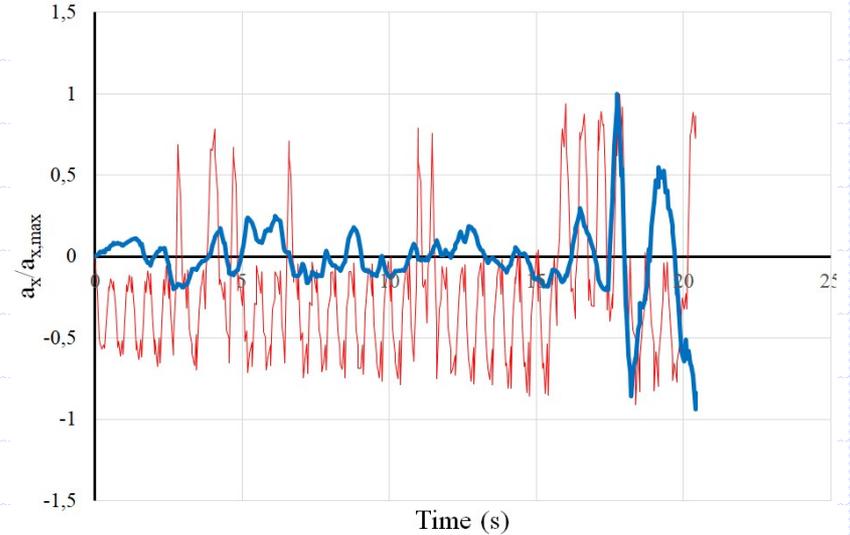
$$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} = Q_i \quad L = E_k - E_p$$

$$\begin{cases} -mr(\ddot{\theta} \sin(\theta) - \dot{\theta}^2 \cos(\theta)) - N \cos(\theta) = -ma_r + R_n; \\ mr^2 \ddot{\theta} \cos(\theta) + Nr \sin(\theta) = r(-ma_\theta + R_\theta); \\ mr^2 (\ddot{\phi} \sin(\theta) + \dot{\phi}^2 \cos(\theta)) = r \sin(\theta) (-ma_\phi + R_\phi). \end{cases}$$

Transient analysis of the structure equipped with base isolation



Displacements



Accelerations

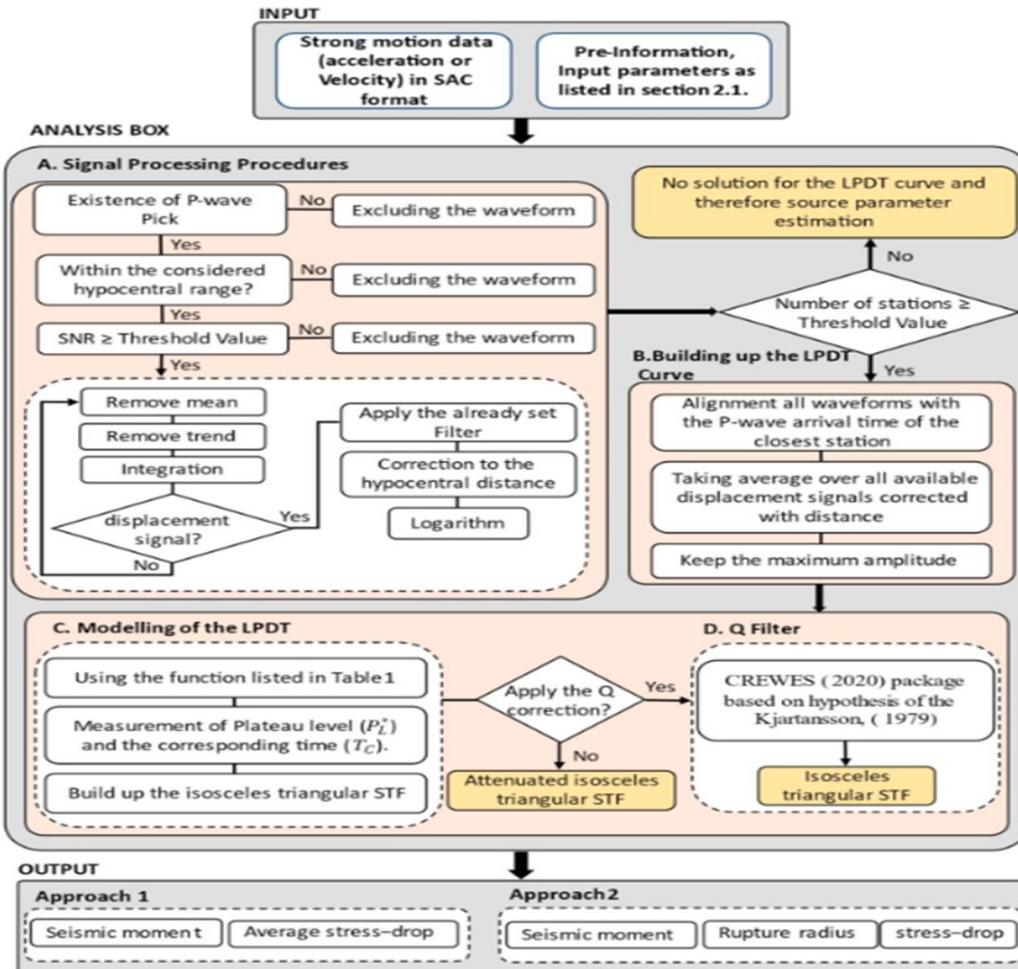
Comparison of the response with and without base isolation, at a specified location



Числено изследване на земеъръсни характеристики

доц. Емил Ойнаков

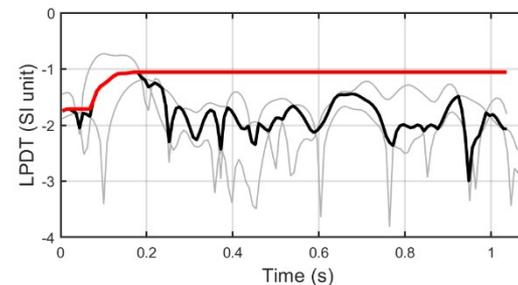
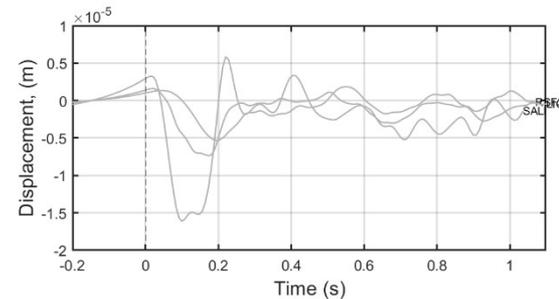
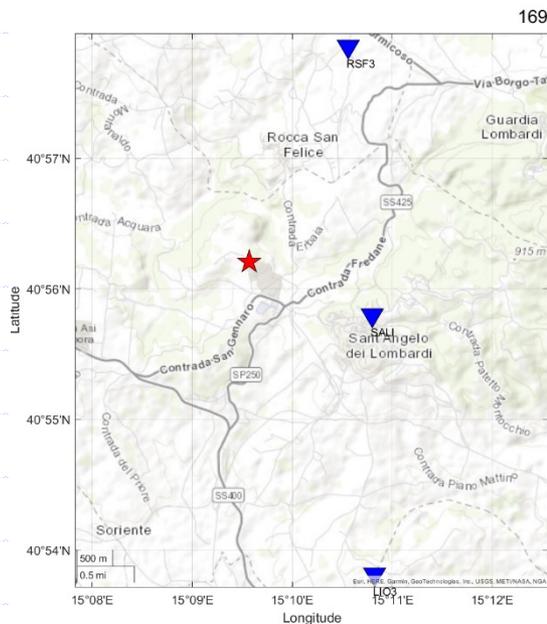
EASOt-AP: пакет MATLAB с отворен код за оценка на сеизмичния момент, радиуса на разкъсване и спада на напрежението при земетресението от времевата оценка на Р-вълната, амплитуда на преместване



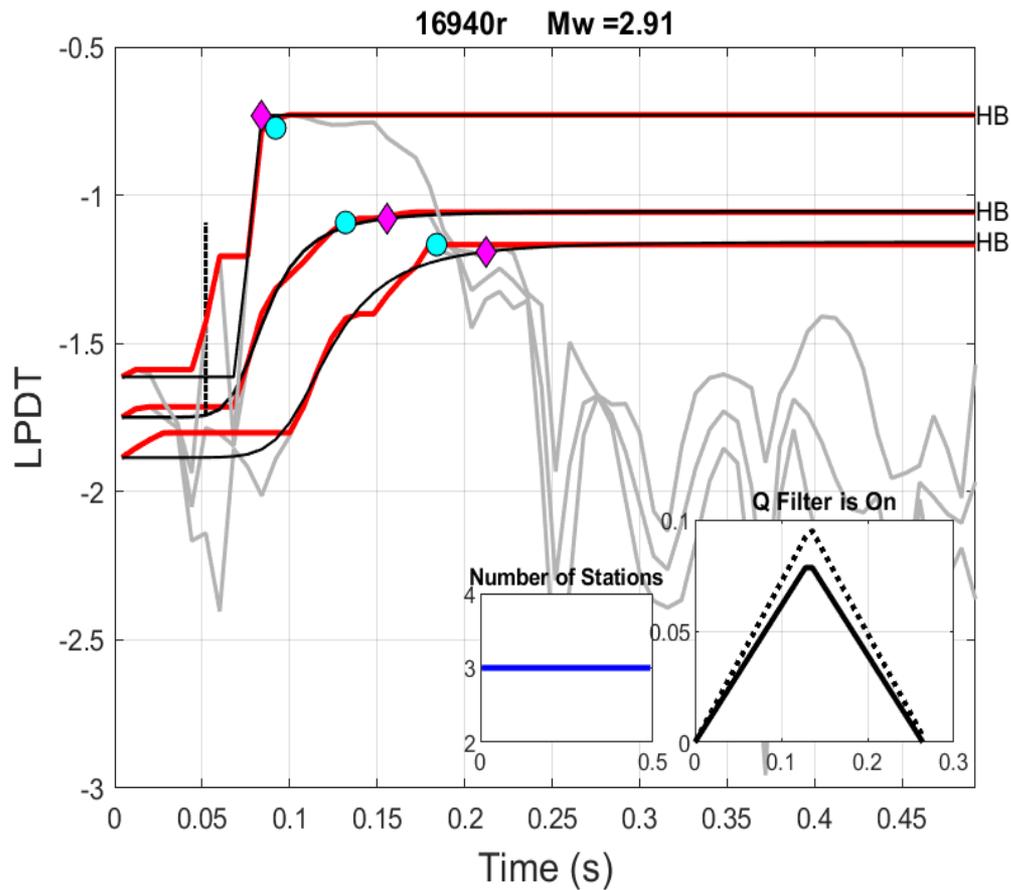
Този пакет изисква SAC форматирани данни за силно движение със следните необходими полета:

- (1) местоположение на земетресение (longitude, latitude, depth) и начално време
- (2) координати на станцията
- (3) време на пристигане на Р-вълната
- (4) разстояние източник-приемник в километри
- (5) магнитуд на събитието (за предпочитане е Mw)

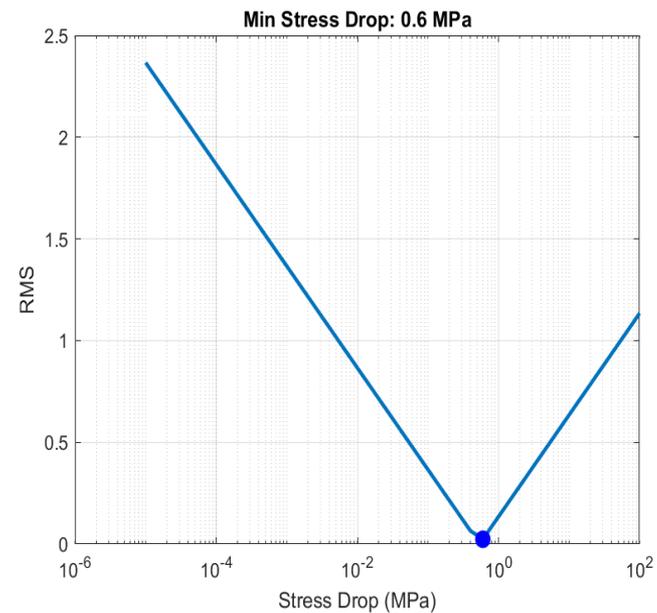
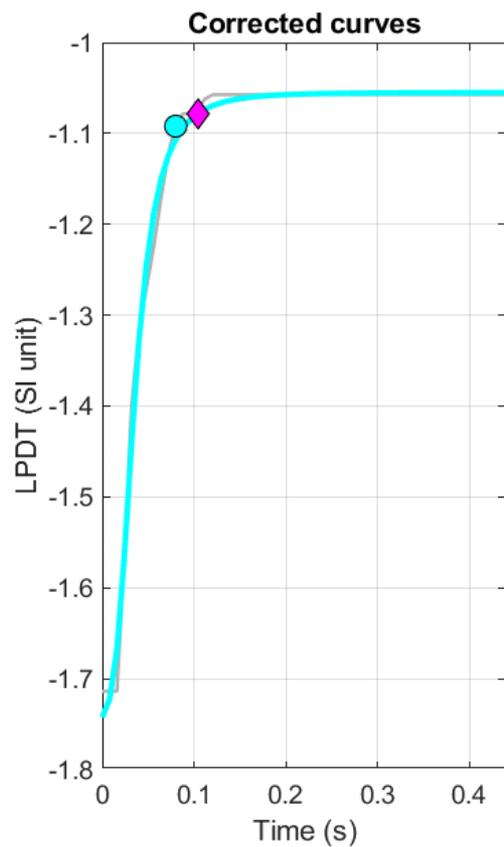
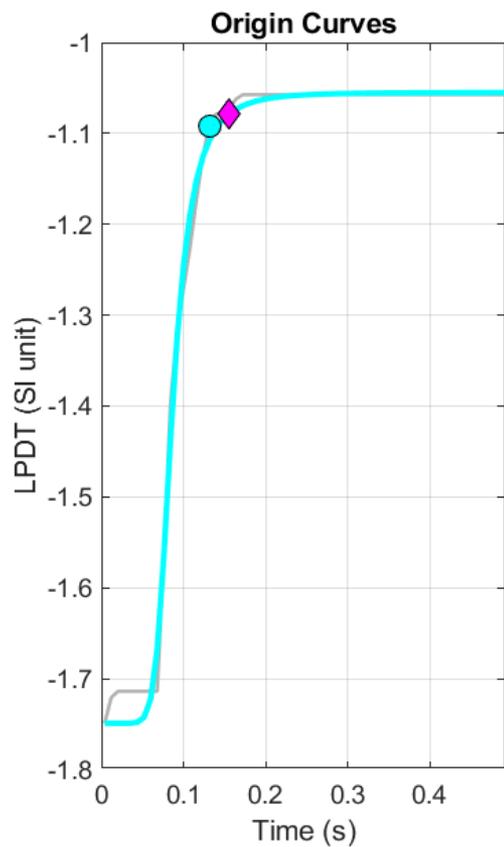
Алгоритъмът, внедрен в този пакет, се основава на бърза и ясна методология, разработена наскоро от Zollo et al. (2021 г.). За тази цел EASOt-AP моделира крива LPDT-средното преместване от Р-вълната спрямо времето в логаритмичната скала.



LPDT крива на събитие с малък магнитуд ($M_w:2,9$), което се е случило в Ирпиния, Южна Италия със значителна грешка в избирането на Р-вълната, причиняваща изместване във времето на кривата LPDT. (а) картата показва геометрия на станциите (сини триъгълници) и епицентър на събитието (червена звезда). (б) графиката представя филтрираните сигнали за преместване. (с) индивидуалната крива на LPDT на всяка станция (сиви криви), LPDTaverage (черно) и LPDTmax (червено).



Всички следи се подравняват спрямо Р-началото на най-близката станция. Следващата стъпка е разглеждане на разпределението на серията от коригирани за разстоянието премествания във всеки времеви интервал (еквивалентен на времето на вземане на данни) отделно от Р-началото до желания времеви прозорец, за да се извлекат средната стойност/медианата и стандартно отклонение на точките, за да се създадат три криви за дадено събитие, наречени средна стойност (LPDPTAverage), и ± 1 -сигма криви (LPDPT \pm SD)

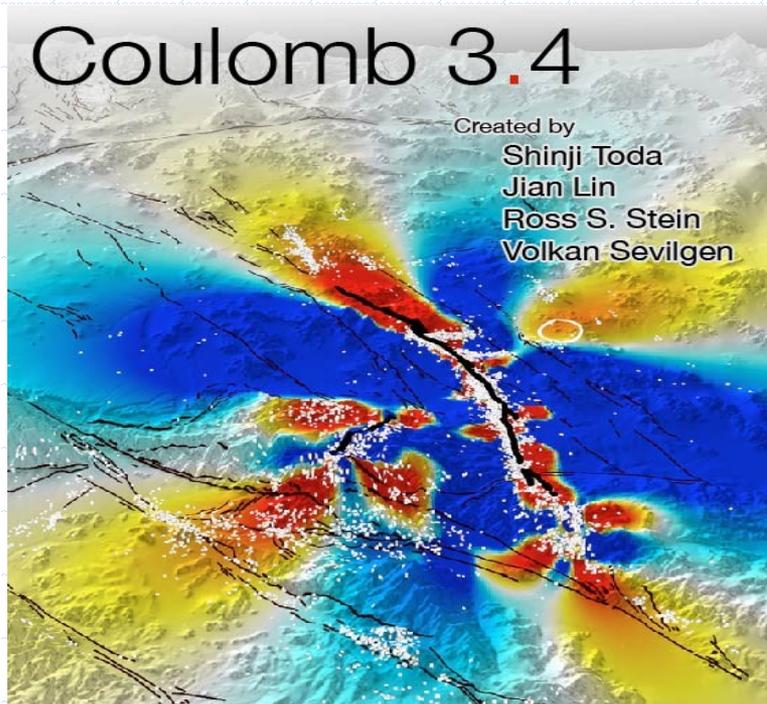


пример за времева оценка на кривата за дадено земетресение

средна стойност на спада на напрежението

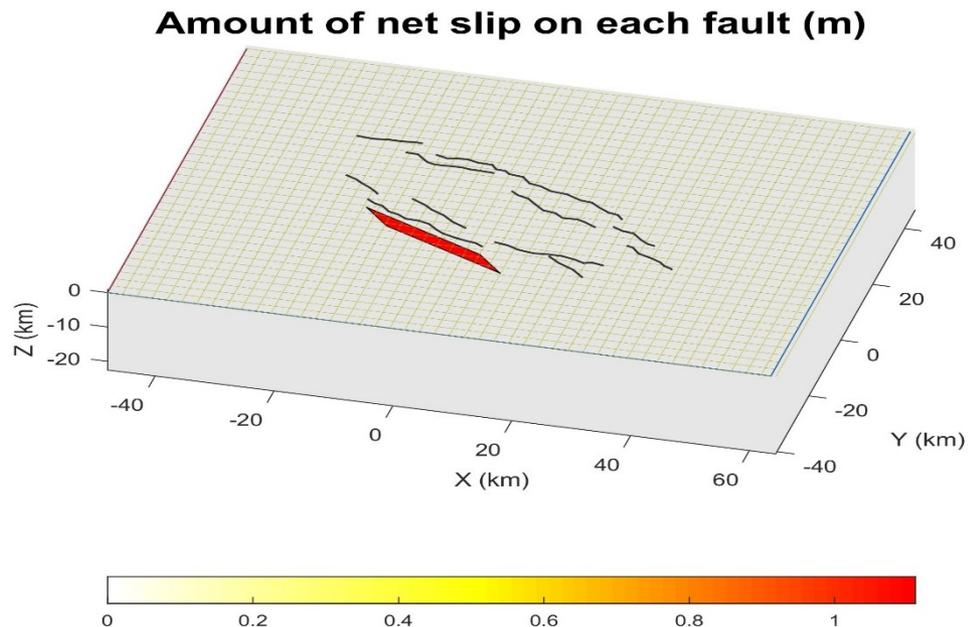
Числено изследване на
напрегнатото и деформирано
състояние на земната кора
вследствие на геодинамични
събития

Оценка на възможни зони на повишен/понижен натиск върху активни разломи след историческото земетресение от 23.04.1918 в района на софийския басейн с координати на хипоцентъра 42.683N/23.317E, дълбочина 7 км и магнитуд $M_w=6,48$ със Софтуер: Coulomb 3.4.2 (GUI върху Matlab).

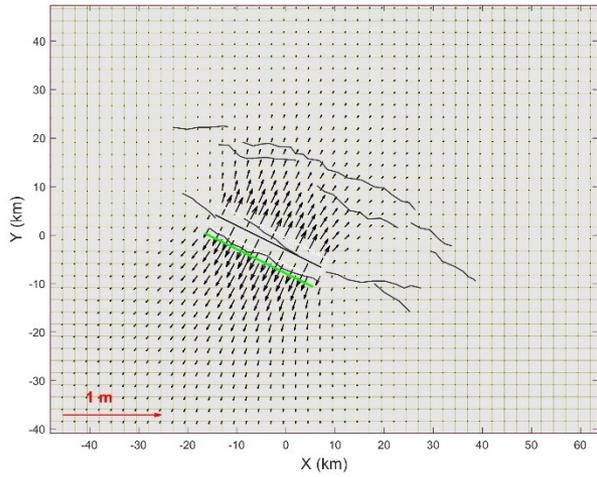


Coulomb е проектиран да позволява изчисляване на статични премествания, деформации и напрежения на всяка дълбочина, причинени от разломно приплъзване, магмено проникване или разширяване/свиване на дига. Могат да се изчисляват статични премествания (на повърхността или на GPS станции), деформации и напрежения, причинени от разломно приплъзване, магмено проникване или разширяване на дигата.

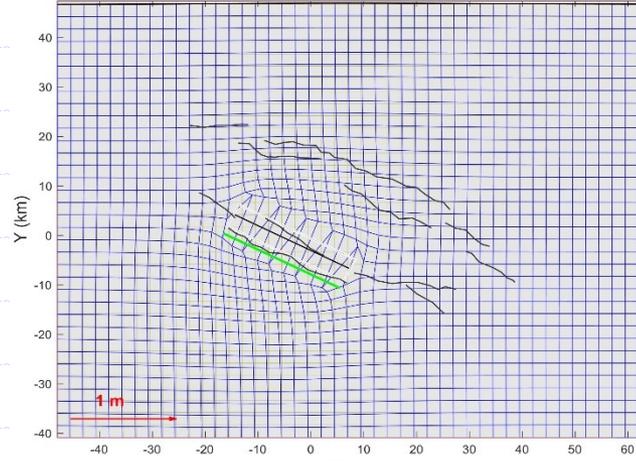
Подготвени са няколко версии на входни данни .inp с разломни сегменти за прозорец 17.5–24.5°E; 33.5–36.5°N. За стабилна работа на GUI са изготвени варианти с 5, 10, 20 разлома, както и „polyline“ версии с всички междинни сегменти (на стъпки по 10/20), в локални X/Y (km) и без „Map information“ при X/Y режим. За набор K34 са създадени .inp файлове за 12 и 13 избрани shape id (вкл. 261), с автоматично изчислен bbox, zero lon/lat и конвертиране в локални X/Y (km). За всеки разлом е използван 1 сегмент (първа→последна точка), като имената са взети от атрибутната таблица, когато е налична.



С черни линии са отбелязани разломи в Софийския басейн. С червена равнина е разлома източник на земетресението от 1818-04-23 с координати 42.683 N; 23.317 E, дълбочина 7 км и магнитуд ММ 6.00 Mw 6.48

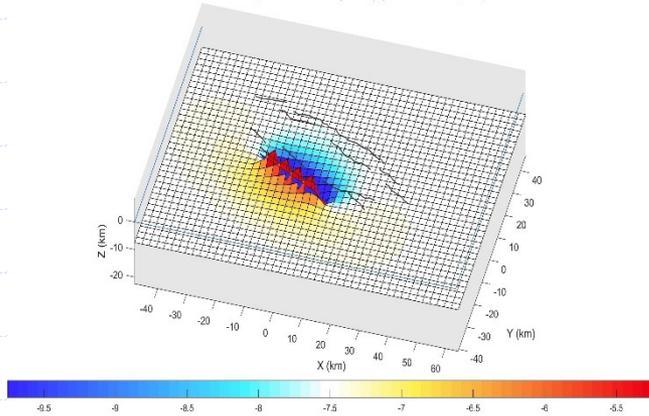


Coulomb 3.4.2 13-Jan-2026 14:09:19 Sof.inp

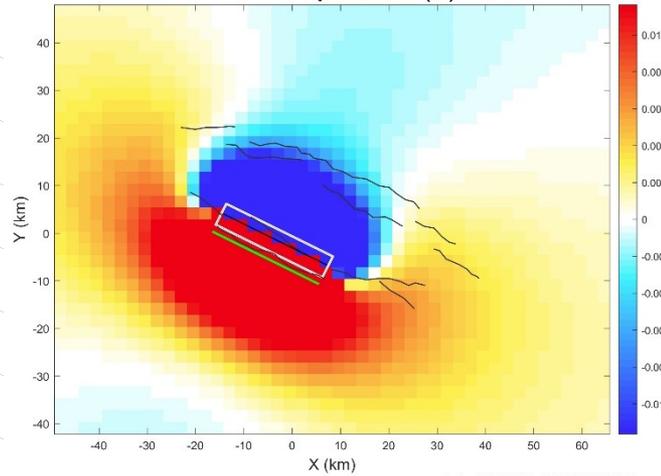


Horizontal displacement

Vertical displacement (exaggerated depth)



Vertical displacement (m)



Coulomb 3.4.2 13-Jan-2026 14:12:57 Sof.inp

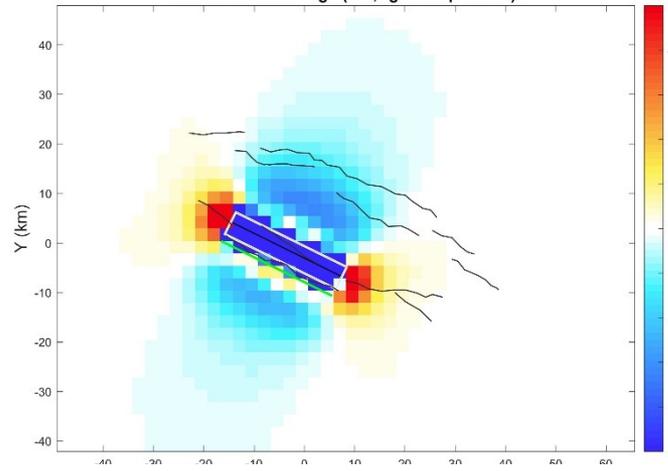
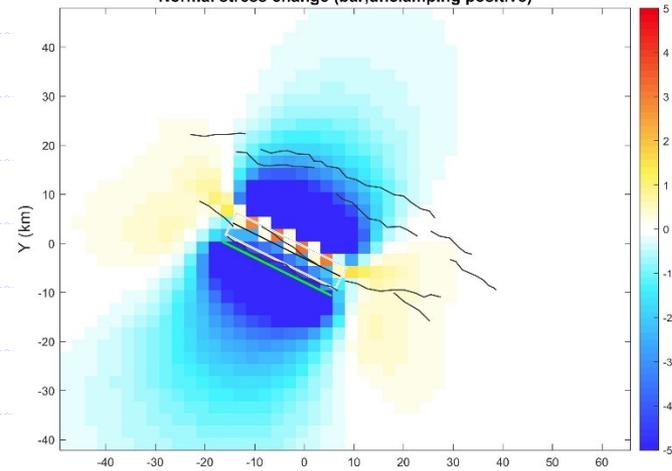
Vertical displacement

Stress change

Dilatation,
Colomb stress change

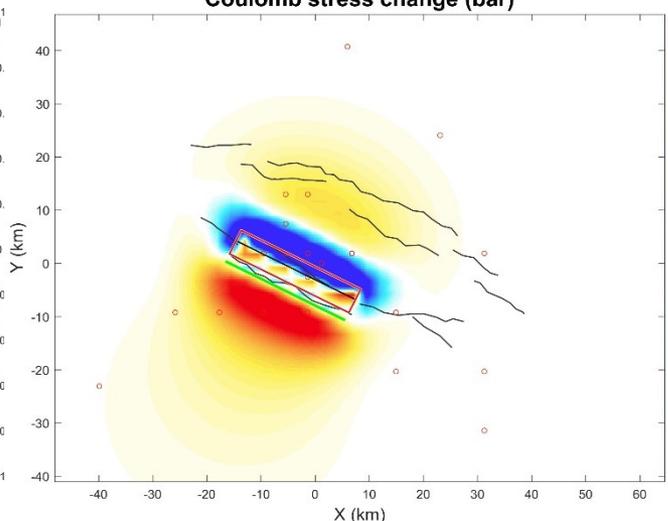
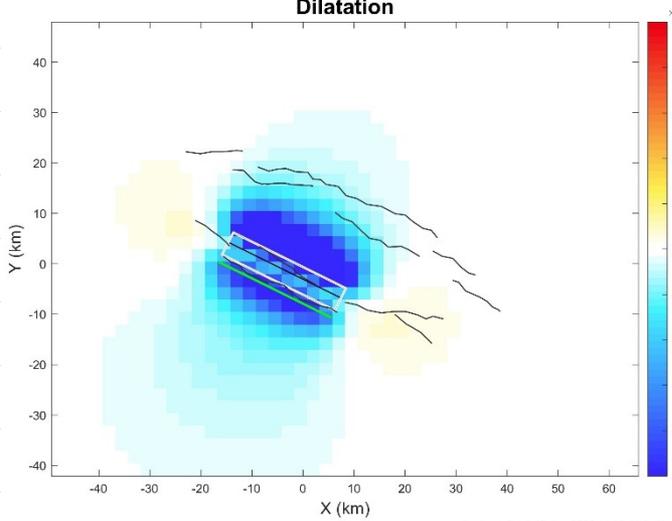
Normal stress change (bar, unclamping positive)

Shear stress change (bar, right-lat. positive)



Dilatation

Coulomb stress change (bar)



Coulomb 3.4.2 13-Jan-2026 14:15:44 Sof.lnp

Coulomb 3.4.2 19-Oct-2025 17:47:59 SOFIA 1818_VITOSHA_alongTrace_SINGI_F_crid2n5km.lnp



Анализ на люлеенето на сгради при земетръс чрез Метода на дискретните елементи

проф. Радан Иванов

Outline of the method

Geometry and inertial properties

$$p = R \cdot p_0 + x$$

$$I = R \cdot I_{body} \cdot R^T$$

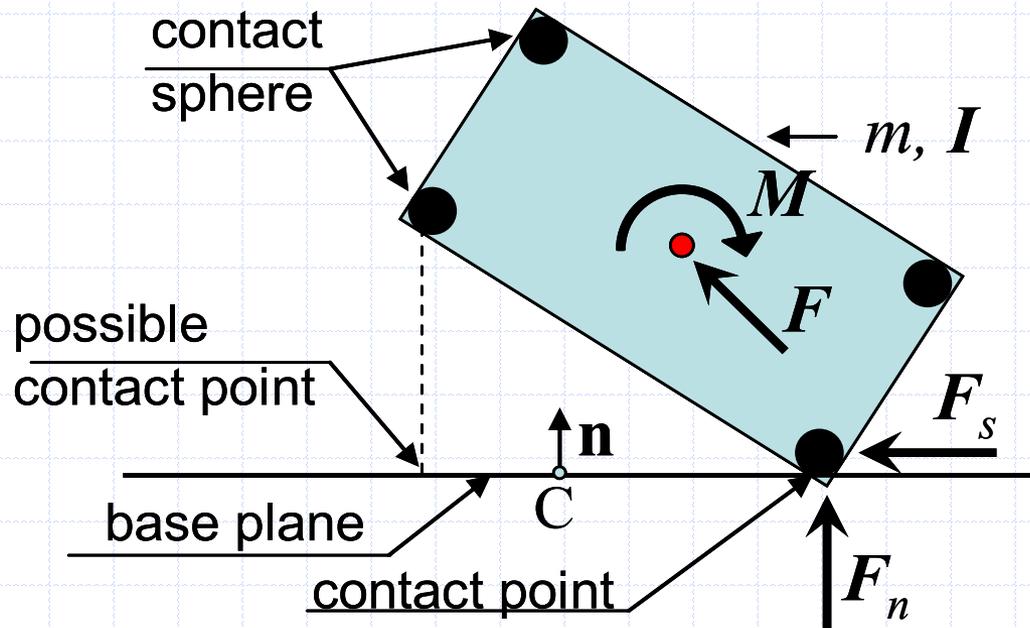
$$I^{-1} = R \cdot I_{body}^{-1} \cdot R^T$$

Motion

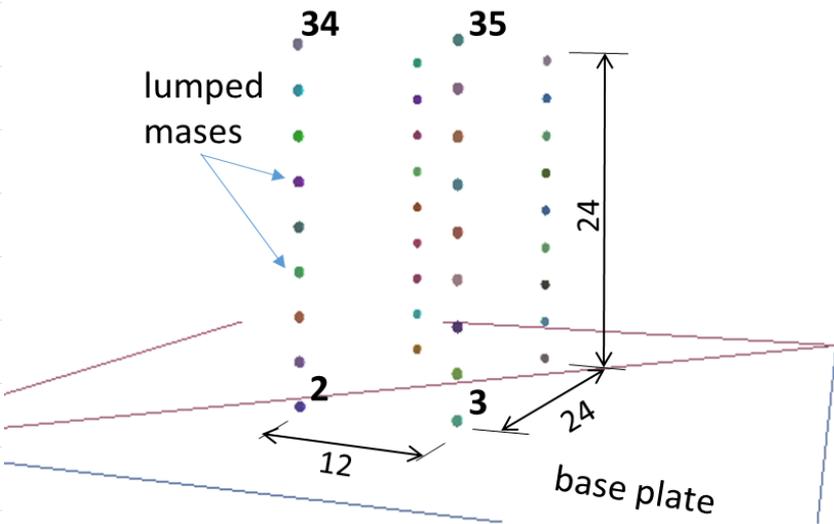
$$\dot{x} = \frac{P}{m}$$

$$I = R \cdot I_{body} \cdot R^T$$

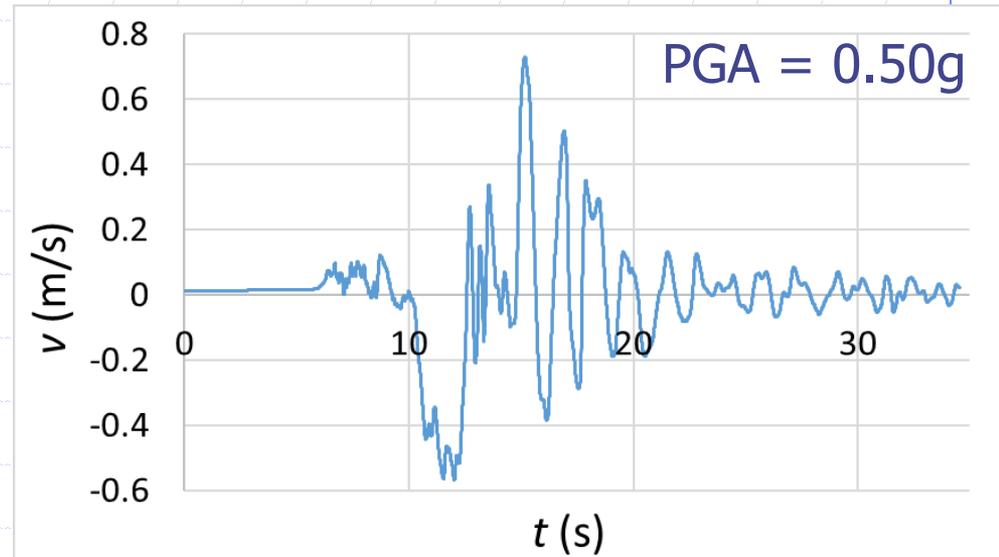
$$\omega = I^{-1} \cdot L$$



DEM model in Yade

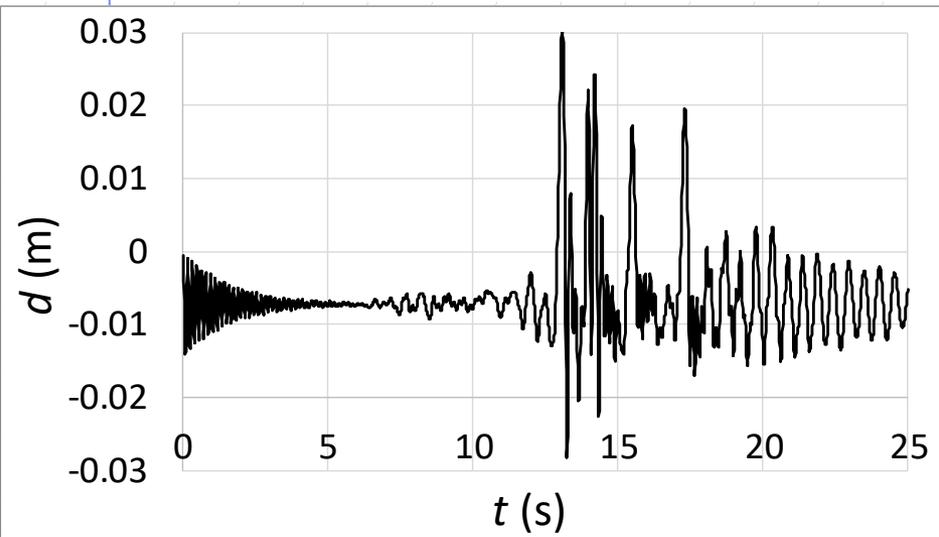


(a) Geometry – perspective.

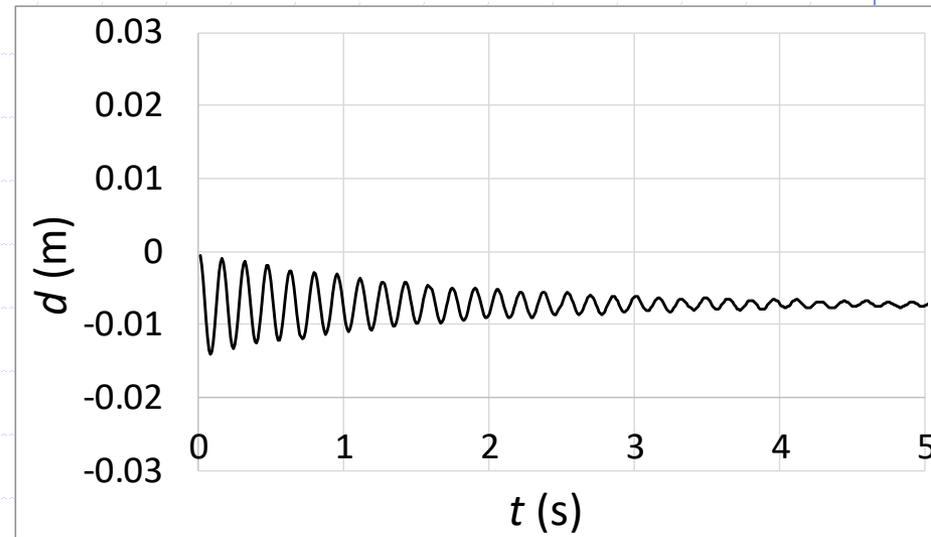


(b) Input motion at the base plate.

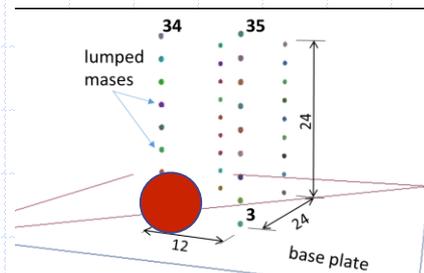
Vertical displacement of node 2



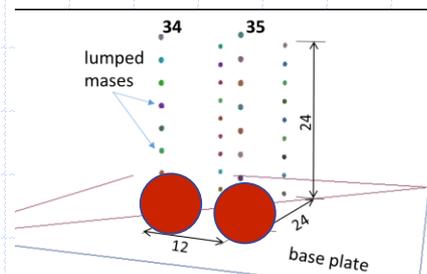
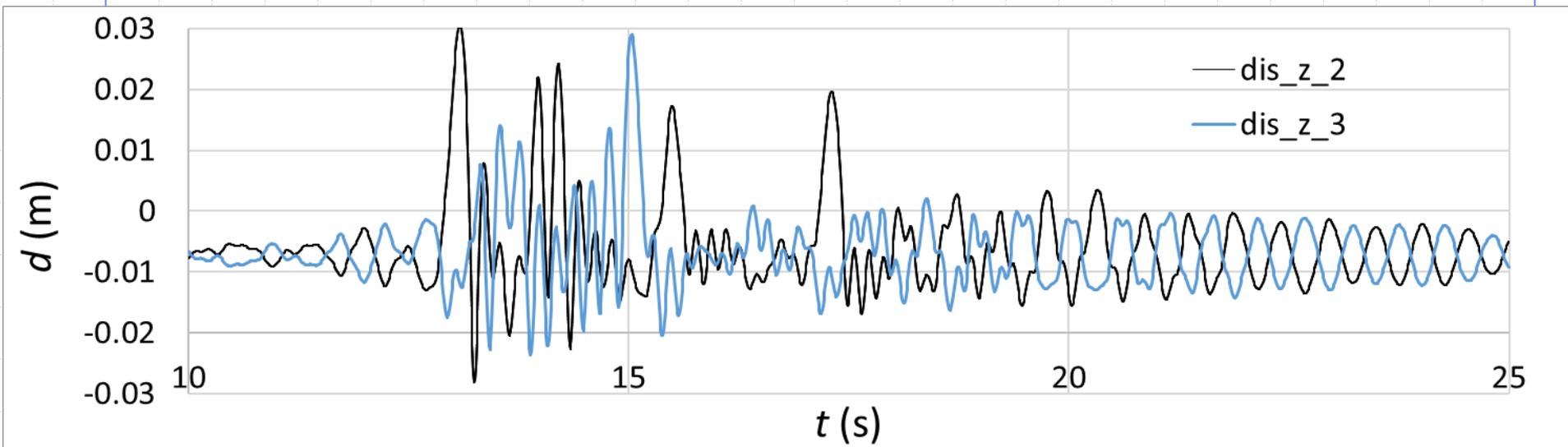
(a) Full time history.



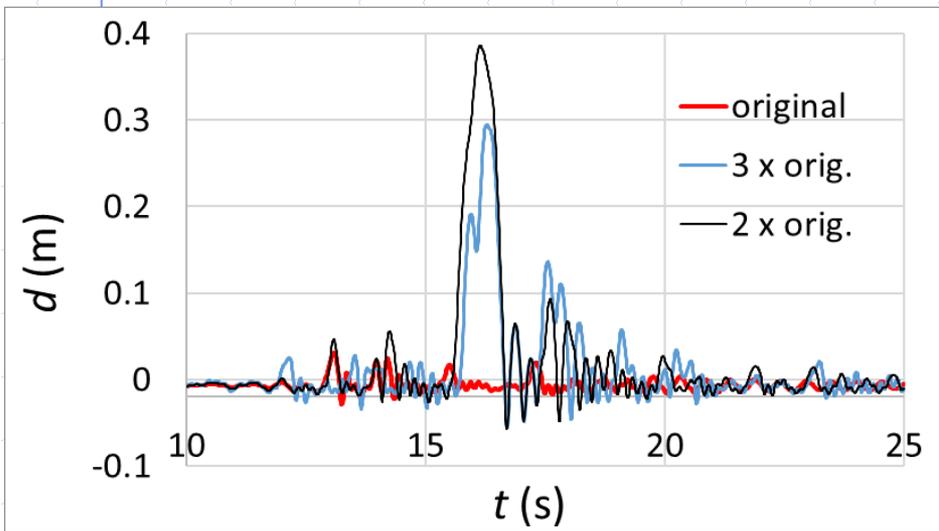
(b) Close-up of first 5 s.



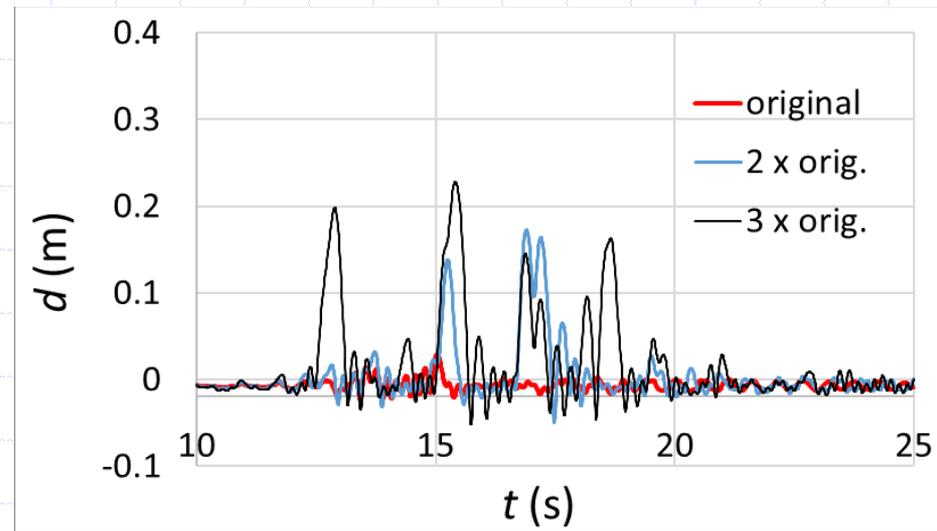
Vertical displacement of nodes 2 and 3 plotted together



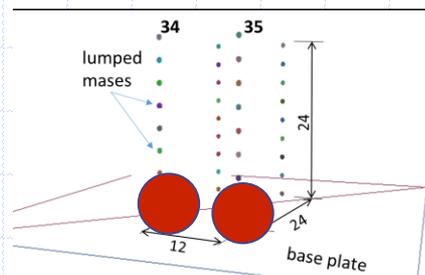
Vertical displacement of nodes 2 and 3 for different ground motion intensities



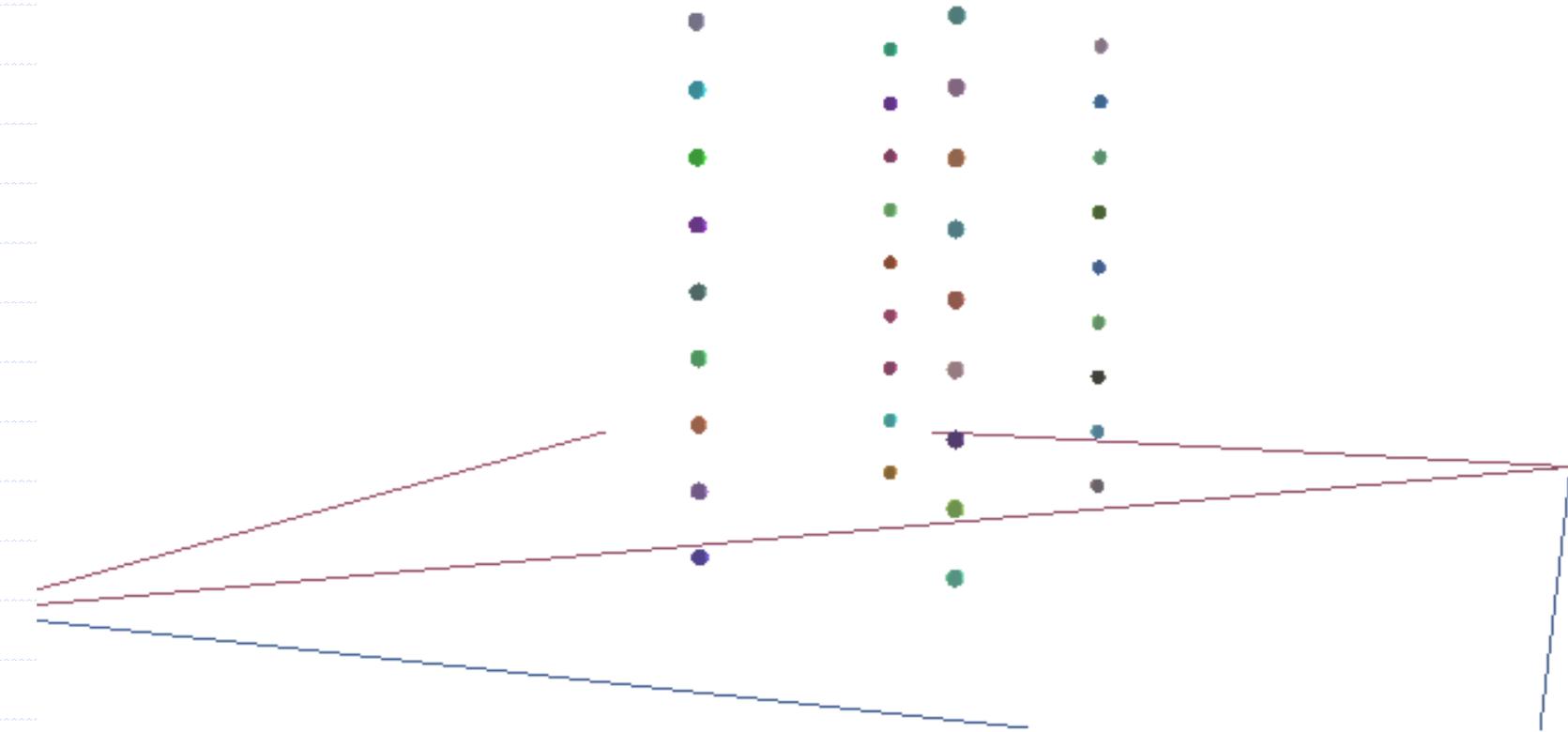
(a) Node 2.



(b) Node 3.

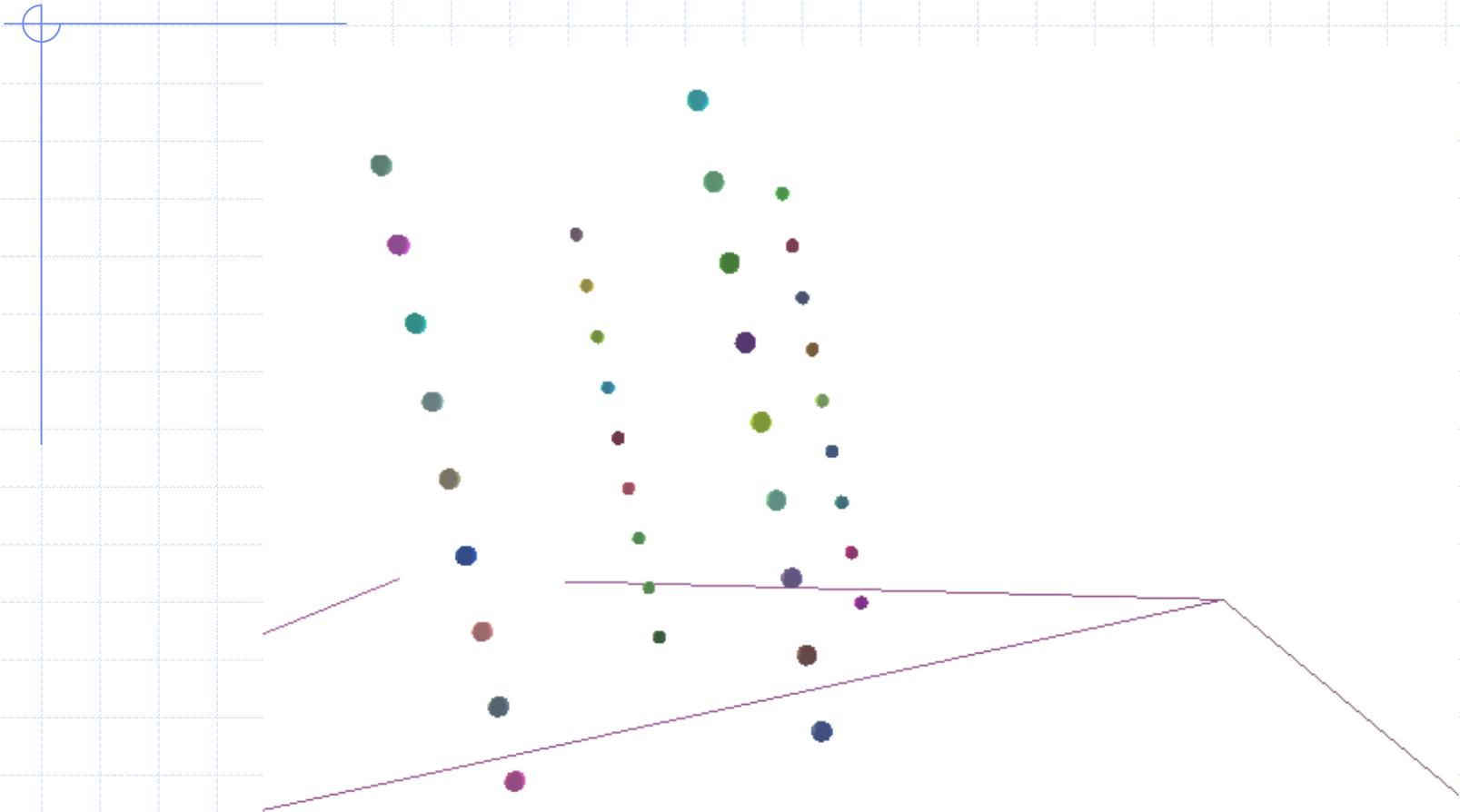


Selected snapshots – PGA = 5g



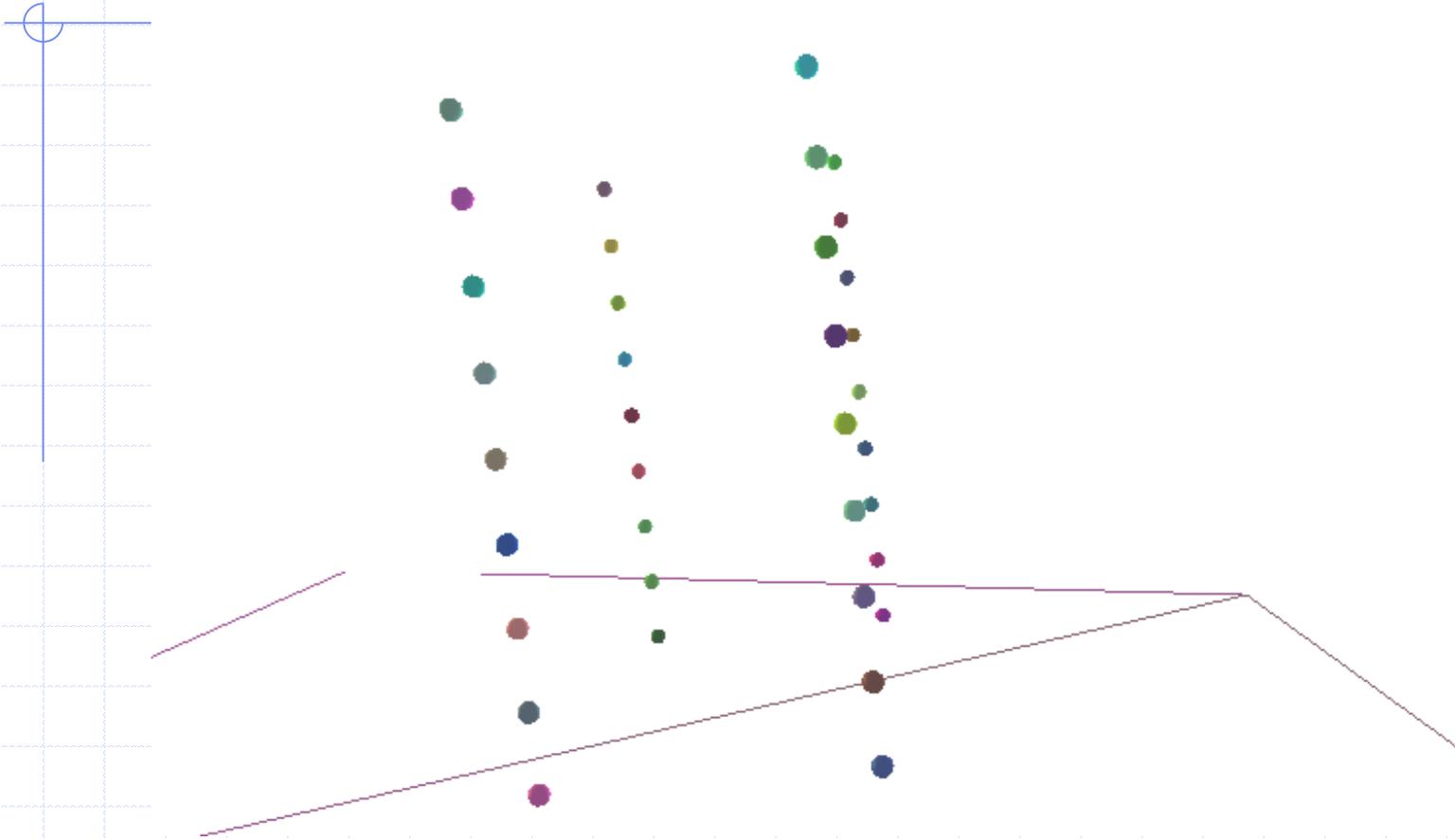
10.0 s.

Selected snapshots



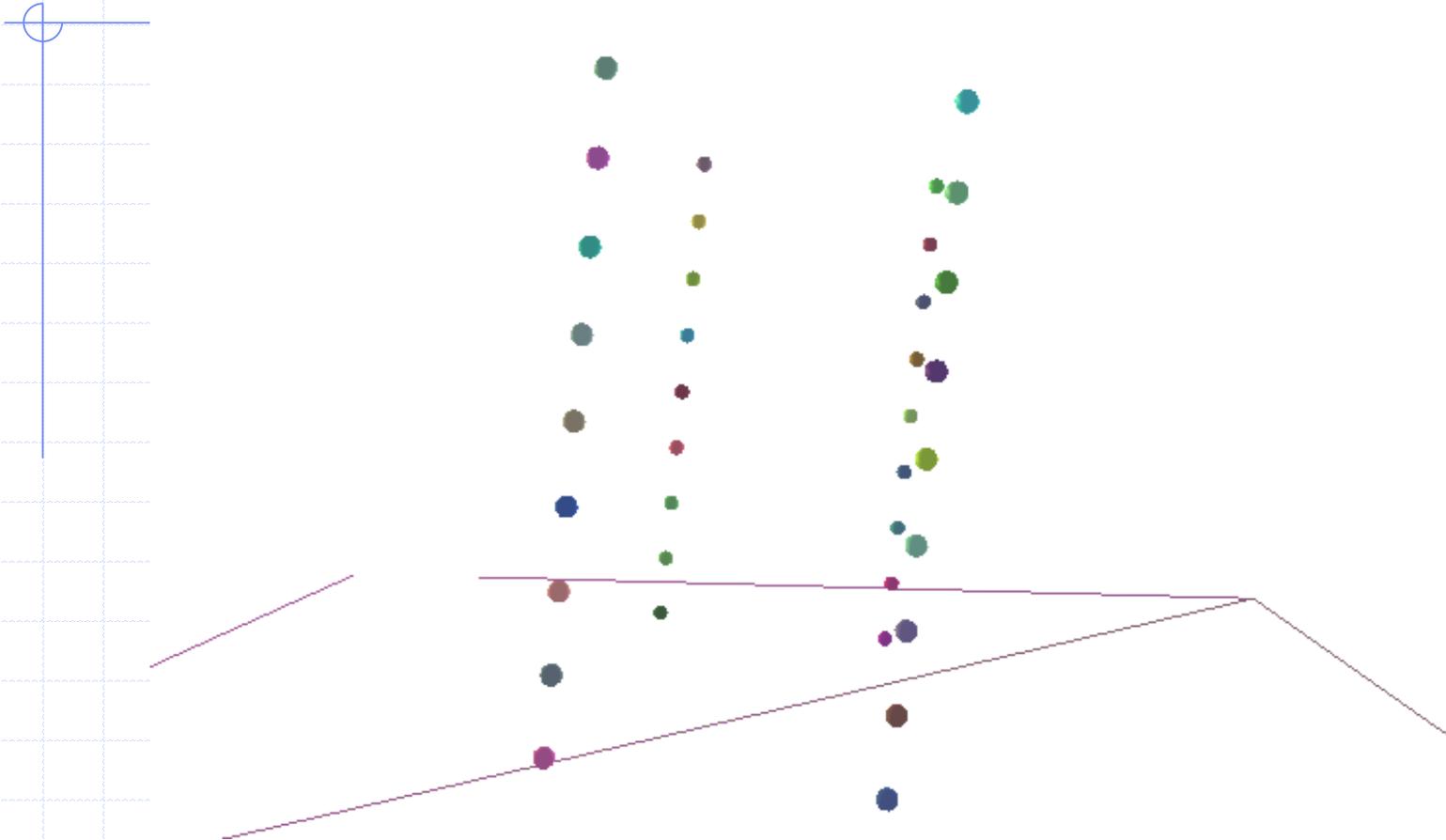
12.0 s.

Selected snapshots

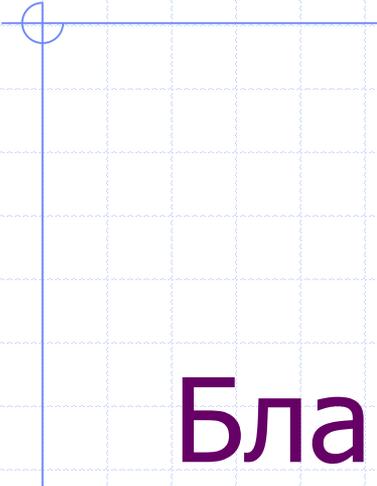


14.0 s.

Selected snapshots



16.0 s.



Благодаря за вниманието!