Developing software to evaluate the liquefaction potential by using 2D numerical modeling: Applications

AUTORES:

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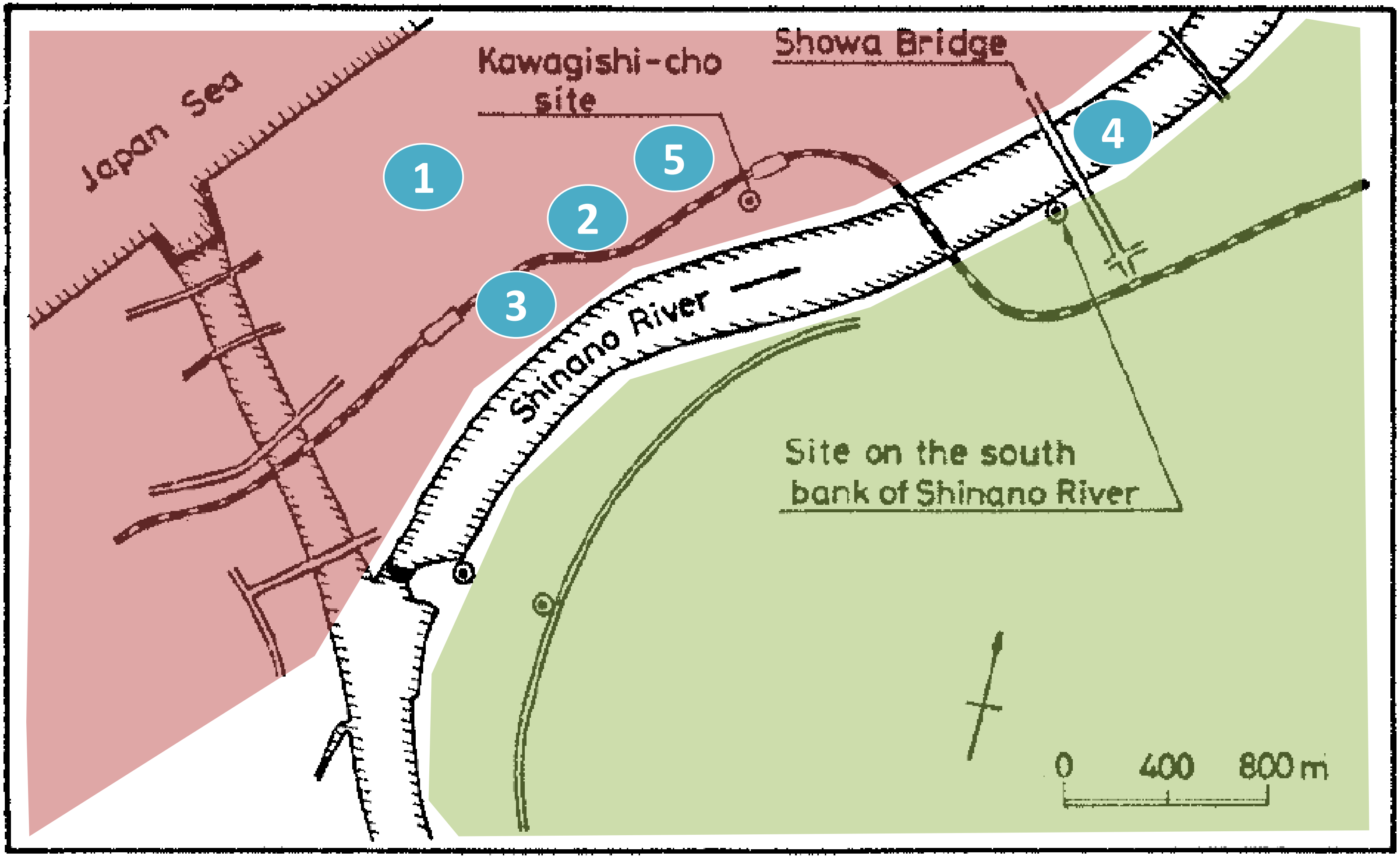

Fig. 2 Map of the city of Niigata - Japan
Source: https://goo.gl/6yvcaQ

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Fig. 3 Differential settlements
Source: https://goo.gl/xYdCvb

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Source: https://goo.gl/fVgHs9

Fig. 5 Sand volcanoes.
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Fig. 6 Failure of Showa bridge boards.
Source: https://goo.gl/LLvR5t

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Fig. 7 Collapse of the apartment complex of Niigata prefecture.
Source: https://goo.gl/zukWJh

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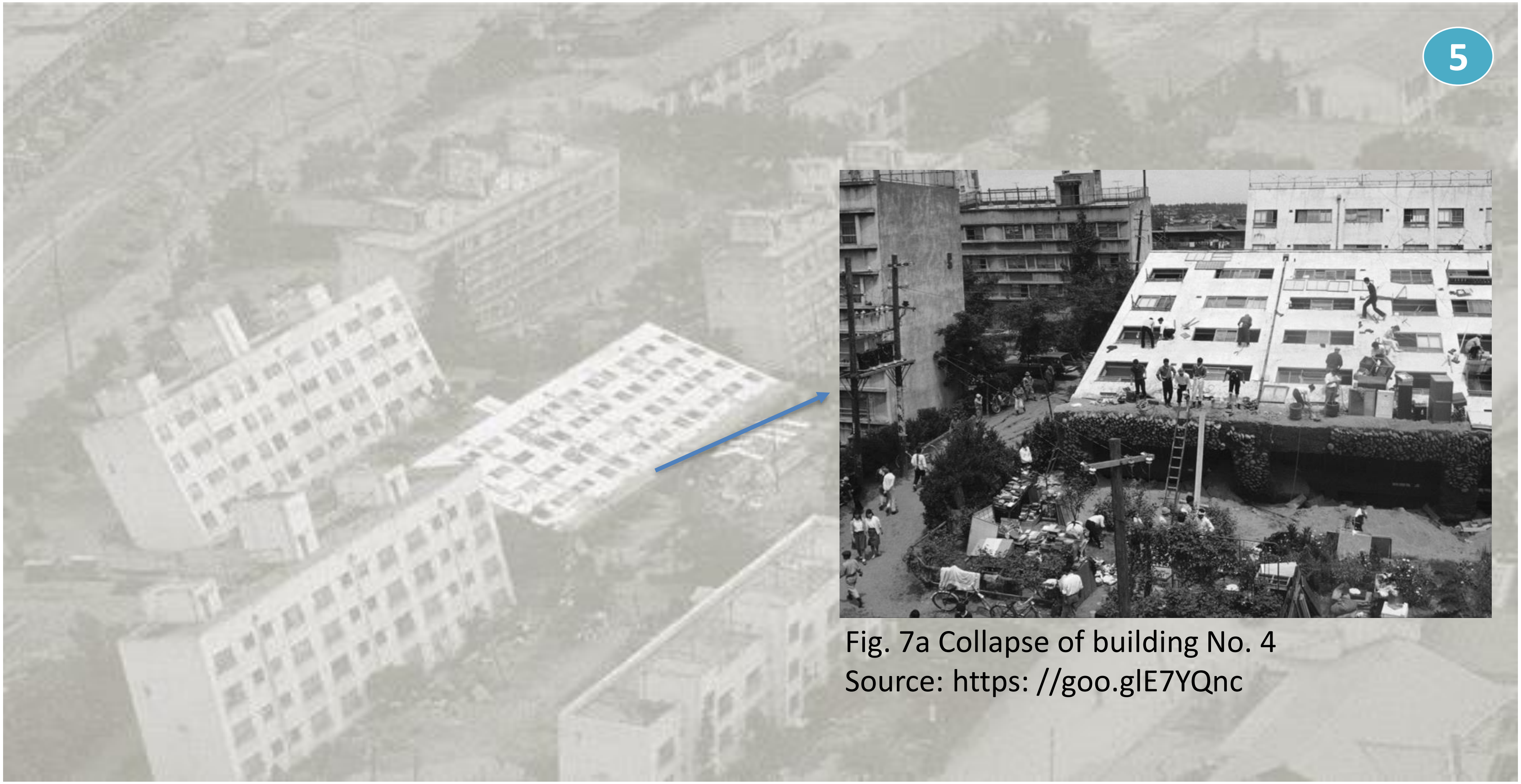

Fig. 7a Collapse of building No. 4
Source: https: //goo.glE7YQnc

Fig. 7 Collapse of the apartment complex of Niigata prefecture.
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Fig. 8 Earthquake of Alaska - USA (1964).
Source: https://goo.gl/uNTxW1

Fig. 10 Earthquake of Loma Prieta - California (1989).
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Fig. 9 Kobe earthquake - Japan (1995)
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Fig. 11 Maule earthquake - Chile (2010).
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Fig. 12 Sismo de Pedernales - Ecuador (2016).
Source: EERI

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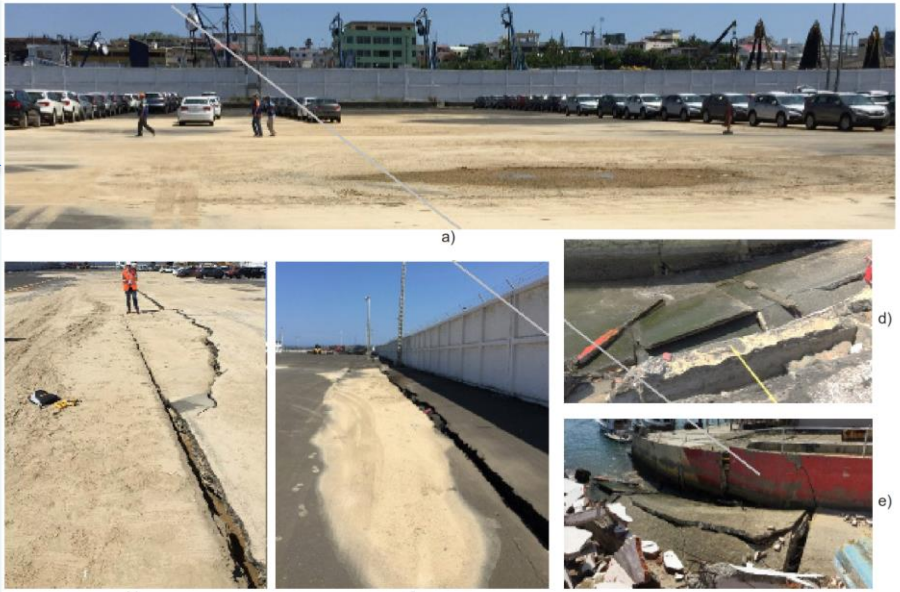

Fig. 13 Port of Manta, Pedernales earthquake - Ecuador (2016).
Source: EERI

Fig. 14 Calceta, Pedernales Earthquake - Ecuador (2016).
Source: EERI

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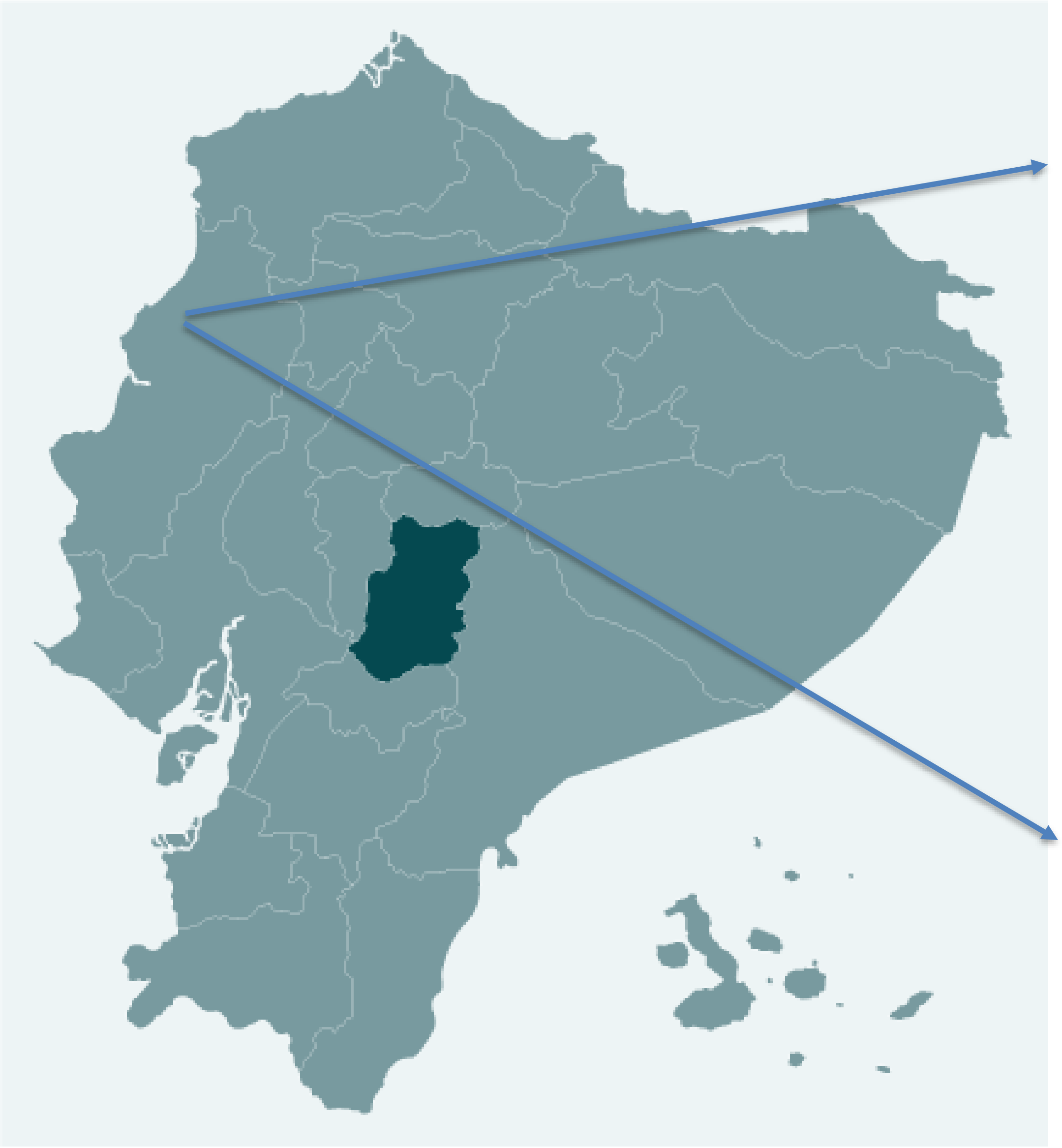

Fig. 15 Manta shrimp, Pedernales earthquake - Ecuador (2016).
Source: EERI

Fig. 16 Manta, Pedernales Earthquake - Ecuador (2016).
Source: EERI

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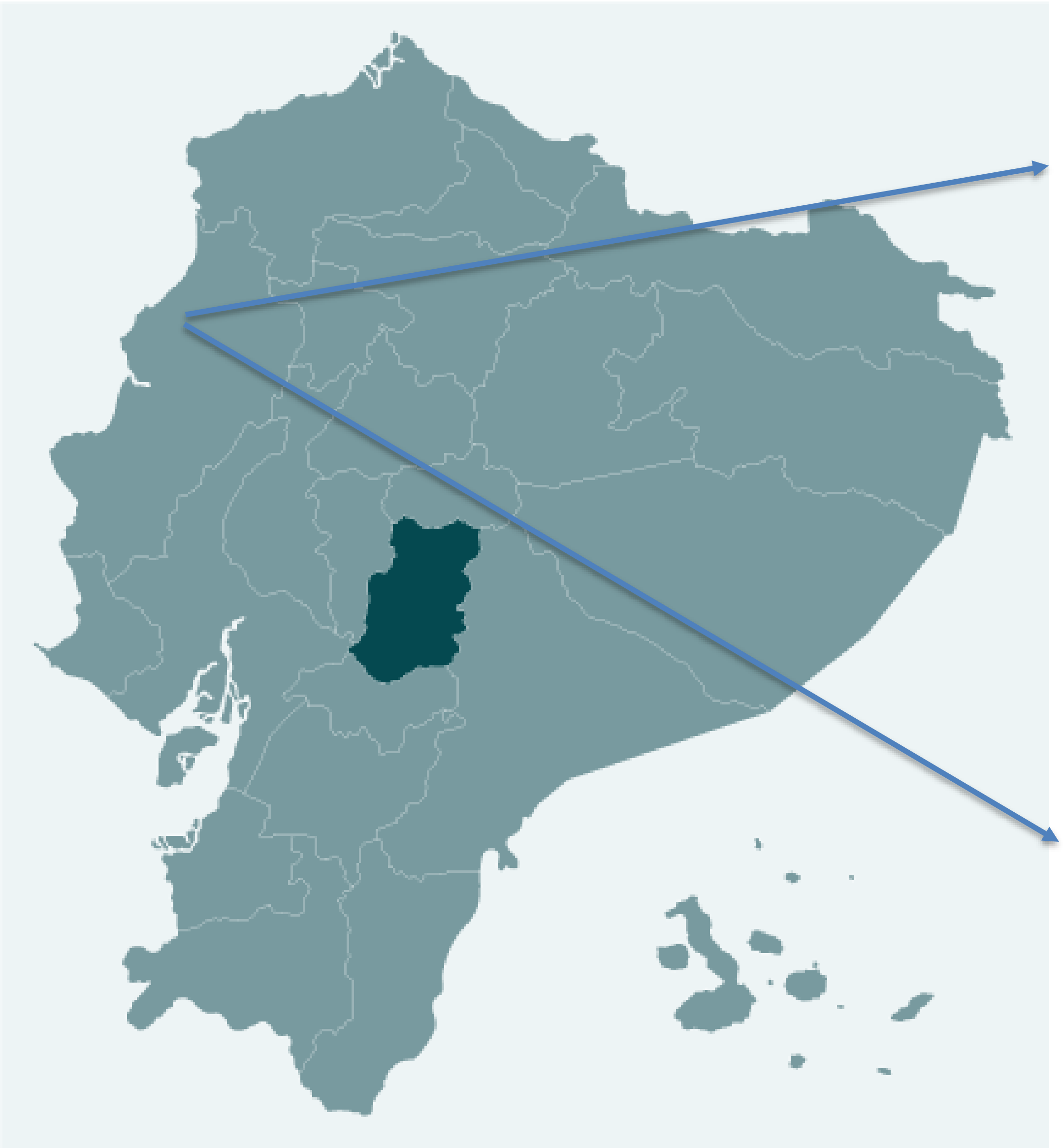

Fig. 17 Sand volcanoes

Fig. 18 Manta, Mass movements

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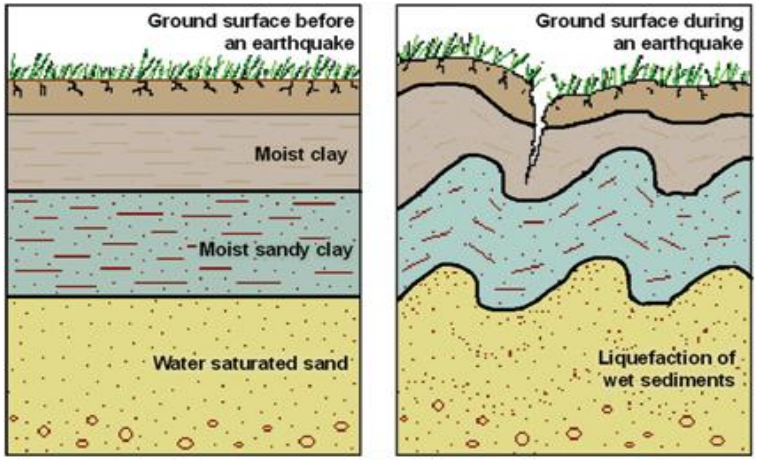


Fig. 19 Deformation of the soil due to liquefaction
Source: https://goo.gl/GGJQRp

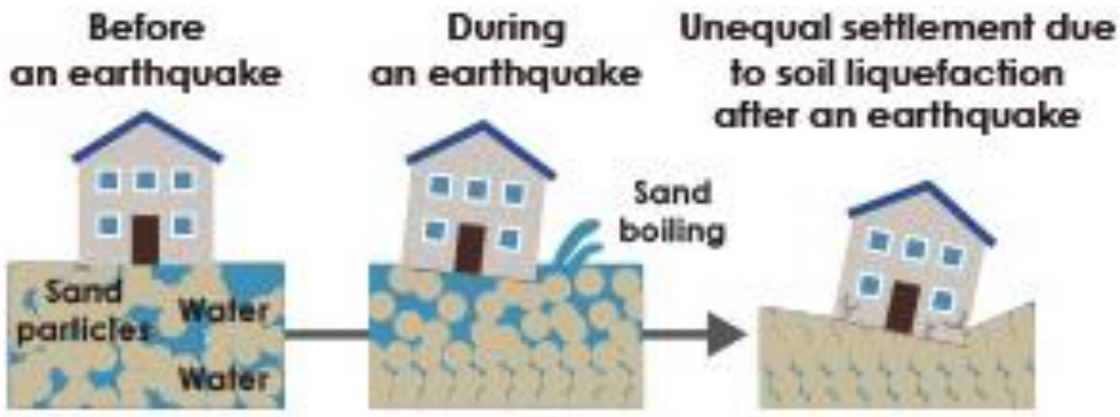


Fig. 20 Representation of the soil during liquefaction.
Source: https://goo.gl/Mz6TJt

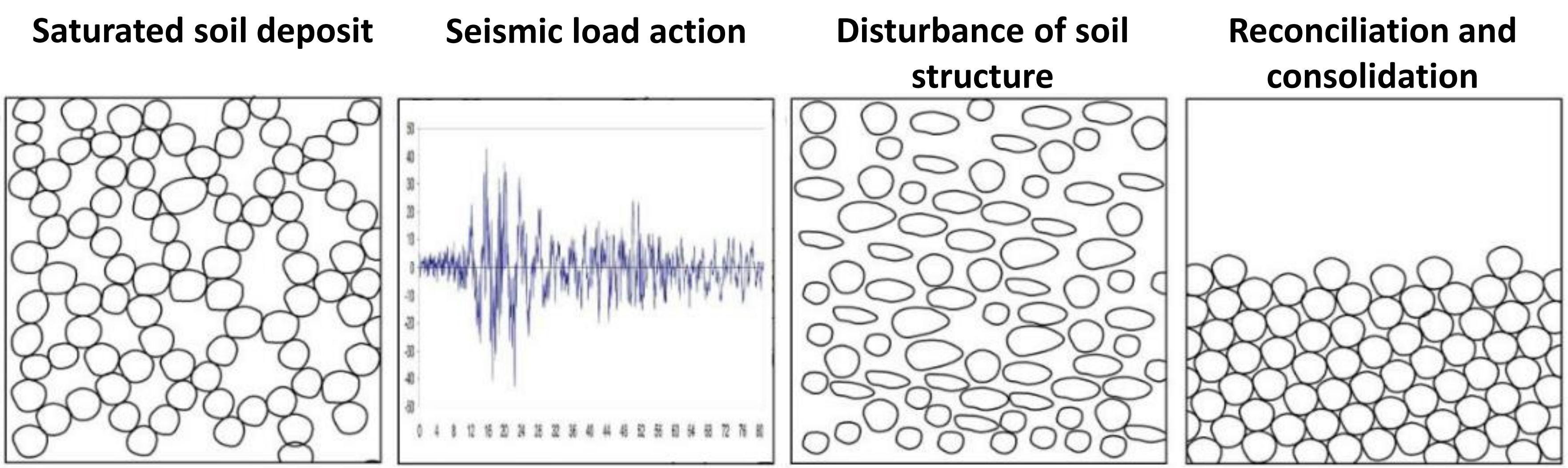


Fig. 21 Proceso de generación del fenómeno de licuefacción.
Fuente: https://goo.gl/emGHJU

Methods to evaluate the liquefaction potential

❑ Empirical Methods

Fig. 22 Field observations.
Source: https://goo.gl/FHbD9Y

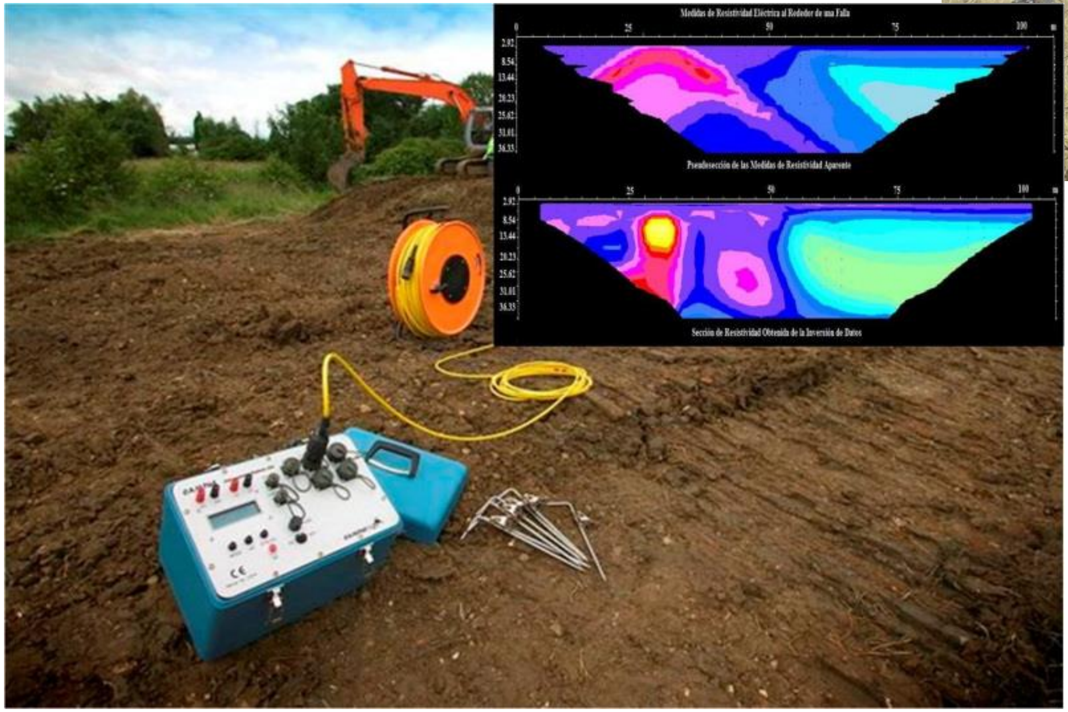


Fig. 23 Geophysical prospecting tests.
Source: https://goo.gl/jgYx9c

Methods to evaluate the liquefaction potential

❑ Semi-empirical methods

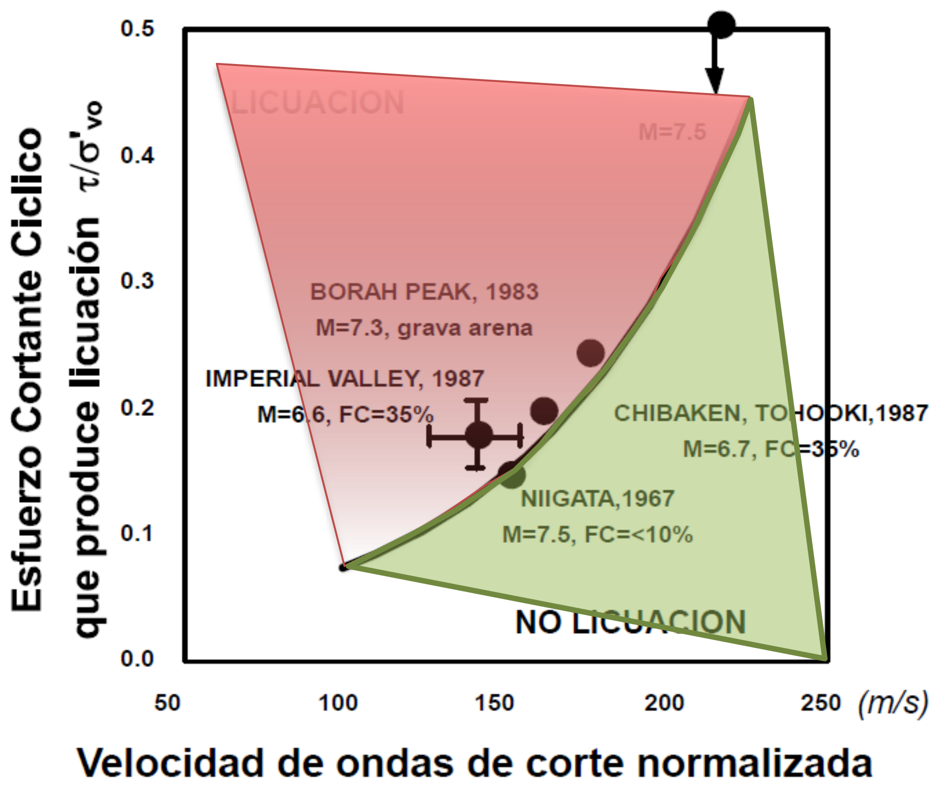


Fig. 24 Correlation A of the simplified method
Source: García Nuñez, 2007

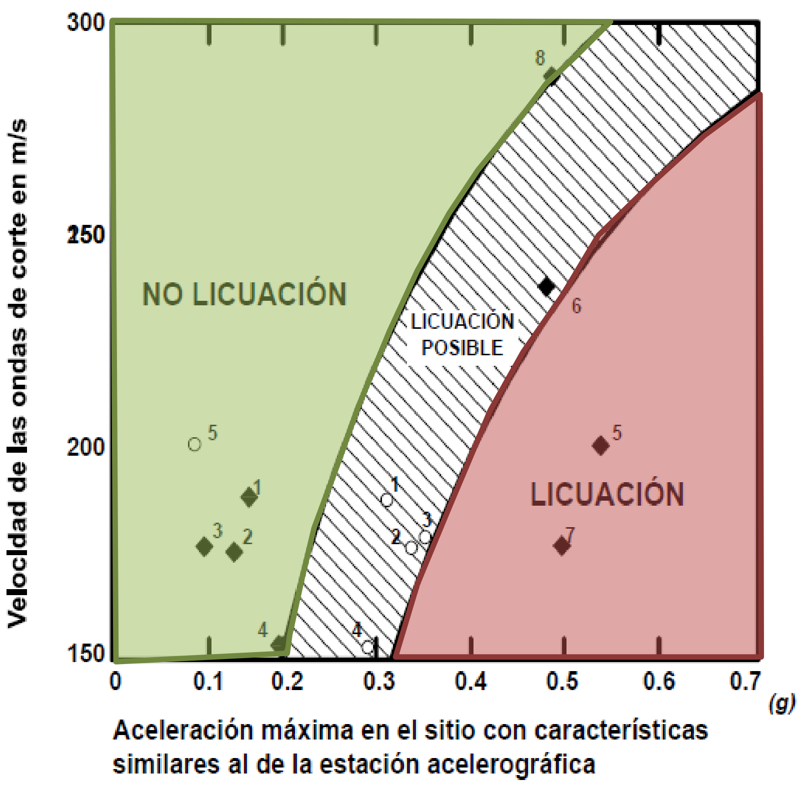


Fig. 25 Correlation B of the simplified method
Source: García Nuñez, 2007

❑ Numerical methods

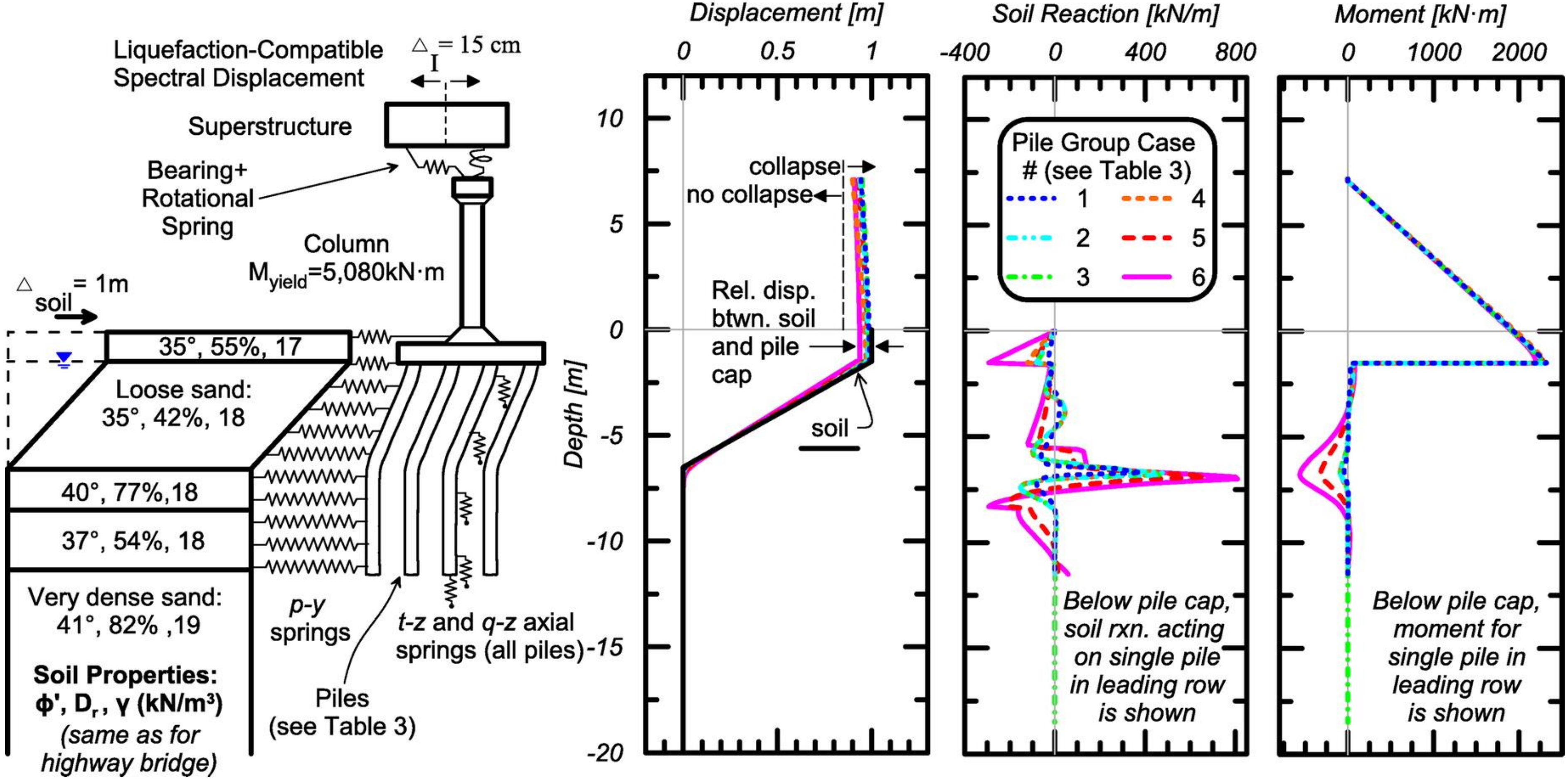
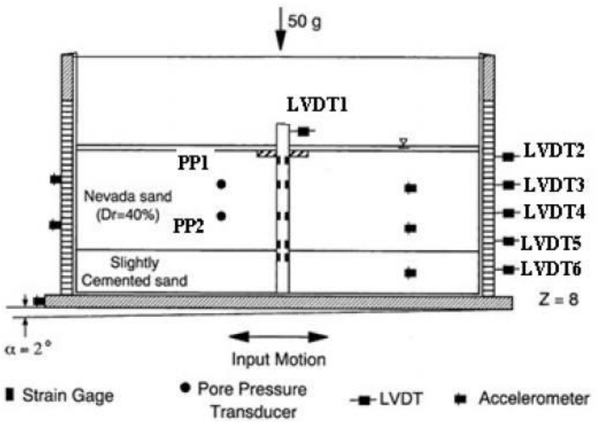


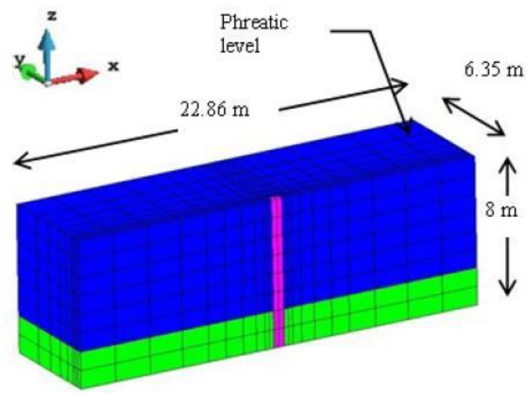
Fig. 26 Numerical representation of a bridge pile affected by liquefaction by finite elements of a physical model.
Source: https://goo.gl/H9gKj4

Methods to evaluate the liquefaction potential

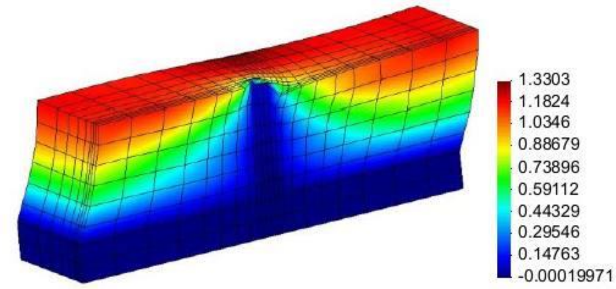
❑ Numerical methods



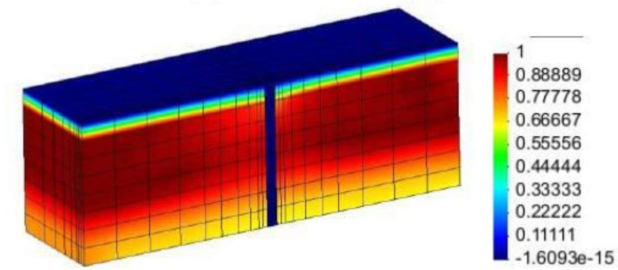
(a) Instrumentation used in model 3



(b) Finite element mesh (in prototype scale)



(a) Deformed mesh (m)



(b) Potential of liquefaction (ru)

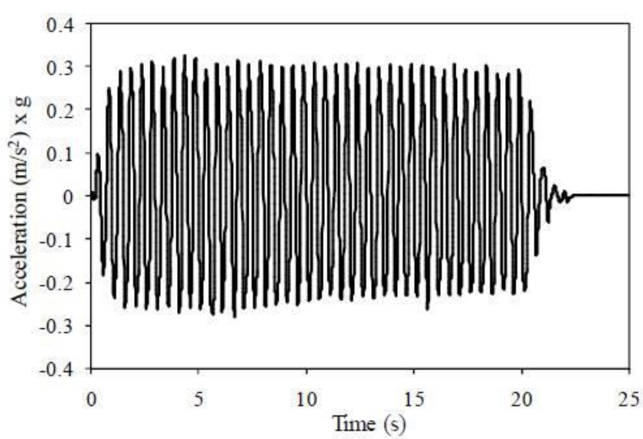
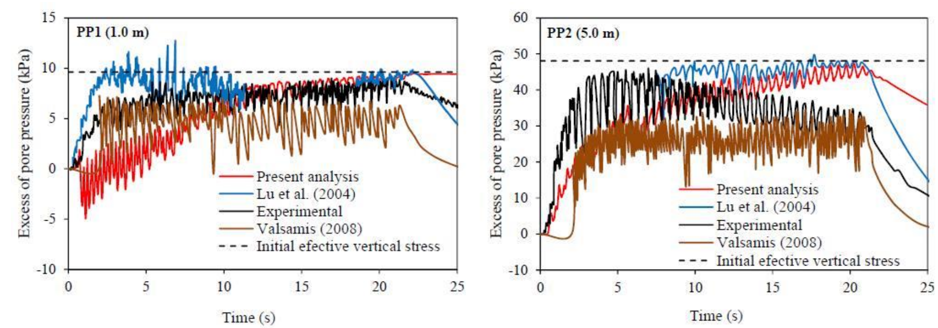


Fig. 27 Soil-Pile System Under Harmonic Load (Abdoun, 1997)



Methods to evaluate the liquefaction potential

❑ Numerical methods

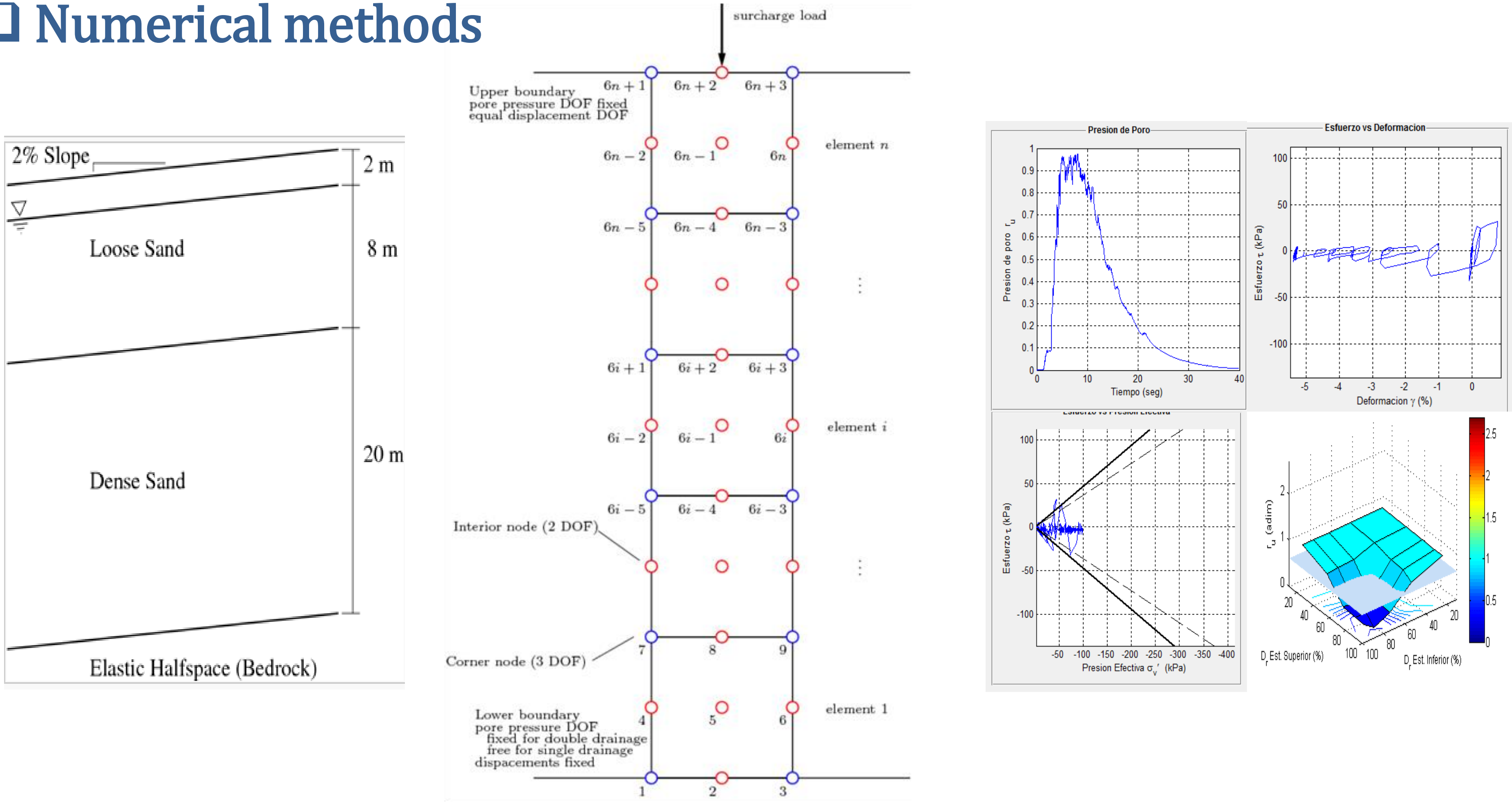


Fig. 28 Representation by finite elements of a physical model.
Source: https://goo.gl/H9gKj4

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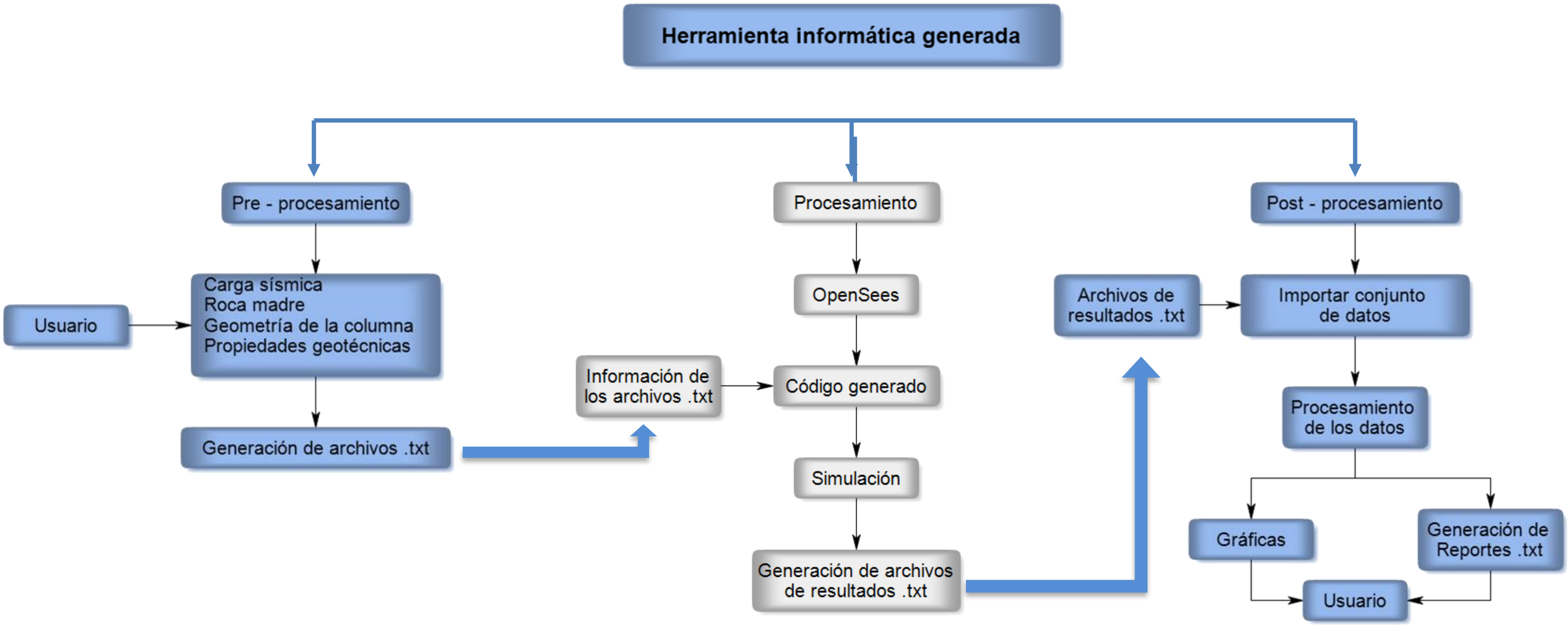
Software development

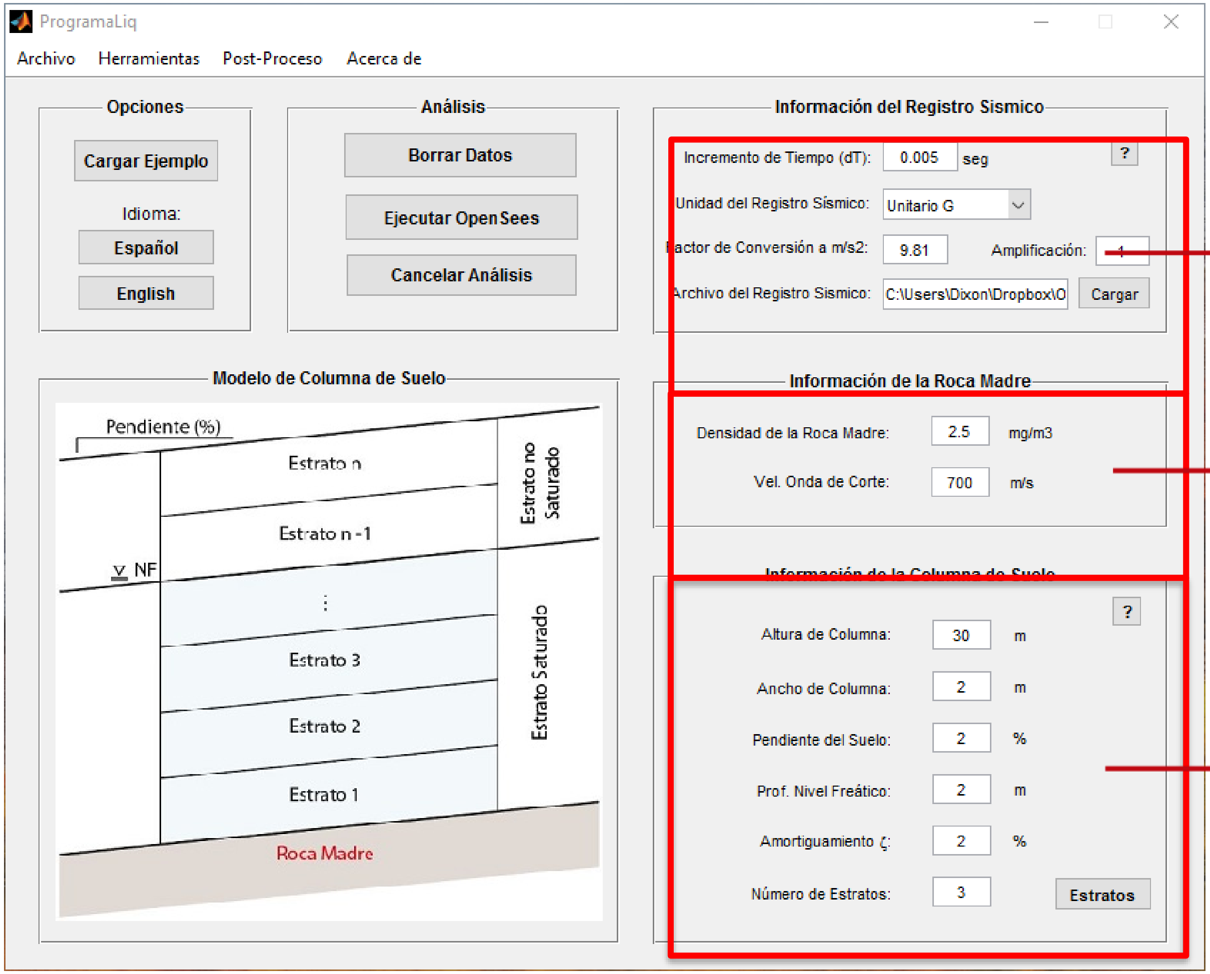
❑ Flowchart



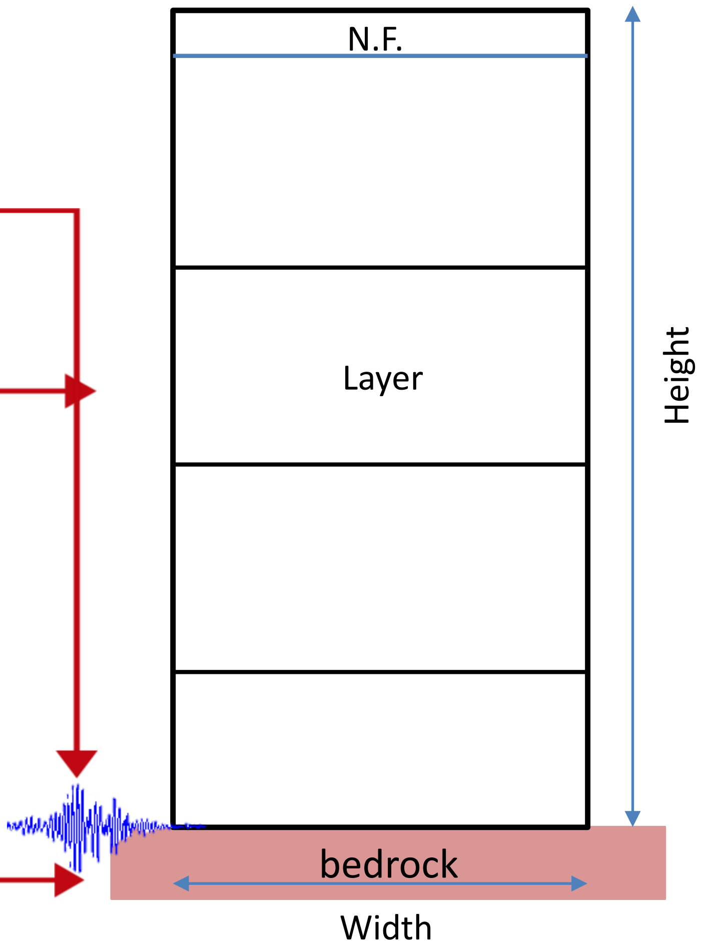
MATLAB OpenSees MATLAB

❑ Pre-process

Main interface



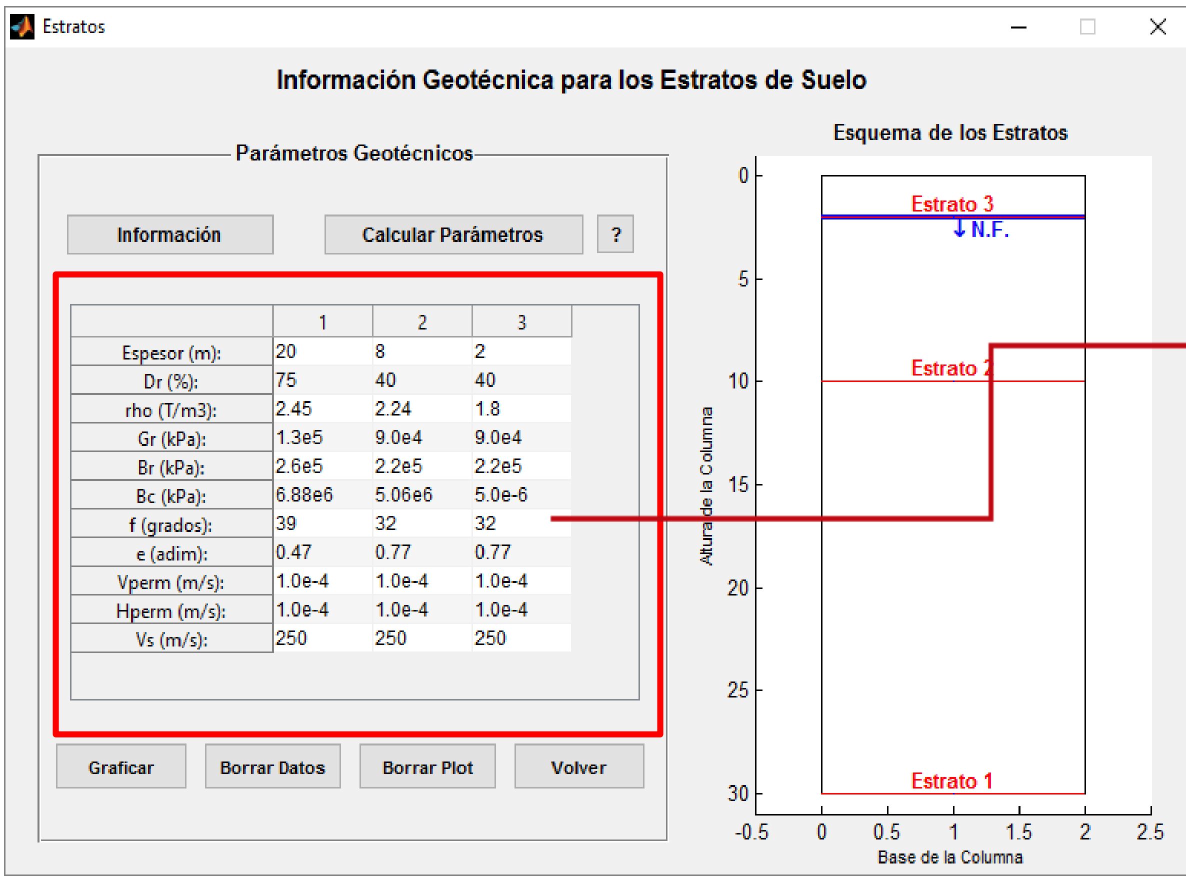
Definition of a soil column



Software development

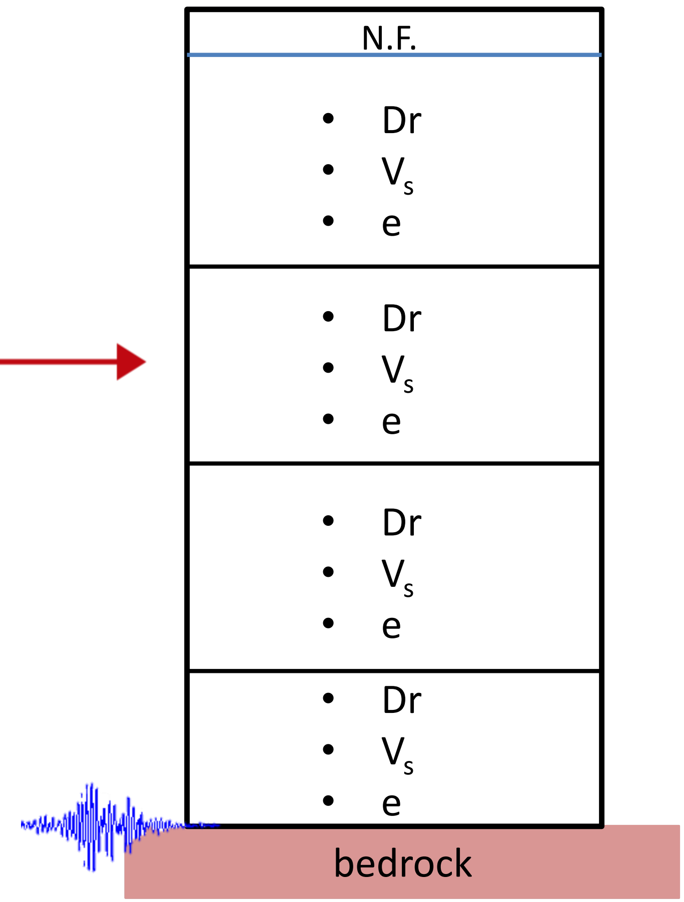
❑ Pre-process

Auxiliary interface



	1	2	3
Espesor (m):	20	8	2
Dr (%):	75	40	40
rho (T/m3):	2.45	2.24	1.8
Gr (kPa):	1.3e5	9.0e4	9.0e4
Br (kPa):	2.6e5	2.2e5	2.2e5
Bc (kPa):	6.88e6	5.06e6	5.0e-6
f (grados):	39	32	32
e (adim):	0.47	0.77	0.77
Vperm (m/s):	1.0e-4	1.0e-4	1.0e-4
Hperm (m/s):	1.0e-4	1.0e-4	1.0e-4
Vs (m/s):	250	250	250

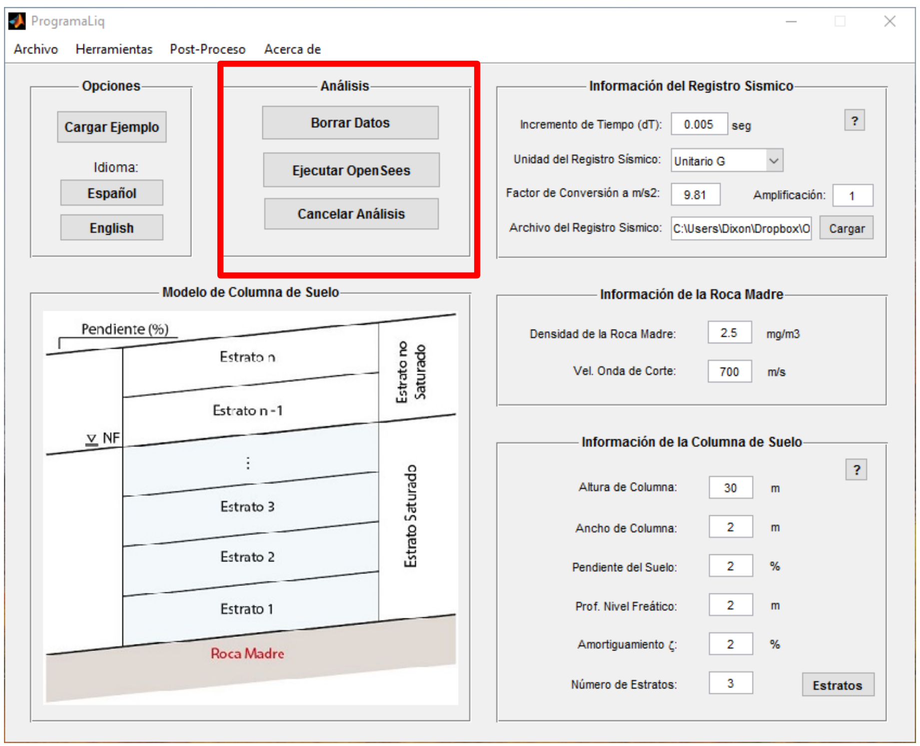
Definition of a soil column



Software development

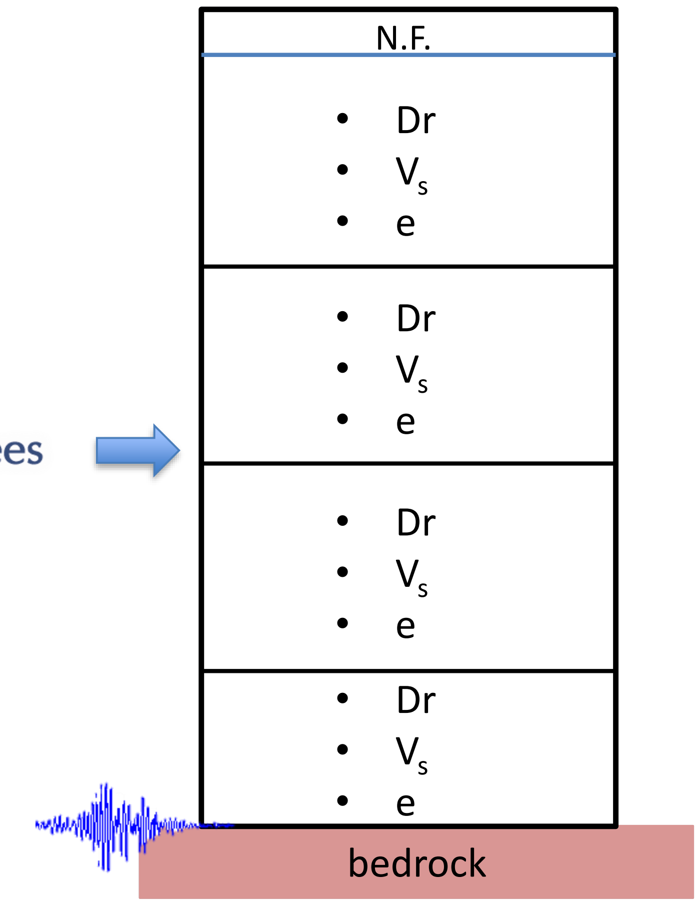
❑ Analysis process

Main interface



OpenSees

Soil column model



❑ Description of the model

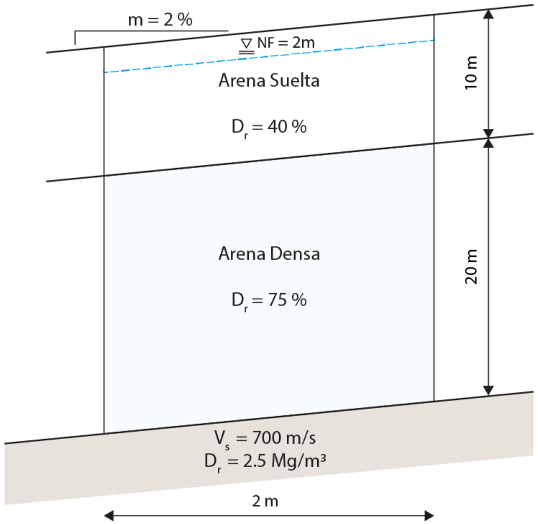


Fig. 29 Stratigraphy

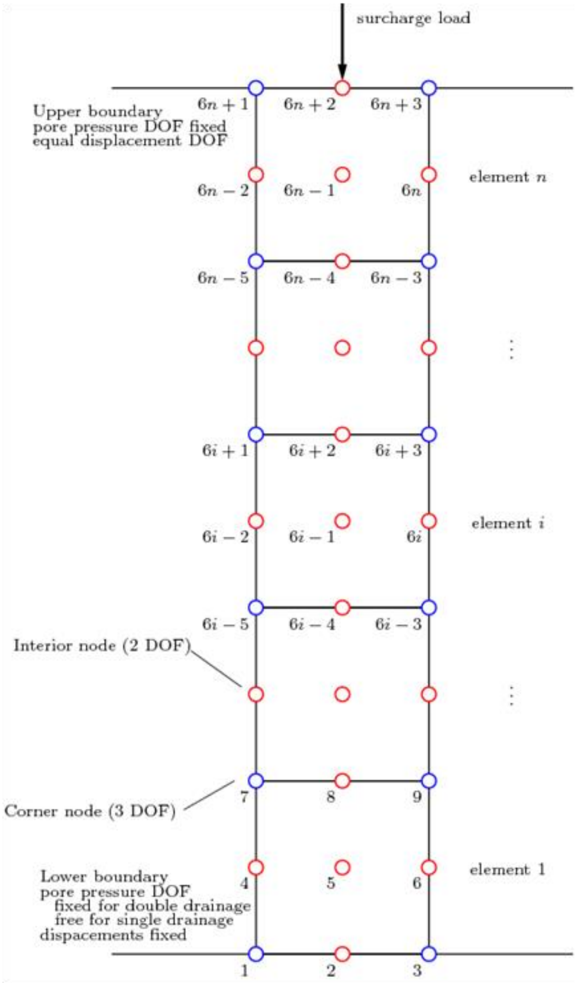
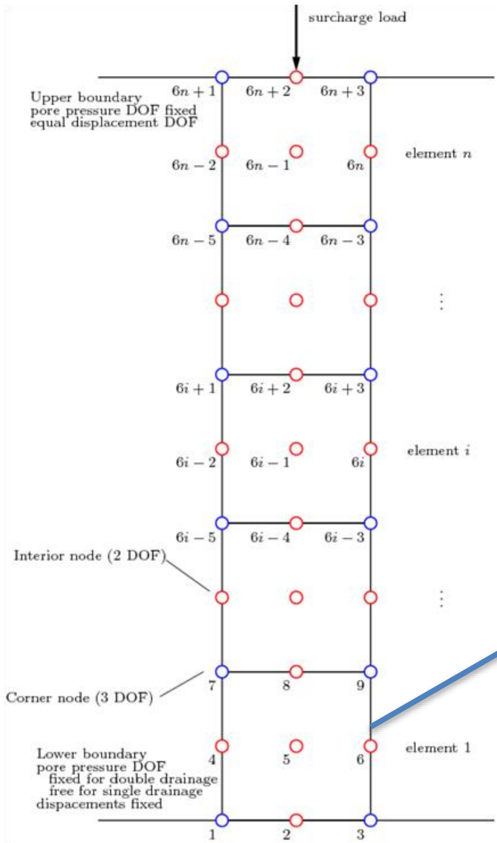


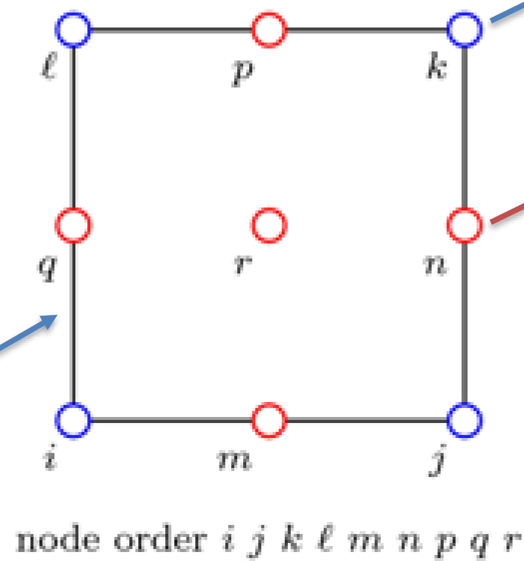
Fig. 30 Generation of a model soil column in OpenSees.

- Definition of meshing
- Geometry of the column
- Support Bedrock
- Definition of the elements
  - Outside nodes
  - Interior nodes
  - Element material
- Static analysis
- Dynamic analysis

Example prepared by: Christopher McGann and Pedro Arduino, University of Washington

❑ Meshing





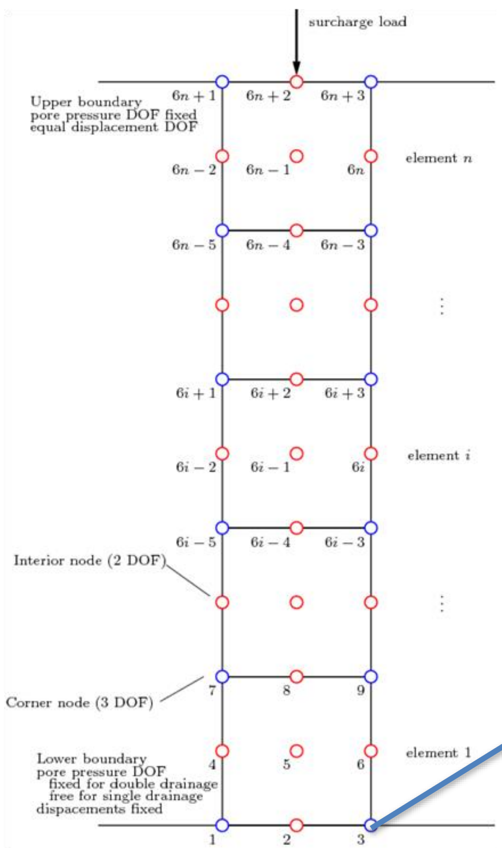
3 DOF
2 Translational
1 Pore pressure

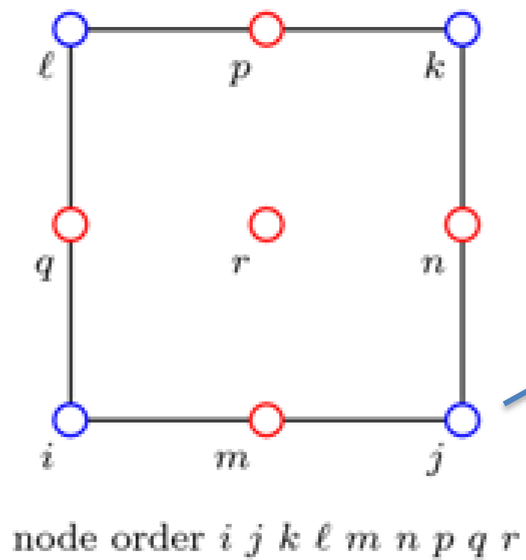
2 DOF
2 Translational

9_4_QuadUP

Model soil column in OpenSees.

❑ Boundary conditions

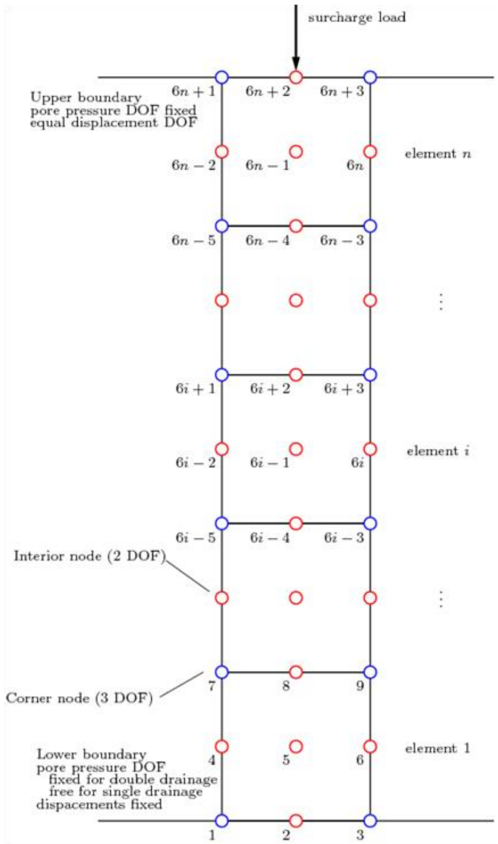




- fixed against vertical translation
- fixed in the pore pressure pore in pressure nodes above the groundwater

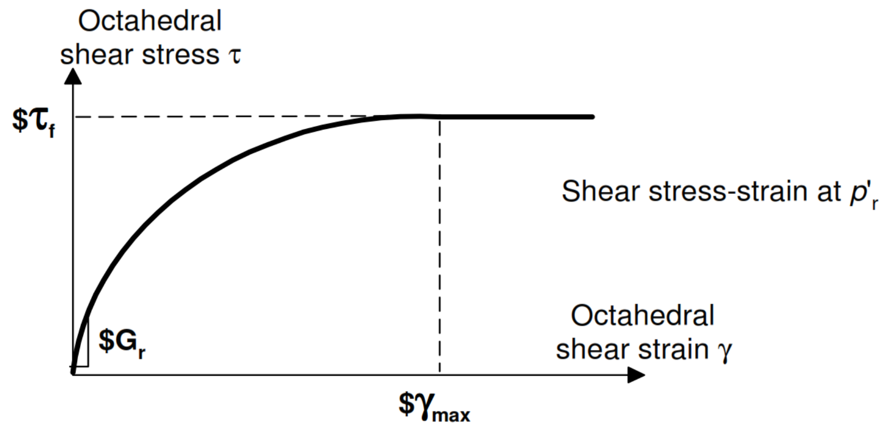
Model soil column in OpenSees.

❑ Material and Element Definitions



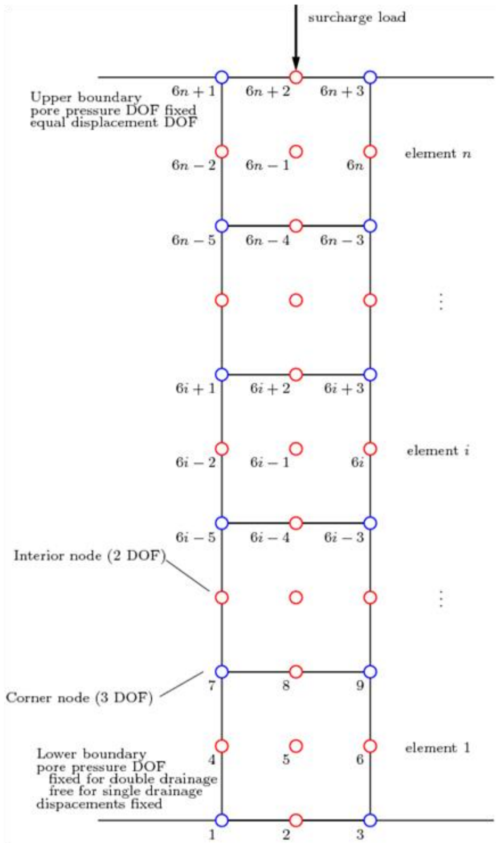
Model soil column in OpenSees.

```
nDMaterial PressureDependMultiYield02 $tag $nd $rho $refShearModul
        $refBulkModul $frictionAng $peakShearStra $refPress
        $pressDependCoe $PTAng $contrac1 $contrac3 $dilat1 $dilat3
        <$noYieldSurf=20 <$r1 $Gs1 …> $contrac2=5. $dilat2=3.
        $liquefac1=1. $liquefac2=0. $e=0.6 $cs1=0.9 $cs2=0.02 $cs3=0.7
        $pa=101>
```



Software development

❑ Recorders and Analysis



Model soil column in OpenSees.

Analysis Gravitation

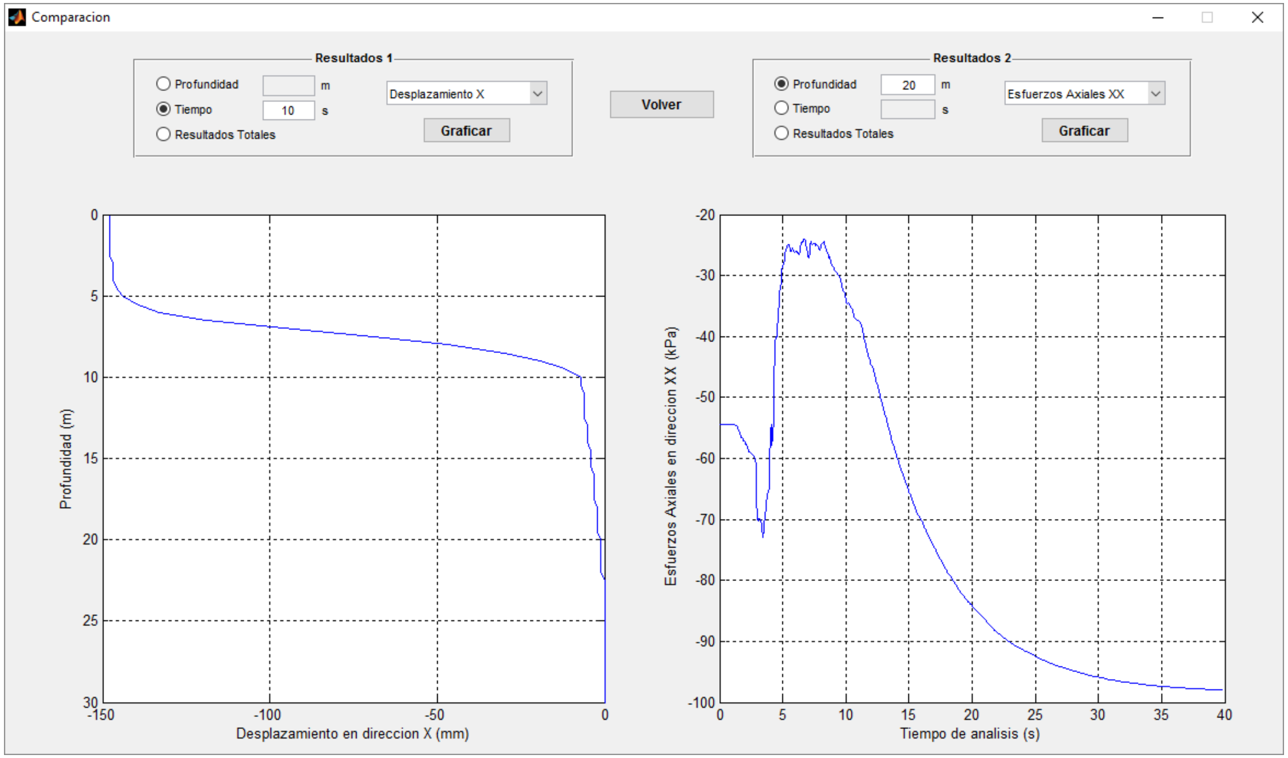
Analysis Dynamic

- Acceleration X y Y
- Displacement X y Y
- PorePressure
- Strain

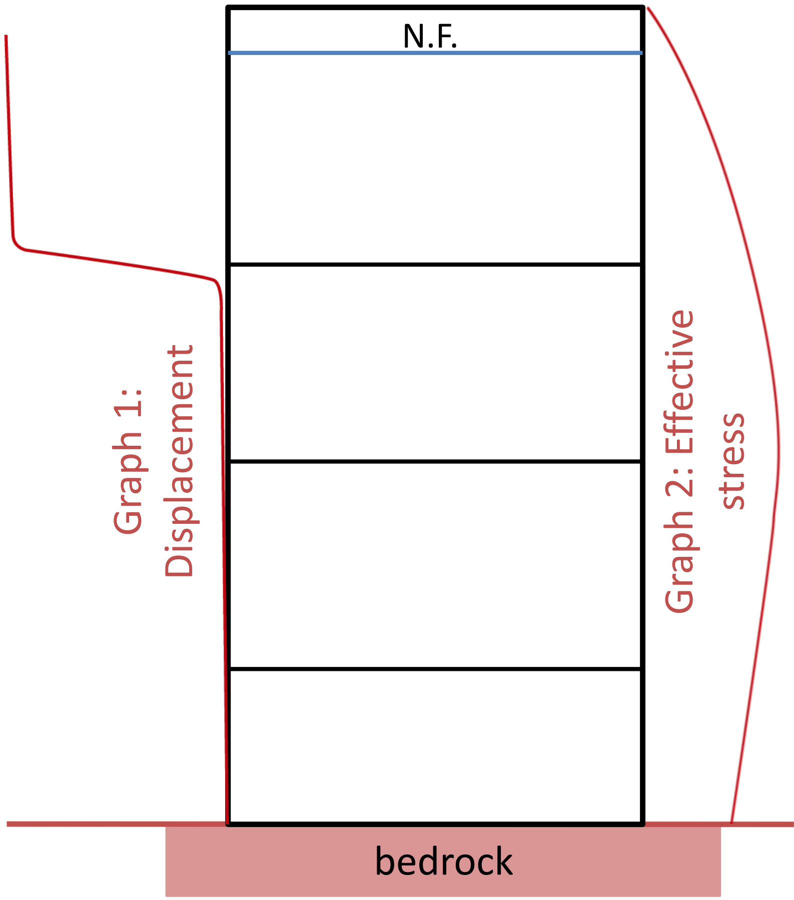
Software development

❑ Post-process

Comparison



Soil column model

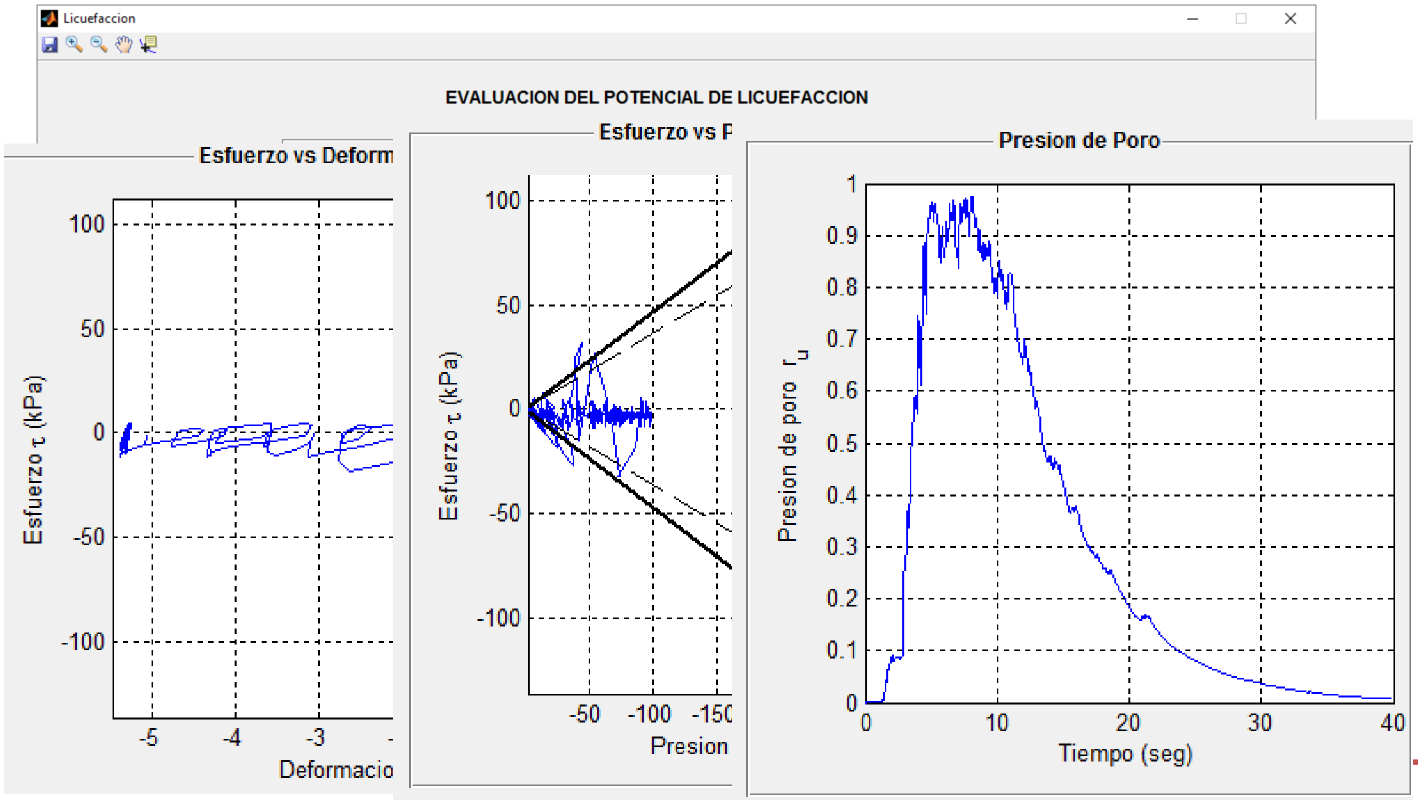


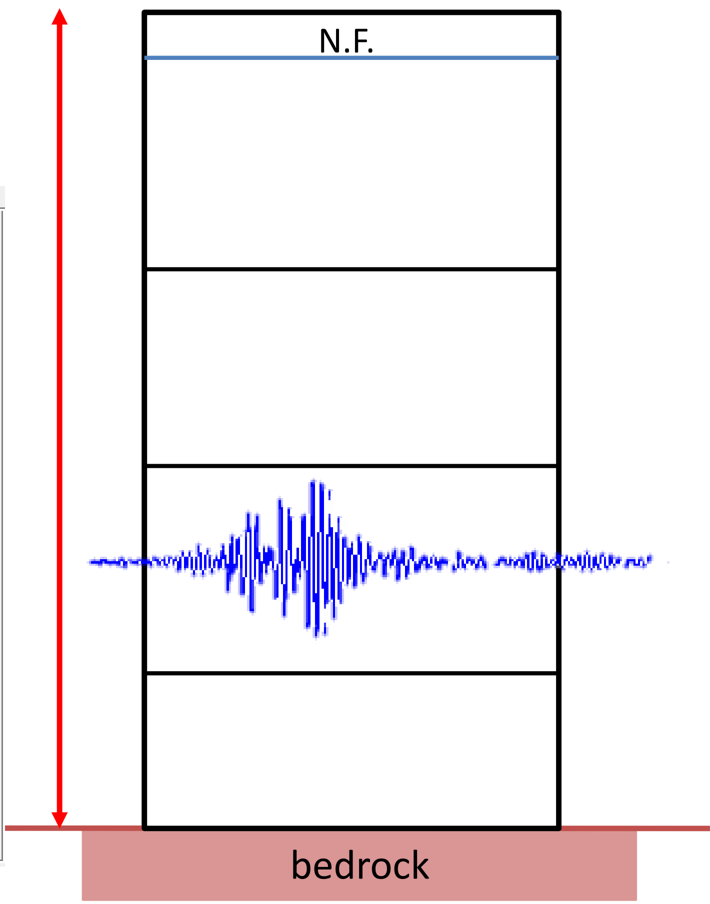
Software development

❑ Post-process

Comparison

Soil column model





Stress vs Deformation

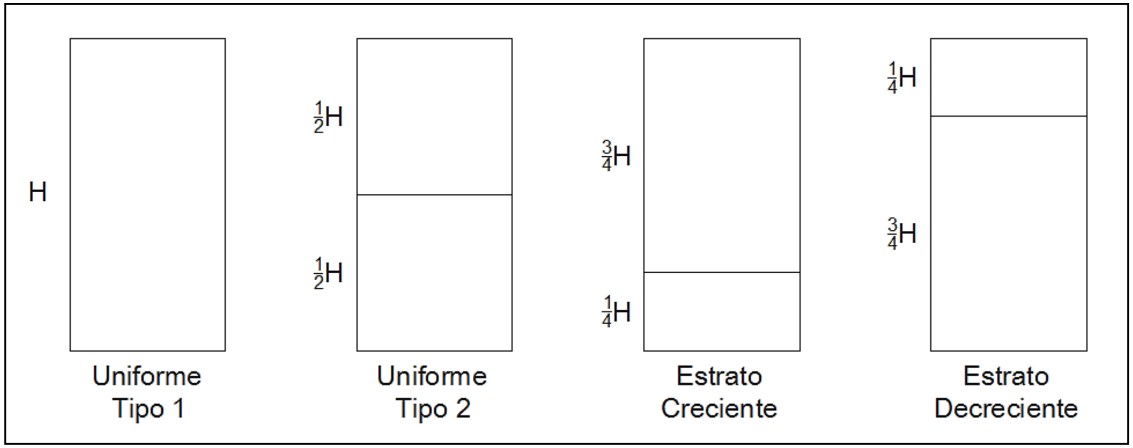
Stress vs. Effective Pressure

Excess pore pressure

Numerical modeling

❑ Definición de escenarios para análisis numérico

- **Height:** 15m 30m 60m
- **Layers:**

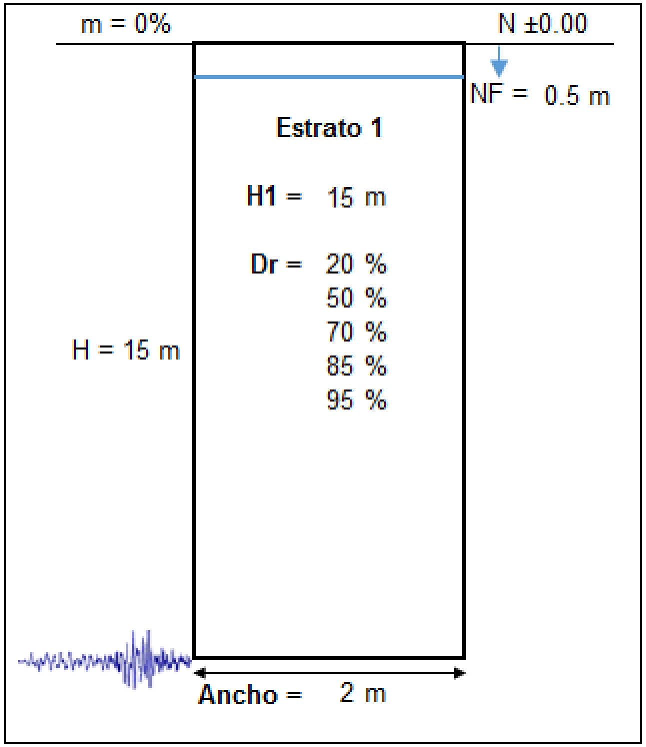


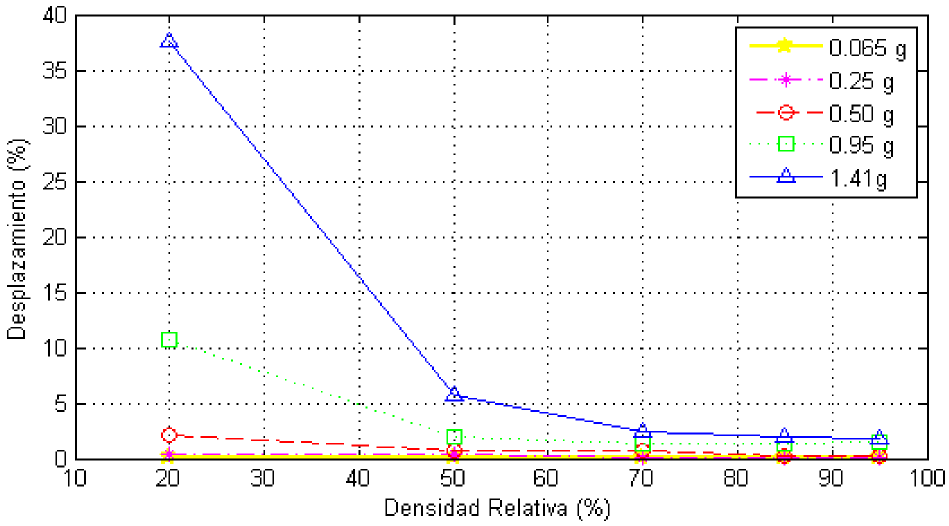
- **Water table:** 0H ¼ H ½ H 1H
- **Seismic load:** 0,065 g 0,25 g 0,50g 0,95 g 1,41g
- **Width:** 2m
- **Slope:** 0%

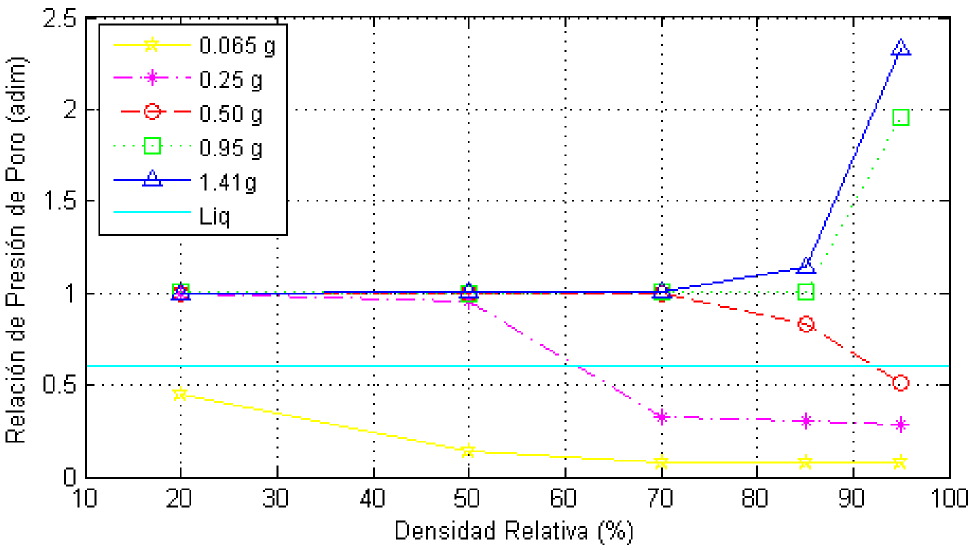
Numerical modeling

- Results of the numerical models for the analysis of soil liquefaction.

Scenario 1



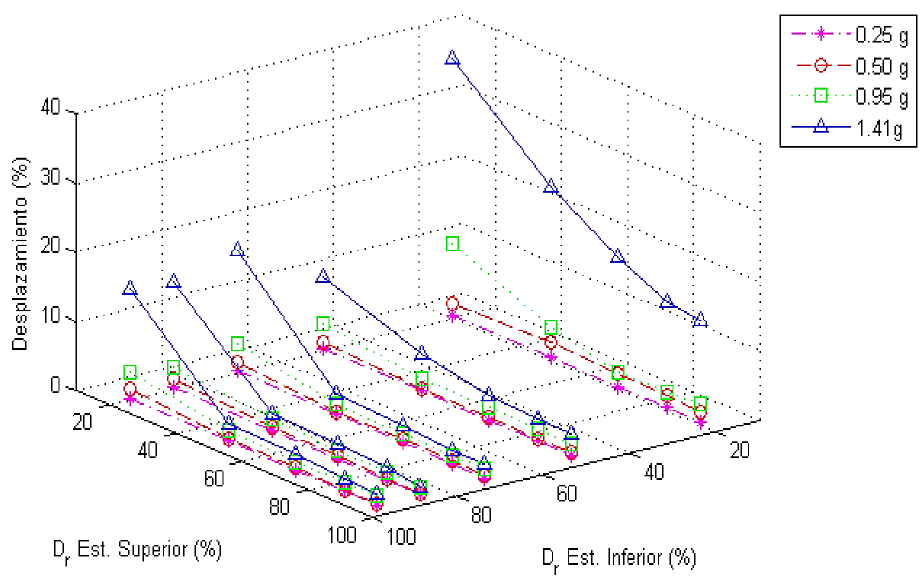




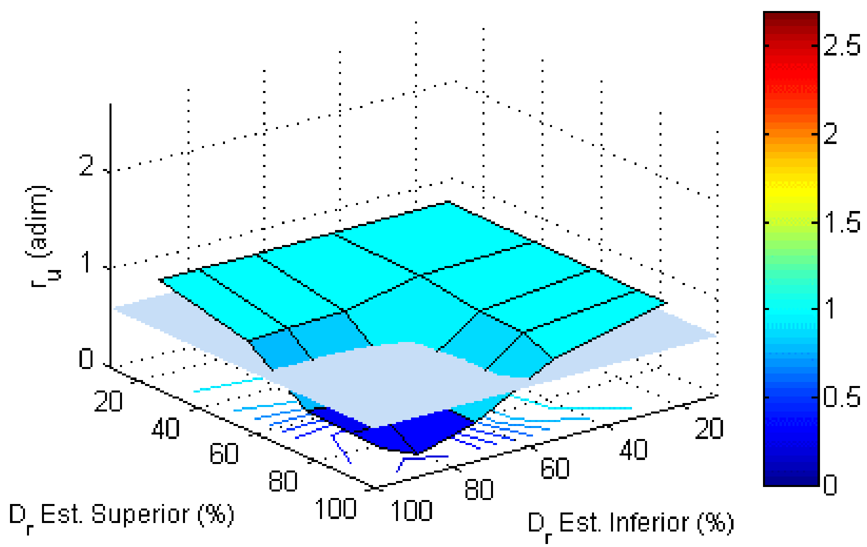
Numerical modeling

- Results of the numerical models for the analysis of soil liquefaction.

Representation of graphs from scenario 2



Graphs of displacement in function of the height of the column of floor

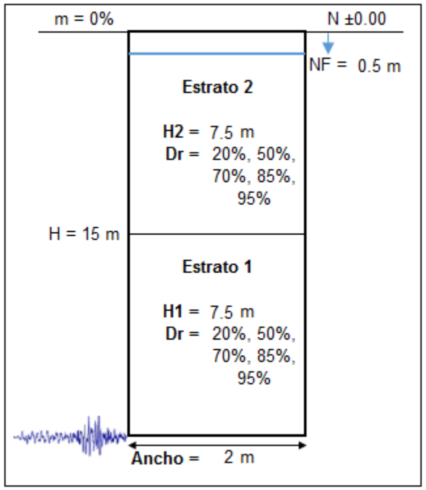


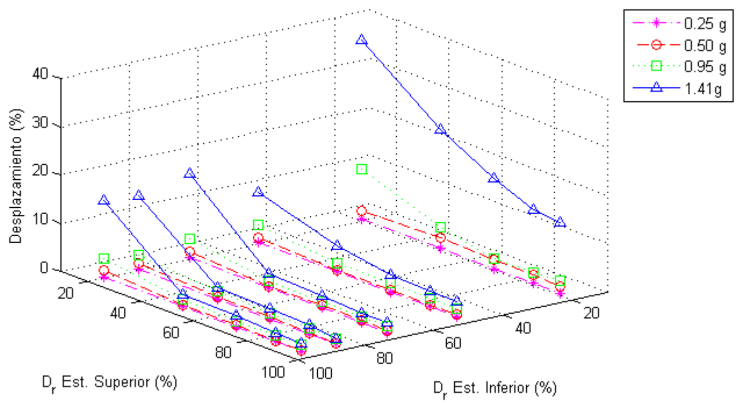
Pore pressure graphs

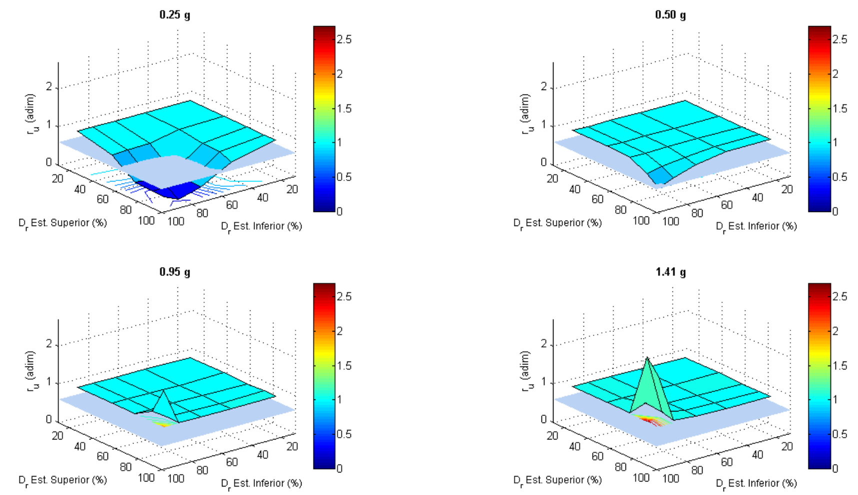
Influence of Soil Stratification

Numerical modeling

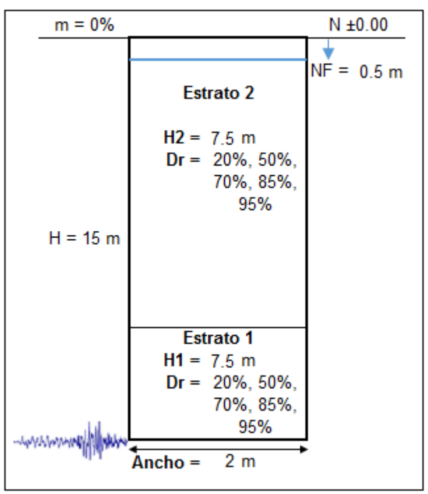
Scenario 2

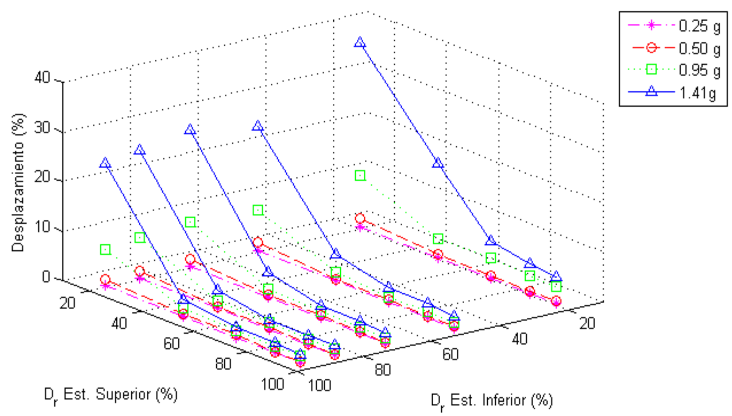


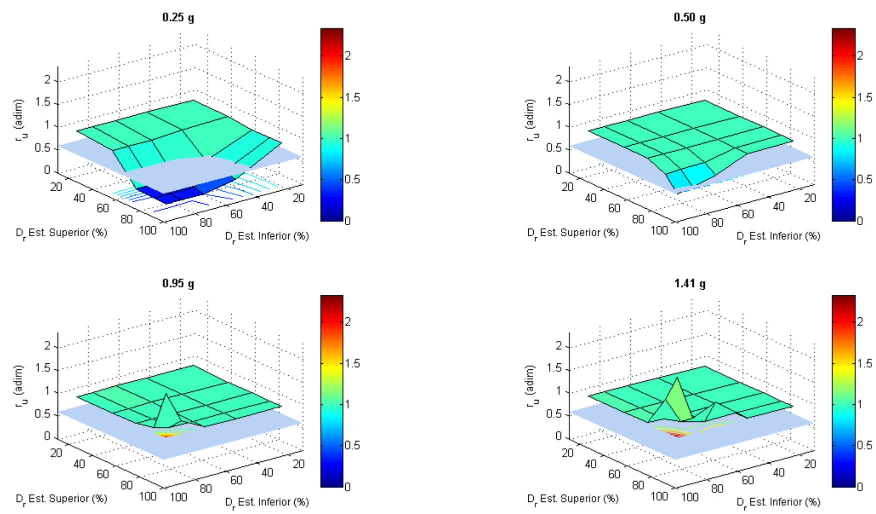




Scenario 6



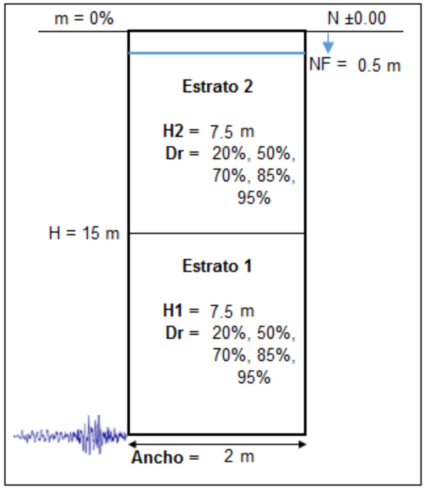


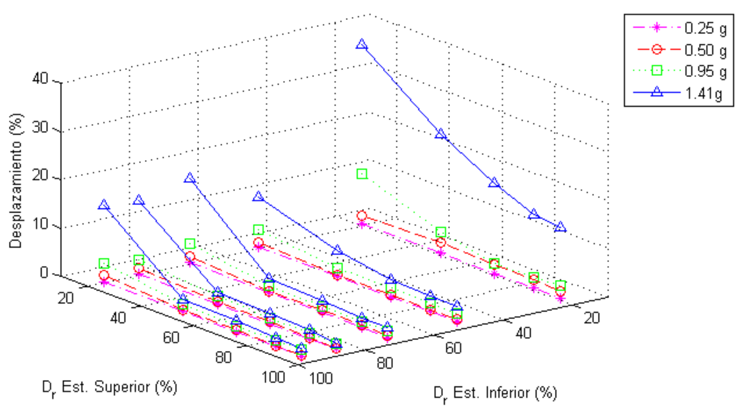


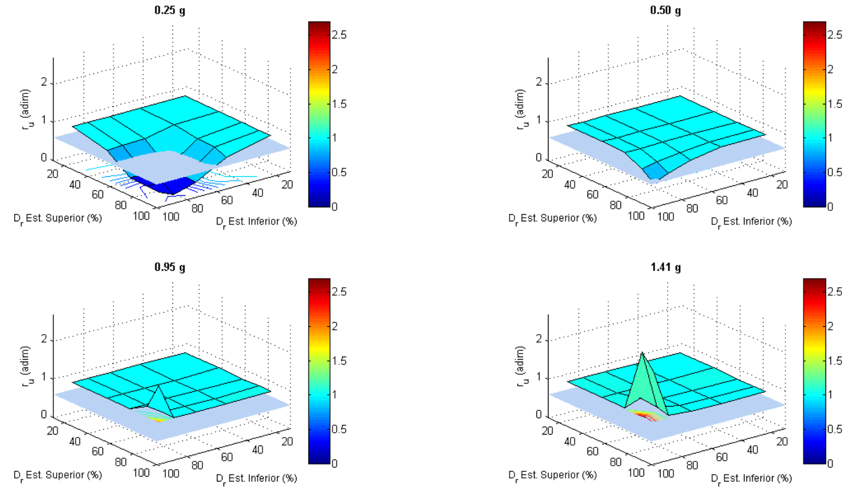
Similar conditions: Height (15m) and NF (0H)

Different conditions: Stratification

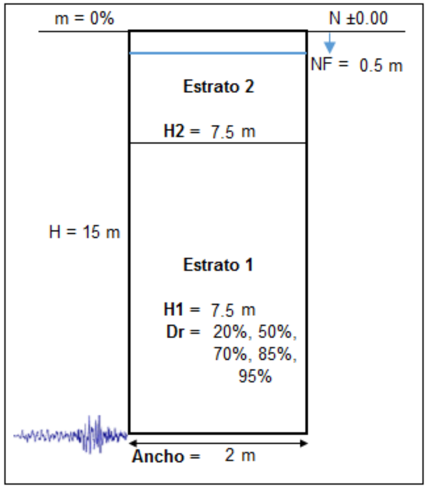
Scenario 2

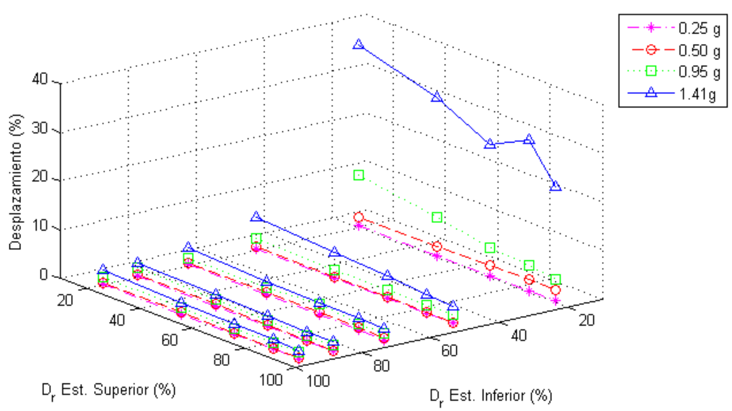


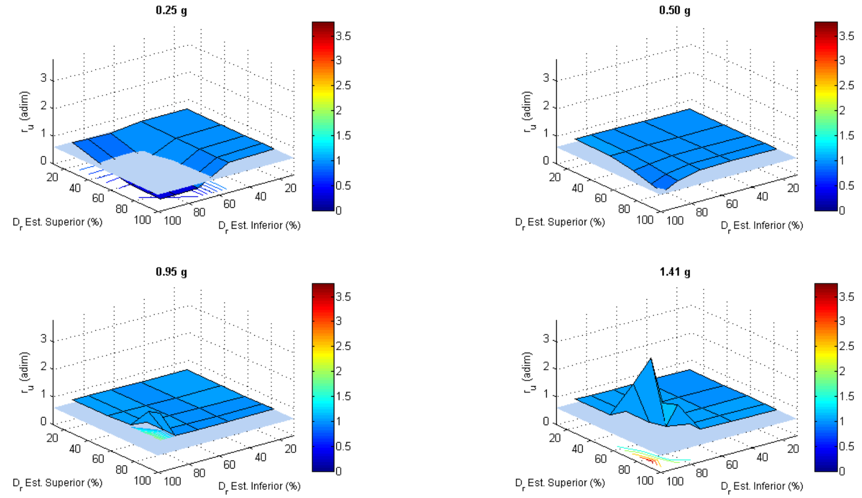




Scenario 9







Similar conditions: Height (15m) and NF (0H) **Different conditions:** Stratification

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Influence of Soil Stratification and Water Level

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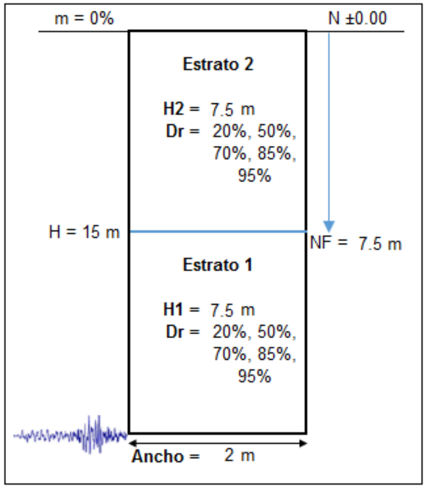
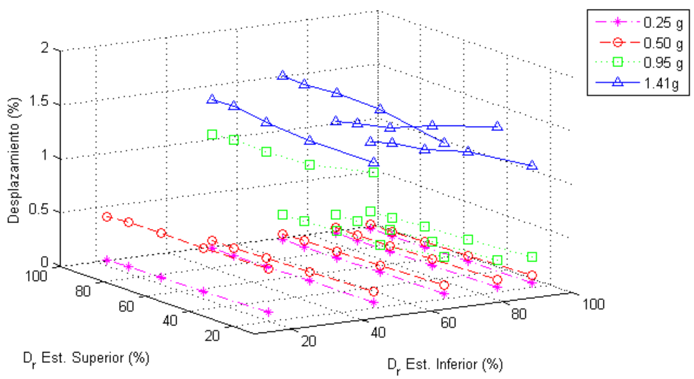
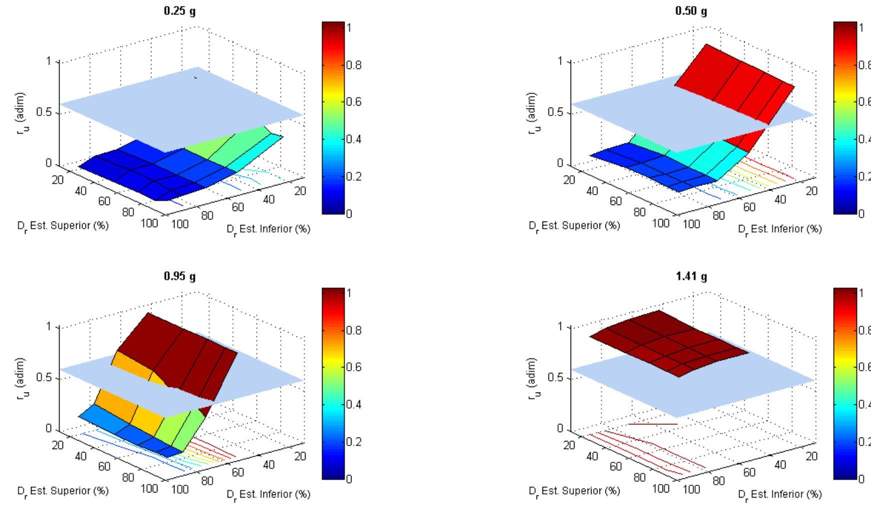
Numerical modeling

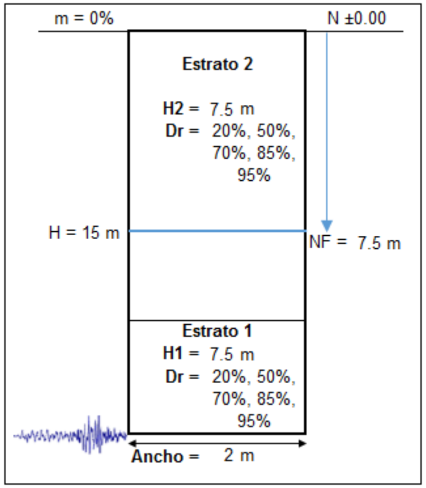
Scenario 4

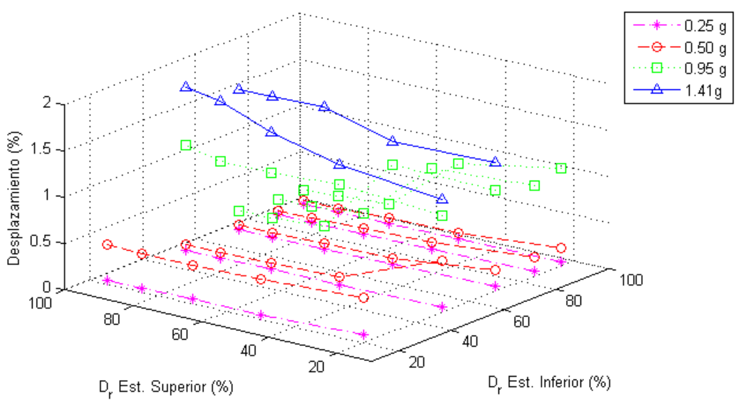


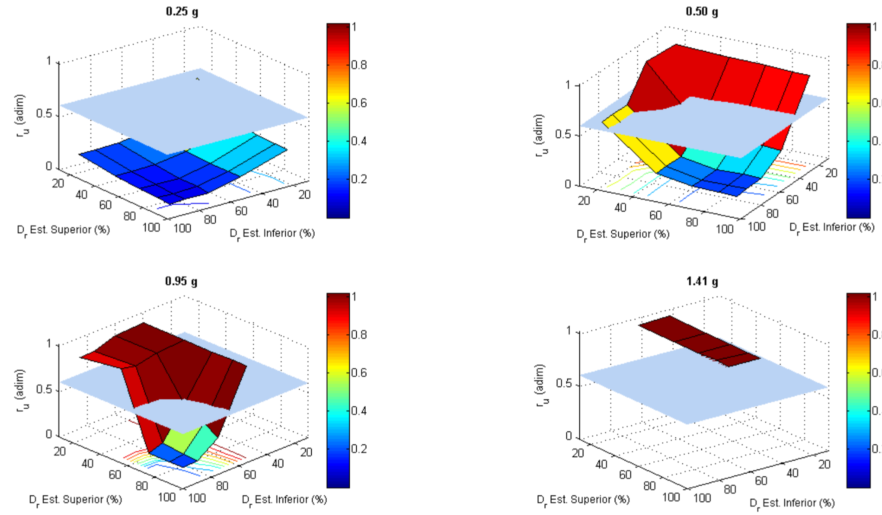




Scenario 8







Similar conditions: Height (15m) and NF (0H) **Different conditions:** Stratification

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Influence of the Water Level

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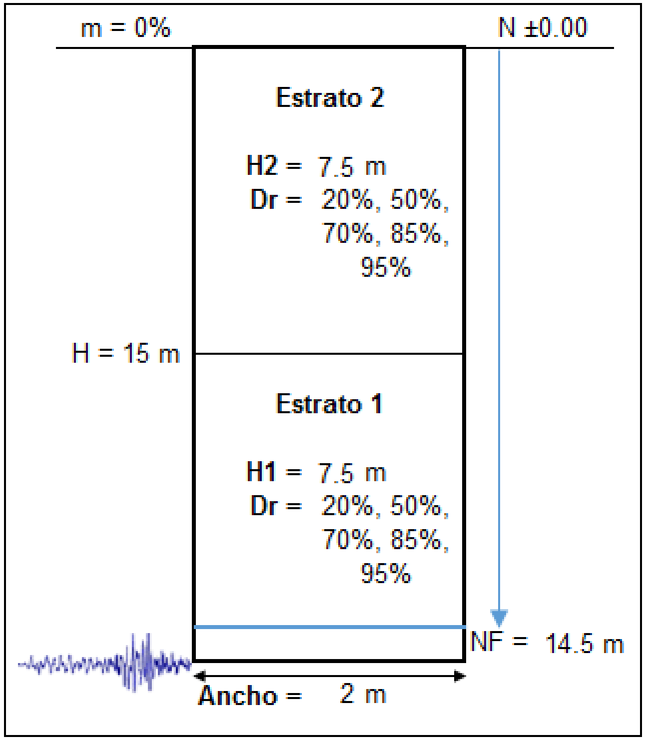
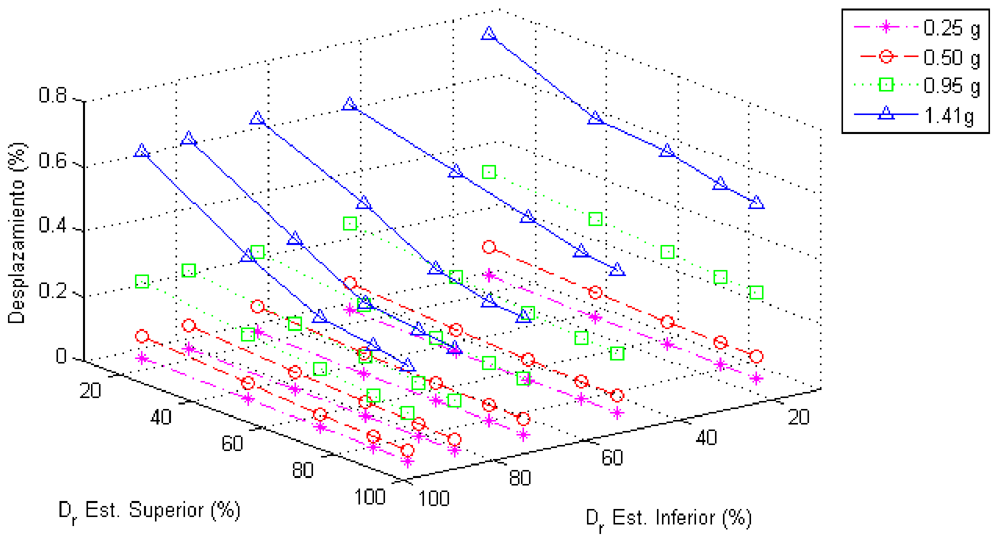
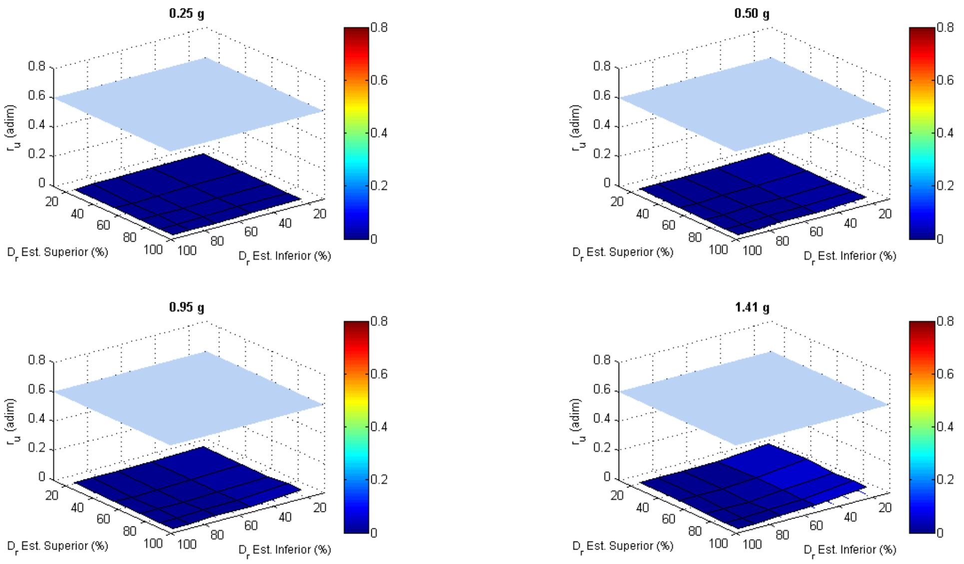
Scenario 4


m = 0%
N ±0.00
Estrato 2
H2 = 7.5 m
Dr = 20%, 50%, 70%, 85%, 95%
H = 15 m
Estrato 1
H1 = 7.5 m
Dr = 20%, 50%, 70%, 85%, 95%
NF = 14.5 m
Ancho = 2 m

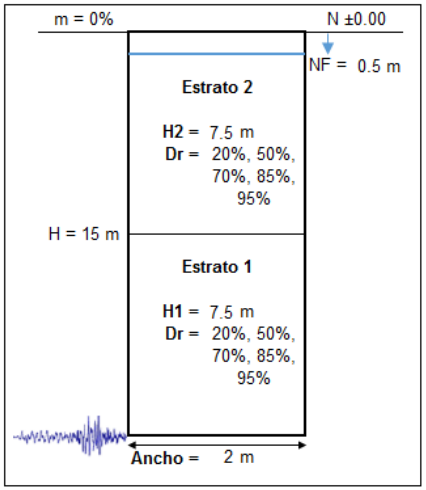

0.25 g
0.50 g
0.95 g
1.41g
Desplazamiento (%)
D_r Est. Superior (%)
D_r Est. Inferior (%)

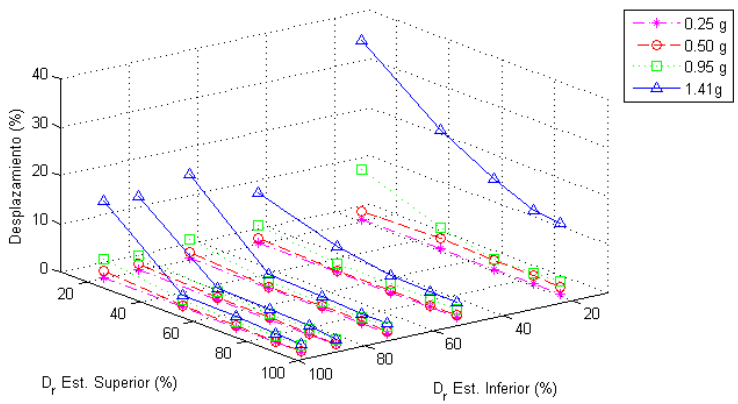

0.25 g
0.50 g
0.95 g
1.41 g
r_u (adim)
D_r Est. Superior (%)
D_r Est. Inferior (%)

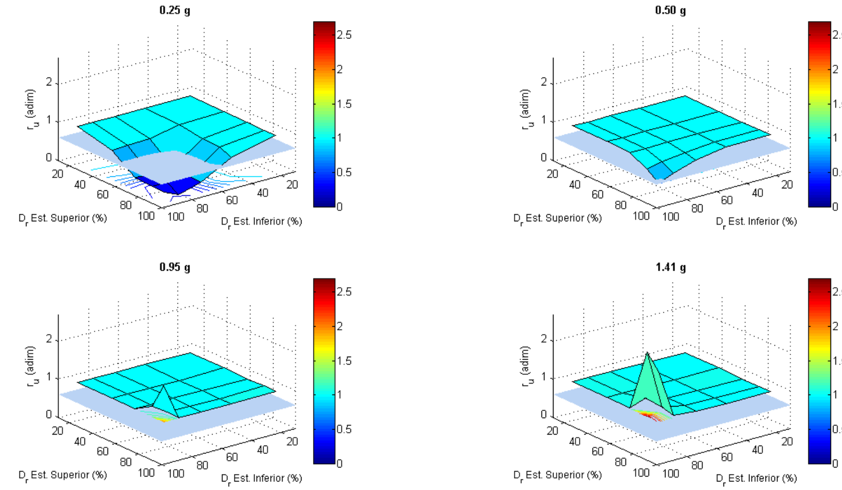
Influence of Height of the floor column

Numerical modeling

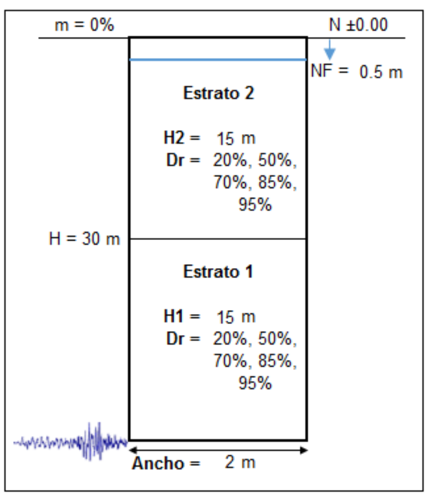
Scenario 2

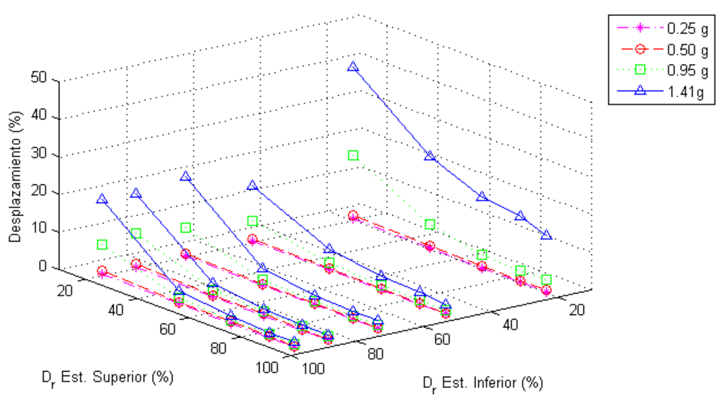


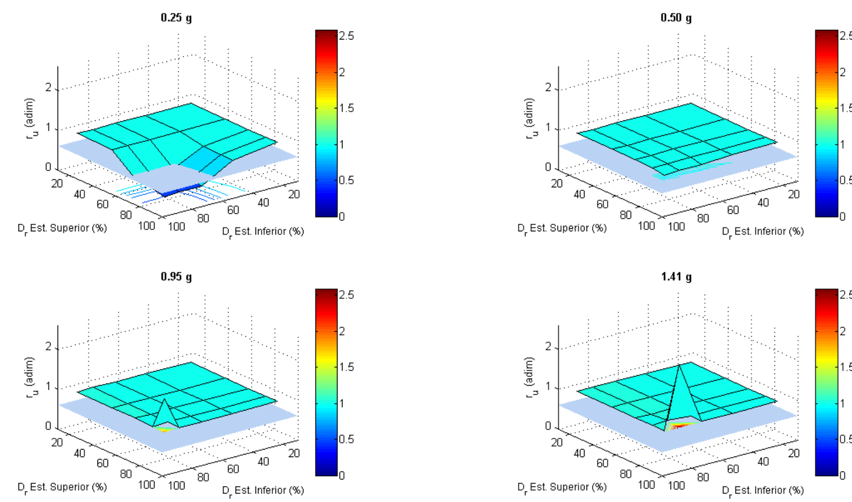




Scenario 10



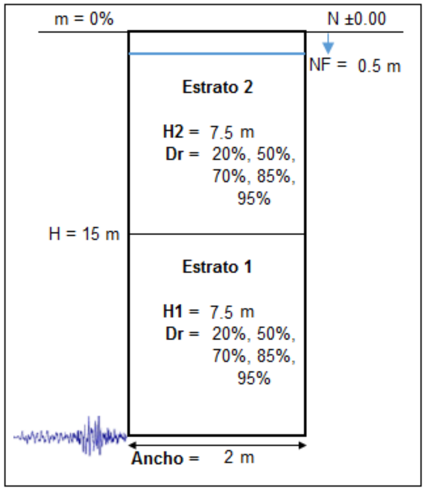


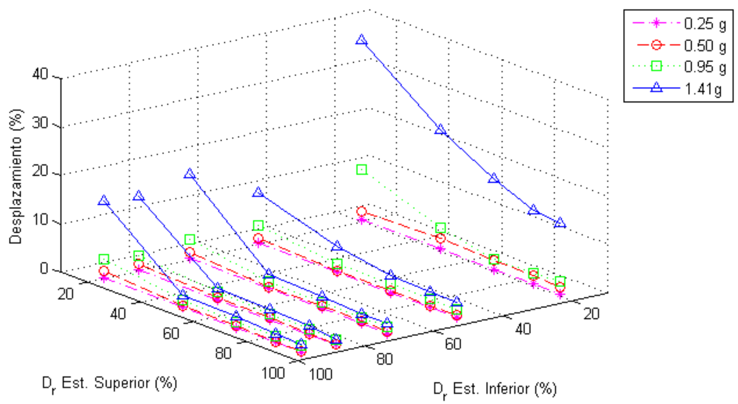


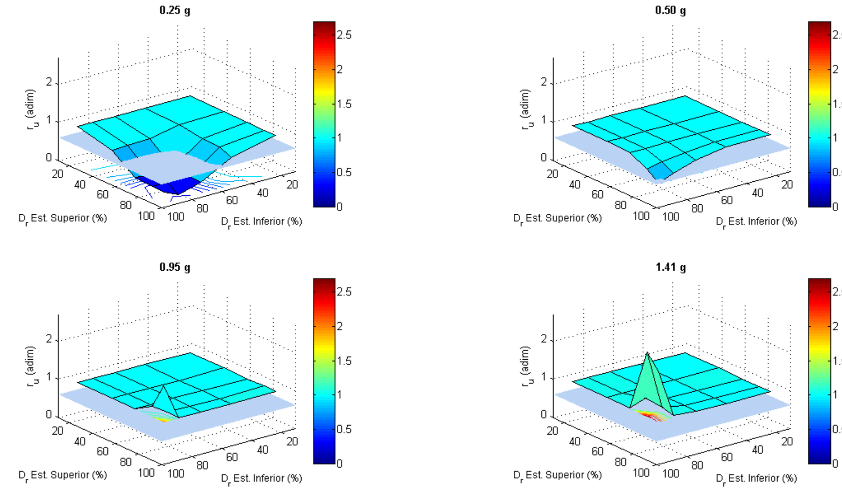
Similar conditions: Height (15m) and NF (0H) **Different conditions:** Stratification

Numerical modeling

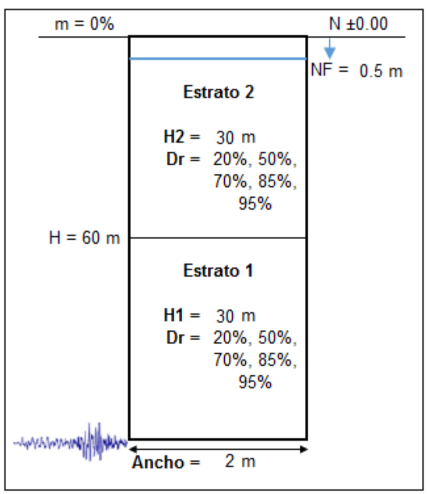
Scenario 2

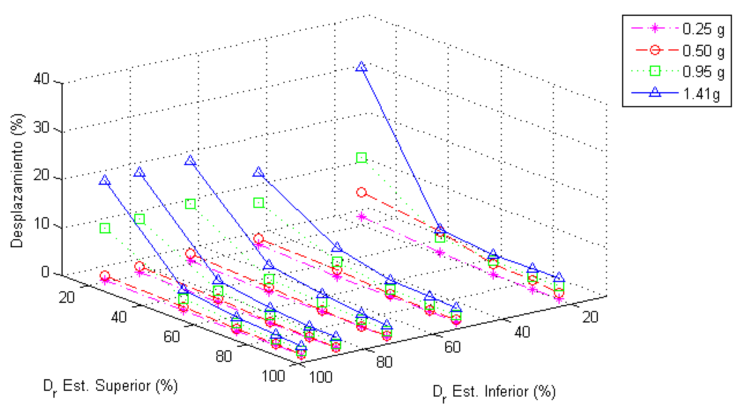


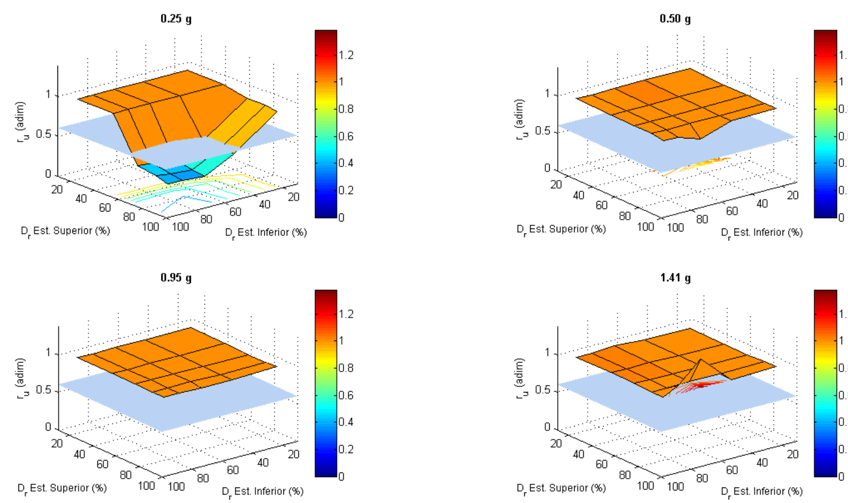




Scenario 13







Similar conditions: Height (15m) and NF (0H) **Different conditions:** Stratification

CONCLUSIONS

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Conclusions

- A computer tool has been created to analyze the phenomenon of soil liquefaction using OpenSees software, which simulates a soil column in two dimensions with the application of a seismic load acting on a base.

- The use of the computer tool for the modeling of different scenarios has allowed to verify certain theoretical foundations on the occurrence of soil liquefaction.

- It was found that the location of the water table is the variable with the highest incidence in the activation of liquefaction.

- It could be inferred that the phenomenon of liquefaction in a soil column is activated for certain intensities of earthquake, in dense soils (Dr> 85%) intensities close to 1g are required, and in shallow soils (Dr <50), intensities from 0.25 g they produce liquefaction.

Conclusions

- The height of the soil column has no significant influence on the manifestation of the soil liquefaction phenomenon when the conditions of seismic load intensities, relative densities and soil stratification are the same.

- The potential of liquefaction of soils did not show significant variations due to stratigraphy as long as the height of the soil column and the water table remain constant.

Gracias

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