Effects of local site conditions on the inelastic dynamic analysis of r/c bridges

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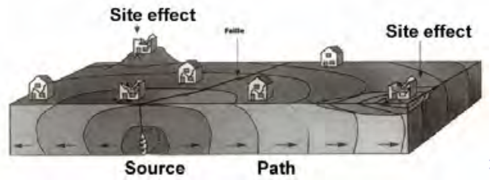
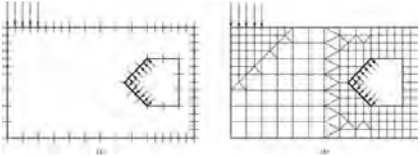
Site effects

- Geological irregularities of any kind produce local distortions in the incoming wave field. These distortions are generally called **site effects**.
- Spatial variation of seismic ground motions denotes the differences in amplitude and phase of seismic motions recorded over extended areas.
- Important effect on the response of lifelines such as bridges, pipelines, communication transmission systems, etc.

- ***Simplified assumptions in the bridge design***:
  (a) seismic motion transmitted to the structure through its supports is **identical** for all piers and abutments,
  (b) **local site conditions** are accounted for in terms of site categorization
- Seismic motions are influenced by:
  (a) wave propagation path
  (b) surface topography at the site of interest
- Local site conditions generate large amplifications as well as strong spatial variations in the seismic motions that must be accounted for in the earthquake resistant design of structures.

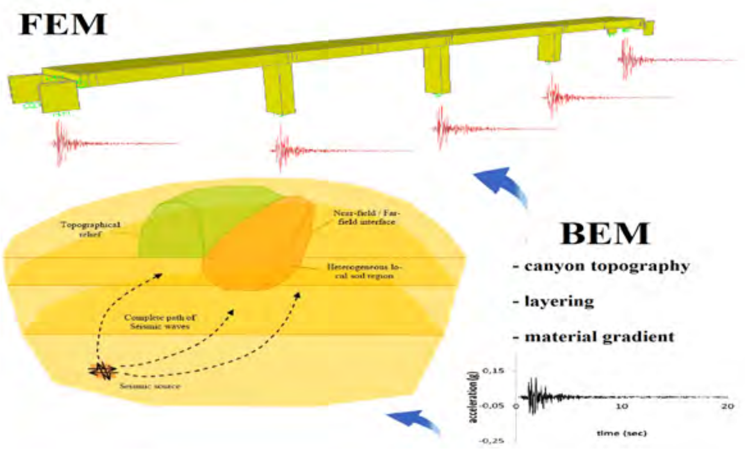


- Several past studies indicate that local site conditions can exert a crucial influence on the severity of structural damage (*Sextos et al.,2003, Pitilakis, 2004 and other*)
- Limitation : Such influence is evaluated using models based on 1D description of local soil profile and seismic wave propagation.
- Development of high-performance computational tools for simulation of 2D complex geological profiles.
- Boundary Element Method (BEM) : dealing with semi-infinite media with high accuracy and minimal modeling effort.



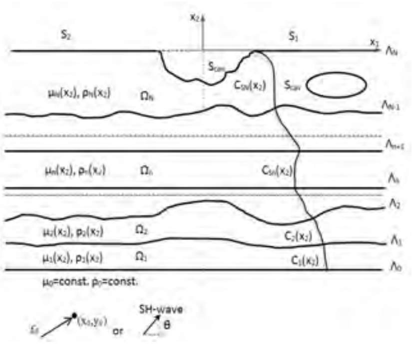
Objective

Investigate the effects of local soil conditions on inelastic dynamic analysis of r/c bridges.



Seismic signal recovering methodology

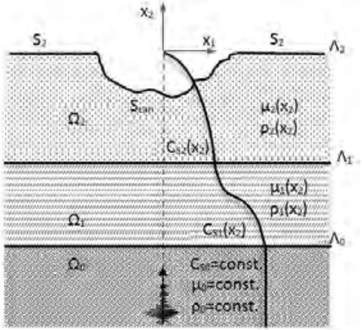
Boundary Element Method is used to model the seismic waves propagating through complex geological profiles so as to recover ground motion records that account for local site conditions.



- 2D wave propagation
- viscoelastic isotropic inhomogeneous half-plane
- consisting of parallel or non-parallel *inhomogeneous layers*
- free- or/and sub- surface relief of arbitrary shape
- incident SH wave or wave radiating from seismic source

Non-conventional BEM

BEM formulation based on Fundamental solution for ***continuously inhomogeneous media*** with *variable wave velocity profile* is applied.



Inhomogeneity: position-dependent shear modulus and density of arbitrary variation in terms of depth coordinate.

Inhomogeneity parameter:

$$c = C_s^{bottom} / C_s^{top}$$

The model is able to account for **wave dispersion phenomena** due to:

(i) viscoelastic material behaviour

(ii) position-dependent material properties

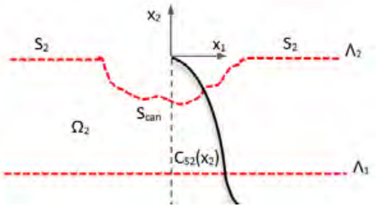
BEM formulation

non-conventional BEM based on new family of fundamental solutions

$$cu_3^{(i)}(x) = -\int_{S_{\Omega_i}} P_3^{*(i)}(x,\xi)u_3^{(i)}(\xi)dS_{\Omega_i} + \int_{S_1} U_3^{*(i)}(x,\xi)t_3^{(i)}(\xi)dS_{\Omega_i}$$

x and ξ position vectors of source and field points, c: jump term
${g_3}^*$ and ${t_3}^{g*}$: displacement and traction Fundamental solution for geol.media with velocity gradient (Manolis and Shaw, 1996a,b; Karakostas and Manolis, 1997)

Discretization area: layer interfaces and free- and sub-surface relief using constant boundary elements following numerical algorithms (Wuttke et al, 2014)



BEM formulation

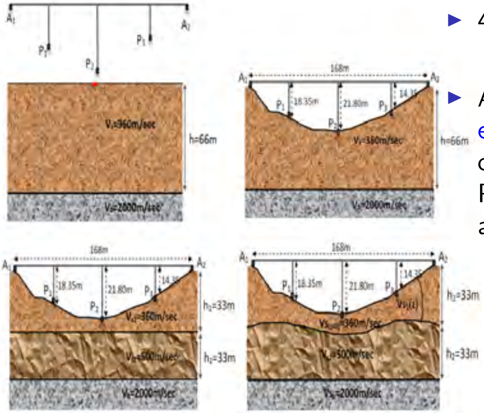
- After discretization of all boundaries the matrix equation system is formed:

  $$[\mathbf{G}]\{\mathbf{t}\}-[\mathbf{H}]\{\mathbf{u}\}=\{\mathbf{0}\}$$

- The BEM numerical implementation is programmed using **Matlab**

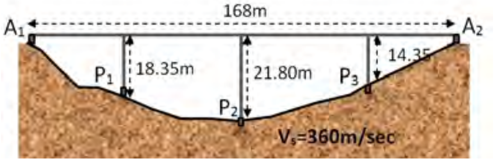
- Generation of **transient seismic signals** from the derived time-harmonic displacements is achieved using inverse Fourier transformation (IFT).

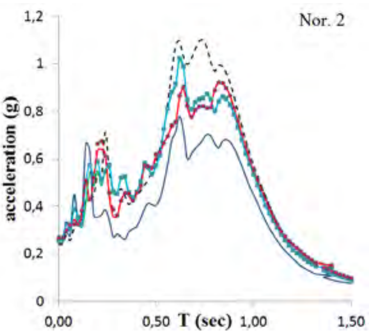
Geological profiles

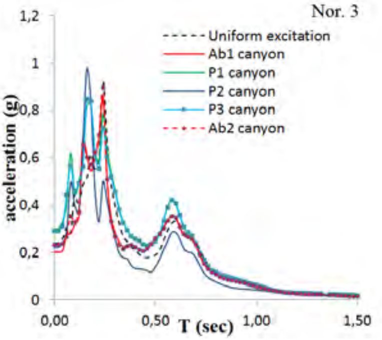


- 4 different geological profiles
- A suite of 7 earthquake excitations recorded at the outcropping rock from the PEER strong motion database are considered as an input

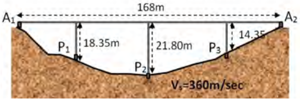
Canyon topography effect



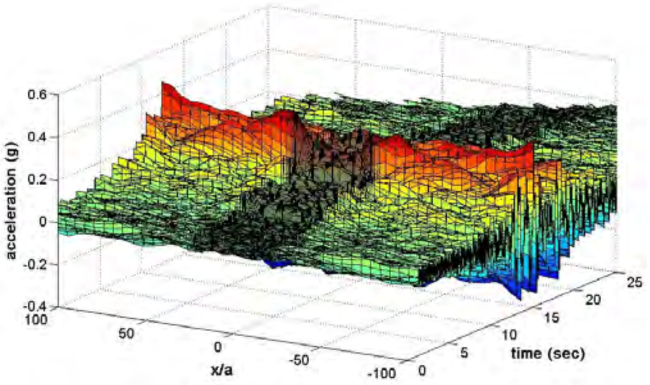




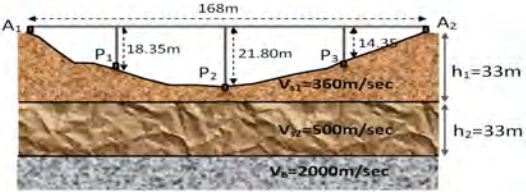
Canyon topography effect

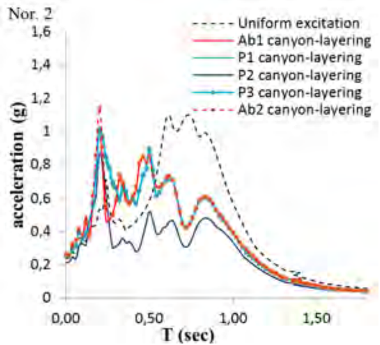


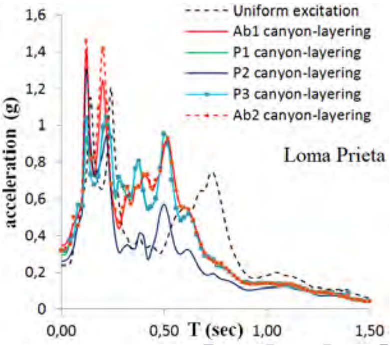
The seismic signal depends strongly on the canyon topographic effects



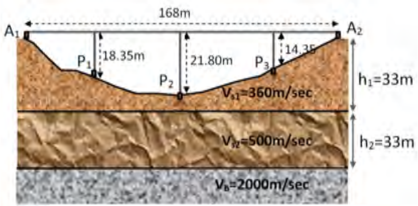
Canyon topography and layering effect



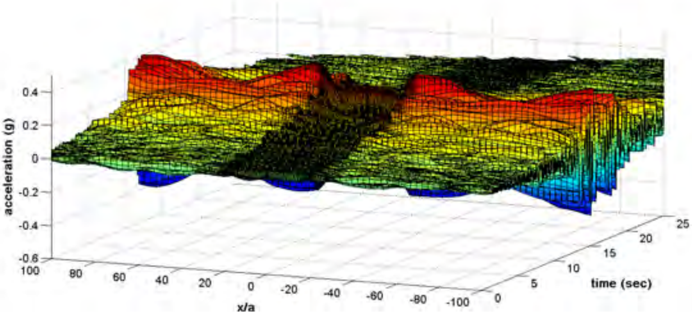




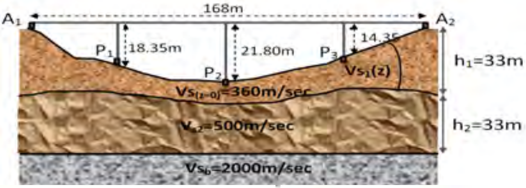
Canyon topography and layering effect

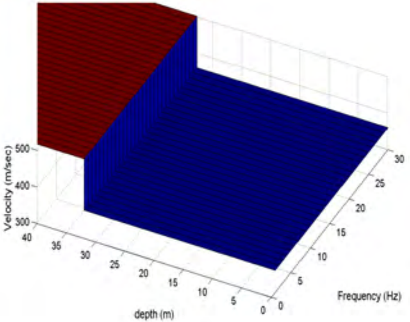


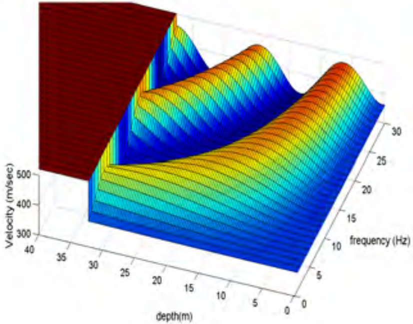
Peaks become smoother due to the increased stiffness of the bottom layer



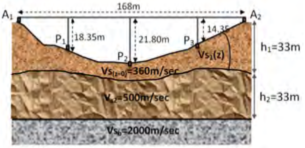
Canyon topography, layering and material gradient effect





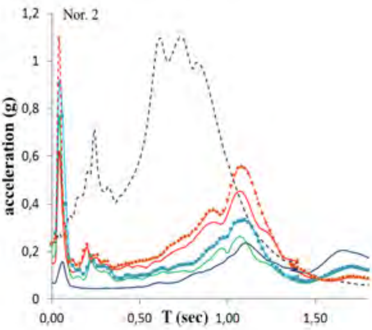


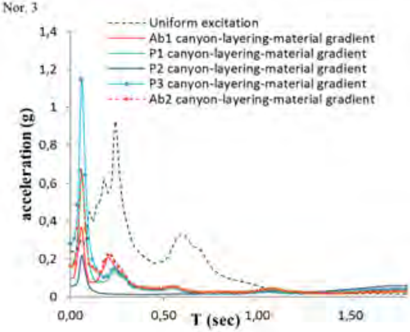
Canyon topography, layering and material gradient effects



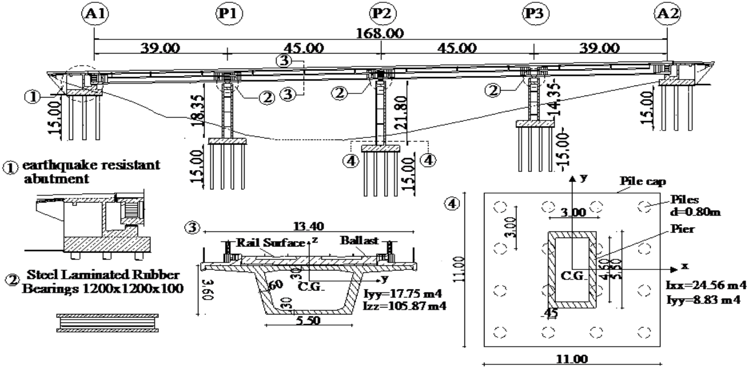
Material gradient: increase material stiffness gradually

Irregular interface: higher amplification



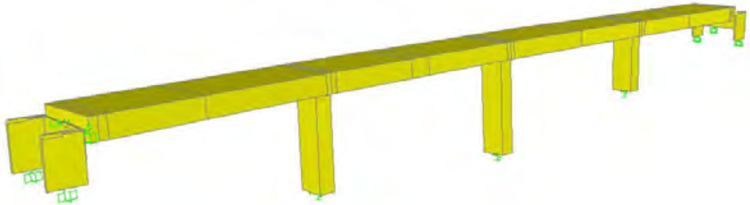


R/C Bridge

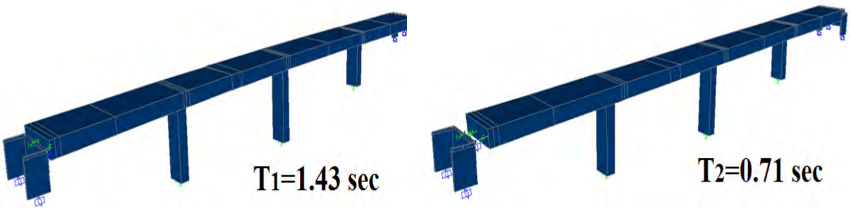


- OSE's railway bridge in Polycastro Greece
- Seismically isolated straight bridge with earthquake resistant abutment
- Elastic analysis and design according to EC8-Part 2

Bridge Modelling



- The bridge is modeled and analyzed using **SAP2000**
- Bearings are modeled by **N-link elements** (translational and rotational stiffness)
- Deck and Piers modelled by **Frame elements**
- Foundation flexibility is considered by six **Spring elements**
- **Gap elements** are used to model the 25mm openings at the expansion joints that separate the backwall from the deck



Nonlinear Time History Analyses are conducted under:

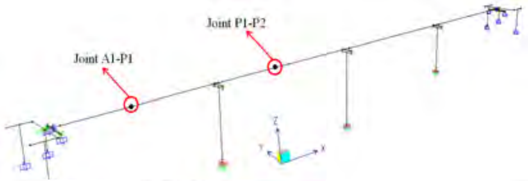
(i) suite of ground motions applied **uniformly** to all support points of the bridge

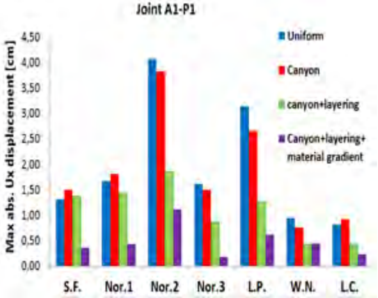
(ii) the same suite of site dependent ground motions; **different** for each support point accounting for:

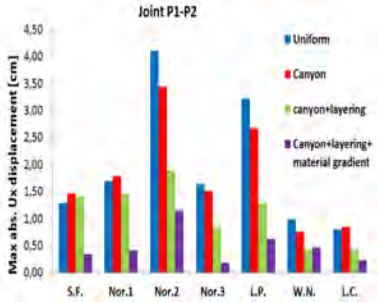
  (a) canyon topography effect
  (b) canyon topography and layering effect
  (c) canyon topography, layering (with irregular interfaces) and material gradient effect

Influence of site effects on structural response

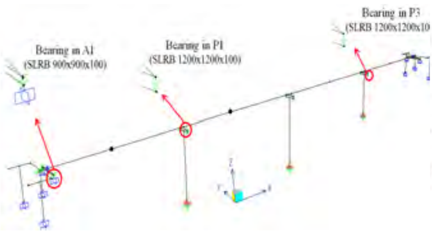
Deck Displacements

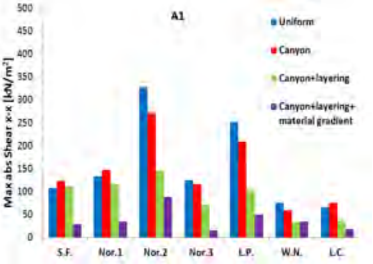


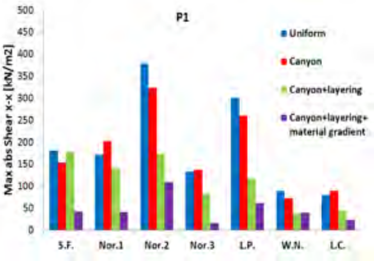


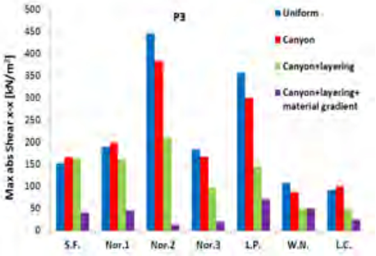


Bearing Shear Stress









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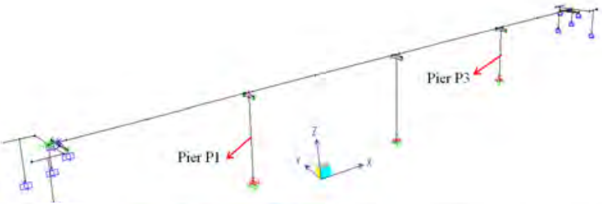
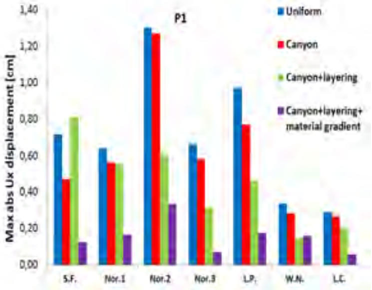
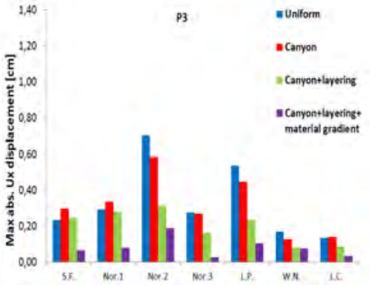
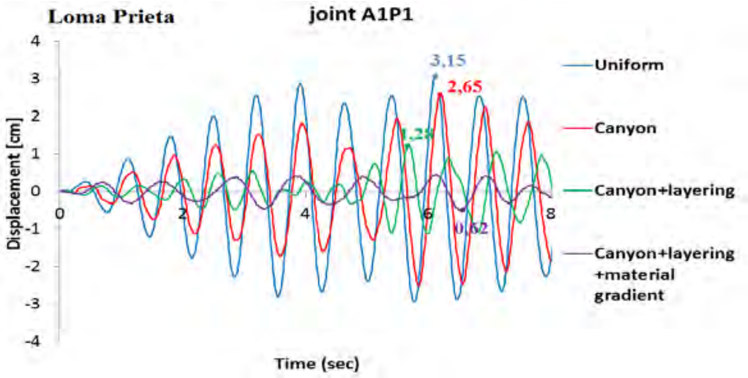
Pier Displacements



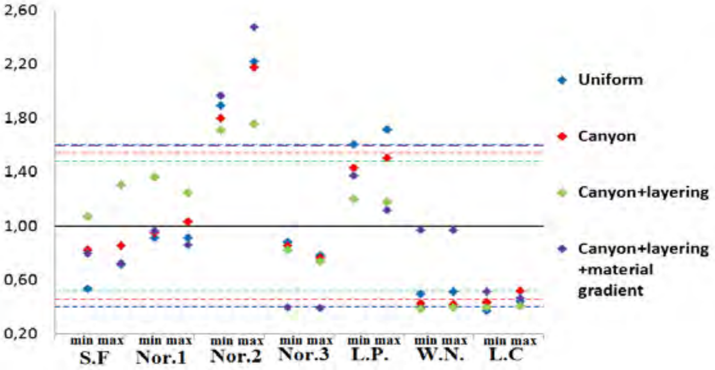




Displacement time history of the deck



Result Trend



Conclusions

(i) Local site conditions cannot be ignored since they significantly influence the inelastic dynamic response of bridges.

(ii) Site dependent ground motions are generated by a new-developed BEM able to account for wave propagation in complex geological media with variable velocity profile, nonparallel layers, surface relief and buried cavities and tunnels.

(iii) The ground motions and the subsequent response of the bridge are strongly affected by the canyon topography and layering effect, and this effect is frequency dependent.

Conclusions

(iv) Not in all cases examined here ignoring site effects and spatial variability of input motions leads to beneficial results for the bridge. It cannot established apriori that site effects have beneficial influence on the seismic response of bridges.

(v) Ignoring site effects may introduce an error around 70% in terms of the kinematic field