Bács-Kiskun Vármegyei Mérnöki Kamara
Szakmai továbbképzés
2024.11.14.

FÖLDRENGÉS SZÁMÍTÁS A HELYI VÁLASZSPEKTRUMOK ALAPJÁN

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BUDAPESTI MŰSZAKI
ÉS GAZDASÁGTUDOMÁNYI EGYETEM
Építőmérnöki Kar - építőmérnöki képzés 1782 óta
Hidak és Szerkezetek Tanszék

1) SZERKEZETEK VISELKEDÉSE ÉS ANALÍZISE FÖLDRENGÉSRE

2) SZERKEZETEK MÉRETEZÉSE AZ EUROCODE 8 SZERINT – ALAPELVEK

3) HELYI SPEKTRUMOK ALKALMAZÁSA A FÖLDRENGÉSI MÉRETEZÉSBEN

Szerkezetek viselkedése és analízise földrengésre

Földrengés számítás a helyi válaszspektrumok alapján

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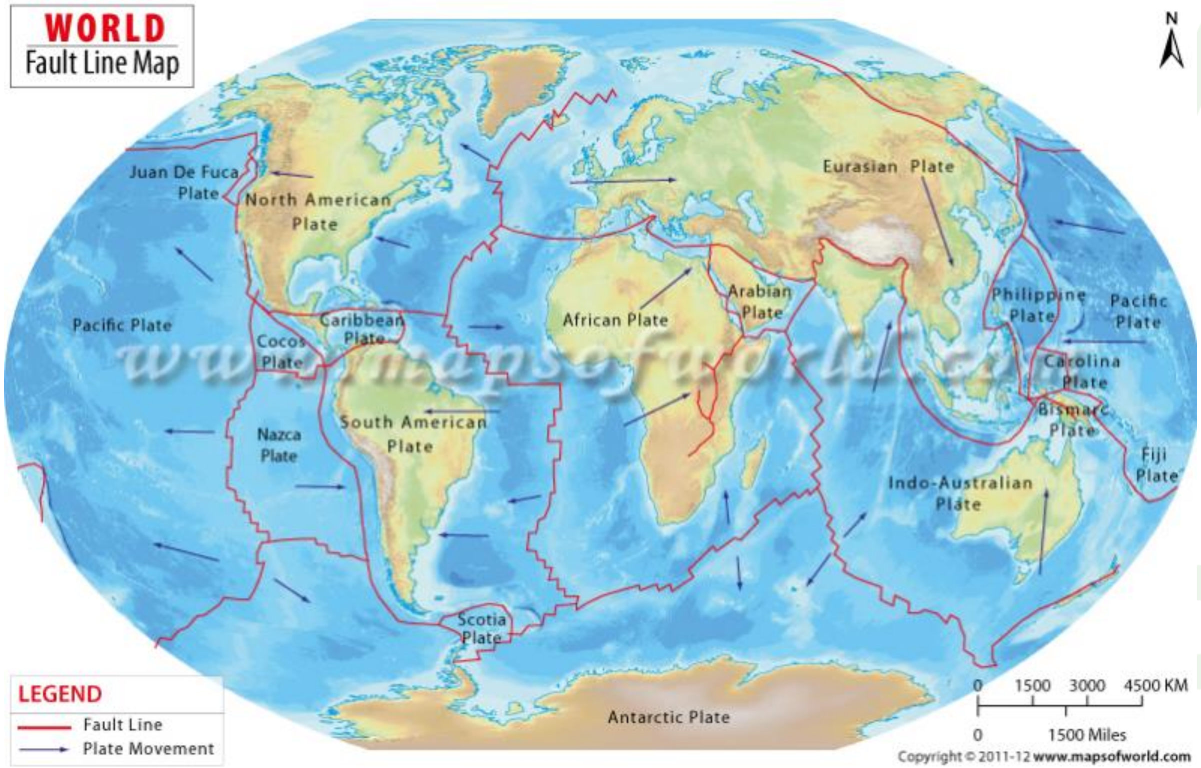
Földrengés keletkezése, jellemzése

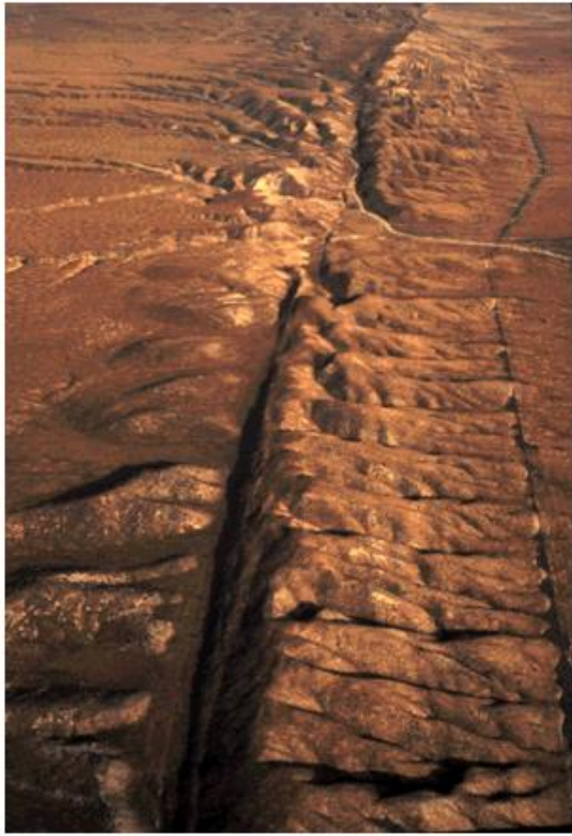
FÖLDRENGÉSEK TÍPUSAI

- **Természetes földrengések**
  - *tektonikus mozgások miatt*
  - *vulkáni tevékenység miatt*
  - *impakt hatás, becsapódás következtében (pl. meteorit becsapódás)*
- **Emberi tevékenység következtében**
  - *víztározók (2008 Sichuan, 8.0)*
  - *bányászat (1989 New Castle, Australia, 5.6)*
  - *fosszilis anyagok, víz kitermelése (2011 Oklahoma?, 5.6)*
  - *vízbányászat (2011 Lorca, 5.1)*
  - *geotermikus energia*

FÖLDRENGÉSEK KIALAKULÁSA

– törésvonalak

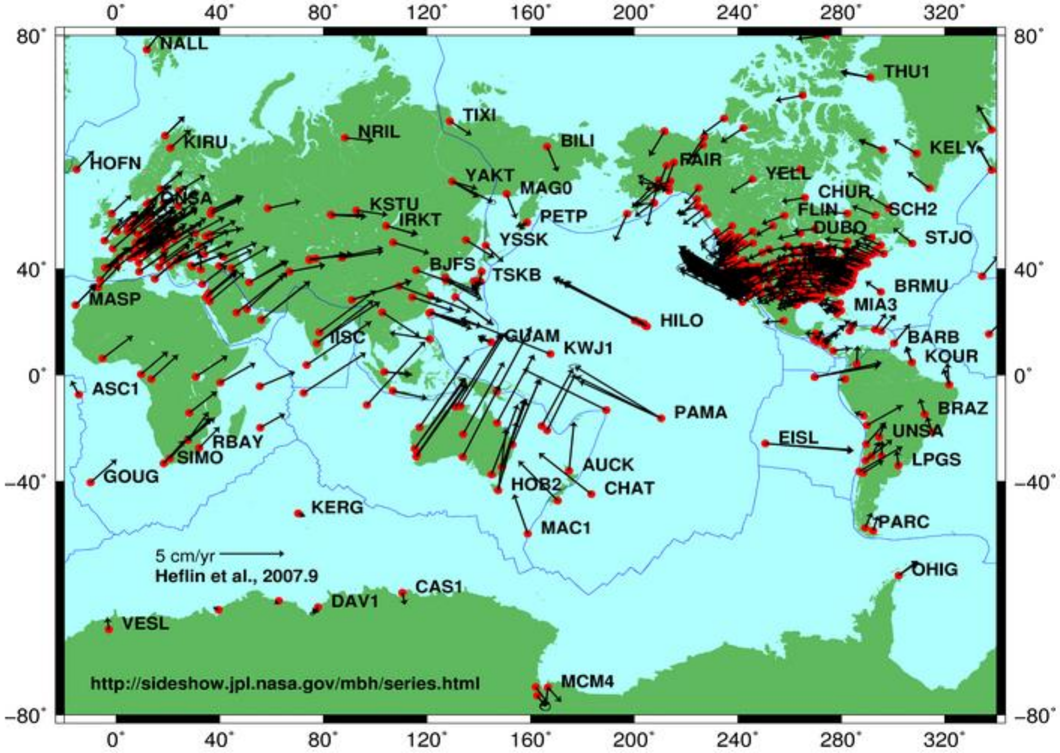


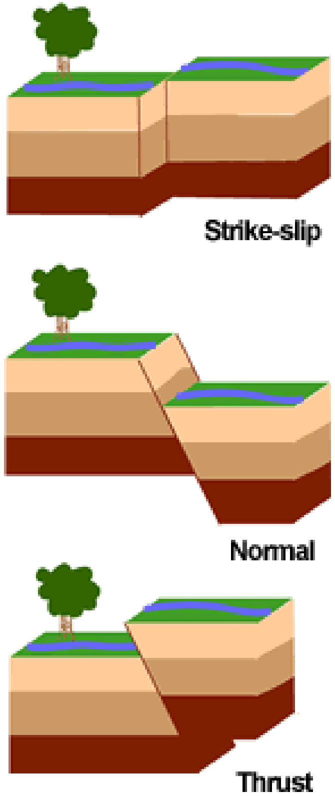


Forrás: Maps of World

http://www.mapsofworld.com/world-maps/fault-lines-map.html

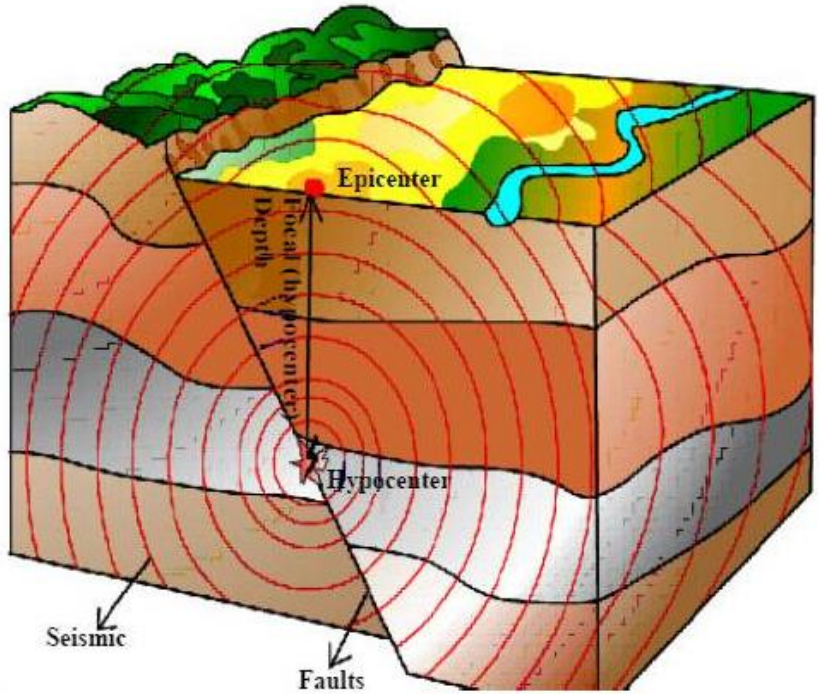
- tektonikus lemezek mozgása, törésvonal típusai





Forrás: Wikipedia
http://en.wikipedia.org/wiki/File:Global_plate_motion_2008-04-17.jpg

– Hipocentrum és epicentrum



Forrás:
http://scweb.cwb.gov.tw/Page.aspx?ItemId=37&NId=179&loc=en

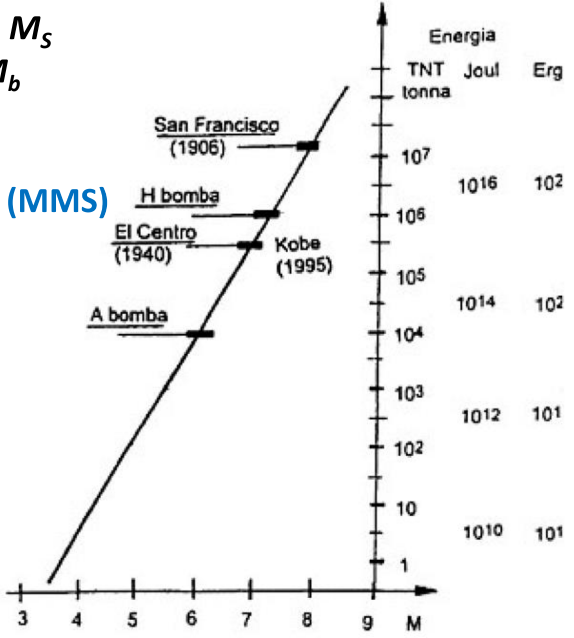
FÖLDRENGÉS JELLEMZÉSE

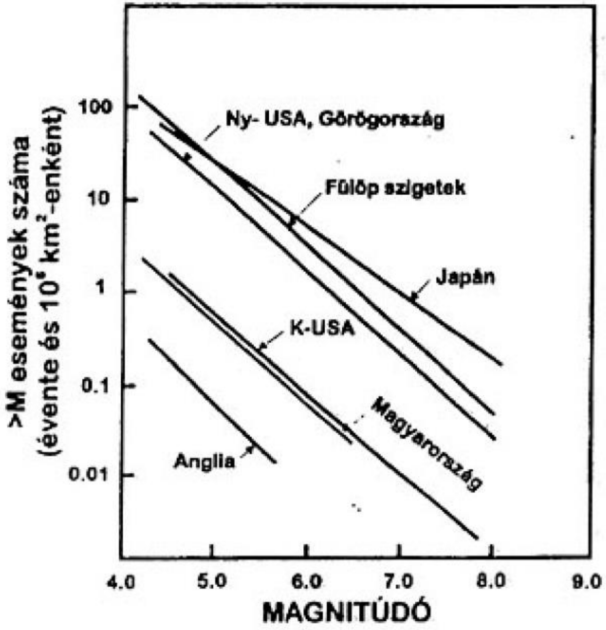
– Magnitúdó:

felszabaduló energiát jellemzi

- **local magnitude, M_L**
- **surface wave magnitude , M_S**
- **body wave magnitude , M_b**
- **moment magnitude , M_W**

- **moment magnitude scale (MMS)**





Forrás: Wikipedia

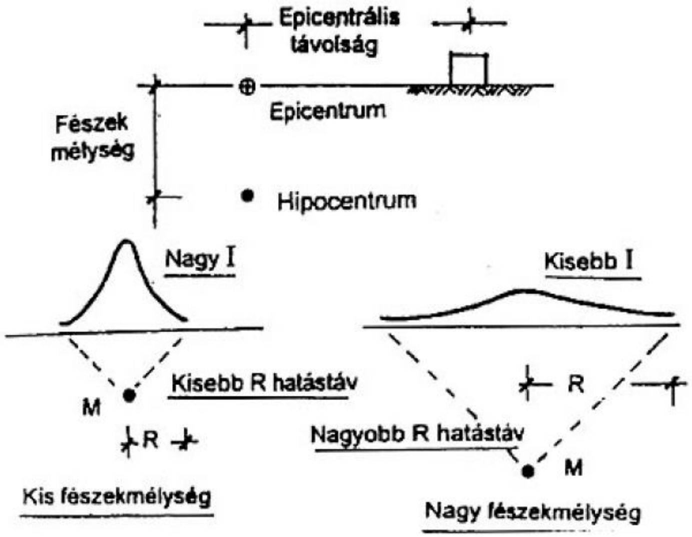
– Intenzitás:

emberek komfortérzete, okozott kár/következmény mértéke

Scale	Effect description
I. Instrumental	Generally not felt by people unless in favorable conditions
II. Weak	Felt only by a couple people that are sensitive, especially on the upper floors of buildings. Delicately suspended objects (including chandeliers) may swing slightly
III. Slight	Felt quite noticeably by people indoors, especially on the upper floors of buildings. Many do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration similar to the passing of a truck. Duration can be estimated. Indoor objects (including chandeliers) may shake
IV. Moderate	Felt indoors by many to all people, and outdoors by few people. Some awakened. Dishes, windows, and doors disturbed, and walls make cracking sounds. Chandeliers and indoor objects shake noticeably. The sensation is more like a heavy truck striking building. Standing automobiles rock noticeably. Dishes and windows rattle alarmingly. Damage none
V. Rather Strong	Felt inside by most or all, and outside. Dishes and windows may break and bells will ring. Vibrations are more like a large train passing close to a house. Possible slight damage to buildings. Liquids may spill out of glasses or open containers. None to a few people are frightened and run outdoors
VI. Strong	Felt by everyone, outside or inside; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight to moderate to poorly designed buildings, all others receive none to slight damage
VII. Very Strong	Difficult to stand. Furniture broken. Damage light in building of good design and construction; slight to moderate in ordinarily built structures; considerable damage in poorly built or badly designed structures; some chimneys broken or heavily damaged. Noticed by people driving automobiles
VIII. Destructive	Damage slight in structures of good design, considerable in normal buildings with a possible partial collapse. Damage great in poorly built structures. Brick buildings easily receive moderate to extremely heavy damage. Possible fall of chimneys, factory stacks, columns, monuments, walls, etc. Heavy furniture moved
IX. Violent	General panic. Damage slight to moderate (possibly heavy) in well-designed structures. Well-designed structures thrown out of plumb. Damage moderate to great in substantial buildings, with a possible partial collapse. Some buildings may be shifted off foundations. Walls can fall down or collapse
X. Intense	Many well-built structures destroyed, collapsed, or moderately to severely damaged. Most other structures destroyed, possibly shifted off foundation. Large landslides
XI. Extreme	Few, if any structures remain standing. Numerous landslides, cracks and deformation of the ground
XII. Catastrophic	Total destruction – everything is destroyed. Lines of sight and level distorted. Objects thrown into the air. The ground moves in waves or ripples. Large amounts of rock move position. Landscape altered, or leveled by several meters. Even the routes of rivers can be changed

– Magnitúdó vs. Intenzitás

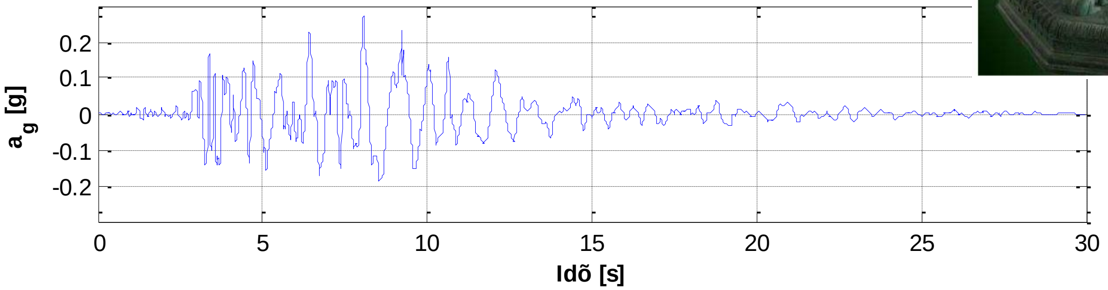
Magnitúdó, M	tipikus maximum módosított Mercalli Intenzitás, I
< 2.0	I
2.0 - 2.9	I – II
3.0 - 3.9	II – IV
4.0 - 4.9	IV – VI
5.0 - 5.9	VI – VIII
6.0 - 6.9	VII – X
7.0 - 7.9	VIII <
8.0 <	IX <



– Szeizmográf, accelerogram

Northridge, 1994

(Beverly Hills-Mulhol station)

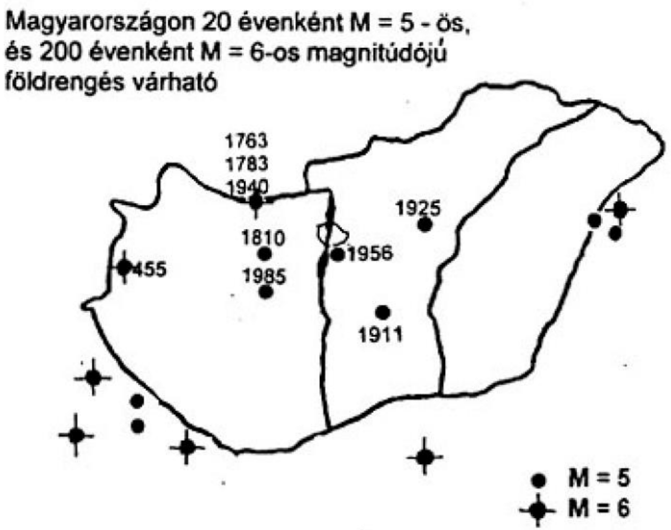


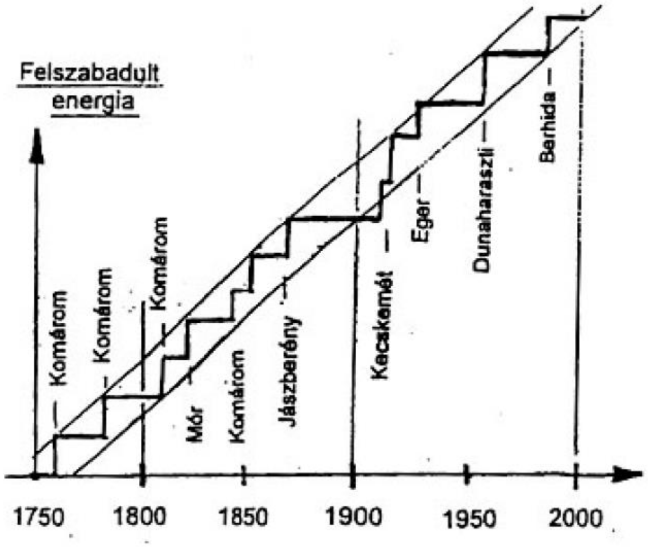
Legnagyobb földrengések

Földrengés	Halálos áldozatok	Moment Magnitúdó	Mercalli intenzitás
1755 Boston/Massachusetts/New England earthquake	0	5.9–6.3	VIII
2011 Christchurch earthquake	182	6.3	IX[13]
1980 Irpinia earthquake	2,914	6.5	X
1994 Northridge/Los Angeles earthquake	60	6.7	IX
1995 Kobe/Great Hanshin earthquake	6,434	6.8–7.3	X–XI[8]
2010 Haiti earthquake	316,000	7.0	X
2010 Canterbury earthquake	0	7.1	X
1908 Messina earthquake	150,000–200,000	7.2	XI
1977 Vrancea earthquake	1,578	7.2	X–XI
2011 Van earthquake	432	7.2	X
1906 San Francisco earthquake	3,425	7.8	X
1920 Haiyuan earthquake	235,502	7.8[5]–8.5[6]	XII
1976 Tangshan earthquake	242,769-650,000[7]	7.8–8.2	XI[8]
2008 Sichuan earthquake	69,195	7.9[9]	XI
1556 Shaanxi earthquake	830,000	7.9–8.0	XI
2011 Japan earthquake and tsunami	18,500. Totals include tsunami.	9.0	IX[12]
2004 Indian Ocean earthquake and tsunami	230,000–280,000. Totals included tsunami.	9.1–9.3	IX[11]
1964 Good Friday/Anchorage/Alaska earthquake	143. Totals include tsunami.	9.2	XI
1960 Valdivia earthquake	2,230–6,000	9.5	XI[10]

Forrás: Wikipedia

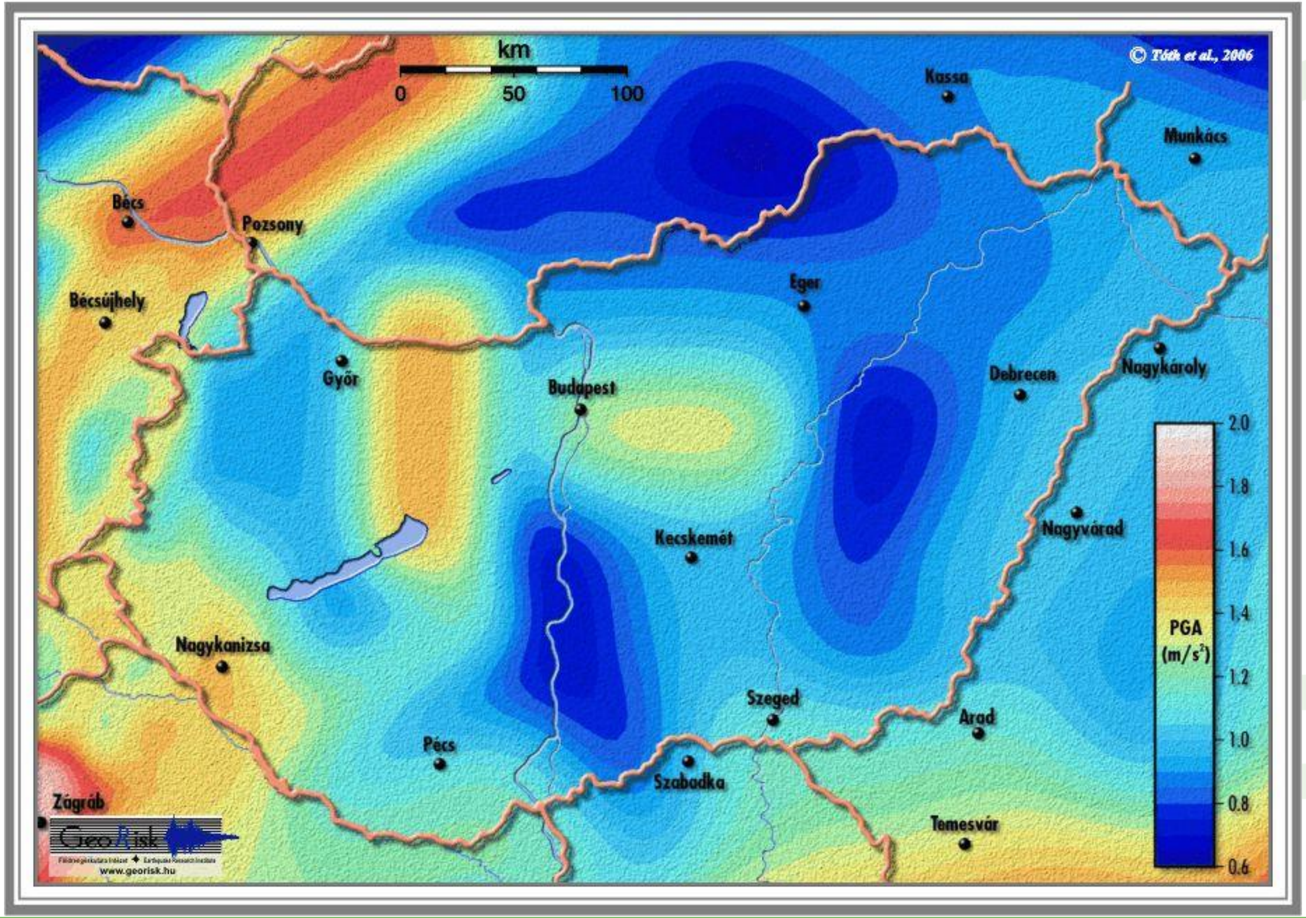
MAGYARORSZÁG





Magyarország földrengésveszélyeztetettsége

Horizontális gyorsulás értékek 50 évre, 10% meghaladási valószínűség mellett (1/475 év gyakoriság) az alapkőzeten, m/s² egységben



Forrás: www.foldrenges.hu

FÖLDRENGÉS OKOZTA KÁROK

Szerkezeti károk

Ground rupture

San Francisco, 1906

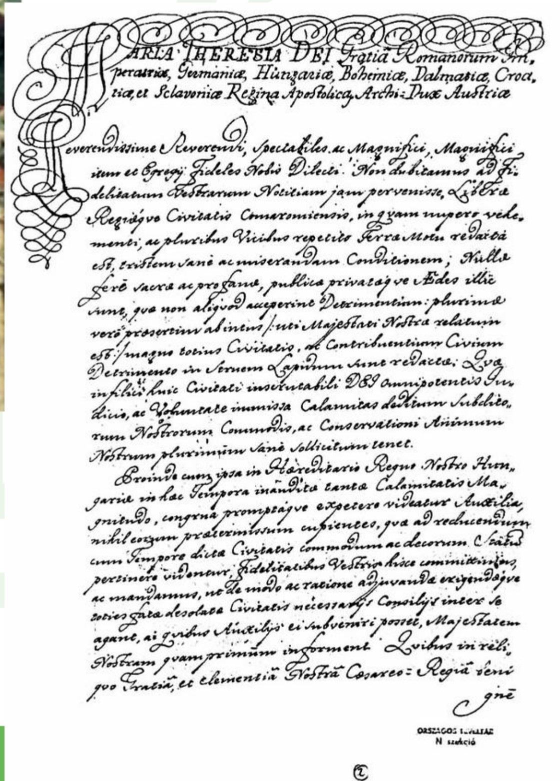
(M 7.8, 40 sec – **tűz** – 315 vagy 3000? halálos áldozat)

Fukui, 1946

(M 7.3, 3500 halálos áldozat)

Komárom, 1763

(M 6.3)



MARIA THERESIA DEI Gratiâ Romanorum Im-
peratrix, Germaniæ, Hungariæ, Bohemiæ, Dalmatiæ, Croa-
tiæ, et Sclavoniæ Regina Apostolica, Archi-Dux Austriæ

Reverendissime Reverendi, Spectabiles ac Magnifici, Magnifici
item et Egregij Fideles Nobis Dilecti. Non dubitamus ad Fi-
delitatum Vestrarum Notitiam jam pervenisse, Liberæ
Regiæque Civitatis Comaromiensis, in quam nupero vehe-
menti; ac pluribus Vicibus repetito Terræ Motu redacta
est, tristem sane ac miserandam Conditionem; Nullæ
ferè sacræ ac profanæ, publicæ privatæque Ædes illic
sunt, quæ non aliquod acceperint Detrimentum: plurimæ
verò præsertim ab intus /: uti Majestati Nostræ relatum
est :/ magno totius Civitatis, ac Contribuentium Civium
Detrimento in Acervum Lapidum sunt redactæ. Quæ
infelici huic Civitati inscrutabili DEI omnipotentis Ju-
dicio, ac Voluntate immissa Calamitas deditium Subdito-
rum Nostrorum Commodis, ac Conservationi Animum
Nostrum plurimum sanè sollicitum tenet.

Proinde cum ipsa in Hæreditario Regno Nostro Hun-
gariæ in hac Tempora inaudita tanta Calamitatis Ma-
gnitudo, congrua promptaque expetere videatur Auxilia,
nihil eorum prætermissum cupientes, quæ ad reducendum
cum Tempore dictæ Civitatis commodum ac decorum Statum
pertinere videntur, Fidelitatibus Vestris hisce committimus,
ac mandamus, ut de modo ac ratione adjuvandæ exigendæque
toties fatæ desolatæ Civitatis necessarijs Consilijs inter se
agant, ac quibus Auxilijs ei subveniri posset, Majestatem
Nostram quamprimum informent. Quibus in reli-
quo Gratiâ, et clementiâ Nostrâ Cæsareo-Regiâ beni-
gnè

ORSZÁGOS LEVÉLTÁR
N szekció

Forrás: foldrenges.hu

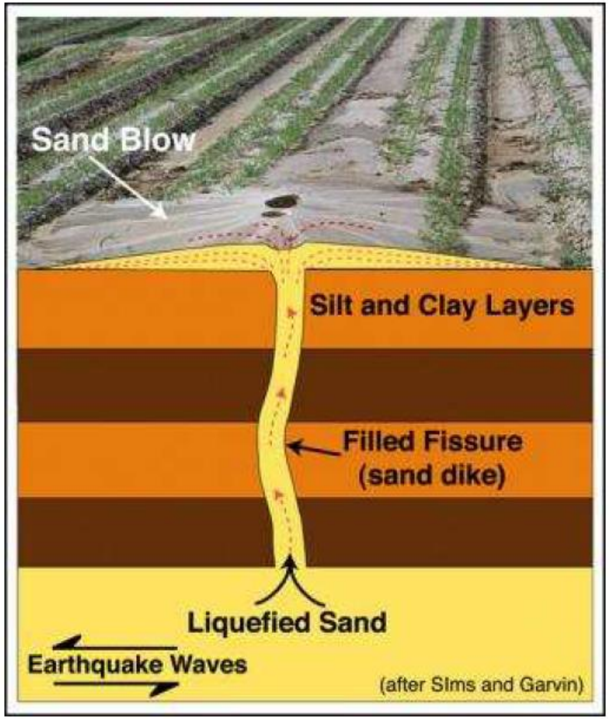
Dunaharaszti, 1956

(M 5.2)

Forrás: foldrenges.hu

Talajfolyósodás

California, 1970



Talajfolyósodás

Japan

Kobe, 1995

(M 7.2, 5.000 halálos áldozat, 190.000 épület)

Indiai-óceán földrengés és cunami, 2004

(M 9.1-9.3)

Forrás: Wikipedia

Tohoku földrengés és cunami, 2011

(M 9.0)

Source: Wikipedia

Fényjelenség

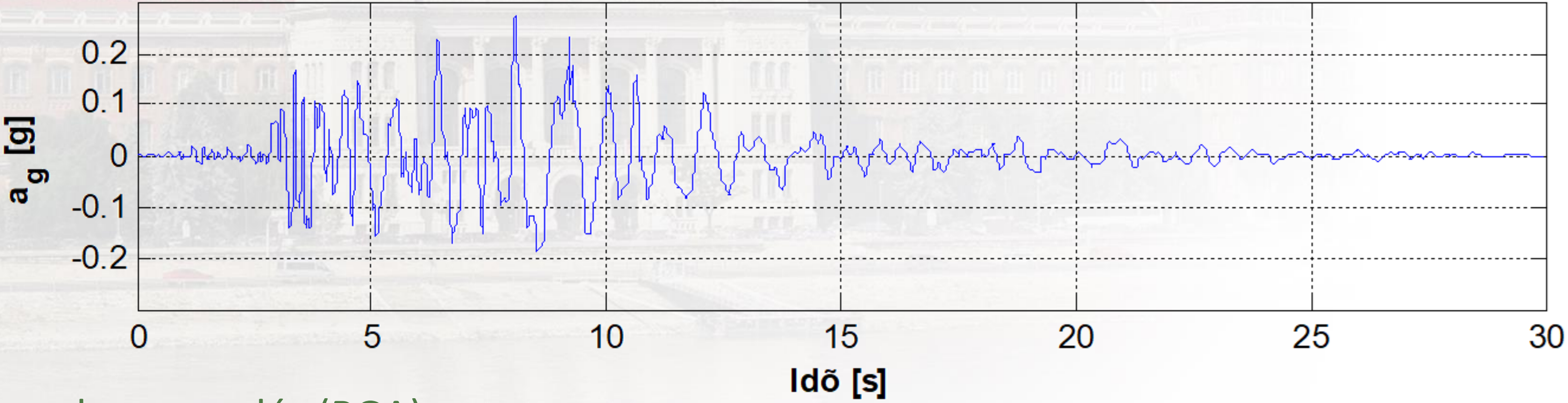
Szerkezetek viselkedése, analízise – Egyszabadságfokú rugalmas rendszer

FÖLDRENGÉS JELLEMZÉSE - SZERKEZETTERVEZÉSHEZ

Northridge, 1994

(Beverly Hills-Mulhol station)

accelerogram – földrengés rekord



- alapgyorsulás (PGA) a_g
- frekvenciatartalom
- időtartam
- irányultság

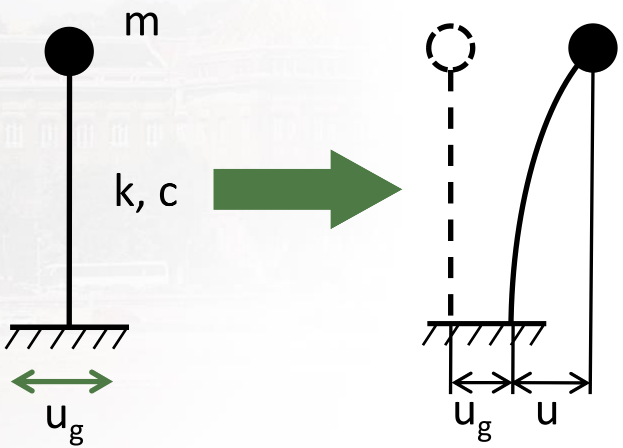
Egyszabadságfokú rugalmas rendszer

Differenciálegyenlet

$$k \cdot u + c \cdot \dot{u} + m\left(\ddot{u}_g + \ddot{u}\right) = 0$$

$$k \cdot u + c \cdot \dot{u} + m \cdot \ddot{u} = -m \cdot \ddot{u}_g$$

$$k \cdot u + c \cdot \dot{u} + m \cdot \ddot{u} = -p(t)$$

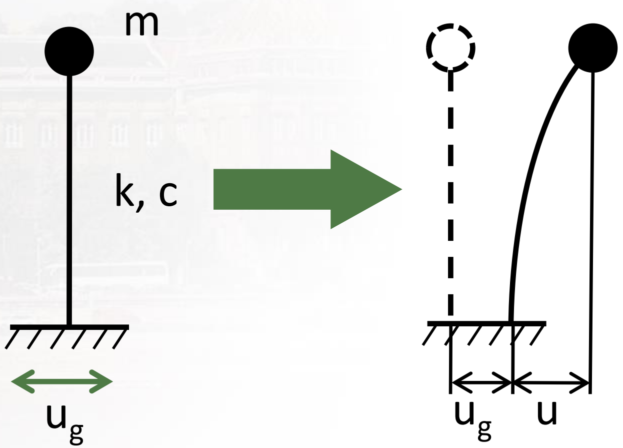


EGYSZABADSÁGFOKÚ RUGALMAS RENDSZER

PERIODIKUS GERJESZTÉSE

$$k \cdot u + c \cdot \dot{u} + m \cdot \ddot{u} = -p(t)$$

$$u = e^{-\xi \omega_n t}\left[A \cos \omega_D t + B \sin \omega_D t\right] + C \sin \omega t + D \cos \omega t$$



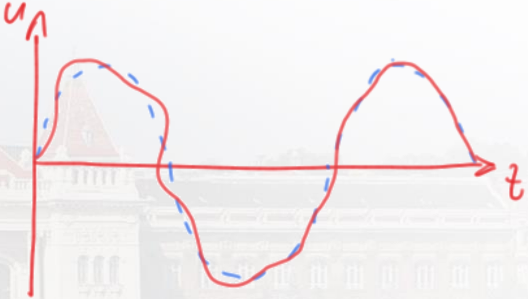
Körfrekvencia $\omega_n = \sqrt{\dfrac{k}{m}}$ $\omega_D = \omega_n \sqrt{1-\xi^2}$

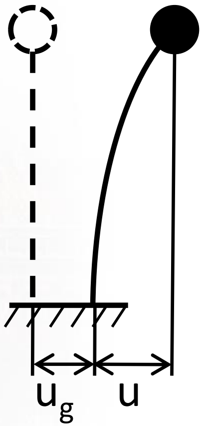
Periódusidő $T_n = \dfrac{2\pi}{\omega_n}$

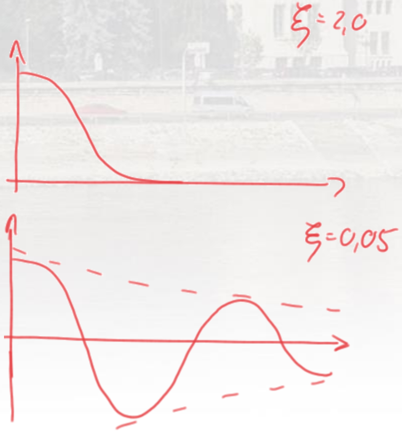
Csillapítás $\xi = \dfrac{c}{c_{cr}}; \quad c_{cr} = 2m\omega_n$

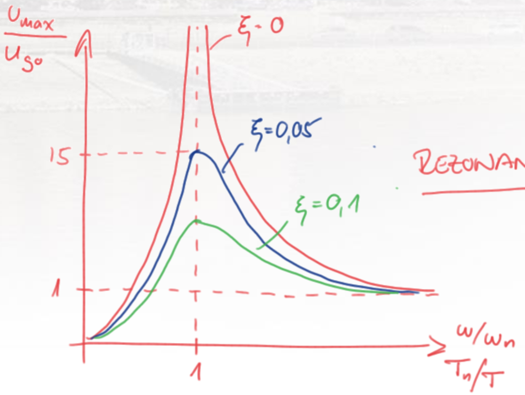
CSILLAPÍTÁS

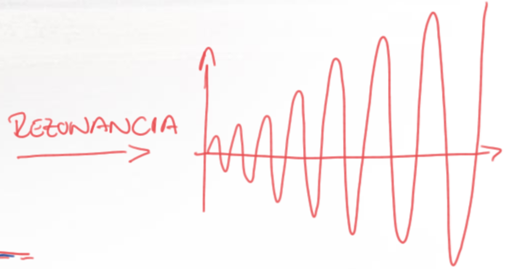
$$\xi = \frac{c}{c_{cr}}; \quad c_{cr} = 2m\omega_n$$











- anyagi csillapítás
- súrlódás
- szerk. kialakítás
- teherszint

Currently Used Damping Values
(Steel Buildings)

Country	Actions/Stress Levels	Joints/Structures	Damping ratios ζ_1 (%)
Australia (AS1170.2)	Serviceability		0.5 – 1.0
	Ultimate & Permissible	Frame Bolted	5
		Frame Welded	2
Austria	(ÖNORM B4014)		
China	(GB50191-93)	Steel (TV) Tower	2
France		Standard Bolt	0.8
		High Resistance Bolt	0.5
		Welded	0.3
	Earthquake	Bolt	4
		Welded	2
Germany	Wind (DIN 1055)		
Italy	Wind (EUROCODE 1)		
	Earthquake		5
Japan	Habitability		1
	Earthquake		2
Singapore			1
Sweden	(Swedish Code of Practice)		0.9
United Kingdom	Wind (ESDU)		
USA (Penzien, US Atomic Energy Commission)			

Forrás: Yukio Tamura, Tokyo Polytechnic University
http://www.wind.arch.t-kougei.ac.jp/info_center/ITcontent/tamura/10.pdf

- anyagi csillapítás
- súrlódás
- szerk. kialakítás
- teherszint

Currently Used Damping Values (RC Buildings)

Country	Actions/Stress Levels	Structures	Damping ratios ζ_1 (%)
Australia (AS1170.2)	Serviceability	RC or Prestressed C	0.5 – 1.0
	Ultimate & Permissible	RC or Prestressed C	5
Austria	(ÖNORM B4014)		
China	(GB50191-93)	RC Structures	5
		RC (TV) Towers	5
		Prestressed RC Tower	3
France		Standard	1.6
		Reinforced	0.65
	Earthquake	Standard	3 - 4
		Reinforced	2
Germany	Wind (DIN 1055)		
Italy	Wind (EUROCODE 1)		
	Earthquake		5
Japan	Habitability		1
	Earthquake		3
Singapore			2
Sweden	(Swedish Code of Practice)		1.4
United Kingdom	Wind (ESDU)		
USA	(US Atomic Energy Commission)		

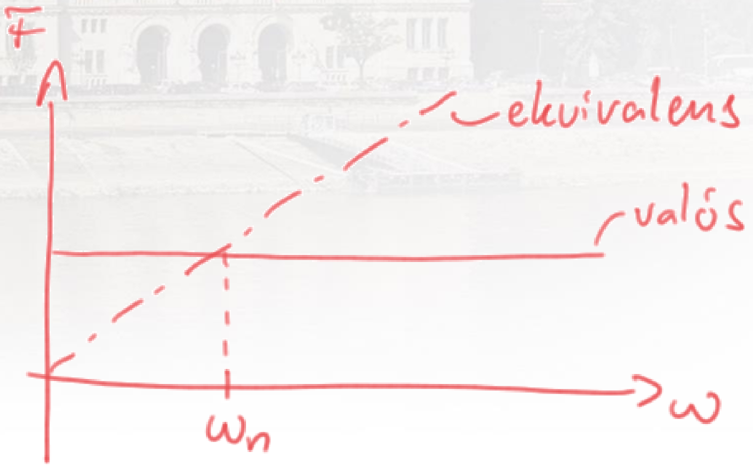
Forrás: Yukio Tamura, Tokyo Polytechnic University
http://www.wind.arch.t-kougei.ac.jp/info_center/ITcontent/tamura/10.pdf

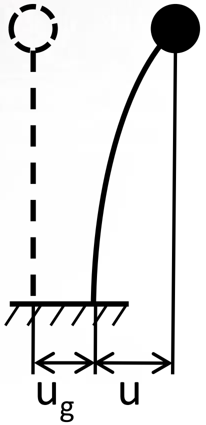
Csillapítás modellezése

$$\xi = \frac{c}{c_{cr}}; \quad c_{cr} = 2m\omega_n \qquad\qquad k \cdot u + c \cdot \dot{u} + m \cdot \ddot{u} = -p(t)$$

valóság: szerkezeti csillapítás sebességfüggetlen

numerikus analízis: sebességfüggő – ekvivalens viszkózus





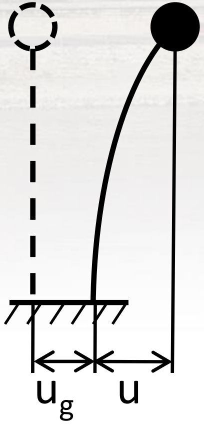
EGYSZABADSÁGFOKÚ RUGALMAS RENDSZER

GERJESZTÉSE FÖLDRENGÉSSEL

Időben tetszőlegesen változó gerjesztőerő

kezdeti érték feladat, numerikus időintegrálás

- centrális differenciák módszere (explicit)
- **Newmark-β (implicit)**
- Wilson-θ (implicit)
- stb



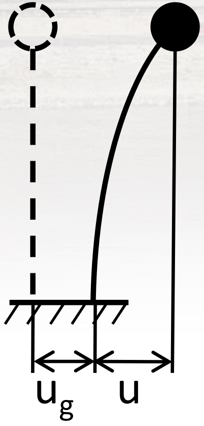
$$m \cdot \ddot{u} + c \cdot \dot{u} + k \cdot u = -p(t)$$

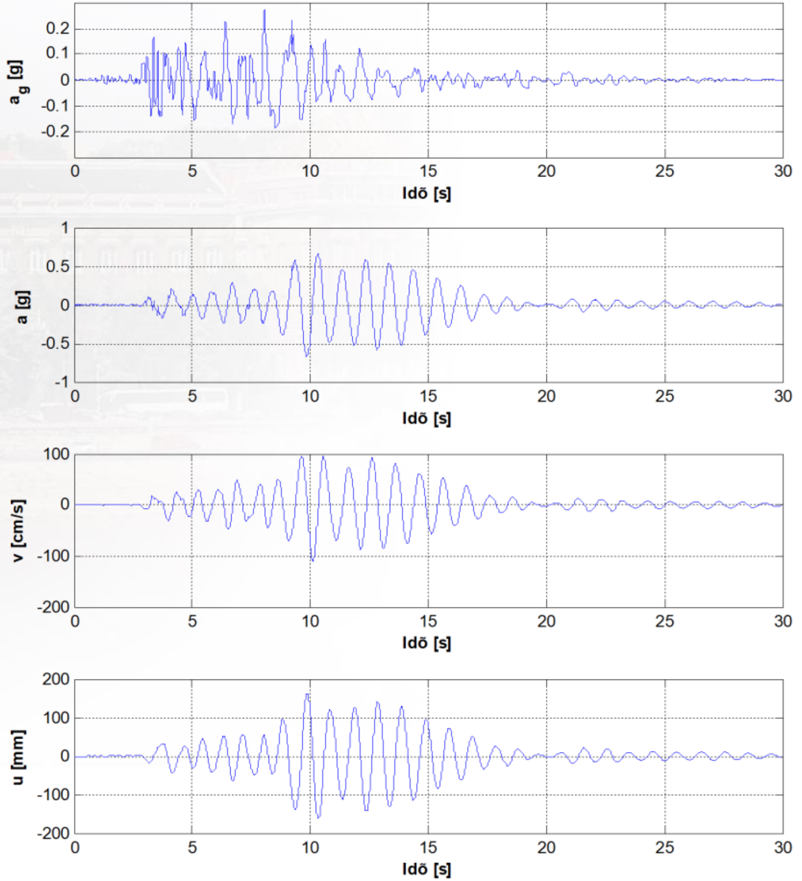
$$t = 0: \ u = 0; \ \dot{u} = 0$$

$$m \cdot \ddot{u}_{i+1} + c \cdot \dot{u}_{i+1} + k \cdot u_{i+1} = -p_{i+1}$$

Northridge, 1994

(Beverly Hills-Mulhol station)

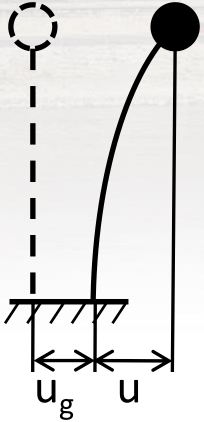


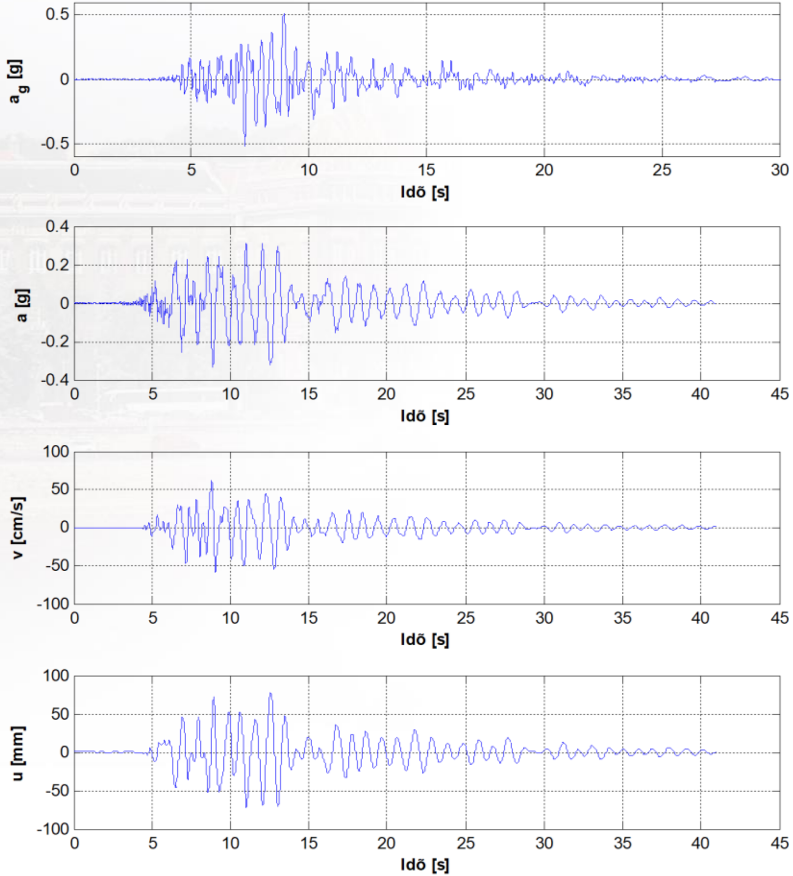


T_n = 1,0 s

Kobe, 1995

(Nishi-Akashi station)

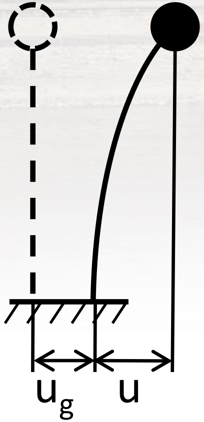




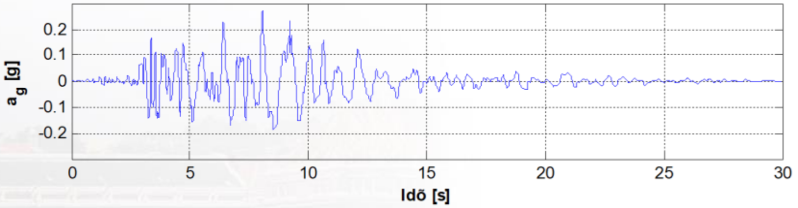
$T_n = 1{,}0$ s

Northridge, 1994

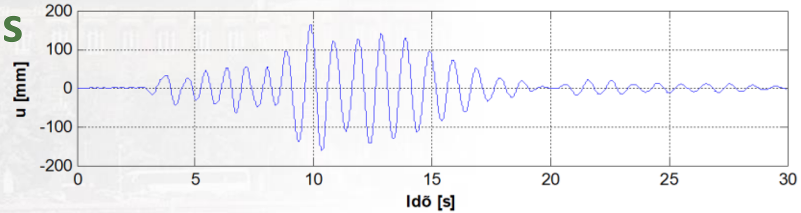
(Beverly Hills-Mulhol station)



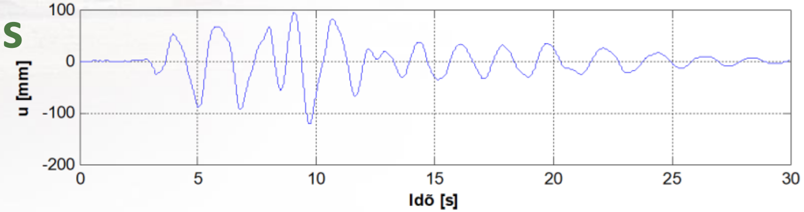
T_n



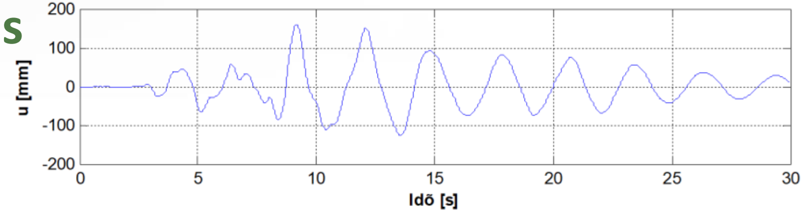
T_n = 1,0 s



T_n = 2,0 s

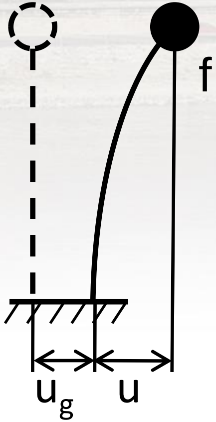


T_n = 3,0 s



rugalmas válaszspektrum:

egy földrengésre adott általános, rugalmas szerkezeti válasz



$$f = kD = m\overbrace{\omega_n^2 D}^{A}$$

T_n

$$\omega_n = \sqrt{\frac{k}{m}}$$

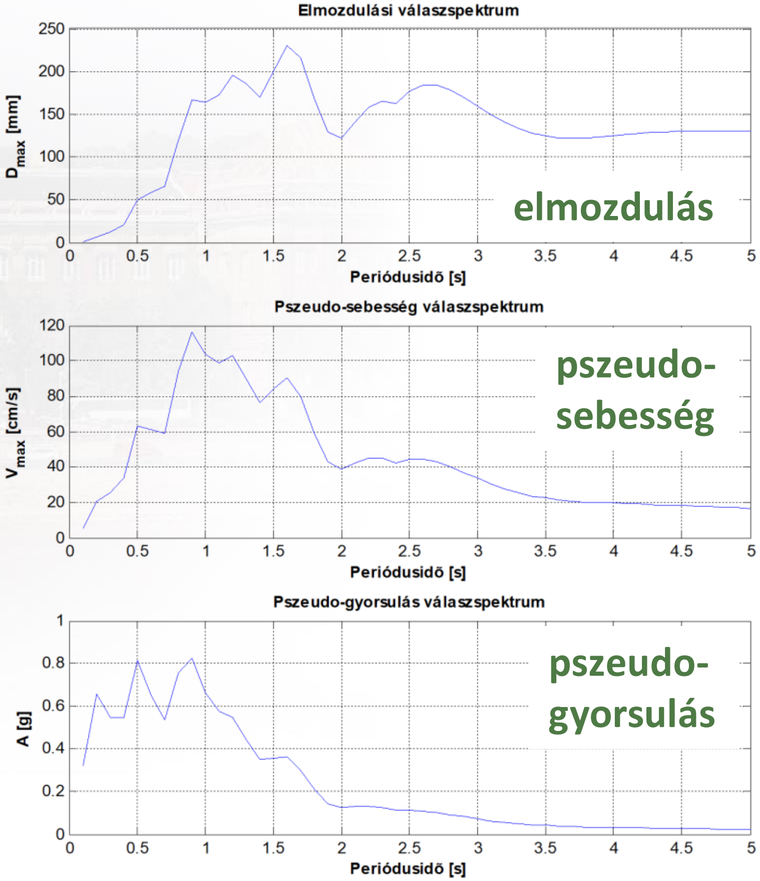
D

$V = \omega_n D$

$A = \omega_n^2 D$

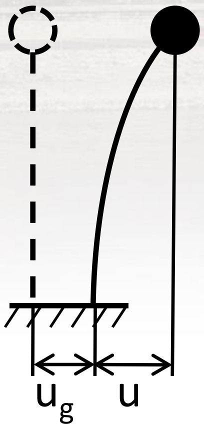
Northridge, 1994

(Beverly Hills-Mulhol station)



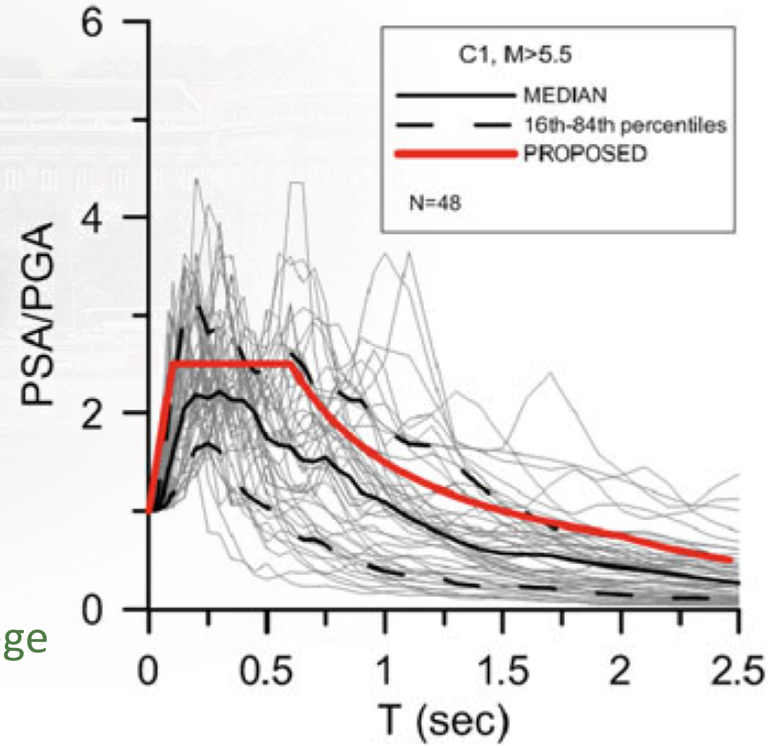
tervezési válaszspektrum:

számos földrengésre adott általános, szerkezeti válaszok jellemző statisztikája



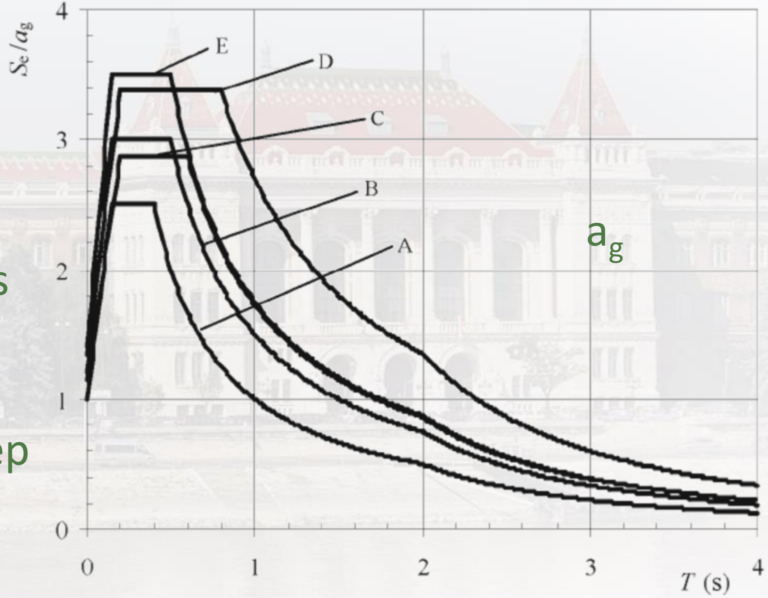
befolyásolja:

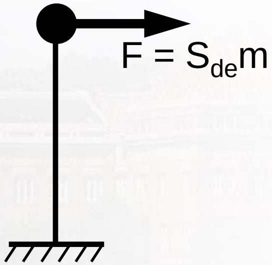
- helyszín (jellemző szeizmicitás)
- talajtípus (talaj erősítő hatása)
- csillapítás mértéke (EC8: 5%)
- szerkezet energiaelnyelő képessége (q – viselkedési tényező)



Forrás: Pitilakis K., Riga E., Anastasiadis A., 2013

ANALÍZIS: HELYETTESÍTŐ TERHEK MÓDSZERE





a_g

alapgyorsulás

földrengéstérkép

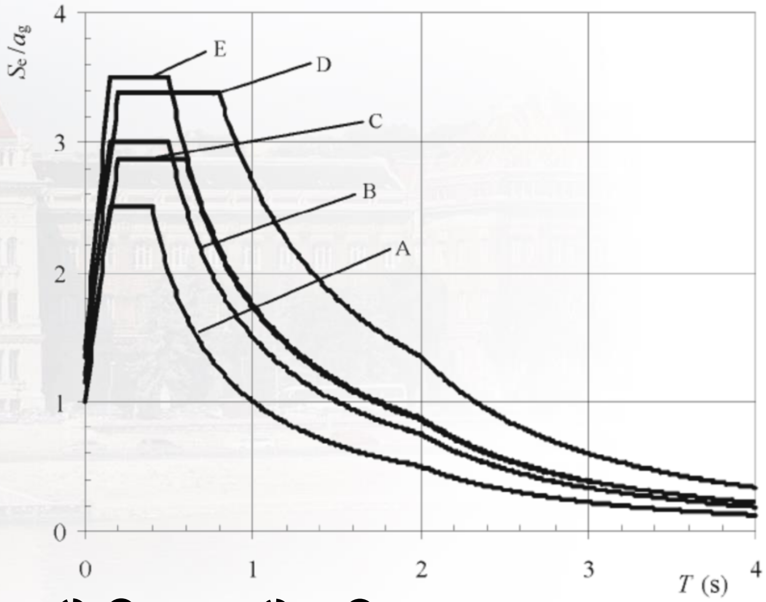
szerkezet → periódusidő

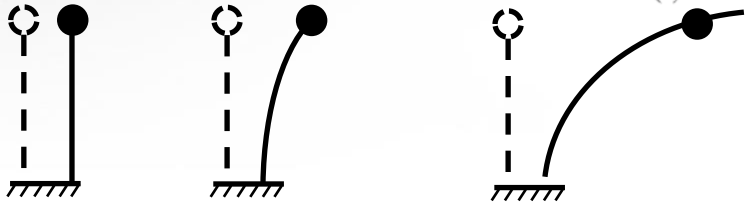
$$\omega_n = \sqrt{\frac{k}{m}} \qquad T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{\mathrm{k}}}$$

teherkombináció

$$\sum_j G_{k,j} \text{"+"} A_{Ed} \text{"+"} \sum_i \varphi \cdot \psi_{2,i} \cdot Q_{k,i}$$

VÁLASZSPEKTRUM





merev → „végtelen” rugalmas

VÁLASZSPEKTRUM

mit mutat meg a válaszspektrum?

növekvő periódusidő:

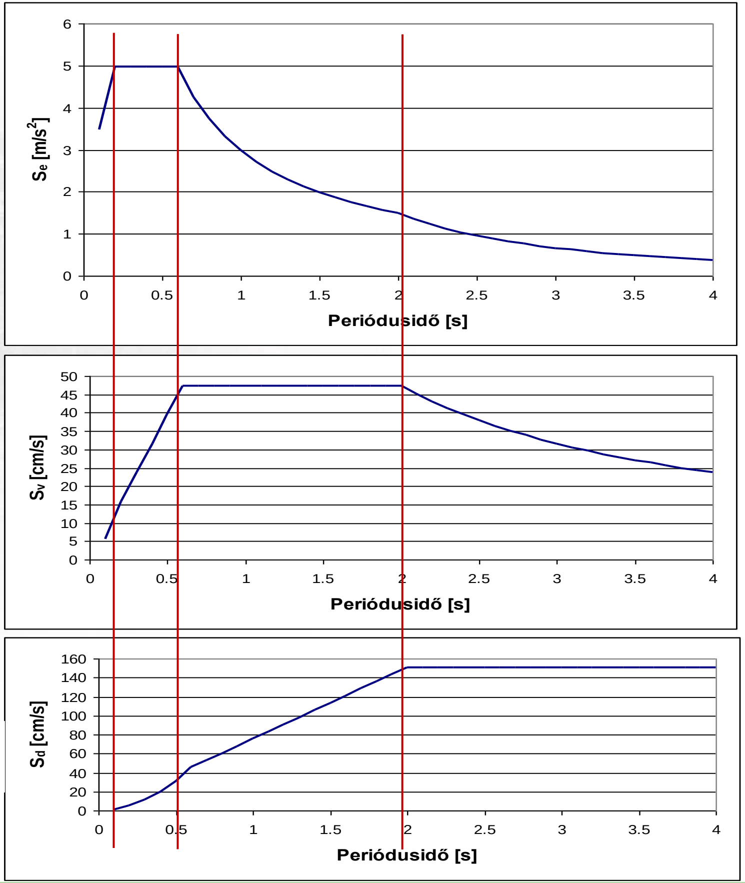
- nagyobb tömeg vagy puhább szerkezet
- csökkenő földrengésteher
- növekvő várható elmozdulás!

$$\omega_n = \sqrt{\frac{k}{m}} \qquad T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{\mathrm{k}}}$$

pszeudo-gyorsulás

pszeudo-sebesség

elmozdulás

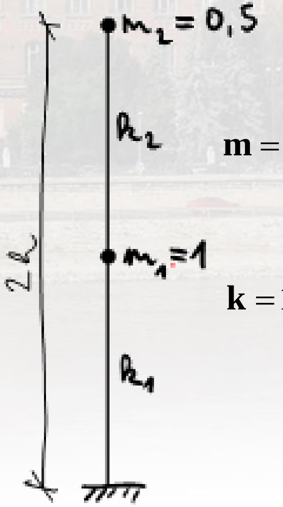


TÖBBSZABADSÁGFOKÚ RENDSZEREK

TÖBBSZABADSÁGFOKÚ RENDSZEREK

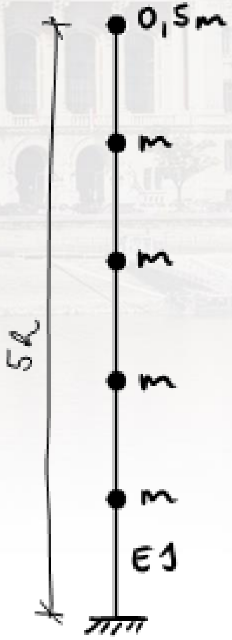
Egyszabadságfokú rendszer: $m\ddot{u} + c\dot{u} + ku = p(t)$

Többszabadságfokú rendszer: $\mathbf{m}\ddot{\mathbf{u}} + \mathbf{c}\dot{\mathbf{u}} + \mathbf{k}\mathbf{u} = \mathbf{p}(t)$



$$\mathbf{m} = \begin{bmatrix} 1 & \\ & 0{,}5 \end{bmatrix}$$

$$\mathbf{k} = 1000 \begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix}$$



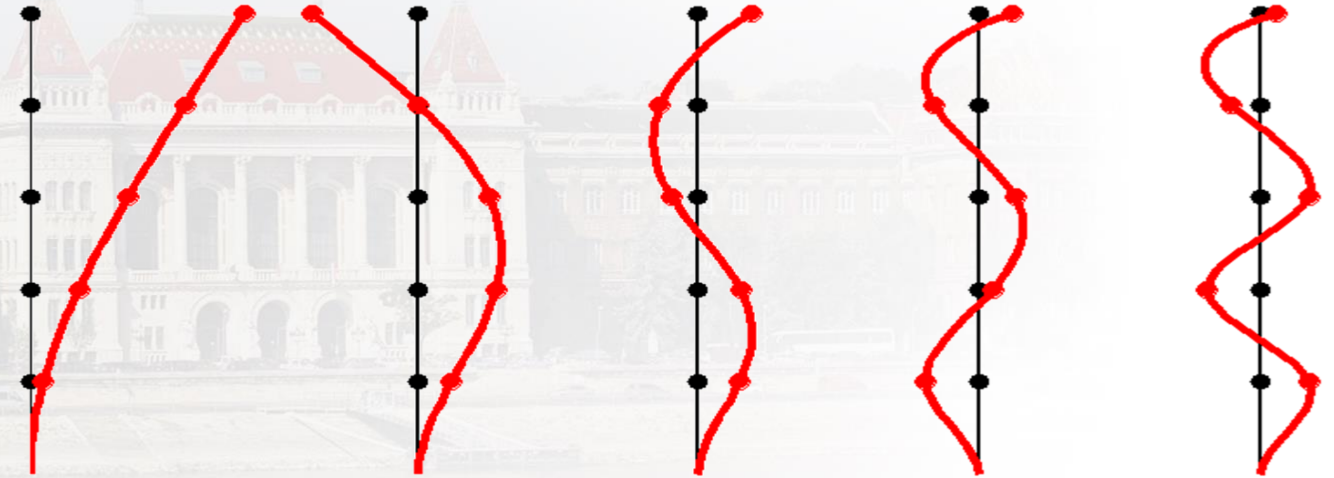
$$\mathbf{m} = 208{,}6 \begin{bmatrix} 1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & 1 & \\ & & & & 0{,}5 \end{bmatrix}$$

$$\mathbf{k} = \frac{5{,}469 \cdot 10^{10}}{120^3} \begin{bmatrix} 18{,}83 & -11{,}9 & 4{,}773 & -1{,}193 & 0{,}1989 \\ & 14{,}65 & -10{,}71 & 4{,}177 & -0{,}6961 \\ & & 14{,}06 & -9{,}514 & 2{,}586 \\ & \text{szimm.} & & 9{,}878 & -3{,}646 \\ & & & & 1{,}608 \end{bmatrix}$$

Forrás: Chopra: Dynamics of structures

TÖBBSZABADSÁGFOKÚ RENDSZEREK

rezgésalakok



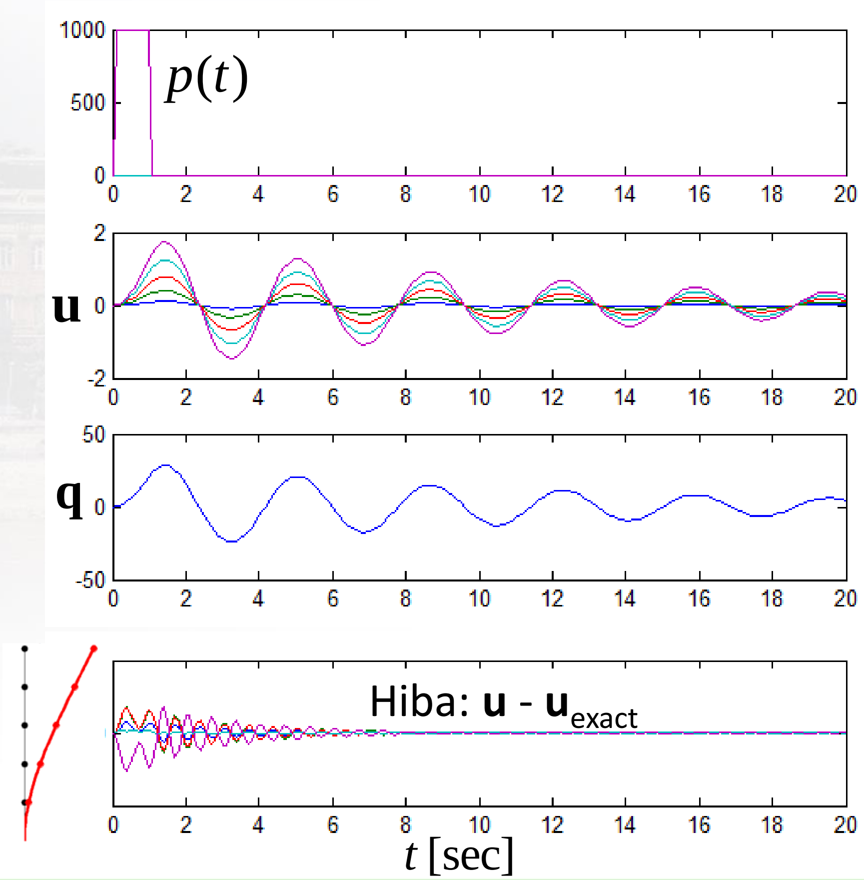
ω_1 = 1.7438 1/s $\quad$ ω_2 = 10.2072 1/s $\quad$ ω_3 = 27.5707 1/s $\quad$ ω_4 = 51.4576 1/s $\quad$ ω_5 = 75.3942 1/s

$$\mathbf{\Phi} = \begin{bmatrix} 0{,}0039 & 0{,}0173 & 0{,}0344 & -0{,}0443 & 0{,}0365 \\ 0{,}0139 & 0{,}0402 & 0{,}0352 & 0{,}0111 & -0{,}0403 \\ 0{,}0280 & 0{,}0369 & -0{,}0214 & 0{,}0298 & 0{,}0360 \\ 0{,}0441 & 0{,}0004 & -0{,}0308 & -0{,}0378 & -0{,}0217 \\ 0{,}0609 & -0{,}0550 & 0{,}0438 & 0{,}0279 & 0{,}0121 \end{bmatrix}$$

Többszabadságfokú rendszerek

modális felbontás

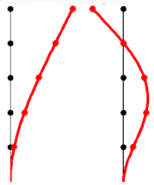
$$\mathbf{u}=\begin{bmatrix}u_1\\u_2\\\vdots\\u_5\end{bmatrix}=q_1\begin{bmatrix}\Phi_{11}\\\Phi_{21}\\\vdots\\\Phi_{51}\end{bmatrix}+q_2\begin{bmatrix}\Phi_{12}\\\Phi_{22}\\\vdots\\\Phi_{52}\end{bmatrix}+q_3\begin{bmatrix}\Phi_{13}\\\Phi_{23}\\\vdots\\\Phi_{53}\end{bmatrix}+q_4\begin{bmatrix}\Phi_{14}\\\Phi_{24}\\\vdots\\\Phi_{54}\end{bmatrix}+q_5\begin{bmatrix}\Phi_{15}\\\Phi_{25}\\\vdots\\\Phi_{55}\end{bmatrix}$$

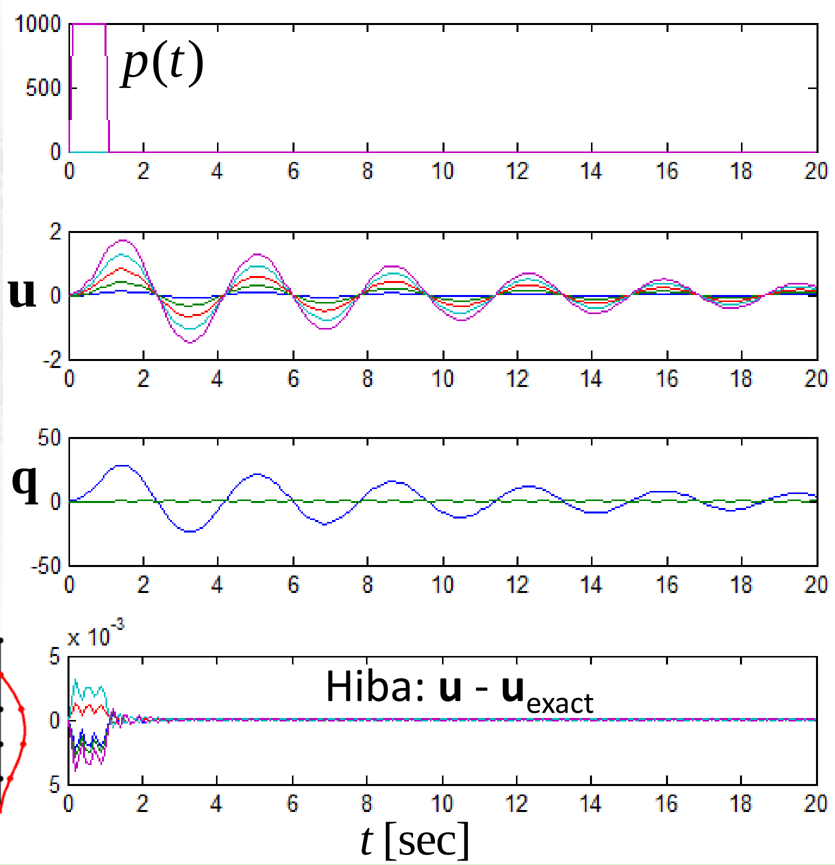


TÖBBSZABADSÁGFOKÚ RENDSZEREK

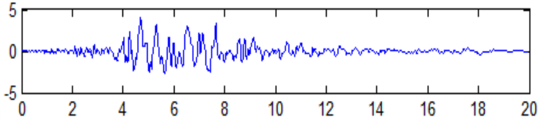
modális felbontás

$$\mathbf{u} = \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_5 \end{bmatrix} = q_1 \begin{bmatrix} \Phi_{11} \\ \Phi_{21} \\ \vdots \\ \Phi_{51} \end{bmatrix} + q_2 \begin{bmatrix} \Phi_{12} \\ \Phi_{22} \\ \vdots \\ \Phi_{52} \end{bmatrix} + q_3 \begin{bmatrix} \Phi_{13} \\ \Phi_{23} \\ \vdots \\ \Phi_{53} \end{bmatrix} + q_4 \begin{bmatrix} \Phi_{14} \\ \Phi_{24} \\ \vdots \\ \Phi_{54} \end{bmatrix} + q_5 \begin{bmatrix} \Phi_{15} \\ \Phi_{25} \\ \vdots \\ \Phi_{55} \end{bmatrix}$$





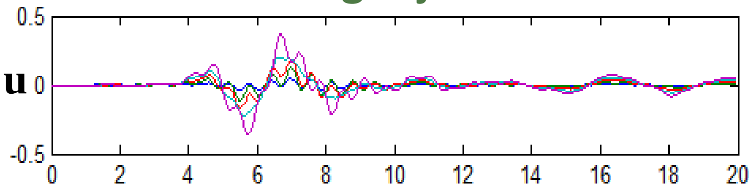
TÖBBSZABADSÁGFOKÚ RENDSZEREK

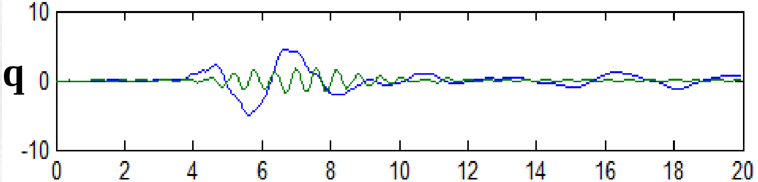


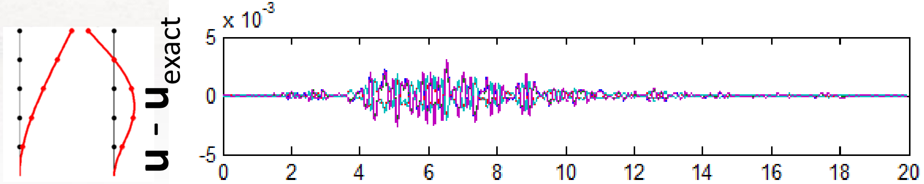
földrengés jelre

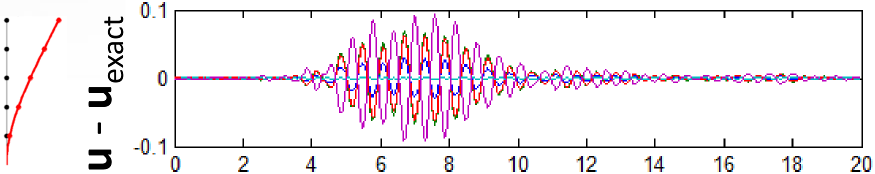
modális felbontás

$$\mathbf{u}=\begin{bmatrix}u_1\\u_2\\\vdots\\u_5\end{bmatrix}=q_1\begin{bmatrix}\Phi_{11}\\\Phi_{21}\\\vdots\\\Phi_{51}\end{bmatrix}+q_2\begin{bmatrix}\Phi_{12}\\\Phi_{22}\\\vdots\\\Phi_{52}\end{bmatrix}+q_3\begin{bmatrix}\Phi_{13}\\\Phi_{23}\\\vdots\\\Phi_{53}\end{bmatrix}+q_4\begin{bmatrix}\Phi_{14}\\\Phi_{24}\\\vdots\\\Phi_{54}\end{bmatrix}+q_5\begin{bmatrix}\Phi_{15}\\\Phi_{25}\\\vdots\\\Phi_{55}\end{bmatrix}$$







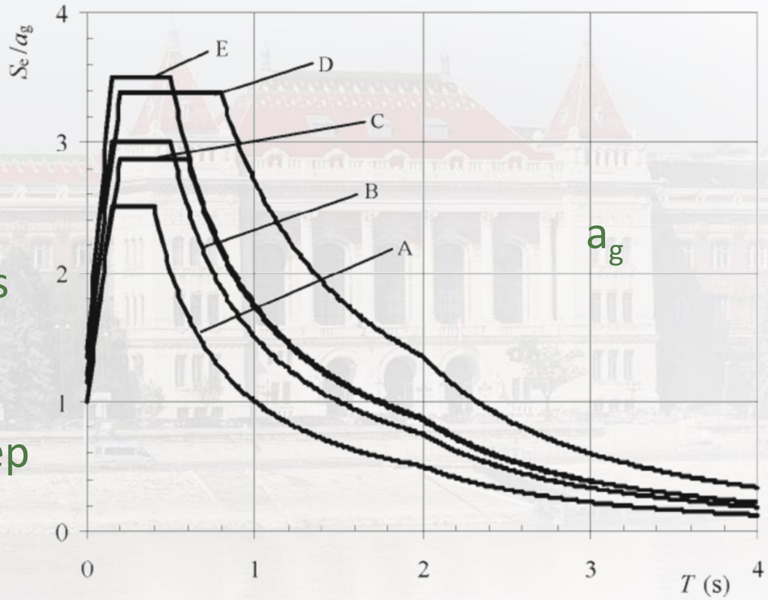


ANALÍZIS: MODÁLIS VÁLASZSPEKTRUM ANALÍZIS

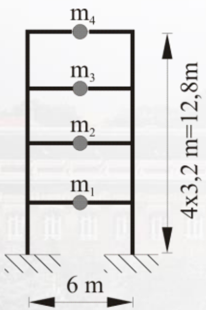
alapgyorsulás

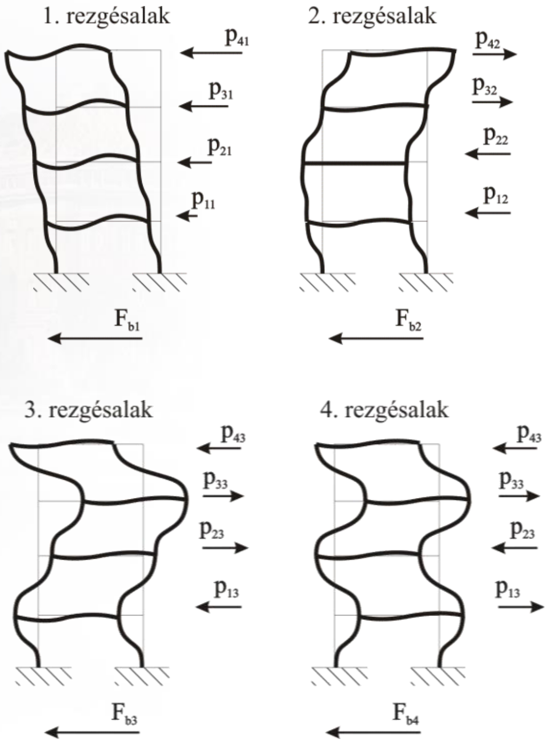
↑

földrengéstérkép



a_g



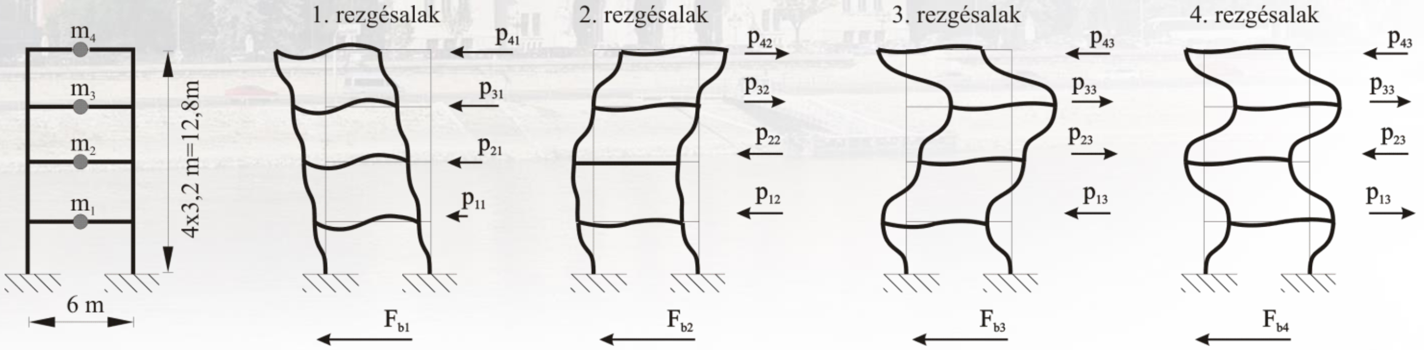


Fontos alakok?

$$m_i^* = \frac{\left(\Phi_i^T \mathbf{m}\,\iota\right)^2}{\Phi_i^T \mathbf{m} \Phi_i}$$

- figyelembe vett modális tömeg > 90%

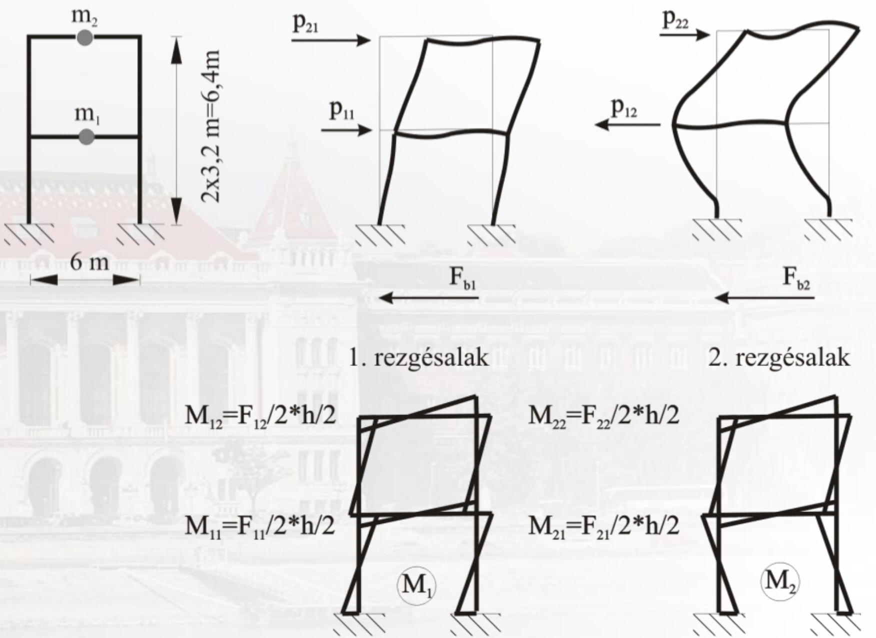
- minden 5%-nál nagyobb modális tömeg figyelembevétele



$$m^* = \begin{bmatrix} 89{,}6 \\ 8{,}2 \\ 1{,}9 \\ 0{,}4 \end{bmatrix} \%$$

Rezgésalakok kombinálása

- ABSSUM
- SRSS
- CQC



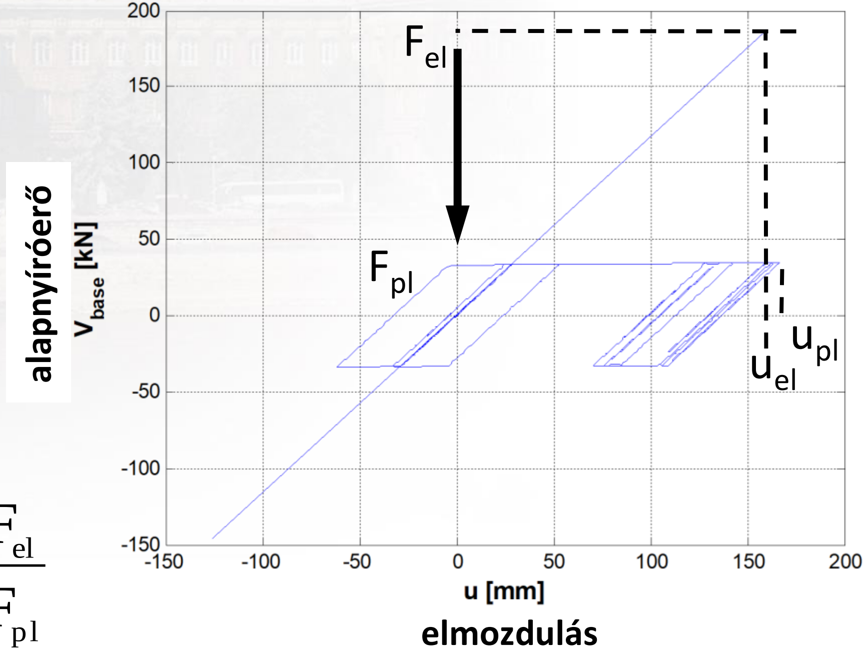
KÉPLÉKENYEDÉS HATÁSA

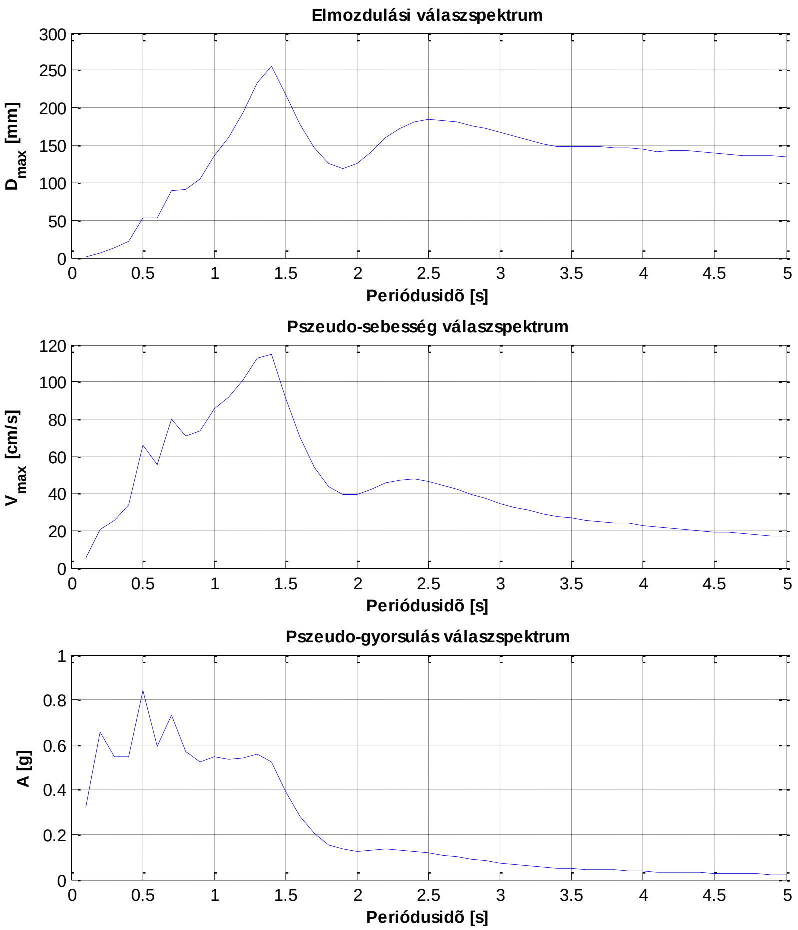
EGYSZABADSÁGFOKÚ KÉPLÉKENYEDŐ RENDSZER GERJESZTÉSE FÖLDRENGÉSSEL

képlékenyedés:

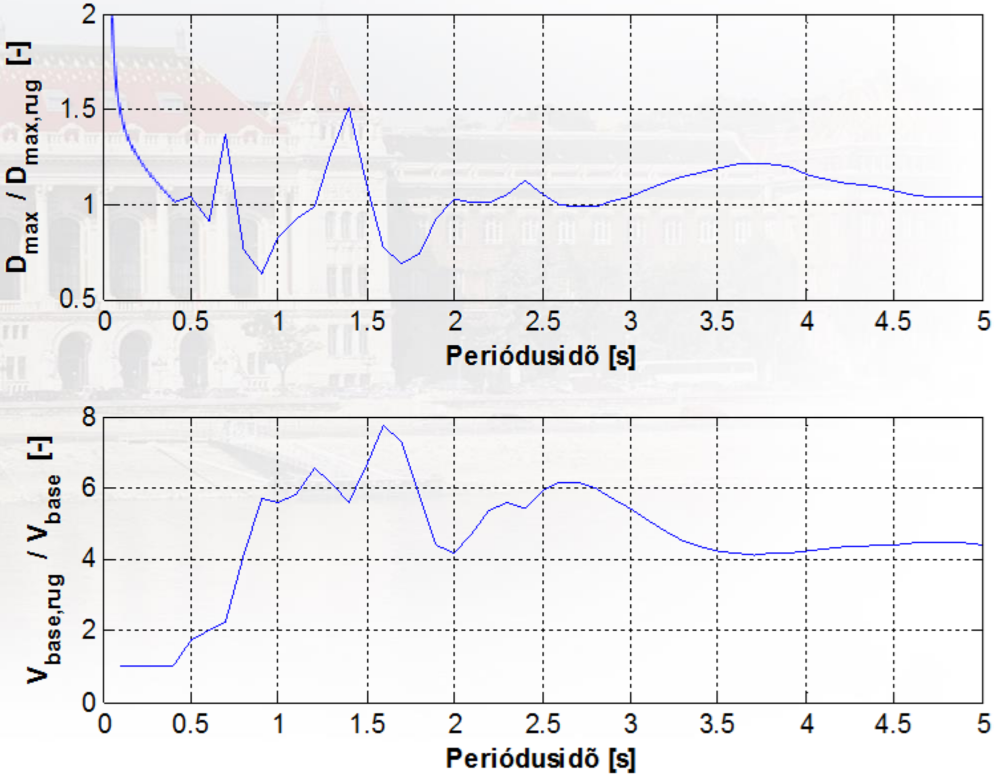
- csökkenő igénybevételek
- duktilitás kiemelten fontos!

viselkedési tényező: $q = \frac{F_{el}}{F_{pl}}$

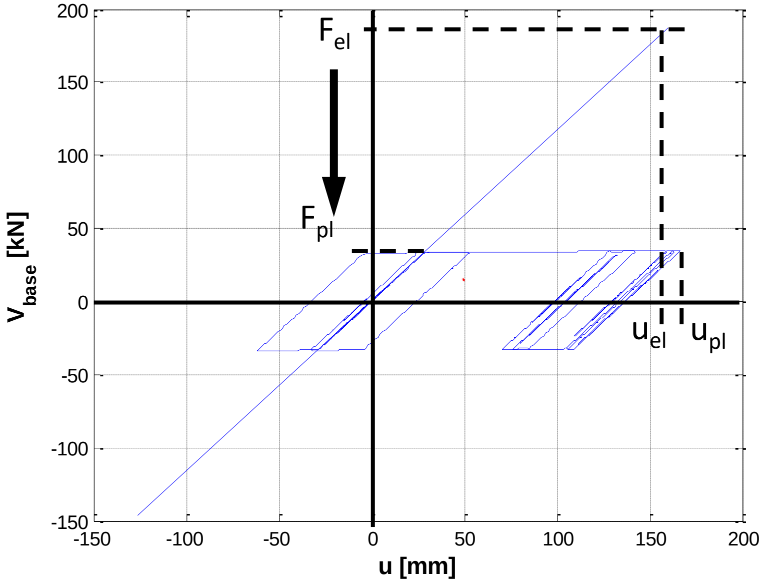



Elmozdulási válaszspektrum
D_{max} [mm]
Periódusidõ [s]
Pszeudo-sebesség válaszspektrum
V_{max} [cm/s]
Periódusidõ [s]
Pszeudo-gyorsulás válaszspektrum
A [g]
Periódusidõ [s]

RUGALMAS VS. KÉPLÉKENY RENDSZER



KÉPLÉKENY RENDSZER TERVEZÉSE, MÉRETEZÉSE



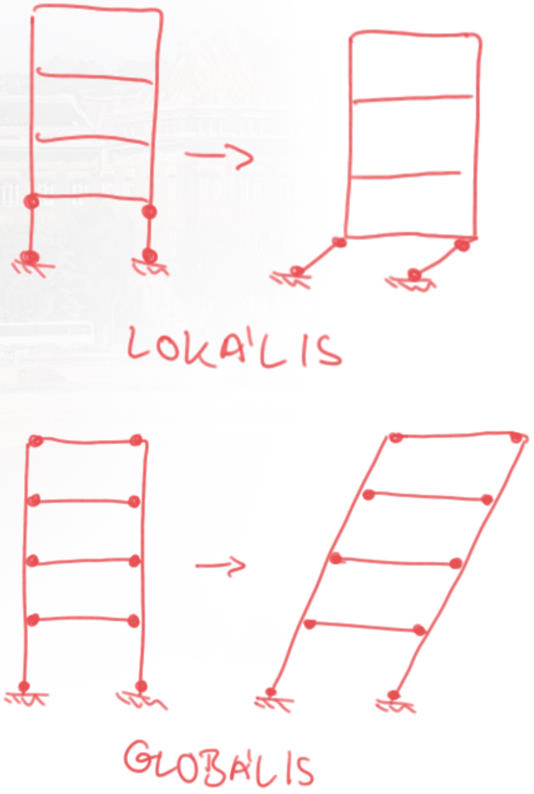
$$q = \frac{F_{el}}{F_{pl}}$$

1) Mire méretezzünk?

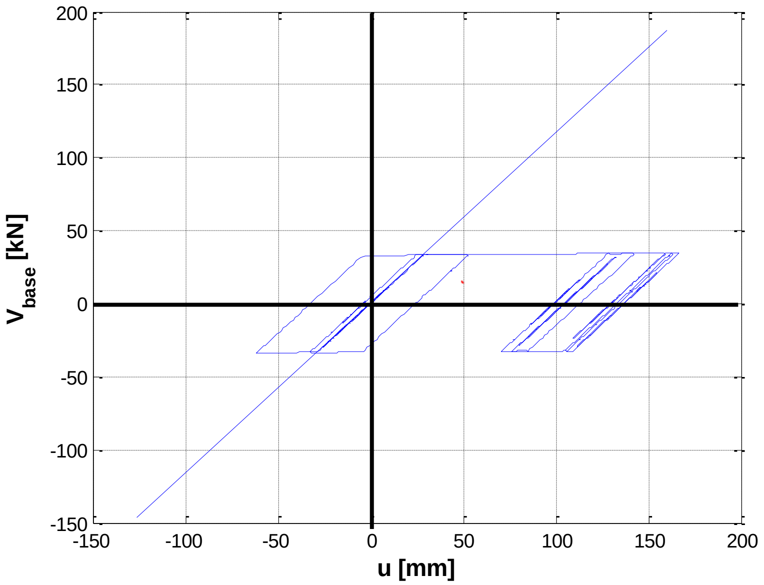
2) Mit tudjon a szerkezet?!

kapacitástervezés:

- képlékenyedés csak előre meghatározott helyen alakuljon ki
- a képlékenyedő szerkezeti elemek kellő elmozdulási kapacitással rendelkezzenek
- a rugalmas szerkezeti elemek kellő teherbírással rendelkezzenek
- globális mechanizmus alakuljon ki
- szabályosság!
- fontos a **teljes kontroll!**



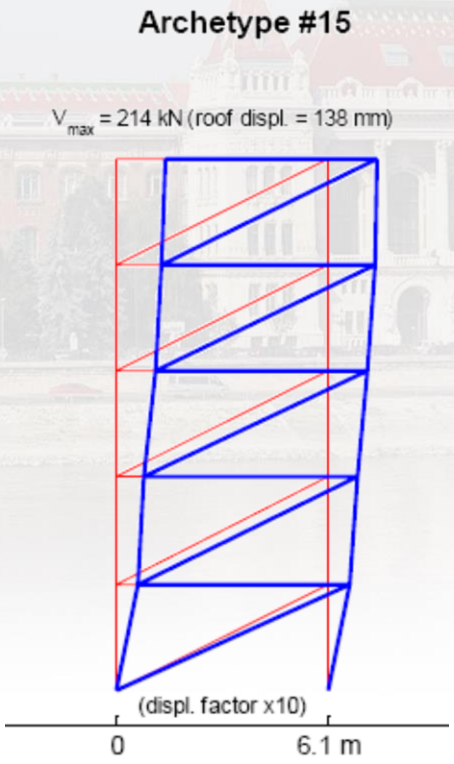
KÉPLÉKENY RENDSZEREK ANALÍZISE

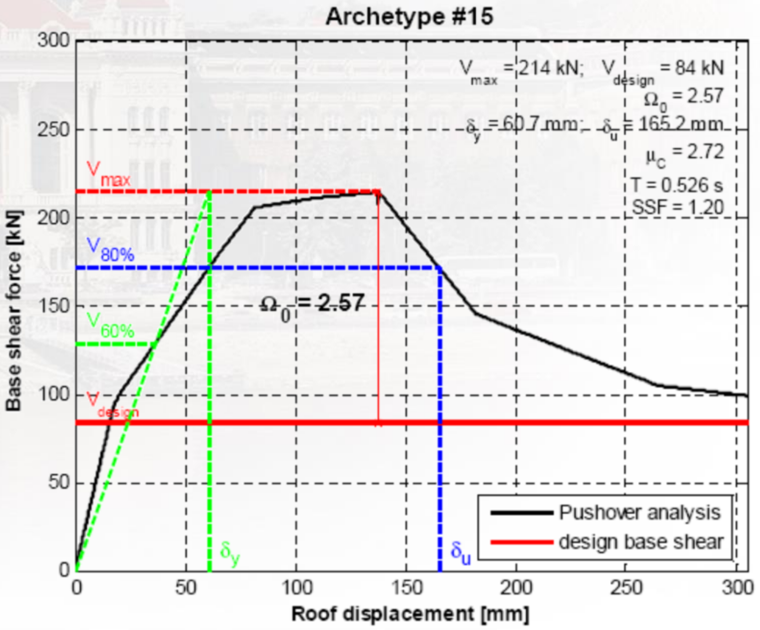


analízis:

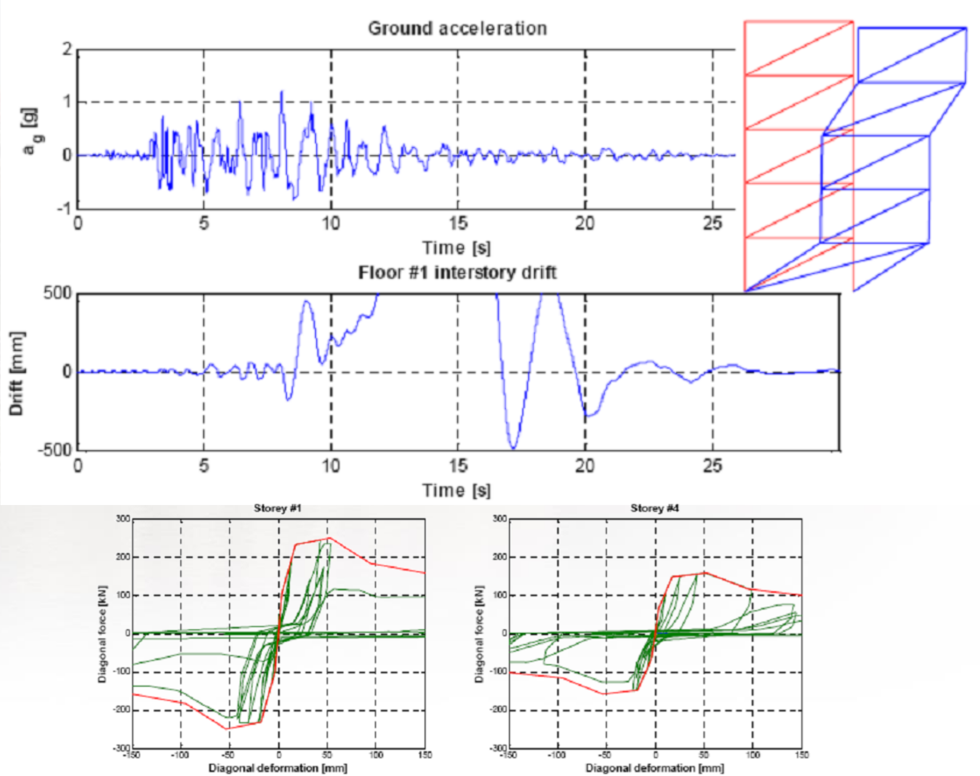
1. lineáris módszerek:
   1. *helyettesítő terhek módszere*
   2. *modális válaszspektrum analízis*
2. eltolásvizsgálat (pushover)
3. időtörténeti vizsgálat (time history)

Eltolás vizsgálat
(nemlineáris statikai)





Időtörténeti vizsgálat (nemlineáris dinamikai)

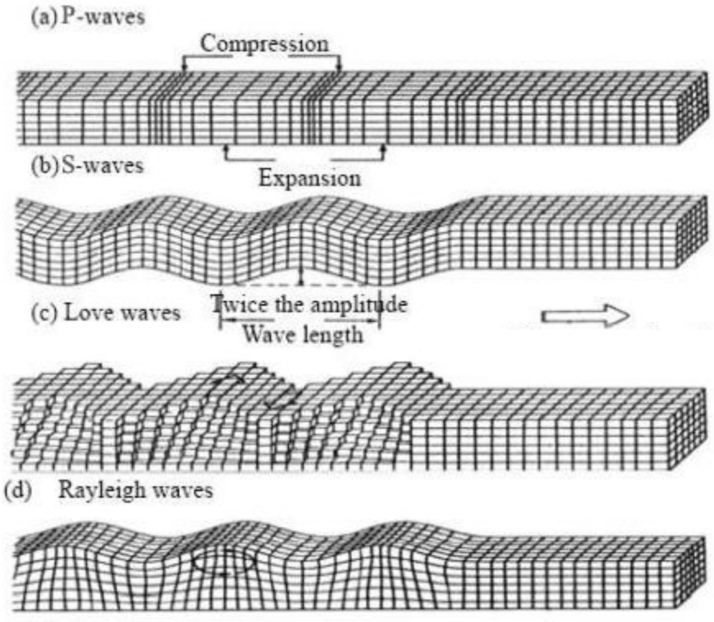


Köszönöm a megtisztelő figyelmet!

Vigh László Gergely

vigh.laszlo.gergely@emk.bme.hu

– Hullám fajtái



Body waves: travel inside the Earth's interior

(i) **P-waves** (primary wave, longitudinal or pressure wave): particles vibrate along or parallel to the direction of wave propagation.

(ii) **S-waves** (shear wave, secondary wave, or transverse wave): particles vibrate perpendicular to the direction of the wave propagation.

Surface waves: travel along the Earth's surface and the layers near the surface

(i) **Love waves**: particles vibrate on a horizontal plane and perpendicular to the direction of wave propagation.

(ii) **Rayleigh waves**: particles vibrate on a vertical plane and follow a retrograde ellipse.

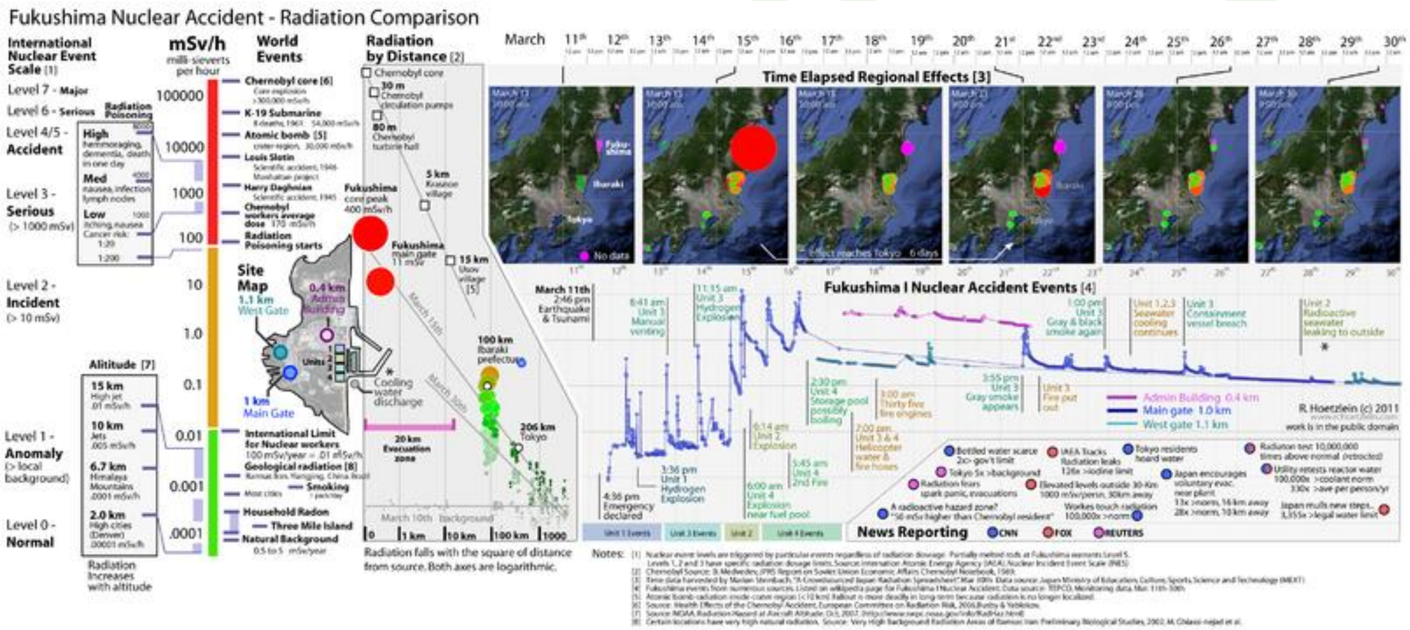
Source: http://scweb.cwb.gov.tw/Page.aspx?ItemId=37&NId=179&loc=en

Magnitude	Description	Average earthquake effects	Average frequency of occurrence (estimated)
< 2.0	Micro	Microearthquakes, not felt, or felt rarely by sensitive people. Recorded by seismographs.	Continual/several million per year
2.0–2.9	Minor	Felt slightly by some people. No damage to buildings.	Over one million per year
3.0–3.9		Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0–4.9	Light	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely. Some objects may fall off shelves or be knocked over.	10,000 to 15,000 per year
5.0–5.9	Moderate	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone. Casualties range from none to a few.	1,000 to 1,500 per year
6.0–6.9	Strong	Damage to a moderate number of well built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly-designed structures receive moderate to severe damage. Felt in wider areas; up to hundreds of miles/kilometers from the epicenter. Strong to violent shaking in epicentral area. Death toll ranges from none to 25,000.	100 to 150 per year
7.0–7.9	Major	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicenter. Death toll ranges from none to 250,000.	10 to 20 per year
8.0–8.9	Great	Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions. Death toll ranges from 1,000 to 1 million.	One per year
9.0 <=		Near or at total destruction - severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography. Death toll usually over 50,000.	One per 10 to 50 years

Forrás: Wikipedia

Country where deaths occurred	Confirmed	Estimated[1]	Injured	Missing	Displaced
Indonesia	130,736	167,799	n/a	37,063	500,000+[55]
Sri Lanka[2]	35,322[56]	35,322	21,411[56]	n/a	516,150[56]
India	12,405	18,045	n/a	5,640	647,599
Thailand	5,395[3][57]	8,212	8,457[58]	2,817[57]	7,000
Somalia	78	289[59]	n/a	n/a	5,000[60]
Myanmar (Burma)	61	400–600[61]	45	200[62]	3,200
Maldives	82[63]	108[64]	n/a	26	15,000+
Malaysia	68[65]	75	299[66]	6	n/a
Tanzania	10[67]	13	n/a	n/a	n/a
Seychelles	3[68]	3	57[68]	n/a	200[69]
Bangladesh	2	2	n/a	n/a	n/a
South Africa	2[4][70]	2	n/a	n/a	n/a
Yemen	2[71]	2	n/a	n/a	n/a
Kenya	1	1	2	n/a	n/a
Madagascar	n/a	n/a	n/a	n/a	1,000+[72]
Total	**~184,167**	**~230,273**	**~125,000**	**~45,752**	**~1.69 million**

Forrás: Wikipedia



Forrás: Wikipedia