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Orientation-Independent Inelastic Spectral Displacement Intensity Measures for the Risk Assessment of Bridges

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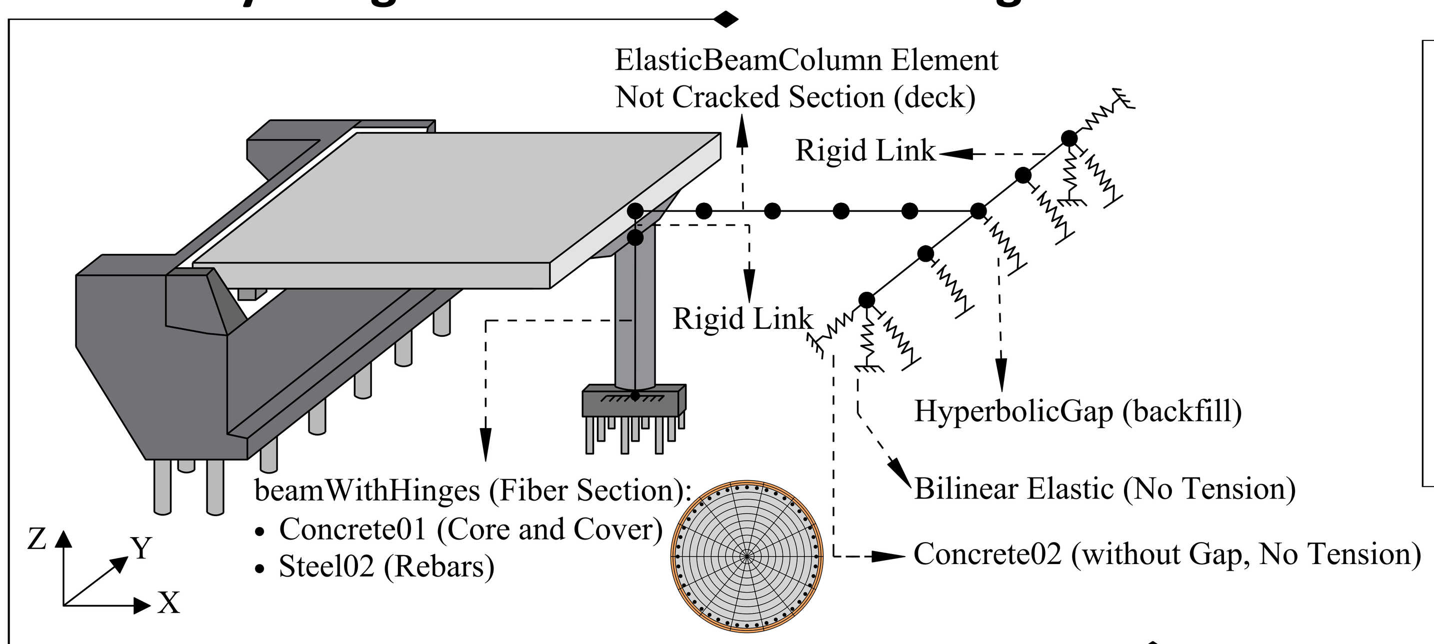
ABSTRACT

A seismic intensity measure (IM) links the seismic hazard and the dynamic response of a structure subjected to ground shaking. The spectral acceleration at the first and usually dominant vibration mode, $Sa(T_1)$, is a popular choice for building structures. However, the IM selection for bridges is non-trivial since they do not typically have a single dominant mode. Even for ordinary bridges with a dominant mode, the behaviour can change significantly in each direction, but also the non-linear behaviour and components' response varies remarkably from bridge to bridge. This study examines the performance of a novel IM in this context: the nnth percentile of all rotation angles of the inelastic spectral displacement, $Sd_{i,RotDnn}$. It was compared with other conventional IMs used in regional bridge assessment. This evaluation was carried out within the context of the seismic risk assessment of an ordinary bridge structure, which is a highway overcrossing located in California with two spans and a continuous prestressed reinforced concrete box girder. A large ground motion set was selected from the NGA-West2 database, and incremental dynamic analysis was performed on the structure to assess each IM's efficiency. Also, different horizontal component definitions were examined in terms of their efficiency. From the results, it can be concluded that $Sd_{i,RotDnn}$ performs very well compared to other IMs. It is also shown that this IM could be a good choice to relate the shaking intensity to the inelastic response that a bridge structure is expected to undergo.

CASE STUDY DESCRIPTION, RECORDS & ANALYSIS METHOD

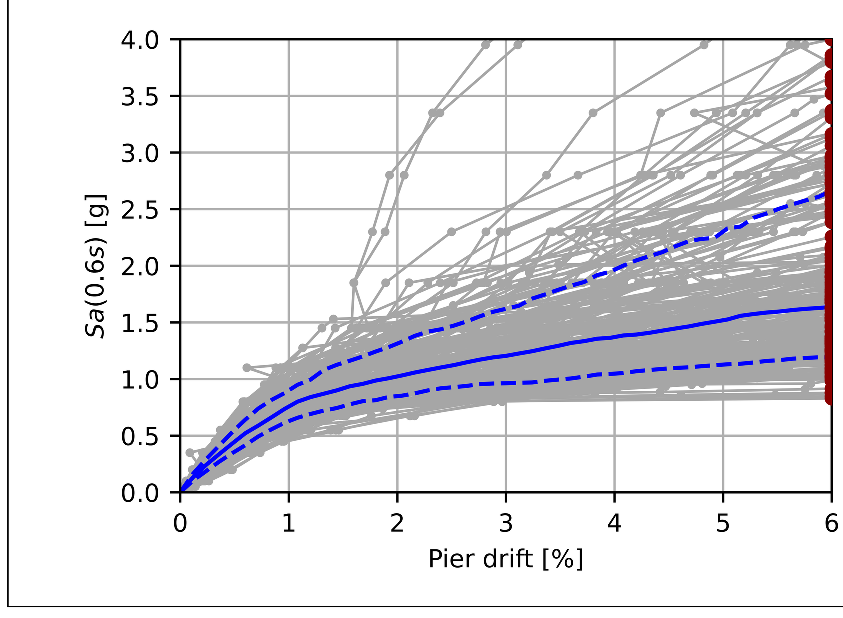
Case study bridge and numerical modelling



Ground motion records

- 200 unscaled GMs from NGA-West2 database
- Large set to ensure accurate marginal distribution of IM|EDP
- Mw = 7.5±0.5; Rrup = 20±20 km; Vs,30 = 400±300 m/s

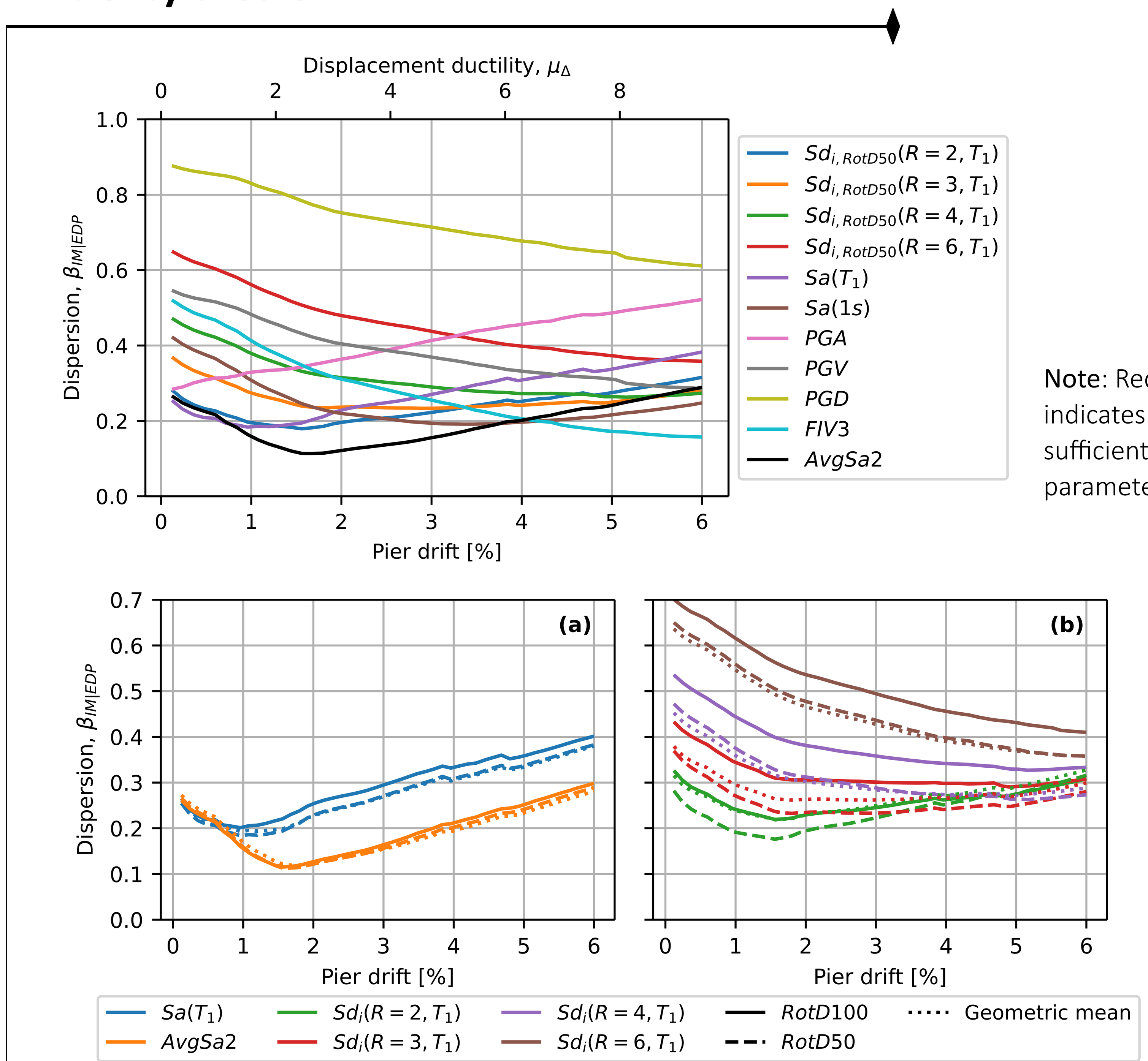
Incremental dynamic analysis



- *PGA*: peak ground acceleration;
- *PGV*: peak ground velocity;
- *PGD*: peak ground displacement;
- $Sa(T_1)$: 5%-damped spectral acceleration at the fundamental period, T_1, of the structure;
- *Sa*(*1s*): 5%-damped spectral acceleration at period equal to 1 s;
- $Sd_{i,RotDnn}$: 5%-tangent-stiffness damped inelastic spectral acceleration, where two *RotDnn* definitions were considered: the 50th and 100th percentile of all rotation angles sorted by amplitude (i.e., *RotD50* and *RotD100*) as defined by Boore (2010);
- *FIV3*: filtered incremental velocity, as defined by Dávalos and Miranda (2019)
- *AvgSa*: average spectral acceleration, which was further subdivided according to the period range as follows:
  - o *AvgSa1* – T ∈ [0.5T1, 1.5T1]
  - o *AvgSa2* – T ∈ [0.5T1, 2T1]
  - o *AvgSa3* – T ∈ [0.5T1, 3T1]

RESULTS & CONCLUSIONS

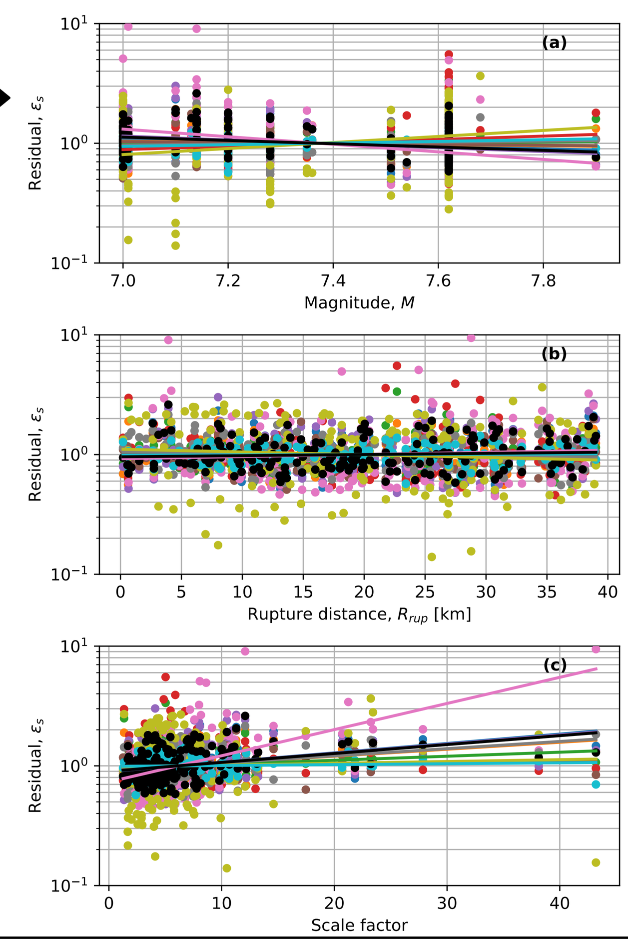
Efficiency checks



Sufficiency checks

Intensity measure	*p*-values			SRS slopes		
	M	R_{rup}	*SF*	*M*	R_{rup}	*SF*
$Sd_{i,RotD50}$ (R=2, T_1)	0.004	0.193	$< 10^{-3}$	-0.248	0.003	0.018
$Sd_{i,RotD50}$ (R=3, T_1)	0.147	0.622	$< 10^{-3}$	-0.111	0.001	0.013
$Sd_{i,RotD50}$ (R=4, T_1)	0.437	0.566	0.031	0.059	-0.001	0.008
$Sd_{i,RotD50}$ (R=6, T_1)	0.001	0.257	0.670	0.324	-0.003	0.002
$Sa(T_1)$	$< 10^{-3}$	0.248	$< 10^{-3}$	-0.365	0.003	0.019
$Sa(1s)$	0.193	0.407	0.355	-0.075	-0.001	0.004
PGA	$< 10^{-3}$	0.250	$< 10^{-3}$	-0.729	0.004	0.050
PGV	0.218	0.117	$< 10^{-3}$	0.096	-0.003	0.014
PGD	$< 10^{-3}$	0.204	0.663	0.581	-0.005	0.004
FIV3	$< 10^{-3}$	0.349	0.351	0.161	0.001	0.002
AvgSa2	$< 10^{-3}$	0.264	$< 10^{-3}$	-0.318	0.002	0.017

Note: Red font color indicates the most sufficient IM against each parameter investigated



Conclusions

- Good performance of the novel IM, $Sd_{i,RotD50}$, both under efficiency and sufficiency checks
- *AvgSa2* was the most efficient for the widest range of structural response. Meanwhile, the period range can have a significant impact
- Regarding the sufficiency checks, it was found that $Sd_{i,RotD50}$(R=4, T_1) and *FIV3* were the most sufficient IMs
- The *RotD50* horizontal component definition exhibited higher accuracy in estimating the

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