EGU General Assembly 2020

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NH4.3 | MON, 04 MAY 2020, 10:45–12:30

Numerical modeling of seismically-induced slope displacements: a comparison between 2D and 3D finite difference models and Newmark-Displacements

UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

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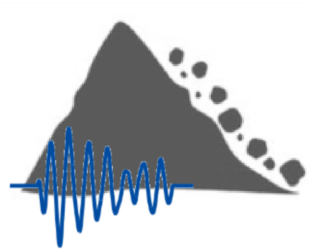
Target question:



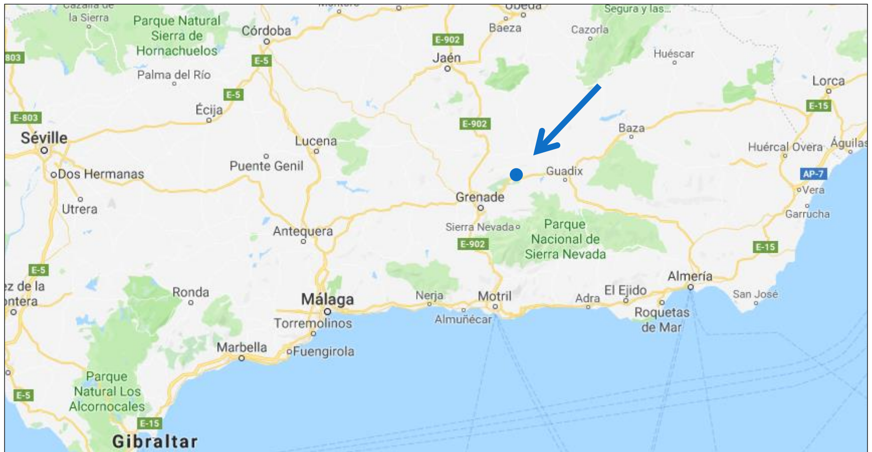
Which slope response is caused by different seismic scenarios?

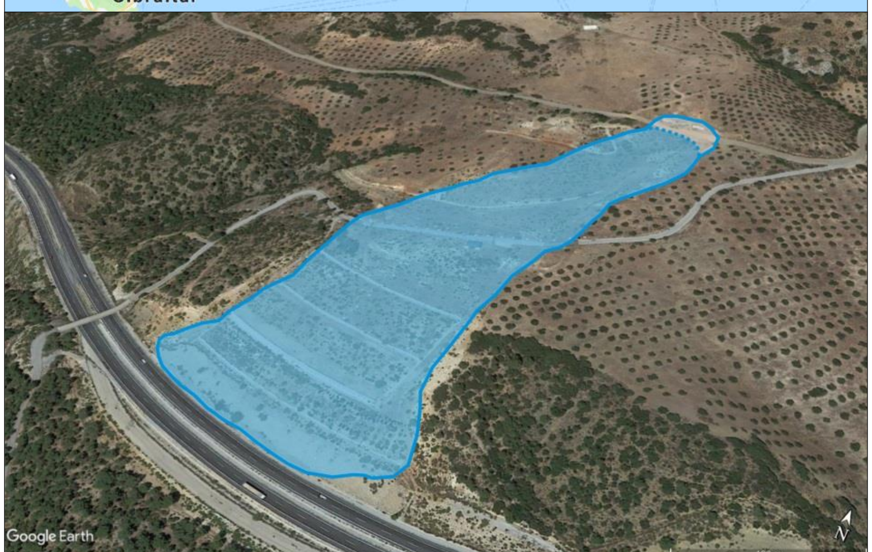
Let’s test in 2D and 3D with FDM and 11 earthquakes …

… and compare to Newmark!

- Domej G., Bourdeau C., ***2020***. Seismically-induced landslide displacements: a comparison between numerical models in 2D and 3D and the Newmark Method. ***Article in preparation***.
- Domej G., Bourdeau C., Lenti L., Martino S., Semblat J. F., 2019. Assessing seismically induced slope deformation of the Diezma Landslide via limit equilibrium analysis and numerical modeling. In: Silvestri F., Moraci N. (Eds.). Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions - Proceedings of the 7th International Conference on Earthquake Geotechnical Engineering (ICEGE 2019), CRC Press, London, p. 2166-2173.
- Domej G., Bourdeau C., Lenti L., Martino S., Semblat J. F., 2019. Assessing seismically induced slope deformation of the Diezma Landslide via limit equilibrium analysis and numerical modeling. Talk. 7th International Conference on Earthquake Geotechnical Engineering (7ICEGE), Italian Geotechnical Society, Rome.
- Domej G., 2018. Seismically induced effects and slope stability in urbanized zones by numerical modeling. Doctoral Thesis, Université Gustave Eiffel (ex: Universté Paris-Est & IFSSTAR), 266 p.

Which landslide to choose as case study and why?





Diezma Landslide

- 25 km NE of Granada, Spain
- translational (11°), 500 m, $1.2 \cdot 10^6$ m³
- so far no reported seismic trigger

1) location:

seismic region

at the A-92 motorway (vibrations)

Which landslide to choose as case study and why?

(particular courtesy: Junta de Andalucía, 2001)

Diezma Landslide

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- translational (11°), 500 m, $1.2 \cdot 10^6$ m^3
- so far no reported seismic trigger

1) location:

seismic region

at the A-92 motorway (vibrations)

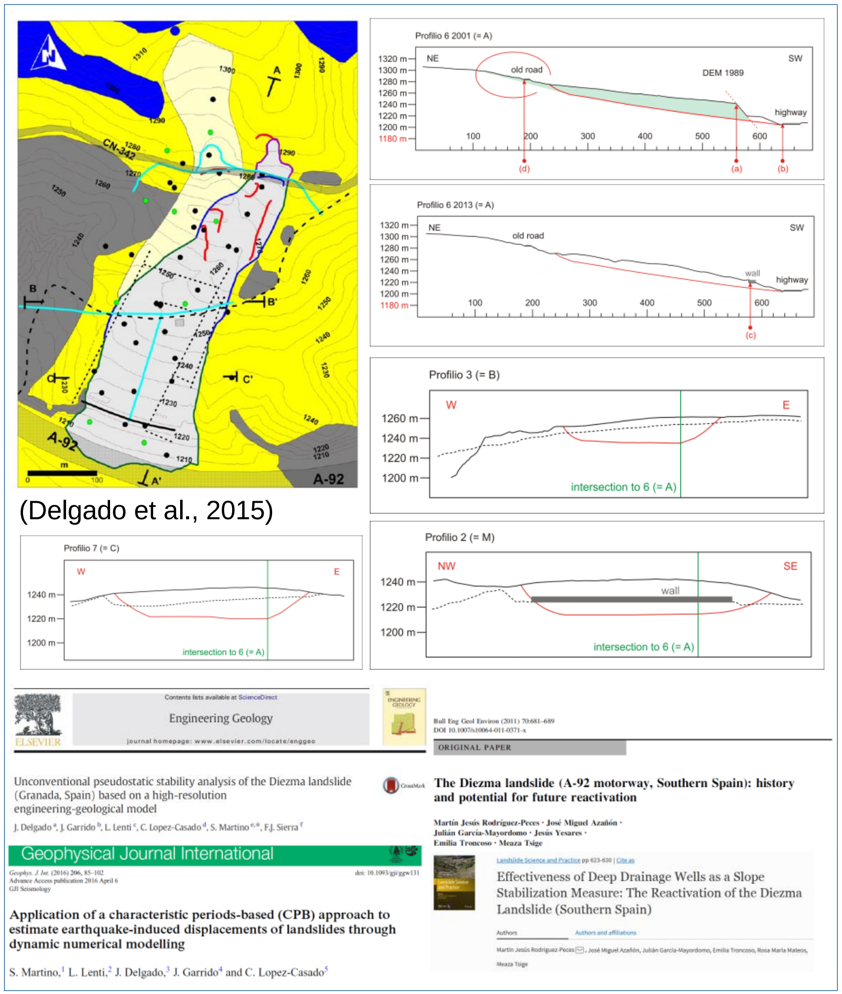
2) activity:

since 1990

18^{th} of March 2001, after rain event

Which landslide to choose as case study and why?

Which landslide to choose as case study and why?



Diezma Landslide

- 25 km NE of Granada, Spain
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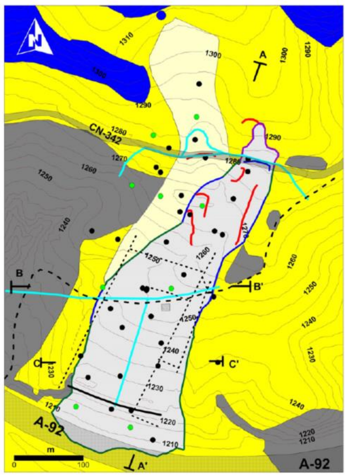
3) documentation:

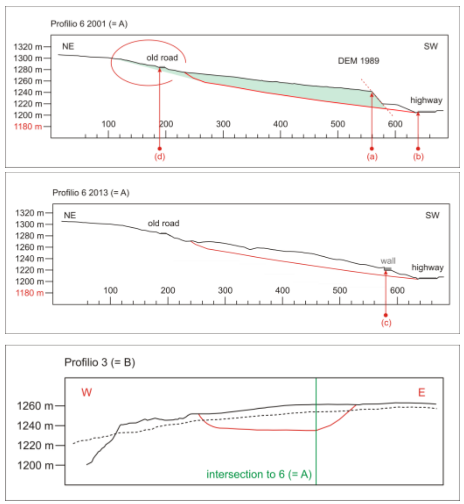
completeness of survey chart (71%)
geology / geotechnics / chronology

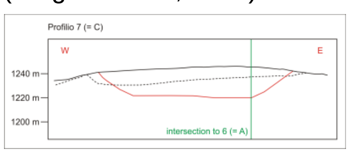
Azañon et al.	(2010)
Delgado et al.	(2015)
Martino et al.	(2016)
Rodríguez-Peces et al.	(2011)

Which landslide to choose as case study and why?



(Delgado et al., 2015)






Engineering Geology

Unconventional pseudostatic stability analysis of the Diezma landslide (Granada, Spain) based on a high-resolution engineering-geological model

J. Delgado, J. Garrido, L. Lenti, C. Lopez-Casado, S. Martino, F.J. Sierra

ORIGINAL PAPER

The Diezma landslide (A-92 motorway, Southern Spain): history and potential for future reactivation

Martín Jesús Rodríguez-Peces · José Miguel Azañón · Julián García-Mayordomo · Jesús Yesares · Emilia Troncoso · Meaza Tsige

Geophysical Journal International

Application of a characteristic periods-based (CPB) approach to estimate earthquake-induced displacements of landslides through dynamic numerical modelling

S. Martino, L. Lenti, J. Delgado, J. Garrido and C. Lopez-Casado

Effectiveness of Deep Drainage Wells as a Slope Stabilization Measure: The Reactivation of the Diezma Landslide (Southern Spain)

Diezma Landslide

- 25 km NE of Granada, Spain
- translational (11°), 500 m, $1.2 \cdot 10^6$ m³
- so far no reported seismic trigger

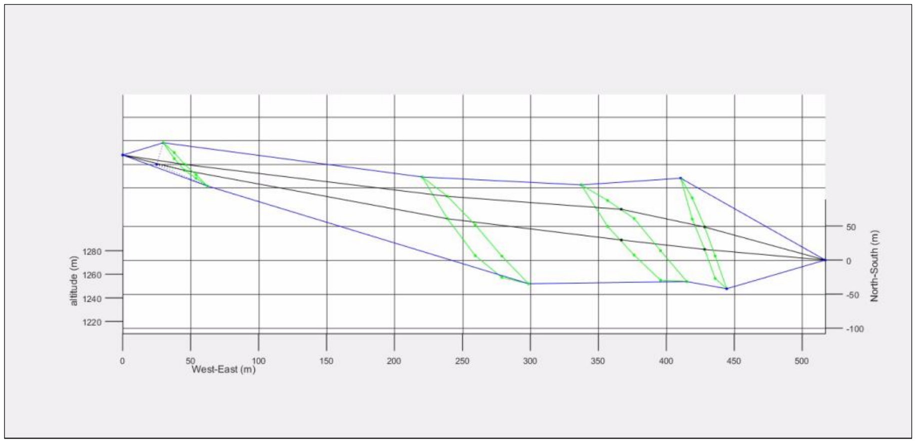
4) parameters:

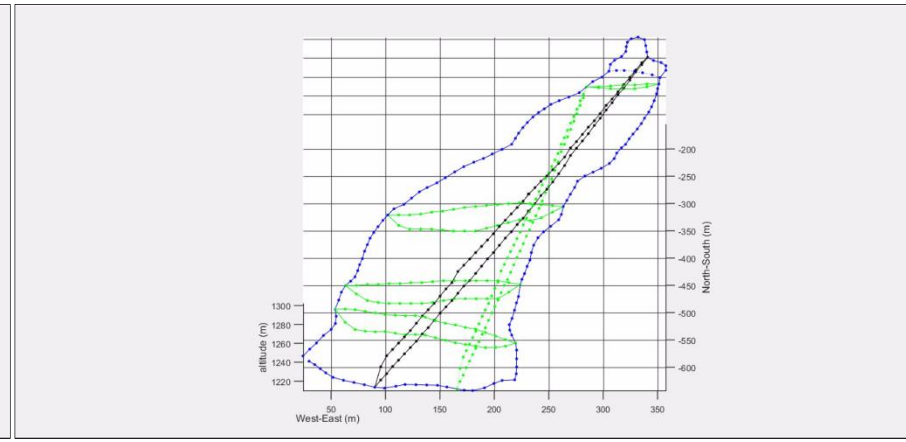
material (plastic clay, silt, marl, blocks)

mechanism (drainage, permeability)

parameter	γ (kN/m³)	γ_{sat} (kN/m³)	c_{peak} (kPa)	c_{res} (kPa)	Φ_{peak} (°)	Φ_{res} (°)	v_s (m/s)	ν (-)
landslide	19.0	21.4	46.0	4.0	26.0	12.0	300	0.25
bedrock	18.2	20.6	05.4	0.6	31.0	11.0	750	0.35

Creating 3D and 2D models in two versions: simple and fine geometries



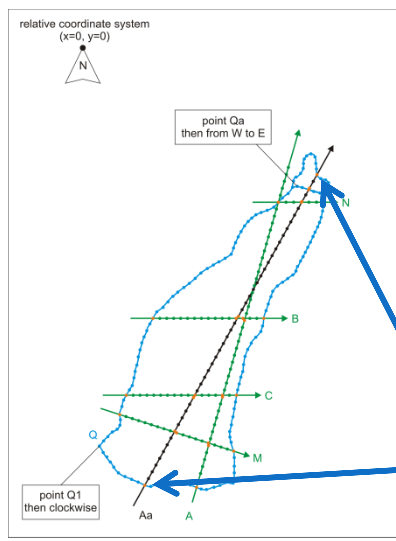


simple 3D geometry:

- 1 LCS (Aa)
- 4 TCS (N, B, C, M)
- 1 trace (Q - **10 points only**)

simple **2D** geometry:

- 1 LCS (Aa - **10 points only**)



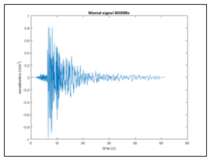
fine 3D geometry:

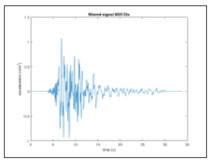
- 2 LCS (A, Aa)
- 4 TCS (N, B, C, M)
- 1 trace (Q - **1 point/10 m**)

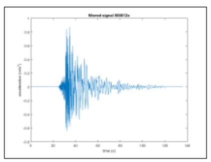
fine **2D** geometry:

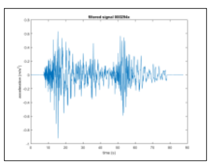
- 1 LCS (Aa - **1 point/10 m**)

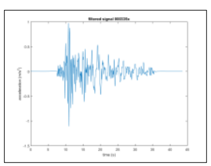
Choosing seismic scenarios that represent the seismicity of Southern Spain



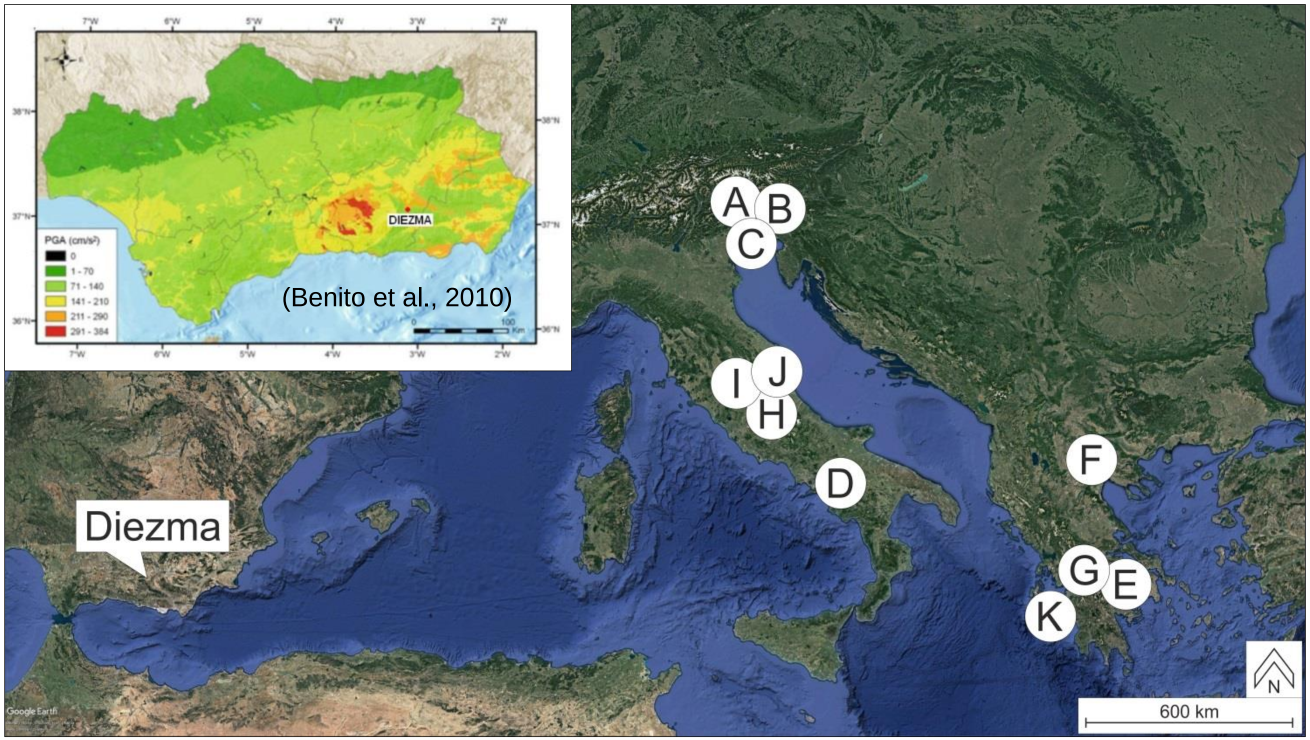


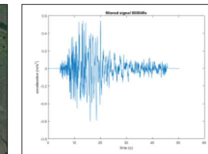


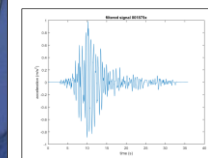


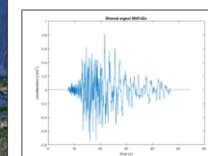


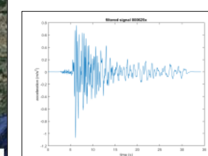
different frequency contents

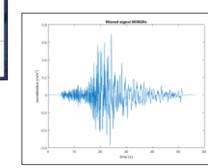


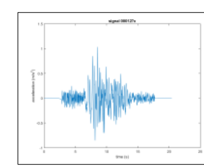








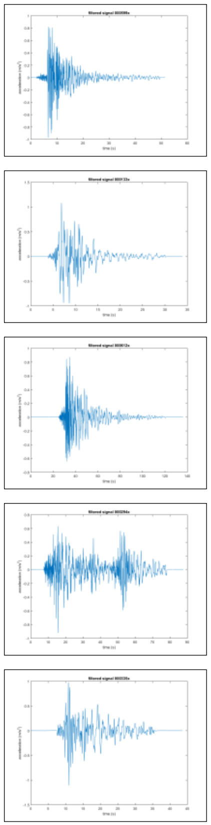


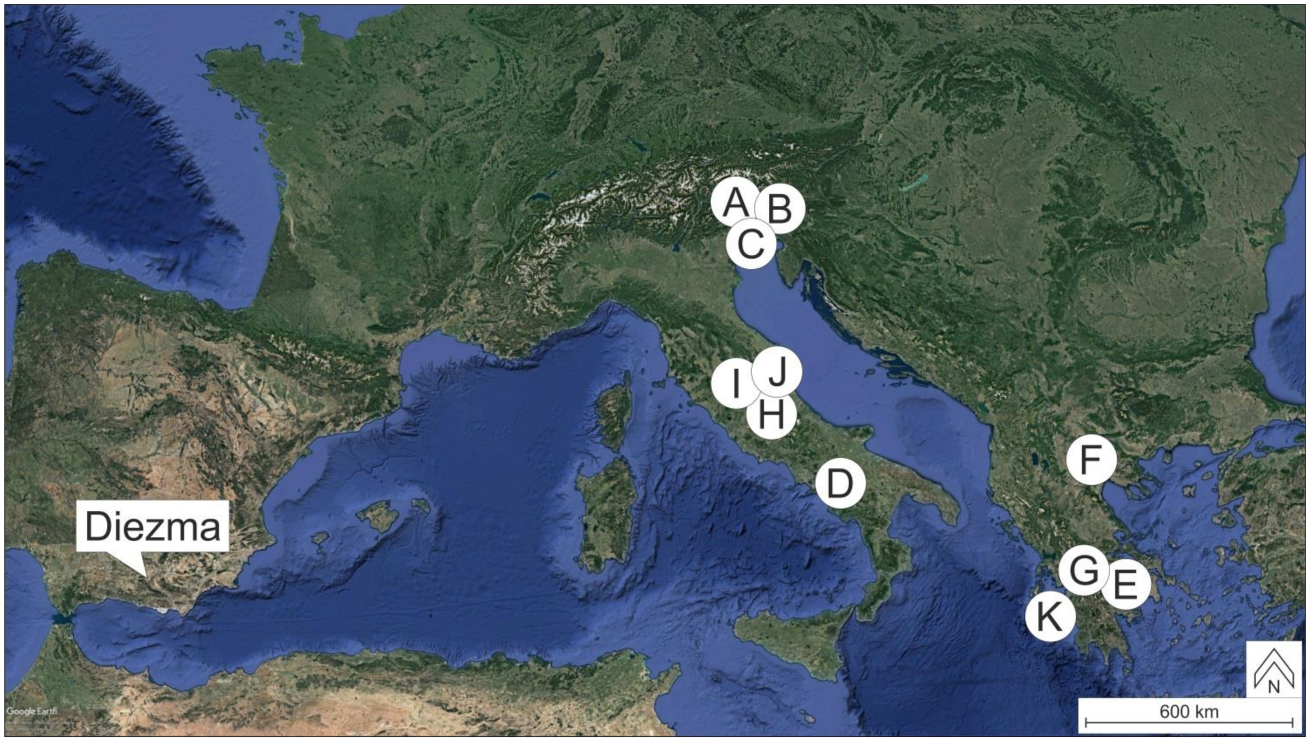


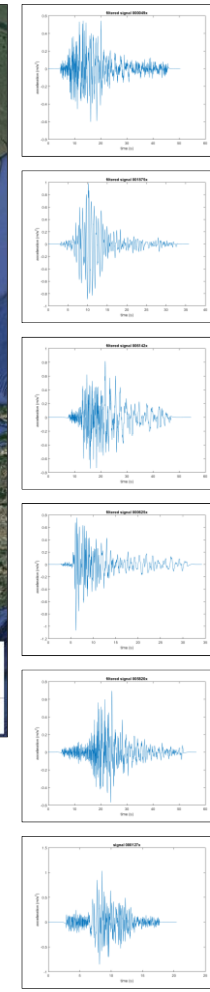
European Strong Motion Database (Ambraseys et al., 2004):

- horizontal components
- M_W = 5.0-7.0
- AI = 0.1-1.0 m/s
- PGA = 0.8-1.2 m/s²

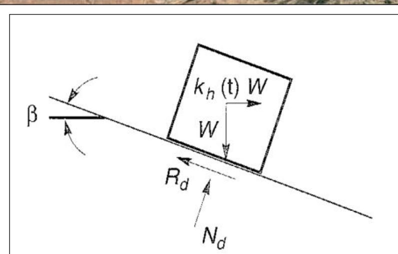
Use these signals for the Newmark-Method (1965) and FDM

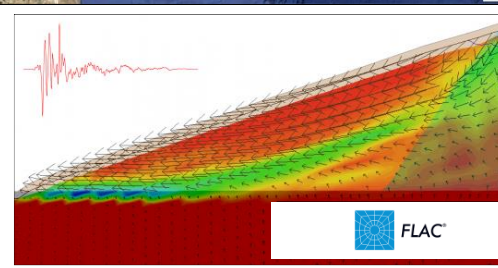






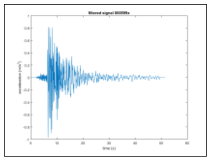
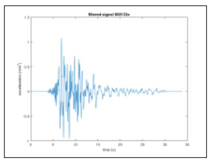
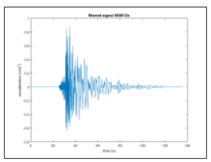
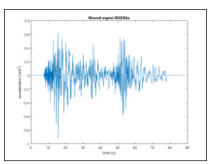
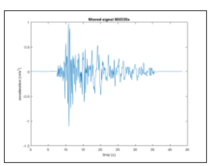
different frequency contents





Newmark-Method (1965) & finite difference method (after Kramer, 1996; ITASCA, 2015)

Use these signals for the Newmark-Method (1965) and FDM

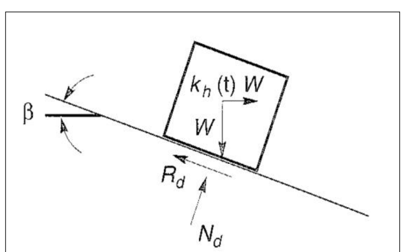






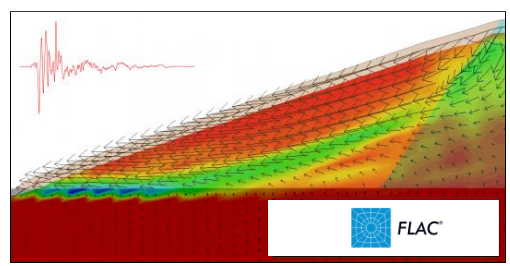
different frequency contents

1) analysis of seismically induced displacements

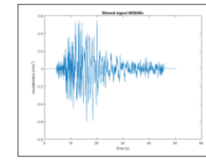
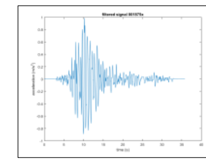
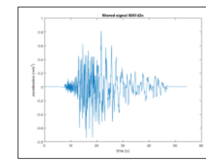
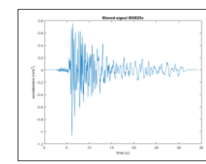
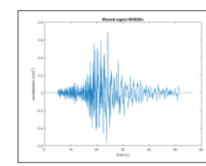
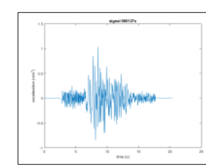
2) comparison of method performance and their applicability

2D simple geometry	2D & 3D simple & fine geometries





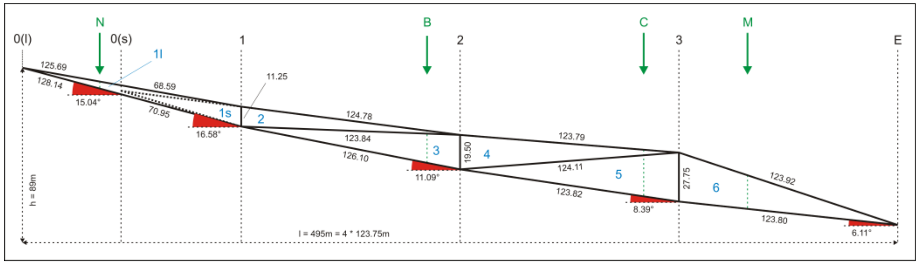
Newmark-Method (1965) & finite difference method (after Kramer, 1996; ITASCA, 2015)

Running Newmark-Models (1965)

Newmark-Method (1965):

- non-numerical method
- pseudostatic limit equilibrium analysis
- dynamic performance of slopes in 2D
- aspects of safety factor & 1 estimation

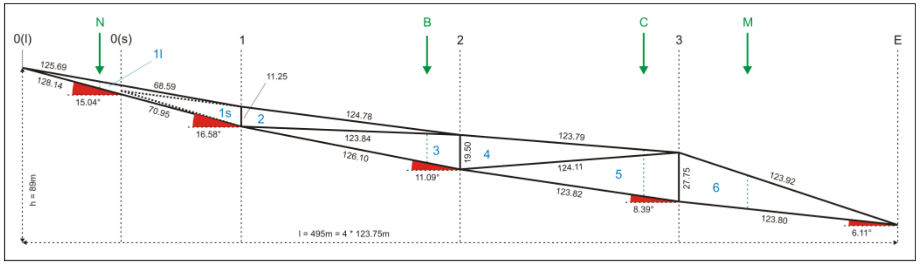


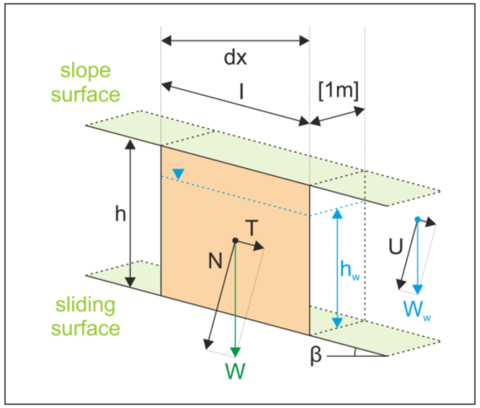
Running Newmark-Models (1965)

Newmark-Method (1965):

- non-numerical method
- pseudostatic limit equilibrium analysis
- dynamic performance of slopes in 2D
- aspects of safety factor & 1 estimation
- rigid block on an inclined plane (Mohr-Coulomb Criterion)

$$SF = \frac{c' \cdot \frac{dx}{\cos(\beta)} \cdot 1 + \left(N - u \cdot \frac{dx}{\cos(\beta)} \cdot 1\right) \cdot \tan(\Phi')}{W \cdot \sin(\beta)} = \frac{holding}{driving}$$





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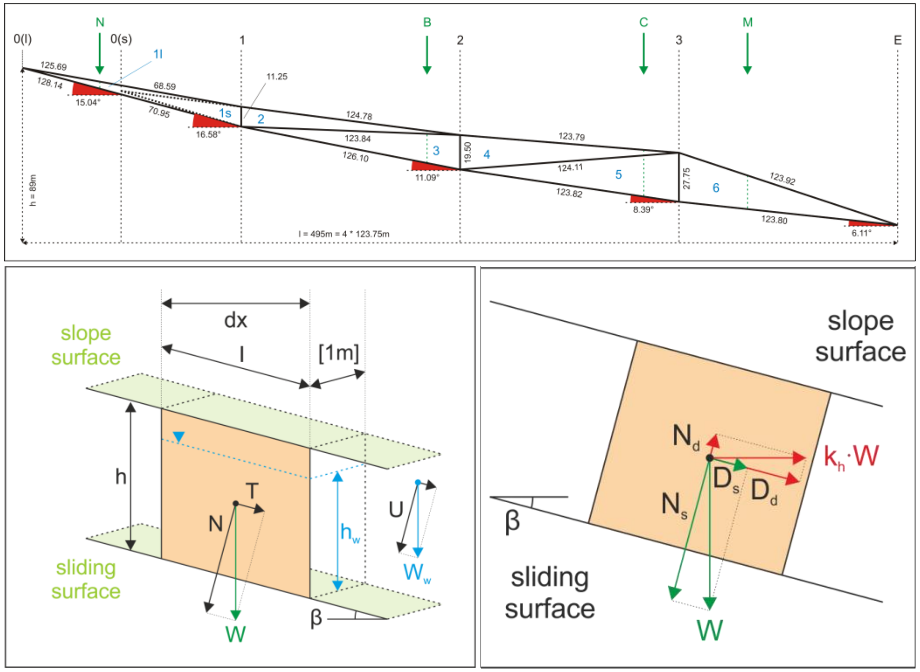

- representation of earthquake as additional horizontal force in equation
- assumes displacement when SF = 1
- deducts a_{crit} (= $k_h \cdot g$) to overcome

Running Newmark-Models (1965)

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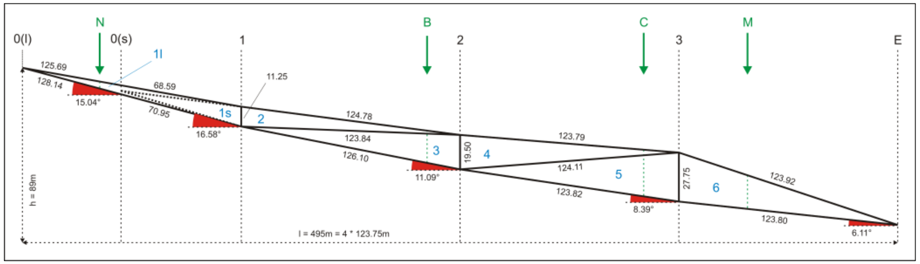
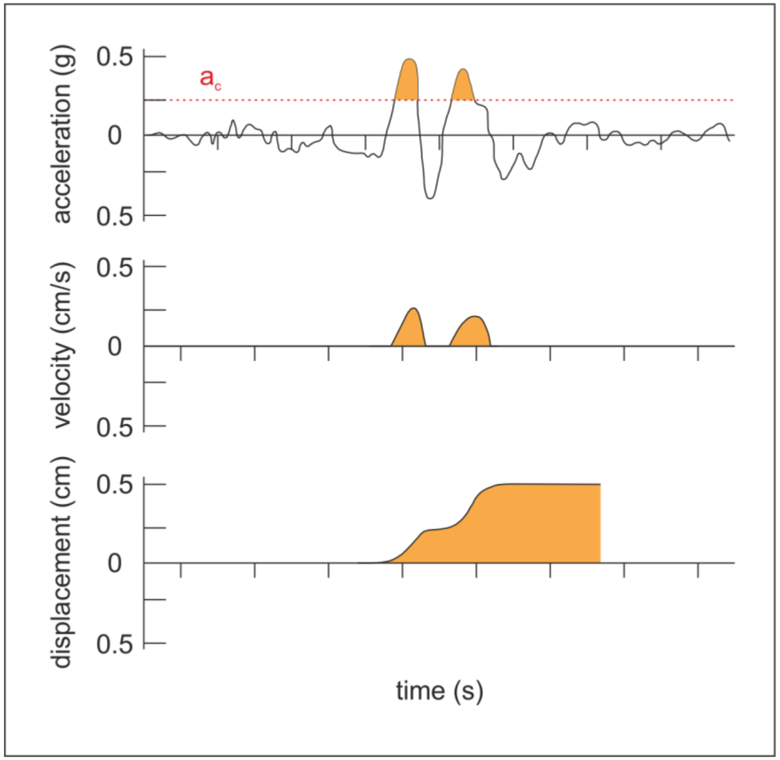
- representation of earthquake as additional horizontal force in equation
- assumes displacement when SF = 1
- deducts a_{crit} (= $k_h \cdot g$) to overcome
- SLAMMER (Jibson et al., 2013)

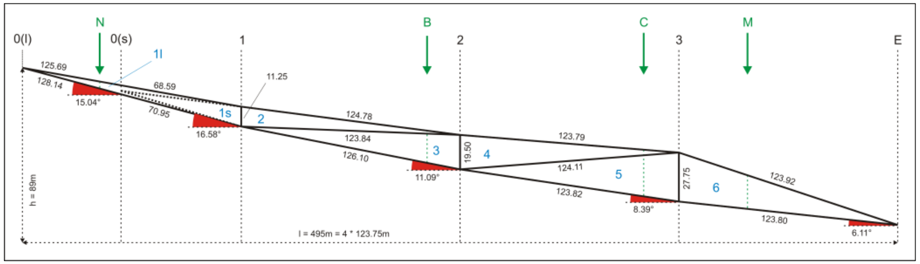




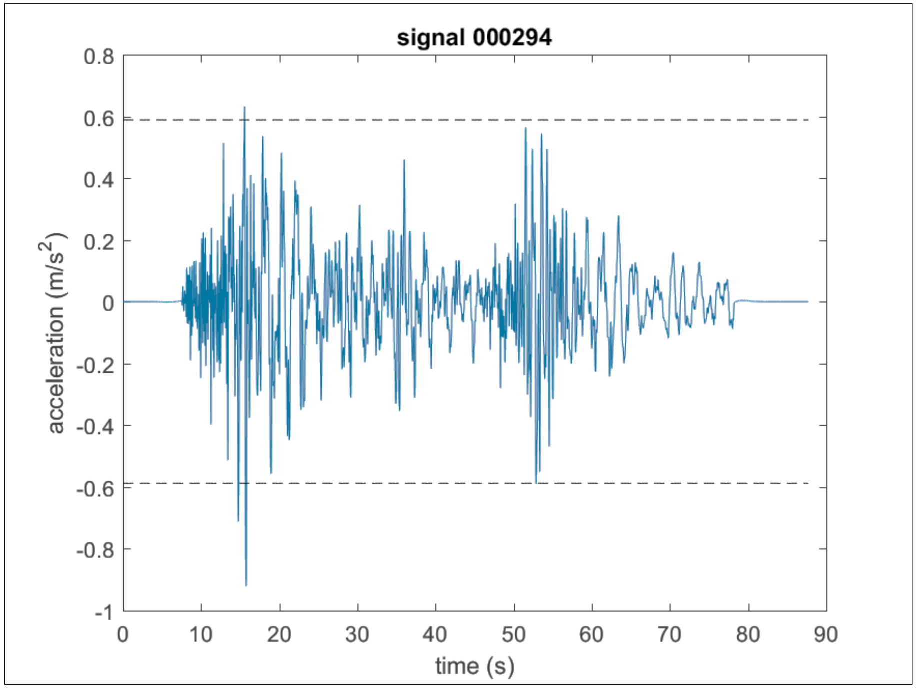
Running Newmark-Models (1965)

Application to the Diezma Landslide:

- threshold, frequency content, duration
- macro-seismic / landslide parameters
- site effects, confinement, deformation



signal	normal d_{cum} (cm)	inverse d_{cum} (cm)
A – 000049	-	**0.0002**
B – 000133	**0.3840**	**0.3510**
C – 000127	**0.1201**	**0.0323**
D – 000294	**0.0038**	**0.3254**
E – 000335	**0.5309**	**0.3699**
F – 001875	**1.4084**	**1.1590**
G – 006142	**0.2138**	**0.0490**
H – 000599	**0.1284**	**0.3034**
I – 000612	**0.1488**	**0.0020**
J – 000625	**0.0488**	**0.3534**
K – 005820	**0.0565**	-



Running FDM-Models

Finite Difference Method:

- numerical method (time domain)
- dynamic performance of slopes in 2D & 3D
- visco-elasto-perfectly-plastic material behavior
- 1 estimation per point

FLAC®

Running FDM-Models

Finite Difference Method:

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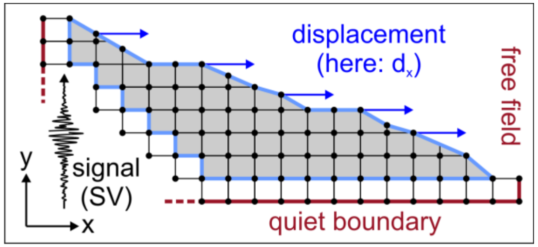
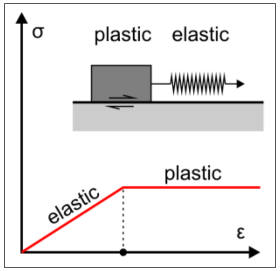


→ geotechnical analysis
→ finite number of grid points
→ stress-/strain-application (finite difference equations)
→ solve for d (here: d_{res})

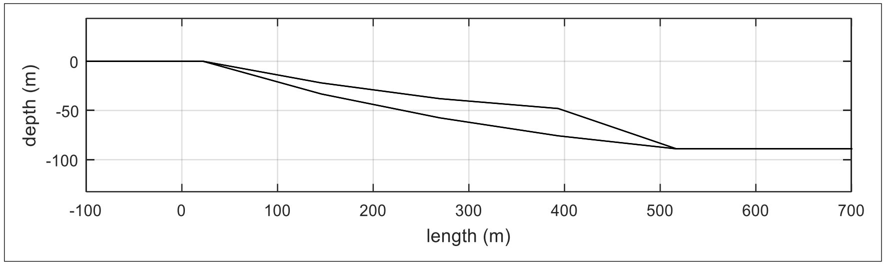


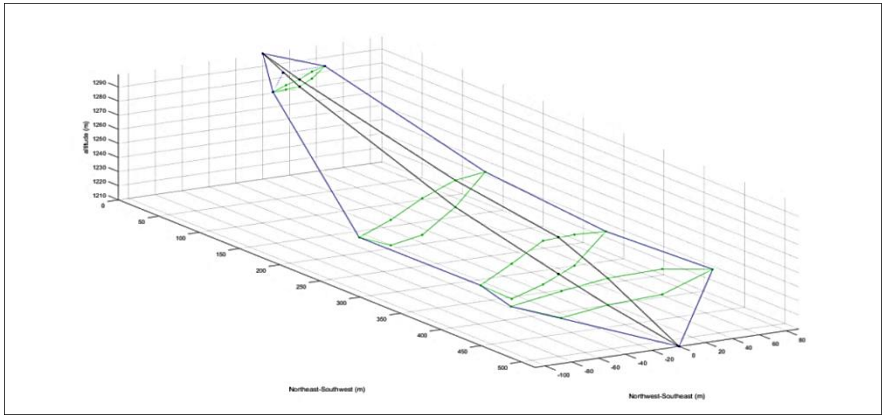
→ static part: settlement due to gravity
→ dynamic part: response to seismic load (Mohr-Coulomb)

Running FDM-Models

Application to the Diezma Landslide:

- geometry: **2D** & **3D** (**simple** & fine)
- mesh: 2D → 1 m (up to 30 Hz)
  3D → 3 m (up to 8 Hz)
- properties: ρ = 2181.4 kg/m³
  ν = 0.25 (-)
  (**landslide**) v_s = 300 m/s
  c' = 46·10³ Pa
  Φ' = 26°

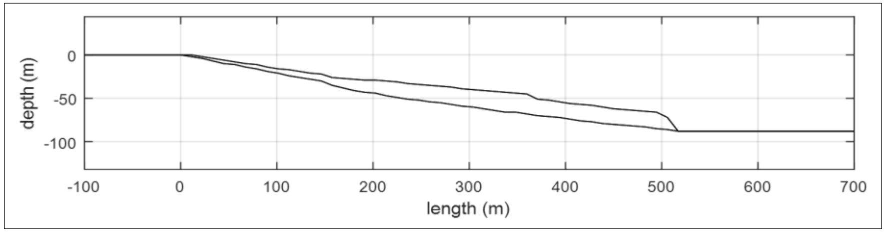




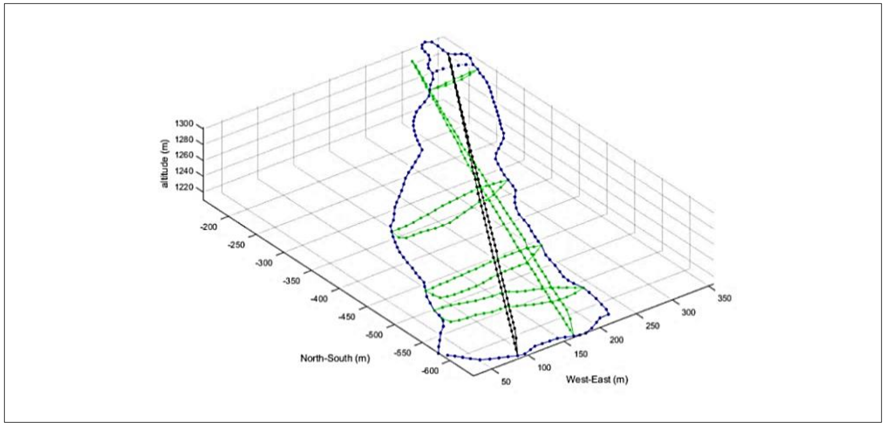
- boundaries: quiet at model base, free field at model sides
- loading: 11 signals (SV vertically to model base → horizontal shear)

Running FDM-Models

Application to the Diezma Landslide:



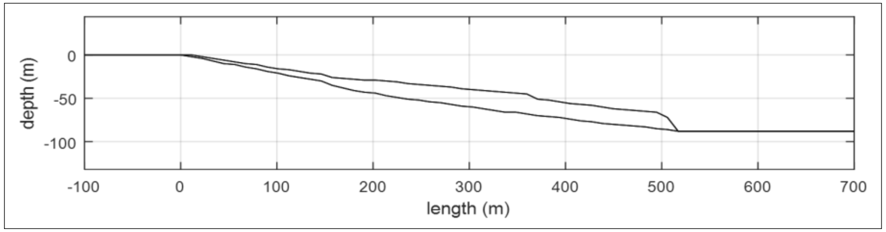
- geometry: **2D** & **3D** (simple & **fine**)
- mesh: 2D → 1 m (up to 30 Hz)
  3D → 3 m (up to 8 Hz)
- properties: ρ = 2181.4 kg/m³
  ν = 0.25 (-)
  (**landslide**) v_s = 300 m/s
  c' = 46·10³ Pa
  Φ' = 26°



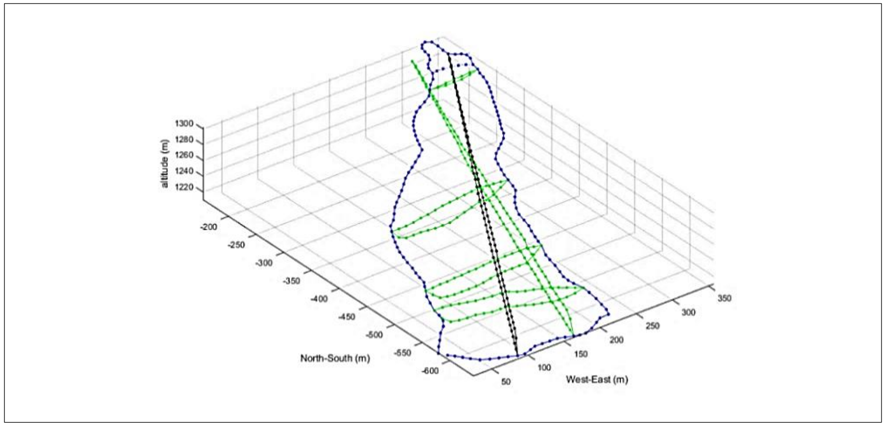
- boundaries: quiet at model base, free field at model sides
- loading: 11 signals (SV vertically to model base → horizontal shear)

Running FDM-Models

Application to the Diezma Landslide:



- geometry: **2D** & **3D** (simple & **fine**)
- mesh: 2D → 1 m (up to 30 Hz)
  3D → 3 m (up to 8 Hz)
- properties: ρ = 2500 kg/m³
  ν = 0.35 (-)
  (**bedrock**) v_s = 1000 m/s
  c' = 4·10⁹ Pa
  Φ' = 30°
- boundaries: quiet at model base, free field at model sides
- loading: 11 signals (SV vertically to model base → horizontal shear)



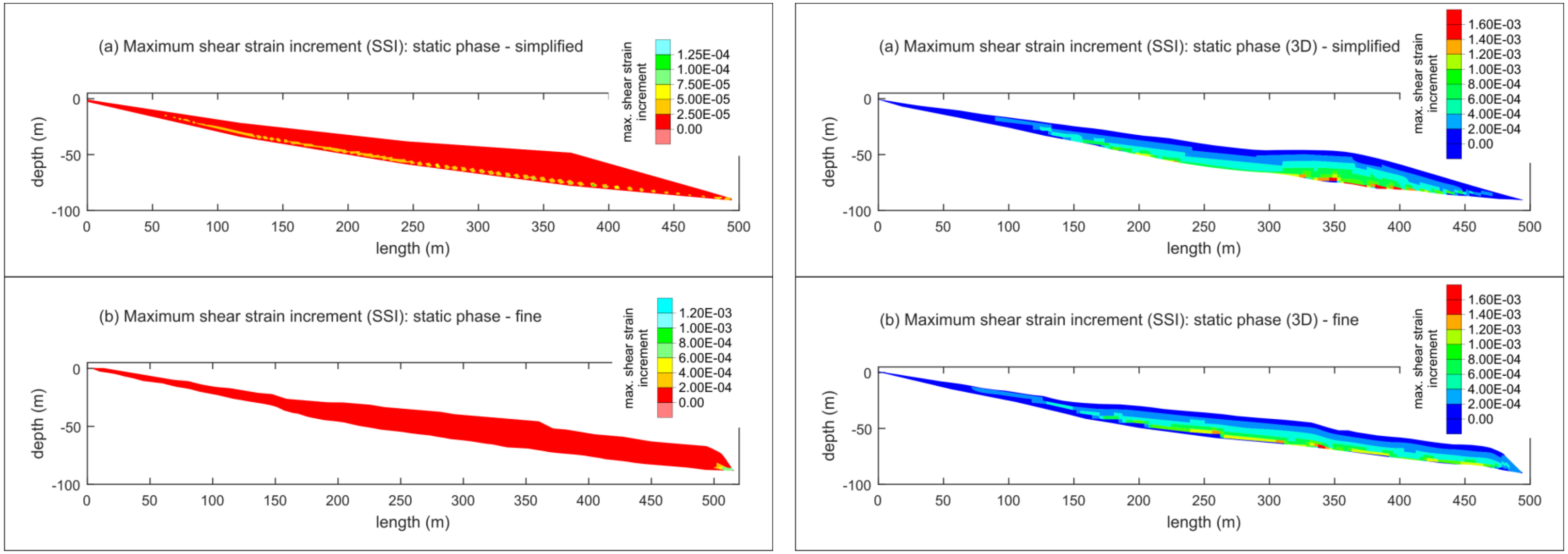
Running FDM-Models

static phases

2D **3D**

simple

fine



simple

fine

- settling due to gravity → stability without external loads
- maximum SSI → concentration of shear strain

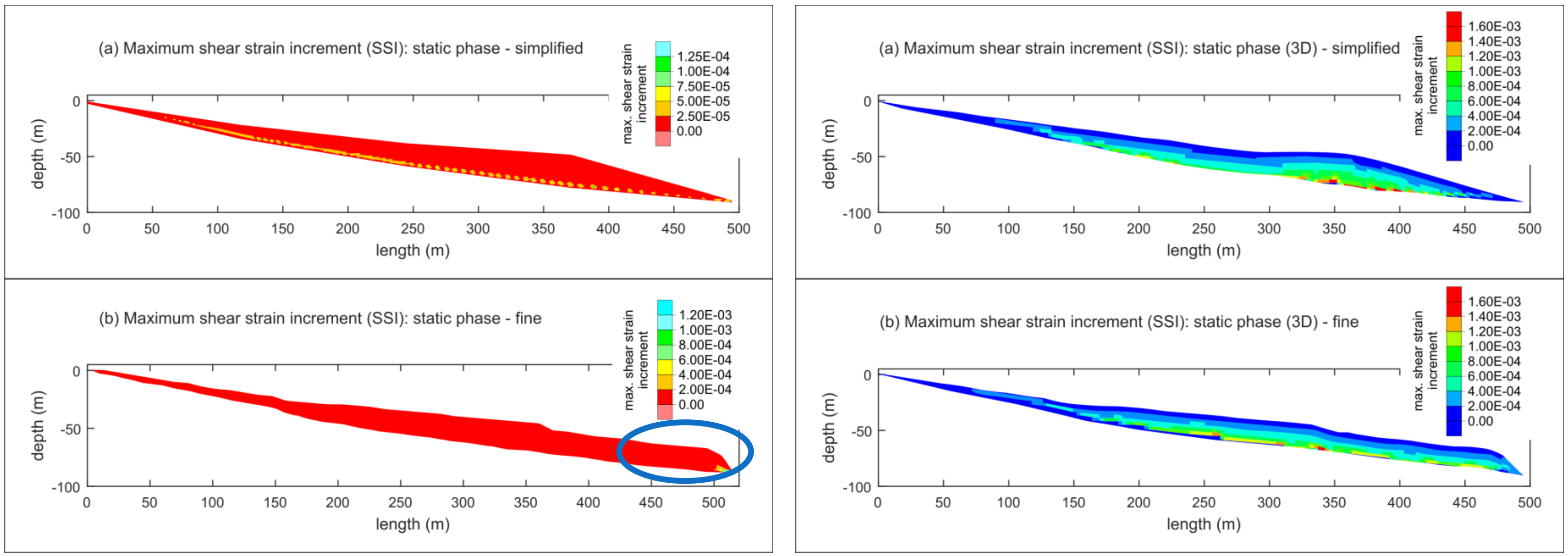
Running FDM-Models

static phases

2D 3D

simple

fine



simple

fine

- settling due to gravity → stability without external loads
- maximum SSI → concentration of shear strain
- different static behavior → different dynamic behavior

Running FDM-Models

dynamic phases

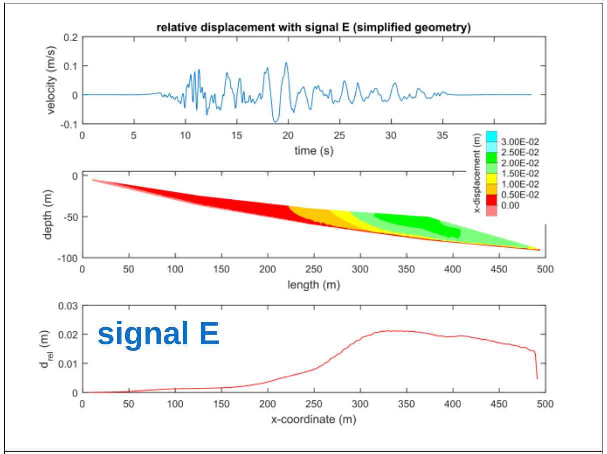
slope response relative to bedrock

qualitative:

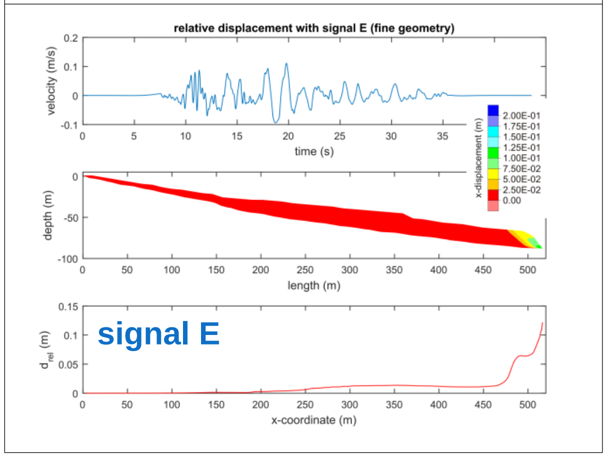
quantitative:

2D

simple

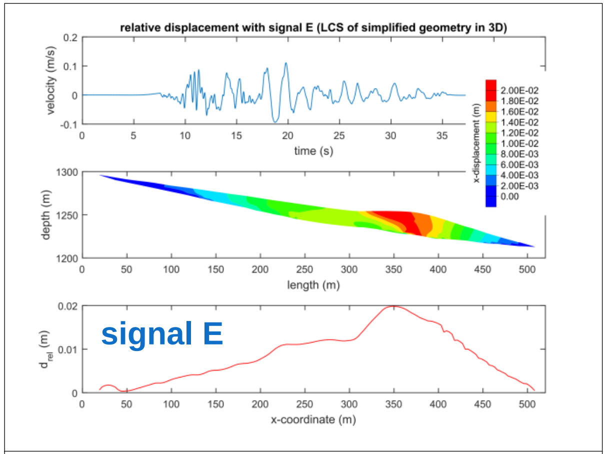


fine

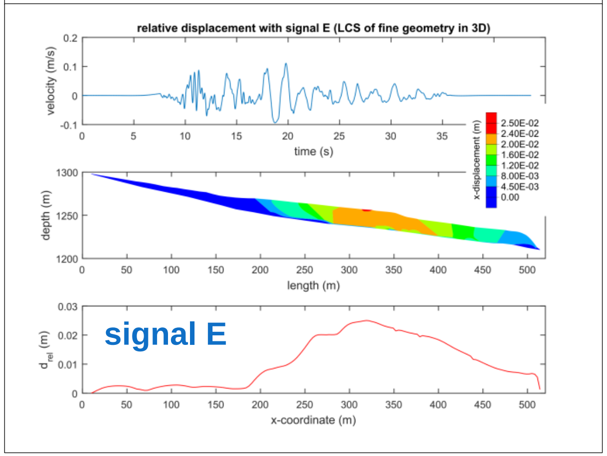


3D

simple



fine

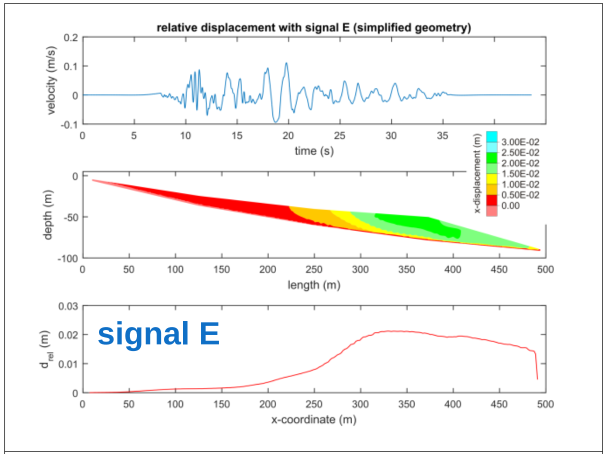


Running FDM-Models

dynamic phases

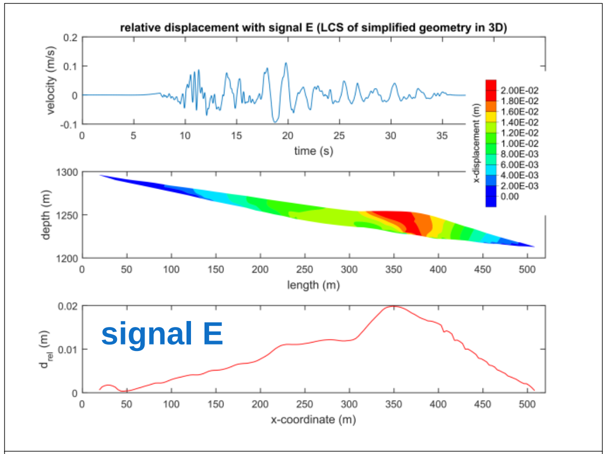
2D | **3D**

simple



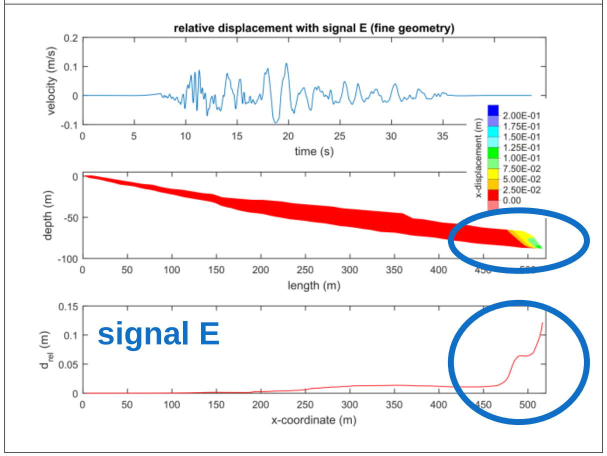
slope response relative to bedrock

qualitative: geometry

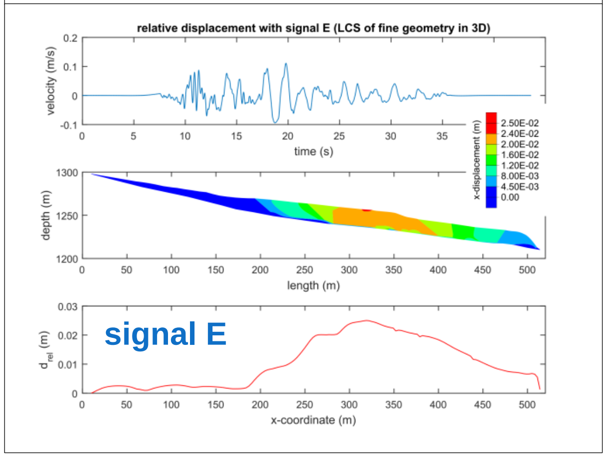


simple

fine



quantitative:



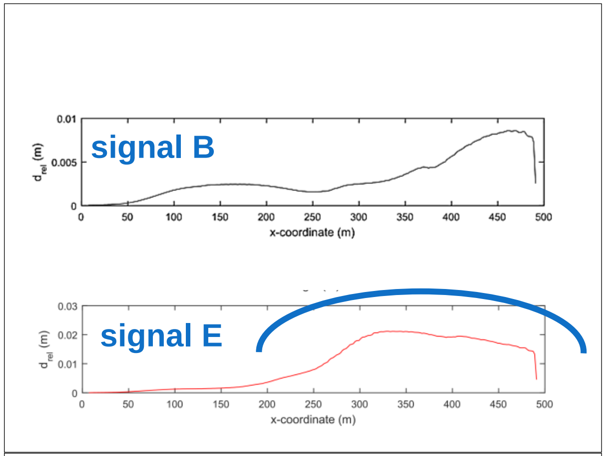
fine

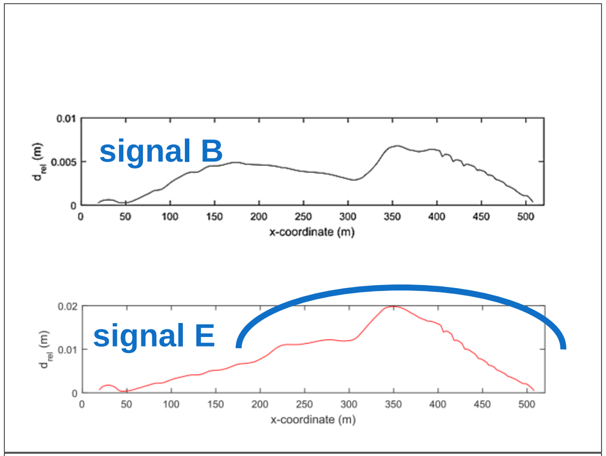
Running FDM-Models

dynamic phases

2D | **3D**

simple





slope response relative to bedrock

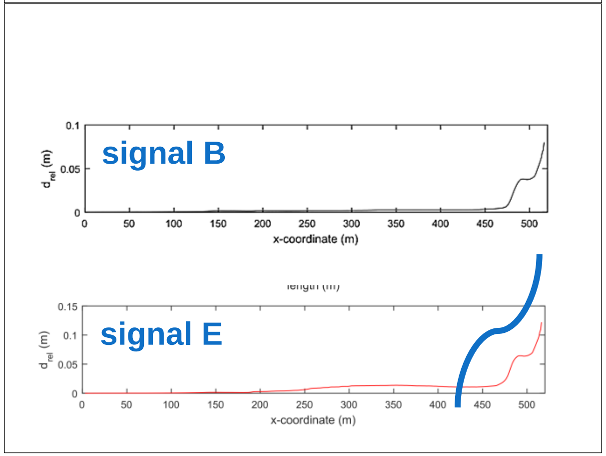
qualitative:

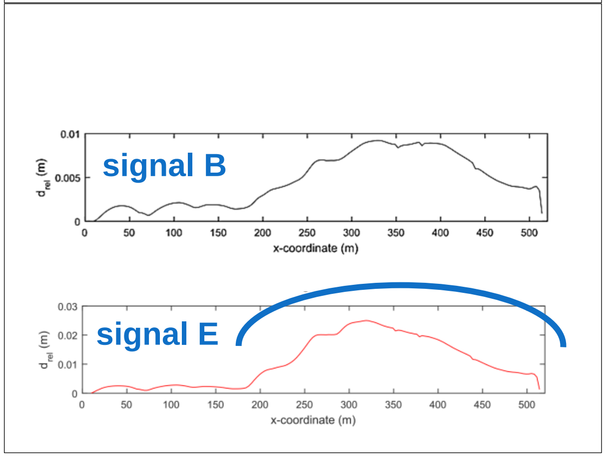
geometry

signal

quantitative:

fine





simple

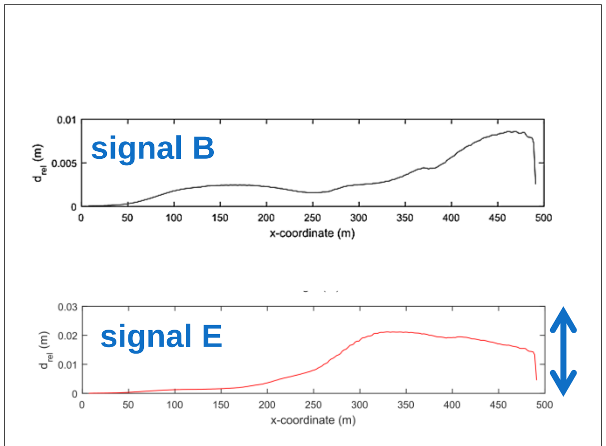
fine

Running FDM-Models

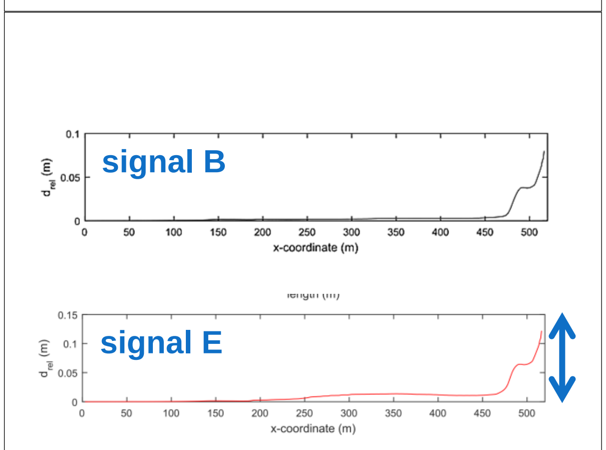
dynamic phases

2D

simple



fine



slope response

relative to bedrock

qualitative:

geometry

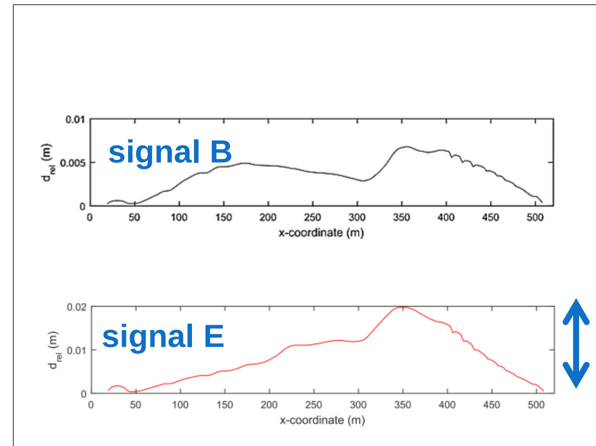
signal

quantitative:

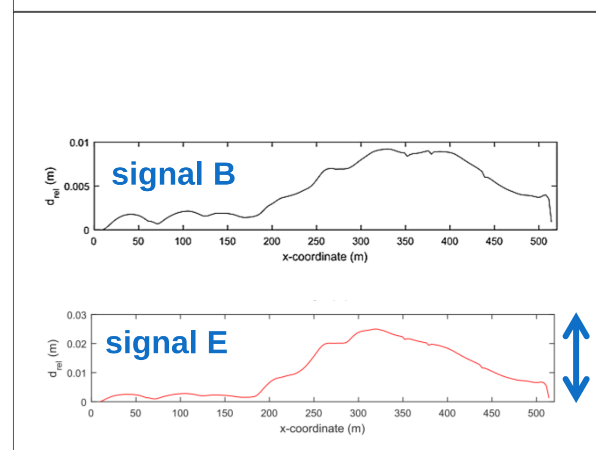
signal

3D

simple



fine

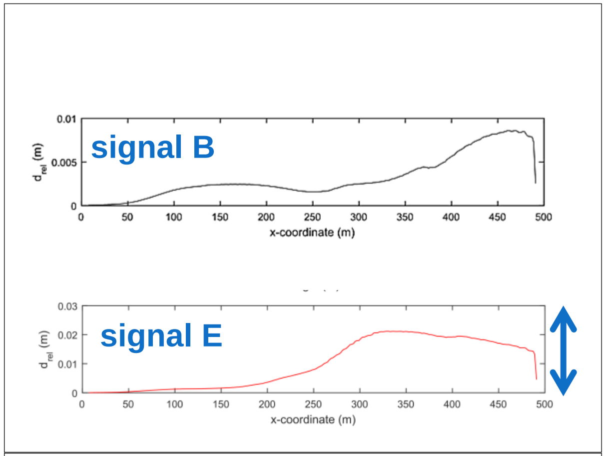


Running FDM-Models

dynamic phases

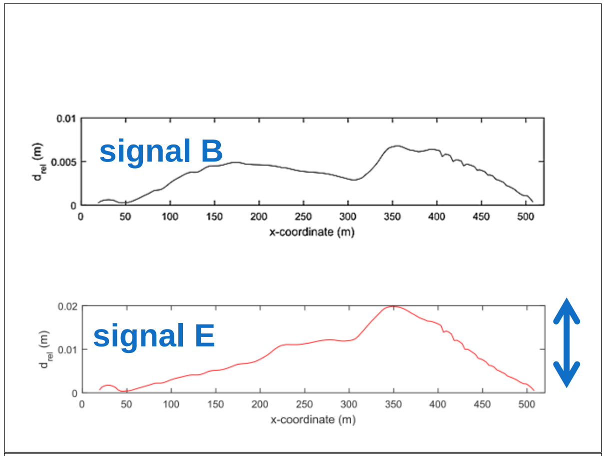
2D | **3D**

simple



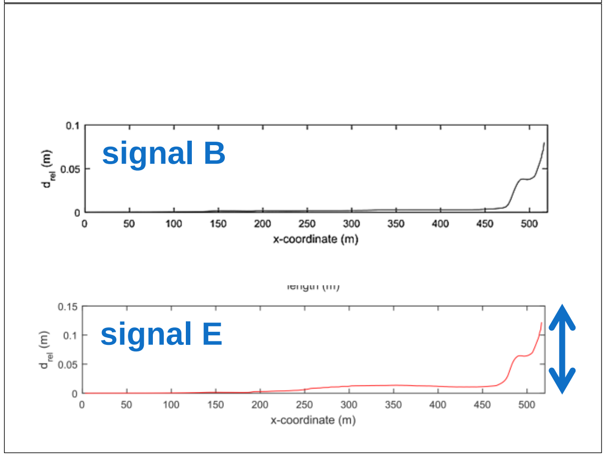
slope response
relative to bedrock

qualitative:
geometry
signal



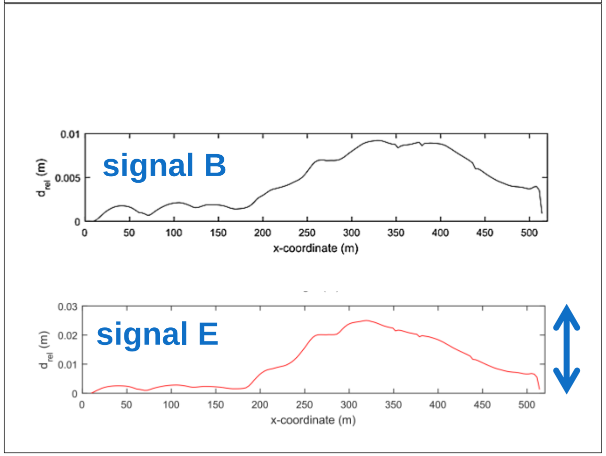
simple

fine



quantitative:
signal

→ 2D fine geometry
not representative



fine

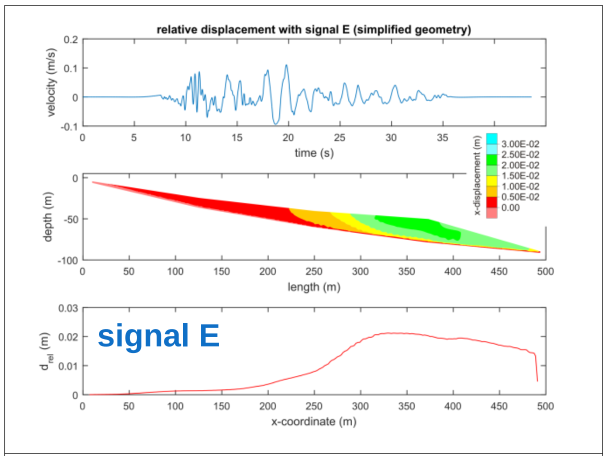
Running FDM-Models

maximum d_{res} (cm)

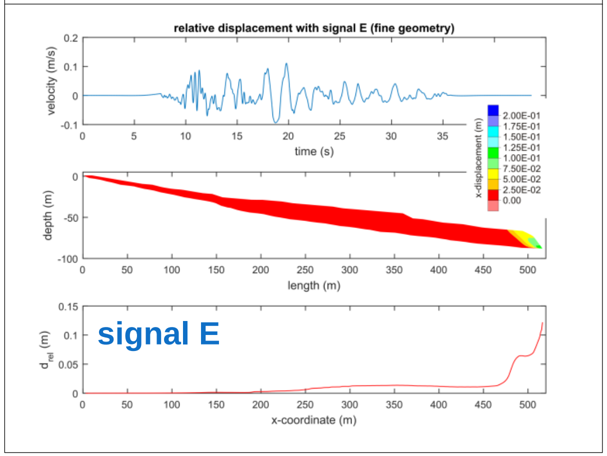
	2D simple	2D fine	3D simple	3D fine
A	0.18	4.25		
B	0.86	7.99	0.68	0.92
C	0.28	5.76		
D	0.98	8.64		
E	2.12	12.20	1.99	2.50
F	2.85	17.06		
G	0.52	6.15		
H	0.69	9.35		
I	0.30	7.08		
J	0.91	9.58		
K	0.17	3.64		

2D

simple

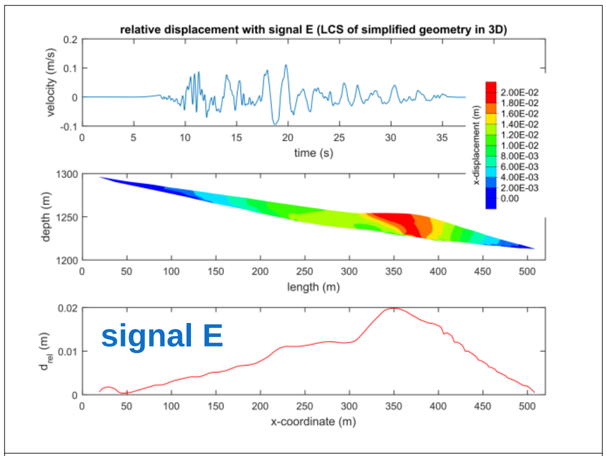


fine

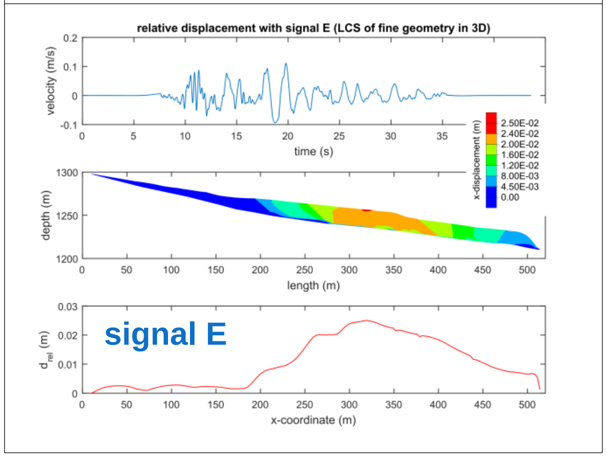


3D

simple



fine

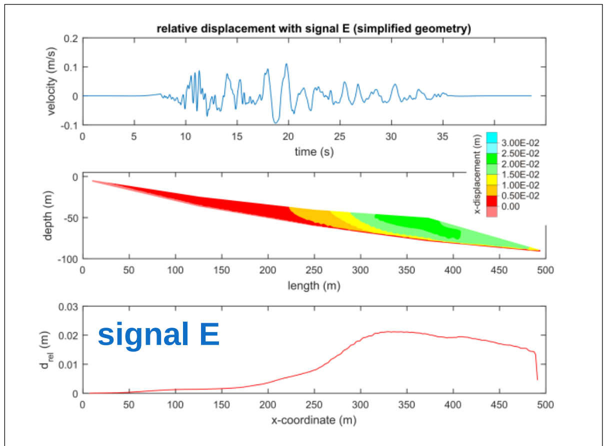


Running FDM-Models

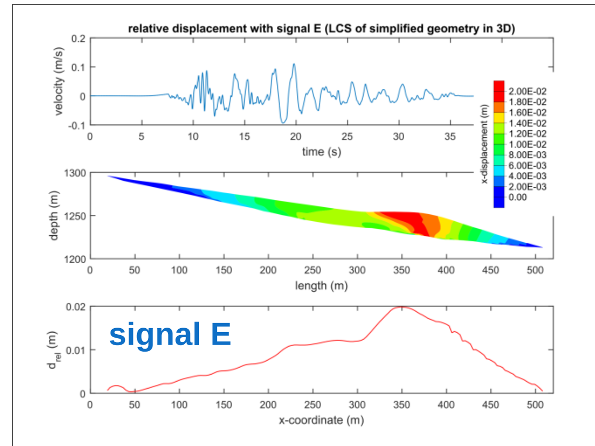
maximum d_{res} (cm)

2D | **3D**

simple

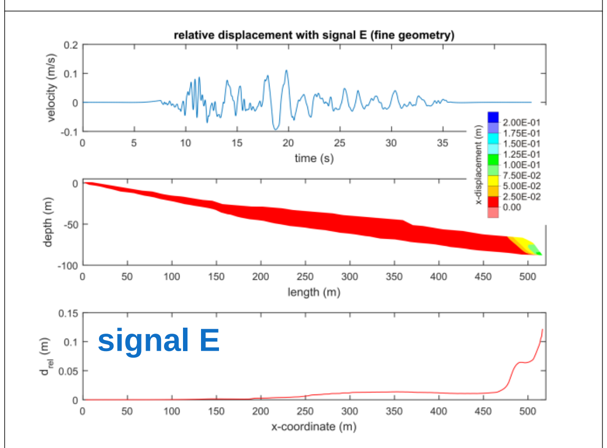


	2D	3D
A	0.18	
B	0.86	0.68
C	0.28	
D	0.98	
E	2.12	1.99
F	2.85	
G	0.52	
H	0.69	
I	0.30	
J	0.91	
K	0.17	

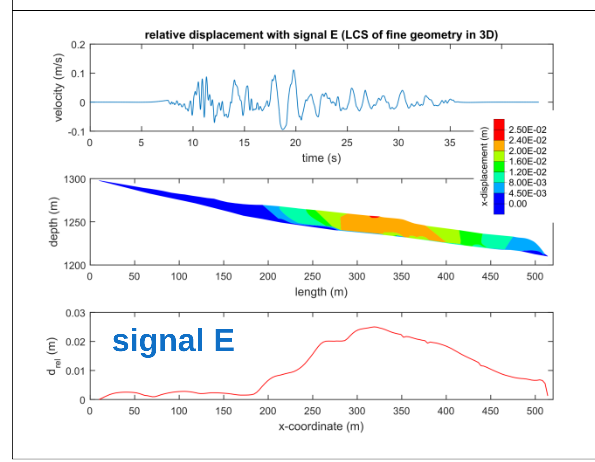


factors 6 to 24

fine



	2D	3D
A	**4.25**	
B	**7.99**	0.92
C	**5.76**	
D	**8.64**	
E	**12.20**	2.50
F	**17.06**	
G	**6.15**	
H	**9.35**	
I	**7.08**	
J	**9.58**	
K	**3.64**	

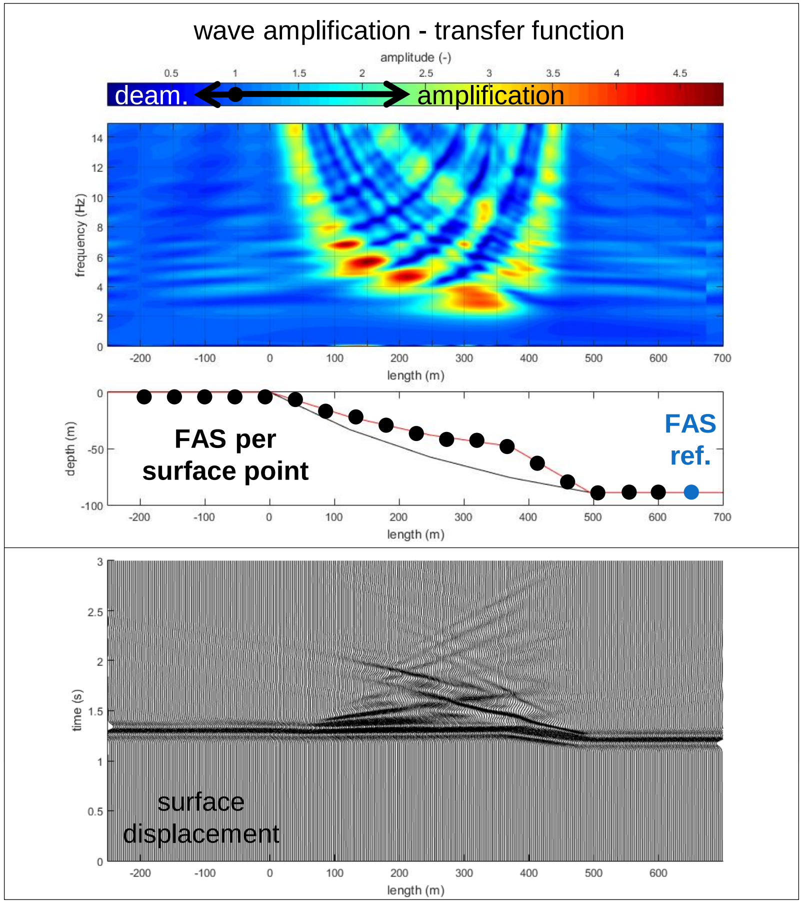


Running FDM-Models

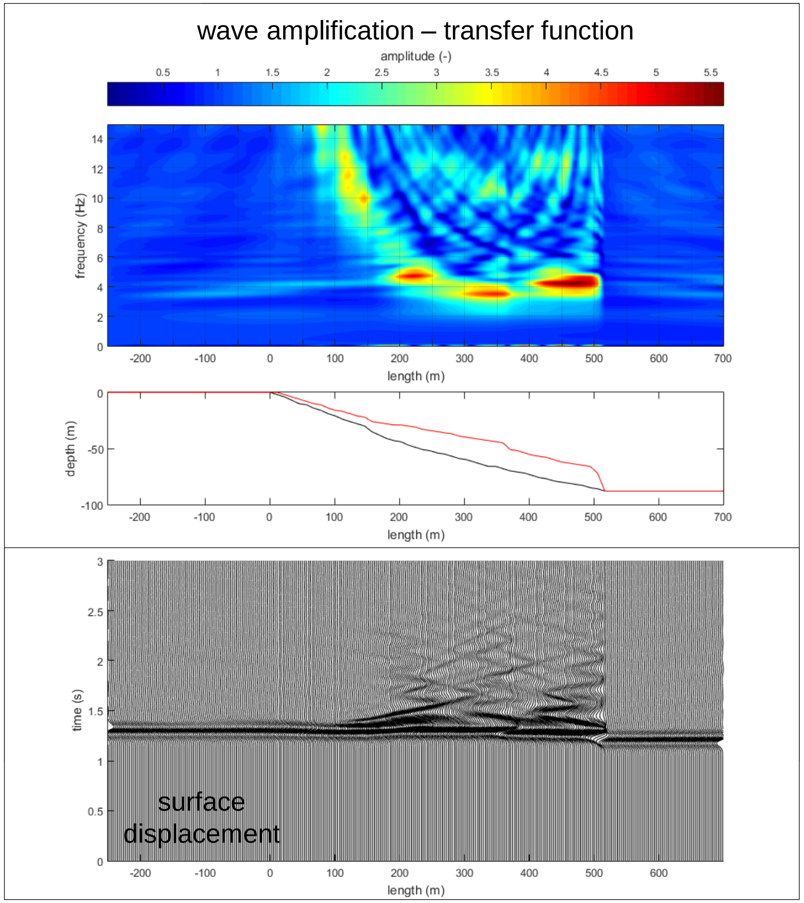
reason 1: site effects

simple

2D



2D

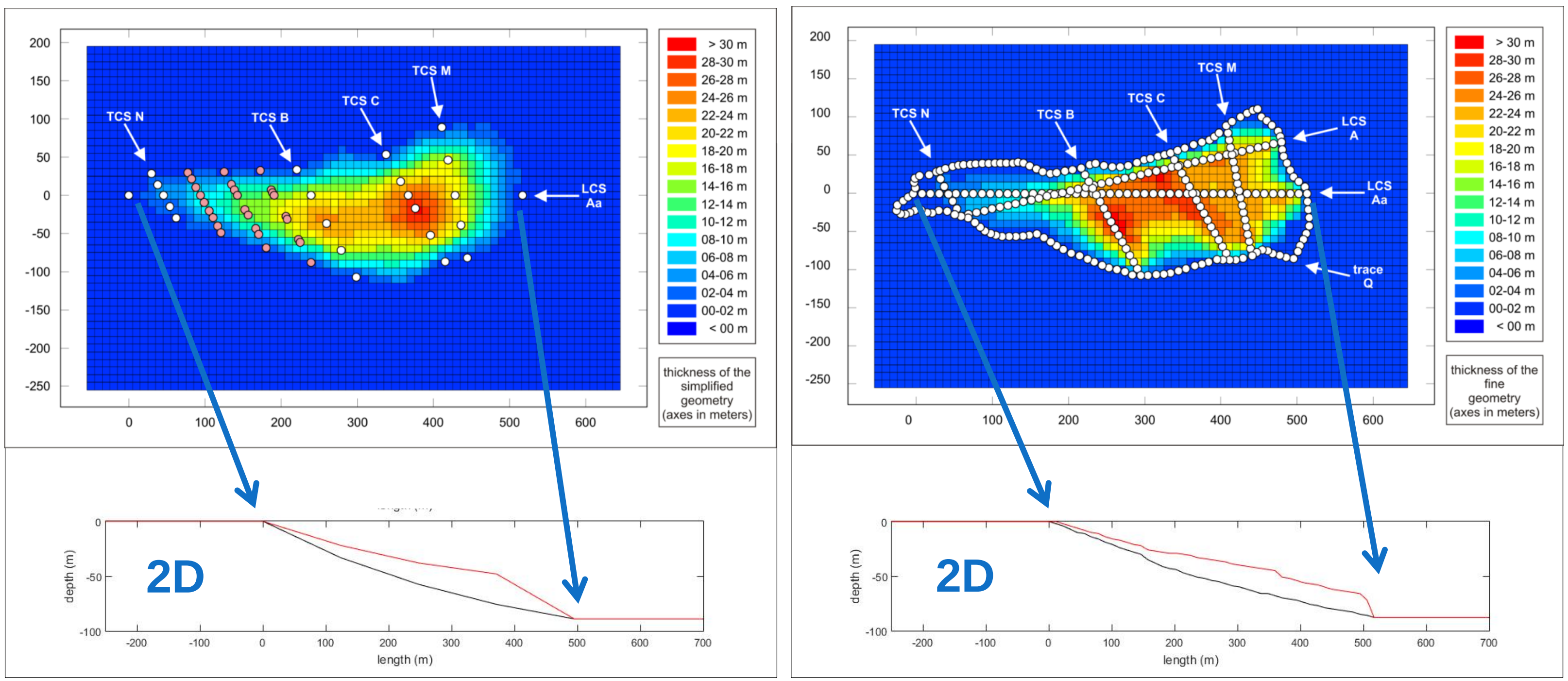


fine

Running FDM-Models

reason 2: thickness

3D (simple) 3D (fine)

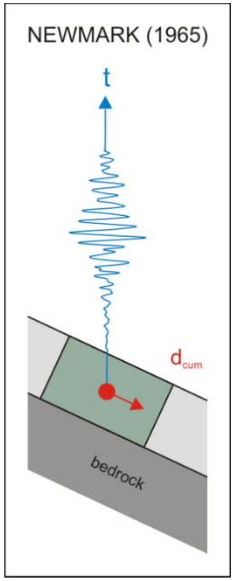


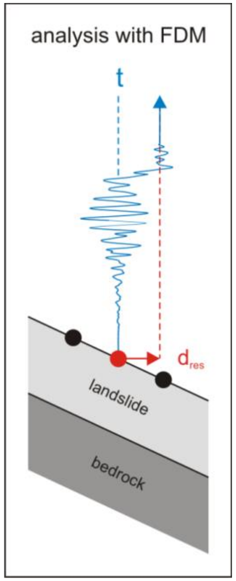
The 2D simple geometry seems much more representative for the entire landslide (in 3D) than the 2D fine geometry. It does not have such a steep toe all along!

Can we compare the two methods, and if yes how?

comparison of Newmark (1965) & FDM

method	geometry	input	signal	output	behavior	domain
Newmark (1965)	2D (simple)	W, l, c, Φ, β	acceleration time-histories	d_{cum} (1 value)	elasto-perfectly-plastic	(time related)
finite difference method	2D & 3D (simple & fine)	v_s, ρ, υ, c', Φ' and as function thereof G, K	velocity time-histories	d_{res} (1 value per point)	visco-elasto-perfectly-plastic	time domain

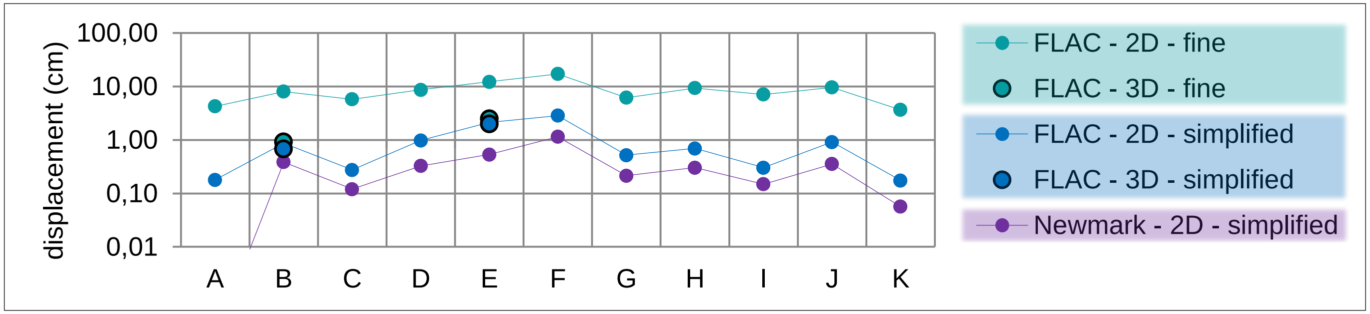




Can we compare the two methods, and if yes how?

comparison of Newmark (1965) & FDM

Signal	Newmark (1965) 2D simple	FDM 2D simple	FDM 2D fine	FDM 3D simple	FDM 3D fine
A	0.00	0.18	4.25		
B	0.38	0.86	7.99	0.68	0.92
C	0.12	0.28	5.76		
D	0.33	0.98	8.64		
E	0.53	2.12	12.20	1.99	2.50
F	1.15	2.85	17.06		
G	0.21	0.52	6.15		
H	0.30	0.69	9.35		
I	0.15	0.30	7.08		
J	0.35	0.91	9.58		
K	0.06	0.17	3.64		
average	0.33	0.90	8.34	1.33	1.71



- max. value policy
- signal priority in 2D (FDM ≈ Newmark)
- all in cm-range
- factors 6-24 for models 2D/fine

Can we compare the two methods, and if yes how?

comparison of Newmark (1965) & FDM

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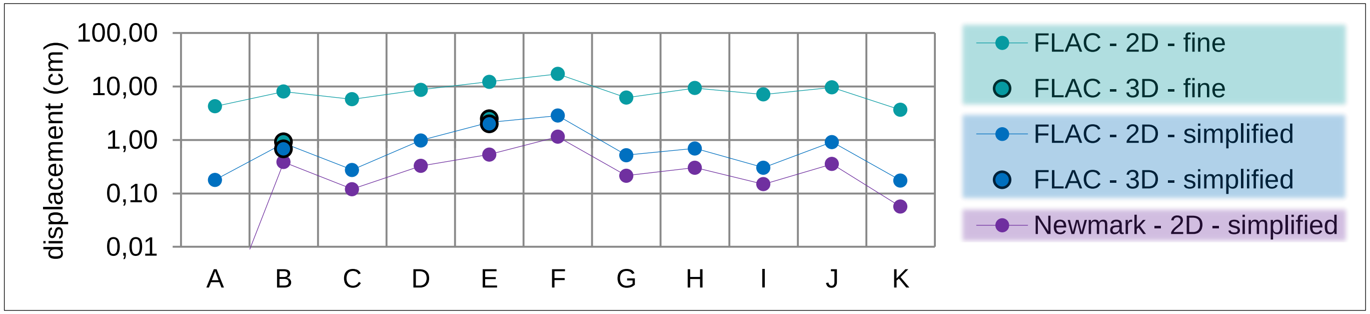

- max. value policy
- signal priority in 2D (FDM ≈ Newmark)
- all in cm-range
- factors 6-24 for models 2D/fine

→ 3D is great!

→ fine models can be misleading

→ Newmark (1965) is better than we think

References

- Ambraseys N. N., et al., 2004. Dissemination of European Strong-Motion Data. Engineering and Physical Sciences Research Council of the United Kingdom, vol. 2, CD ROM collection.
- Azañon J. M., et al., 2010. Regional-scale high-plasticity clay-bearing formation as controlling factor on landslides in Southeast Spain. Geomorphology, vol. 120/1-2, p. 26-37.
- Benito M. B., et al., 2010. A new seismic hazard assessment in the region of Andalusia (Southern Spain). Bulletin of Earthquake Engineering, vol. 8, p. 739-766.
- Delgado J., et al., 2015. Unconventional pseudostatic stability analysis of the Diezma landslide (Granada, Spain) based on a high-resolution engineering-geological model. Engineering Geology, vol. 184, p. 81-95.
- Jibson R. W., et al., 2013. SLAMMER—Seismic LAndslide Movement Modeled using Earthquake Records. United States Geological Survey Techniques and Methods, vol. 12/B1, version 1.1 - Nov. 2014, p. ?.
- Martino S., et al., 2016. Application of a characteristic periods-based (CPB) approach to estimate earthquake-induced displacements of landslides through dynamic numerical modelling. Geophysical Journal International, vol. 206/1, p. 85-102.
- Newmark N. M., 1965. Effects of earthquakes on dams and embankments. Géotechnique, vol. 15/2, p. 139-160.
- Rodríguez-Peces M. J., et al., et al., 2011. The Diezma landslide (A-92 motorway, Southern Spain): history and potential for future reactivation. Bulletin of Engineering Geology and the Environment, vol. 70/4, p. 681-689.

Images (other than own photos and exports from CorelDRAW/Google Earth/Google Maps/MATLAB):

- ITASCA, 2015. Finite difference analysis. Download on 5th of October 2018 from www.itasca.com.
- Kramer S. L., 1996. Geotechnical Earthquake Engineering. Prentice Hall, ed. ?, 653 p.

Thank you for reading our display,
we look forward to chat with you
on Monday, May 4th, from 10:45 to 12:30!