Nonlinear response of high-rise buildings subjected to rocking motion induced by passage of Rayleigh waves

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(1) Bureau de Recherches Géologiques et Minières

brgm – Géosciences pour une Terre durable

(2) Universtity of Patras, Greece

UNIVERSITY OF PATRAS

Kristel MEZA FAJARDO[(1)] & Apostolos PAPAGEORGIOU[(2)]

k.mezafajardo@brgm.fr

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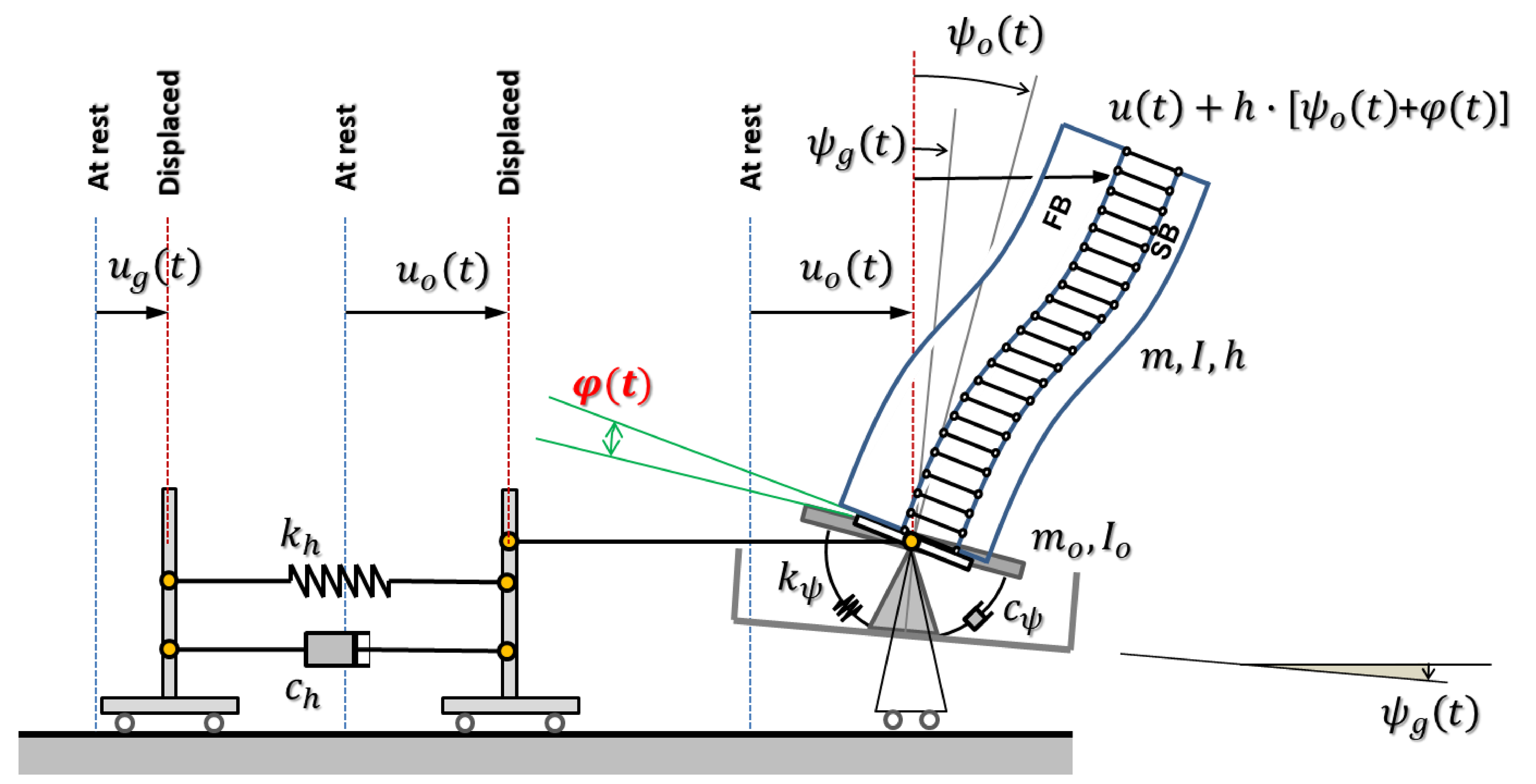
Summary

In the present work we investigate the impact of rocking due to Rayleigh wave passage on ductility demands of several high-rise buildings. The buildings are modeled with a flexure-shear coupled-beam. We expand this analytical model to introduce interaction with a flexible underlying soil. We also take into account the stiffness reduction (damage) of the building using a rigid-elastic rotational spring at its base.

Structural model

- Flexural deformation (due to connection rotation), characteristic of tall buildings, is allowed using a Euler-Bernoulli beam.
- Soil-structure interaction is implemented using impulse response functions of a massless circular disk supported in a viscoelastic half-space.



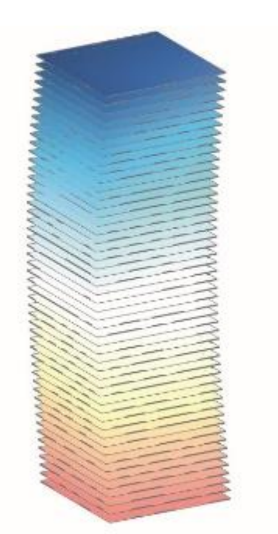
Selected buildings

- The first 5 building modes are considered for the dynamic response

No.	Symbol	Height (m)	Period (s)	c_s(m/s)	No.	Symbol	Height (m)	Period (s)	c_s(m/s)
1	●	13.50	0.22	214	21	●	130.66	1.84	408
2	▶	13.50	0.15	214	22	▶	15.24	0.67	805
3	✱	13.07	0.71	153	23	✱	15.24	0.66	805
4	▲	17.42	0.52	265	24	▲	17.42	0.69	305
5	■	17.42	0.28	195	25	■	17.42	0.71	305
6	▼	27.44	0.37	341	26	▼	24.39	0.82	192
7	◆	27.44	0.26	341	27	◆	75.78	3.2	354
8	◀	30.05	0.53	270	28	◀	75.78	3.1	354
9	★	28.75	0.97	279	29	★	95.82	3.45	299
10	●	39.63	0.9	348	30	●	95.82	3.89	299
11	●	94.95	2.45	137	31	●	33.97	0.92	299
12	▶	94.95	2.65	137	32	▶	30.49	1.54	223
13	✱	23.52	0.5	141	33	✱	31.36	1.32	242
14	▲	23.52	1.25	141	34	▲	31.36	1.22	242
15	■	24.39	0.66	212	35	■	32.23	2.01	259
16	▼	24.39	0.64	212	36	▼	32.23	2.08	259
17	◆	36.59	1.11	674	37	◆	180.31	5.03	146
18	◀	36.59	0.85	674	38	◀	47.47	2.13	221
19	★	38.76	1.25	268	39	★	47.47	2.17	221
20	●	13.50	1.04	268	40	●	180.31	5.7	402

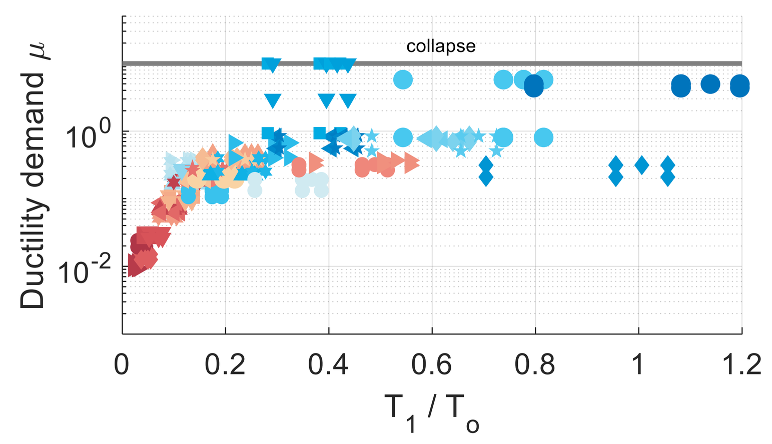
Building response to Rayleigh waves

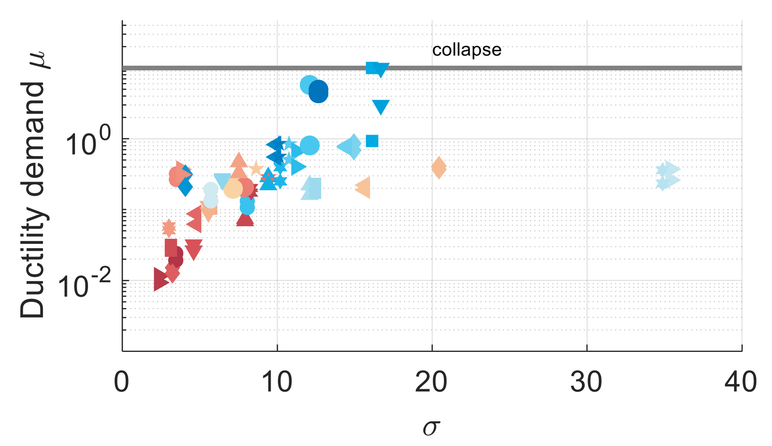
- Response is evaluated in terms of ductility demand μ



$$\mu = \frac{\max_t\{\overline{DR}_T\}}{\overline{DR}_y}$$

$$\max_t\{\overline{DR}_T\} \leq 3\%$$



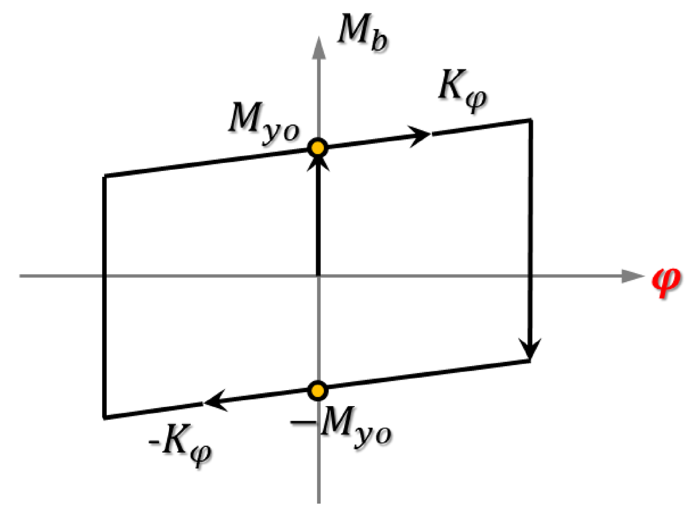


- Controlling parameters:

Fundamental period T1,
Relative (soil-structure) stiffness σ

Inelastic rotation φ(t)

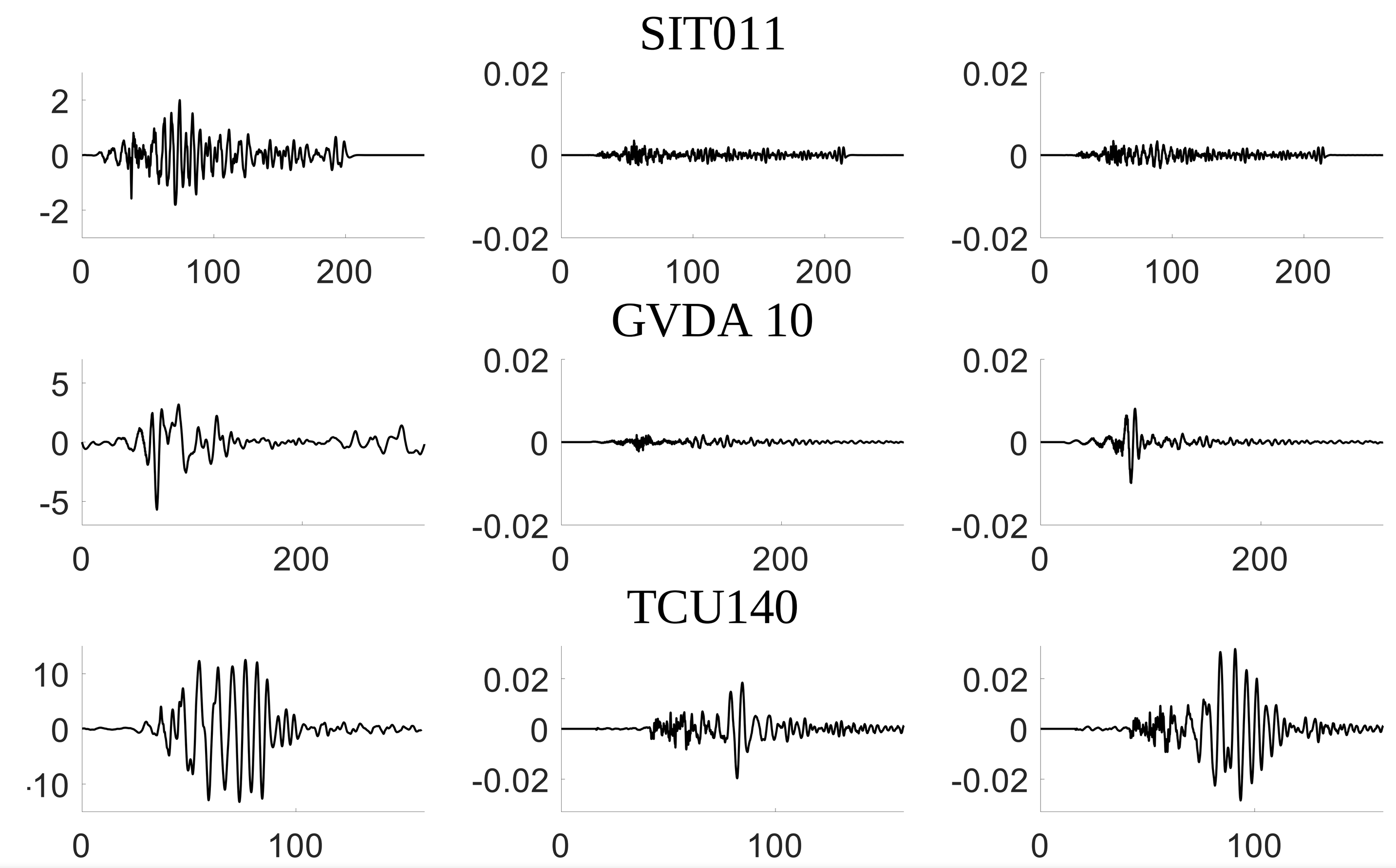
- Superstructure remains elastic except at its base.
- When the base moment Mb exceeds the yield point, an inelastic rotation φ(t) starts accumulating.



$$\varphi(t) = \begin{cases} \varphi & \text{if} \quad \Delta M_b(t-\Delta t)\cdot\Delta M_b(t) \leq 0 \\ \dfrac{M_b(t+\Delta t) - M_{yo}\cdot sgn[\Delta M_b]}{K_\varphi} & \text{if} \quad \Delta M_b(t-\Delta t)\cdot\Delta M_b(t) > 0 \end{cases}$$

Input motion

- We use time histories of *recorded* translation and rocking
- Rocking is computed separately for body and Rayleigh waves



Response with vs without Rayleigh waves

- We evaluate the ratio:

Ductility with R-waves / Ductility without R-waves

- For structures yielding at higher drift ratios $\overline{DR}_y$, the ductility demands are smaller under intense ground motion.
- Response with Rayleigh waves can be as high as 10 times the building response without R-waves
- We conclude that *Rayleigh waves contribute dominantly in the overall response of tall buildings*.