Research in progress concerning the seismic vulnerability

Liquefaction induced damage in earthquake loss estimation

V Encuentro Ingenieros de Suelos y Estructuras ESCUELA COLOMBIANA DE INGENIERÍA JULIO GARAVITO -7-9.05.2009 Research in progress concerning the seismic vulnerability

> Fernando LOPEZ-CABALLERO



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SSI analyses

Structural model Structural response Reliability analyses

Vulnerability reduction Soil inclusions Reliability analyses

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Seismic vulnerability : susceptibility of a building to undergo of the damage during a seismic movement.

Vulnerable conventional houses ¹:





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¹[Okazaki, 2006]

 Need for understanding mechanisms controlling liquefaction induced damage in earthquake loss estimation; Research in progress concerning the seismic vulnerability

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- Need for understanding mechanisms controlling liquefaction induced damage in earthquake loss estimation;
- Improve and validate traditional approaches and evaluation methods of the seismic vulnerability of structures;

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- Need for understanding mechanisms controlling liquefaction induced damage in earthquake loss estimation;
- Improve and validate traditional approaches and evaluation methods of the seismic vulnerability of structures;
- 3 Several non linear phenomena :
 - · Soil behaviour,
 - Building damages,
 - · Soil-Structure interaction,
 - Soil Foundation interface,
 - ...

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- Need for understanding mechanisms controlling liquefaction induced damage in earthquake loss estimation;
- Improve and validate traditional approaches and evaluation methods of the seismic vulnerability of structures;
- 3 Several non linear phenomena :
 - · Soil behaviour,
 - · Building damages,
 - · Soil-Structure interaction,
 - Soil Foundation interface,
 - ...
- Use of numerical methods in order to facilitate the comprehension of the global problem via parametric analyses.

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UMR 8579



Incremental lateral loading (static), Fixed base condition

Vulnerability reduction Soil inclusions

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Including of SSI effects

6.0m

ISS-FF

problem

Proposed approaches [Saez, 2009] :

 $a_{out}(t)$

Outcropping

Deconvolution

Bedrock

0

 $a_{bed}(t)$

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 $a_{ff}(t)$

Fixed base

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Reference case³:



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³[Lopez-Caballero and Modaressi-Farahmand-Razavi, 2008]

GEFDYN - ECP's numerical tool

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The ECP's elastoplastic multi-mechanism model, "*Hujeux*" model. ⁴

- · The model is written in terms of effective stress,
- Coulomb type failure criterion,
- Critical state concept,
- Progressive friction mobilization with shear,
- Roscoe's dilatancy law,
- Isotropic yield surface.

⁴[Aubry et al. 1982, Hujeux, 1985, Aubry and Modaressi, 1996]

Laboratory test simulation

Saturated sand :



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Laboratory test simulation

Saturated sand :



Simulated sand model liquefaction curves

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Response spectra of input earthquake motions (outcropping) :



Generated by a non-stationary stochastic simulation ⁵

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Liquefaction profile :



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Definition of liquefied layer thickness :



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Fragility values and functions for liquefaction thickness :



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Ground response analysis :



PGA - a_{max out} - Monte-Carlo simulations

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Response spectra at FF surface :



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Response spectra at FF surface :





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SDOF Capacity Curve :



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Co-seismic uniform structural settlement :



Liquefaction index $Q_{H=16m}$ - $\left(Q = \frac{1}{H} \int_{0}^{H} \frac{\Delta \rho_{W}(t,z)}{\sigma'_{VO}(z)} dz\right)$

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Global seismic response of structure :



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Soil mitigation method

Effect on liquefaction :



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Soil mitigation - Rigid inclusions

Performance assessment :



Ductility Ratio $\Delta \mu$ and Liquefaction index ΔQ

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- Ghizlane Benosman (Ph.D student ECP) ;
- Fabian Bonilla (IRSN).

References

Aubry, D., Hujeux, J.-C., Lassoudière, F., Meimon, Y., 1982. A double memory model with multiple mechanisms for cyclic soil behaviour. In: Int. Symp. Num. Mod. Geomech. Balkema, pp. 3–13.



Aubry, D., Modaressi, A., 1996. GEFDYN. Manuel scientifique, Ecole Centrale Paris, LMSS-Mat.



Hujeux, J.-C., 1985. Une loi de comportement pour le chargement cyclique des sols. In: Génie Parasismique. V. Davidovici, Presses ENPC, France, pp. 278–302.



Lopez-Caballero, F., Modaressi-Farahmand-Razavi, A., 2008. Numerical simulation of liquefaction effects on seismic SSI. Soil Dynamics and Earthquake Engineering 28 (2), 85–98.



Okazaki, K., 2006. New strategy for earthquake risk management - How to motivate people for safety. First European Conference on Earthquake Engineering and Seismology. Geneva, Switzerland.



Pousse, G., Bonilla, F., Cotton, F. and Margerin, L., 2006. Non stationary stochastic simulation of strong ground motion time histories including natural variability: Application to the K-net Japanese database. Bulletin of the Seismological Society of America 96 (6), 2103–2117.



Saez, E., 2009. Dynamic non-linear Soil-Structure Interaction, PhD Thesis, École Centrale Paris, France.

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