reluis

RETE DEI LABORATORI UNIVERSITARI
DI INGEGNERIA SISMICA

DIPARTIMENTO DELLA
PROTEZIONE CIVILE

Progetto Speciale – RS2

Annualità 2014

Kick-off meeting

Simulazioni di terremoti: effetti near-source

UR: Unina- DiSt

Coordinatore: Iunio Iervolino

Componenti Unità di Ricerca:

Iunio Iervolino, professore associato, Univ. Napoli Federico II

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OBIETTIVI DI RICERCA

Analisi di fattibilità normativa per quanto riguarda:

1. la modellazione delle azioni sismiche elastiche e inelastiche delle strutture in condizioni near-source.
2. l’analisi sismica delle strutture in condizioni near-source mediante analisi statica-non lineare.

DESCRIZIONE DEL LAVORO

- ✓ Valutazione dell’applicabilità dei metodi, sviluppati nei precedenti progetti RELUIS, per l’analisi di pericolosità sismica rilassando gli attuali vincoli sulla dettaglia conoscenza delle faglie.
- ✓ Essendo già stato sviluppato un metodo per l’analisi delle strutture in condizioni near-source attraverso il Displacement Coefficient Method (Fema 440), si investigherà la possibilità di trasportare questo metodo nel contesto normativo italiano che fa riferimento al Capacity Spectrum Method.

RISULTATI DISPONIBILI ALLA FINE DELL’ANNALIALITÀ

- ➢ Identificazione dei requisiti minimi per poter includere gli effetti near-source nella pericolosità sismica normativa;
- ➢ Modellazione delle azioni sismiche elastiche ed inelastiche sulle strutture;
- ➢ Formulazione di un metodo tipo capacity-spectrum in condizioni near-source.

OUTLINE

- INTRODUCTION – NEAR-SURCE FORWARD DIRECTIVITY EFFECTS
- NEAR-SOURCE PROBABILISTIC SEISMIC HAZARD ANALYSIS: FRAMEWORK AND MAIN LIMITATIONS
- DESIGN EARTHQUAKES AND DESIGN SCENARIOS
- INELASTIC DEMAND
- DISPLACEMENT COEFFICIENT METHOD

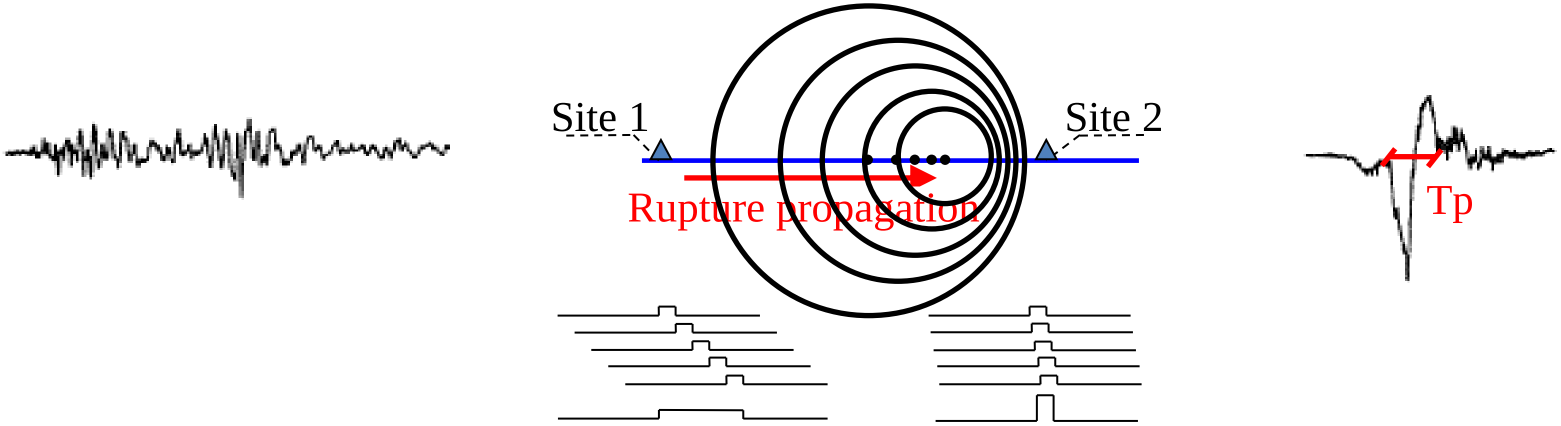
FORWARD RUPTURE DIRECTIVITY

Forward rupture directivity may occur if three condition are meet:

- Rupture propagates toward the site;
- The direction of slip on the fault is aligned with the site;
- The propagation velocity of rupture is almost as large as the share wave velocity.

There is a **probability** that shear wave fronts generated along the fault arrive simultaneously at near-source sites and are in *constructive interference* producing a double-sided pulse appearing early in the velocity recording of the fault-normal component of ground motion.

Strike Slip Case



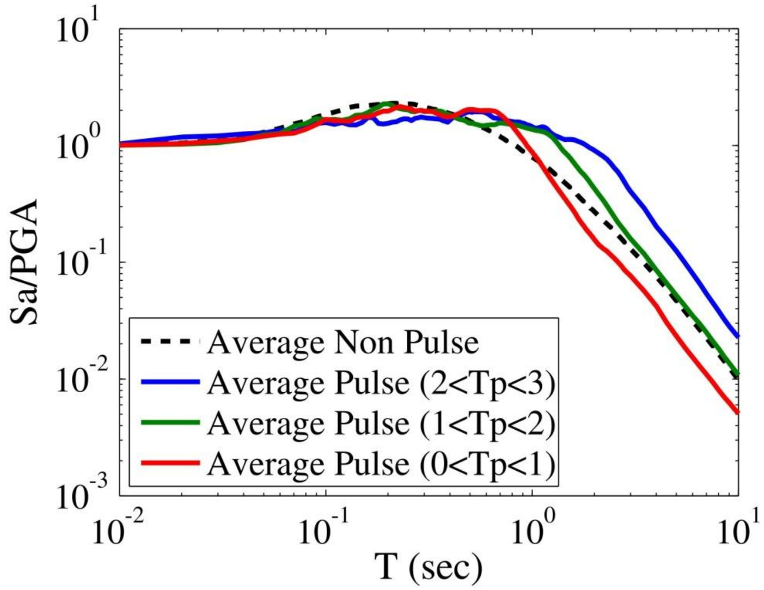
Somerville PG, Smith NF, Graves RW, Abrahamson NA. (1997) Modification of empirical strong motion attenuation relations to include the amplitude and duration effect of rupture directivity. *Seism. Res. Lett.*; **68**(1):199–222.

FORWARD RUPTURE DIRECTIVITY

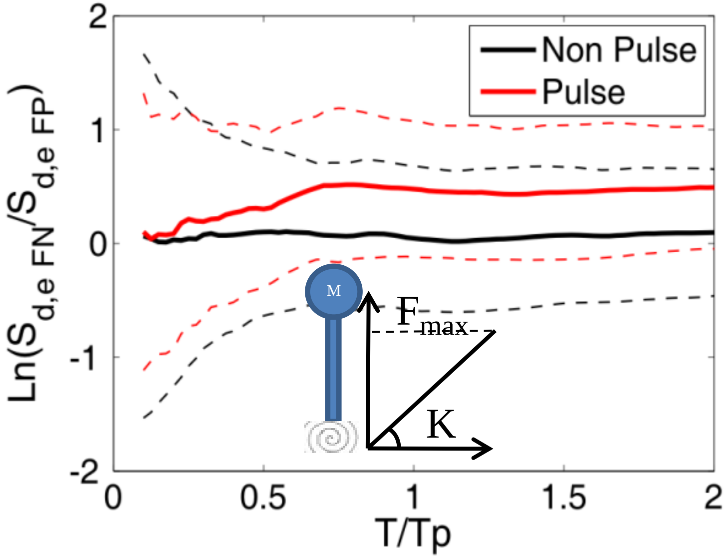
Structural consequences are that:

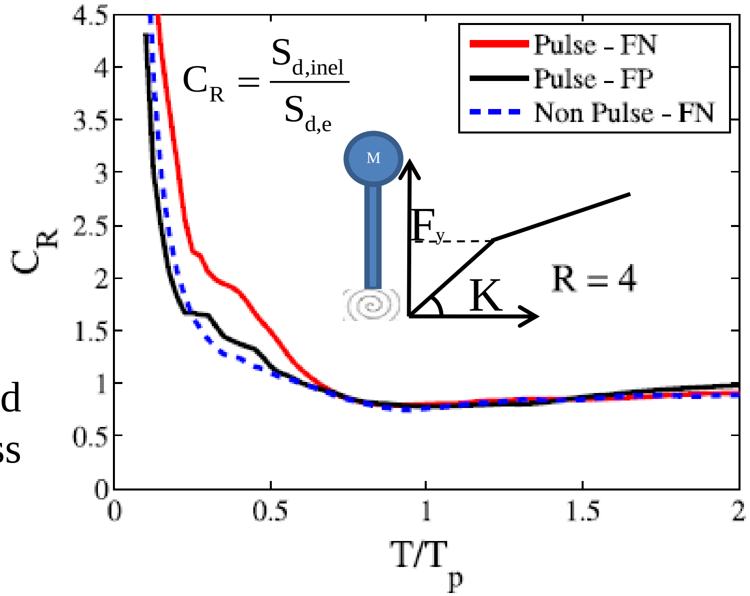
1) More energetic FN component with respect to FP

2) Narrowband amplification of spectral pseudo-acceleration around the pulse period.



3) Fault-normal component exhibits greater inelastic demand than fault-parallel component or ordinary signals, at periods less than a certain fraction of the pulse period.





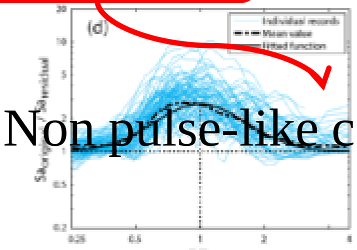
Chioccarelli, E., Iervolino, I. (2010). Near-Source Seismic Demand and Pulse-Like Records: a Discussion for L'Aquila Earthquake, Earthquake Engineering and Structural Dynamics, 39(9), 1039-1062. DOI: 10.1002/eqe.987

NS-PSHA

$$\lambda_{Sa,NS}(x) = \boxed{\lambda_{Sa,NS\&Pulse}(x)} + \boxed{\lambda_{Sa,NS\&NoPulse}(x)}$$

Pulse-like contribution

Non pulse-like contribution



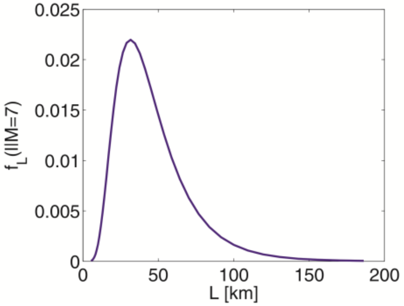
Modified GMPE (Baker, 2008; Shahi and Baker, 2011)

Pulse-like contribution:

Pulse occurrence probability (Iervolino and Cornell, 2008)

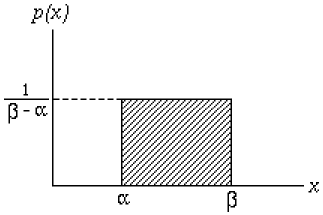
$$\lambda_{Sa,NS\&Pulse}(x) = \nu \cdot \int_m \int_l \int_p \int_{t_p} \int_e \boxed{P[Pulse|l,p,e]}\,\boxed{G_{Sa,\mathrm{mod}|Pulse,M,L,P,T_p}(x|m,l,p,t_p)}\,\boxed{f_{T_p|M}} \cdot f_{L,P|M,E} \cdot f_M \cdot f_E \cdot dt_p \cdot dl \cdot dp \cdot dm \cdot de$$

L = Rupture length (Wells e Coppersmith, 1994)

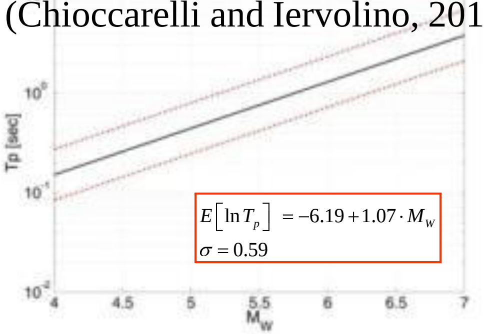


E = Epicenter position on the rupture

P = Rupture position



Pulse period distribution (Chioccarelli and Iervolino, 2010)



Tothong P, Cornell CA, Baker JW. (2007) Explicit directivity-pulse inclusion in probabilistic seismic hazard analysis. *Earthquake Spectra*; **23**(4):867–891.

NS-PSHA

$$\lambda_{Sa,NS}(x) = \lambda_{Sa,NS\&Pulse}(x) + \lambda_{Sa,NS\&NoPulse}(x)$$

Pulse-like contribution:

$$\lambda_{Sa,NS\&Pulse}(x) = \nu \cdot \int_m \int_l \int_p \int_{t_p} \int_e P\left[Pulse|l,p,e\right] \cdot G_{Sa,\mathrm{mod}|Pulse,M,L,P,T_p}\left(x|m,l,p,t_p\right) f_{T_p|M} \cdot f_{L,P|M,E} \cdot f_M \cdot f_E \cdot dt_p \cdot dl \cdot dp \cdot dm \cdot de$$

Non pulse-like contribution :

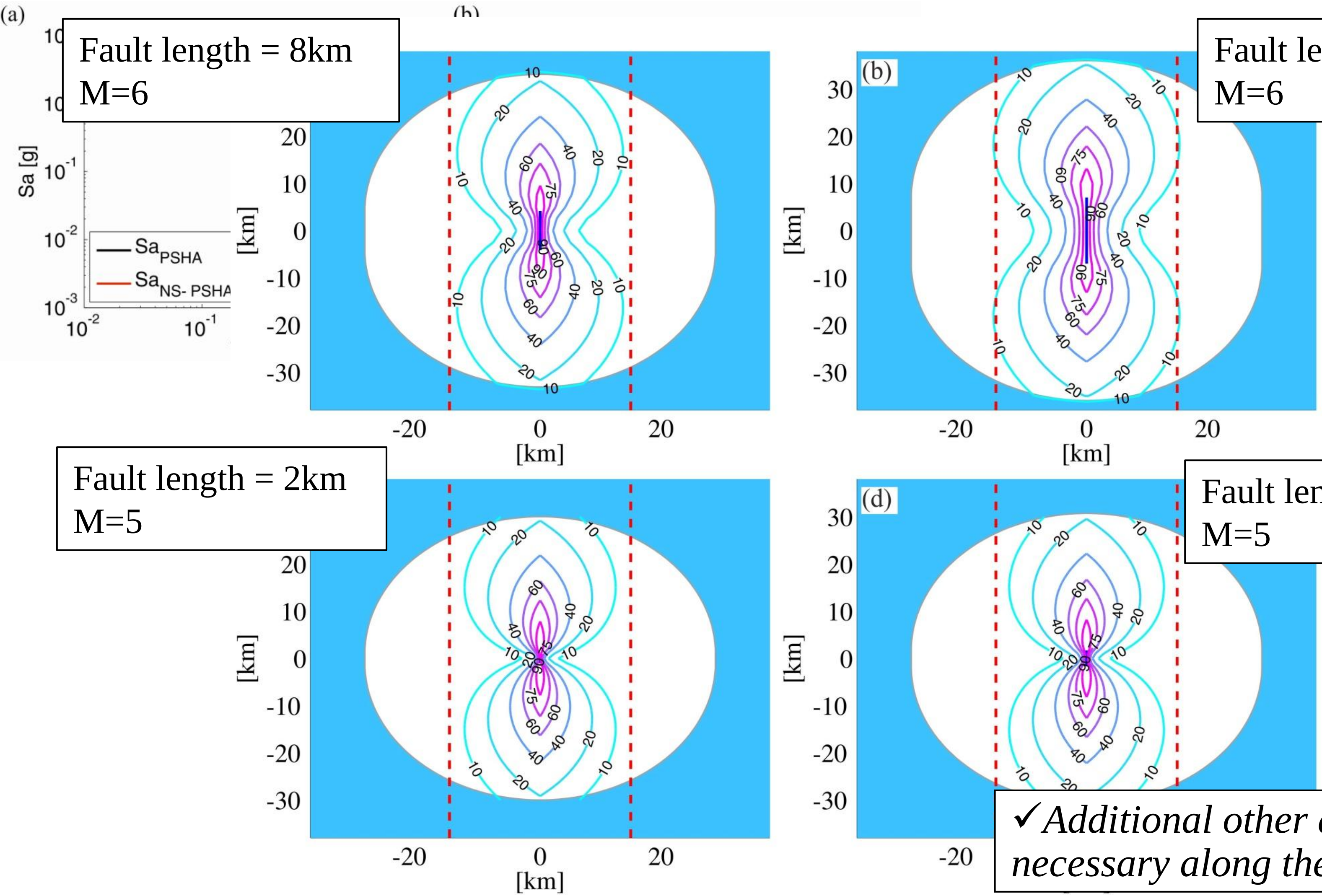
$$\lambda_{Sa,NS\&NoPulse}(x) = \nu \cdot \int_m \int_l \int_p \int_e \left(1 - P\left[Pulse|l,p,e\right]\right) \cdot G_{Sa|M,L,P}\left(x|m,l,p\right) f_{l,p|M,E} \cdot f_M \cdot f_E \cdot dl \cdot dp \cdot dm \cdot de$$

✓*Implementation of NS-SPHA requires the knowledge of fault geometry and locations. In the cases of seismogenic sources, the whole procedure should be adapted for example introducing some geometrical parameters as random variables.*

Tothong P, Cornell CA, Baker JW. (2007) Explicit directivity-pulse inclusion in probabilistic seismic hazard analysis. *Earthquake Spectra*; **23**(4):867–891.

SENSITIVITY ANALYSIS

In few cases, quantification of directivity effects nearby seismic sources has been proposed.



Fault length = 8km
M=6

Fault length = 14km
M=6

Fault length = 2km
M=5

Fault length = 3.2km
M=5

✓*Additional other analyses are necessary along these same lines.*

Chioccarelli, E., Iervolino, I. (2013). Sensitivity analysis of directivity effects on PSHA, Bollettino di Geofisica Teorica e Applicata (International Journal of Earth Sciences), Special issue on *Seismic hazard for critical facilities*, DOI: 10.4430/bgta0099.

DESIGN EARTHQUAKES

Similarly to ordinary cases, disaggregation can be written in NS case as follow:

$$\lambda_{Sa,NS}(x)=\lambda_{Sa,NS\&Pulse}(x)+\lambda_{Sa,NS\&NoPulse}(x)$$

Disaggregation

$$f\;\;m,l,p,e,\varepsilon\,\big|\,x=x_0\;\;=\frac{\nu\cdot P\big[x=x_0\,\big|\,m,l,p,e,\varepsilon\big]\cdot f\;\;m,l,p,e,\varepsilon}{\lambda_{x_0}}$$

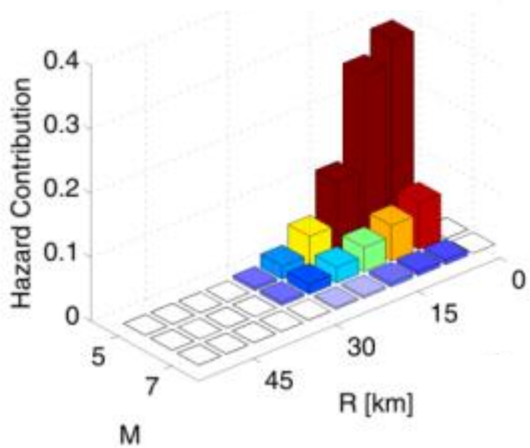
$$\Downarrow$$

$$f\;\;m,l,p,e,\varepsilon\,\big|\,x=x_0\;\;=$$

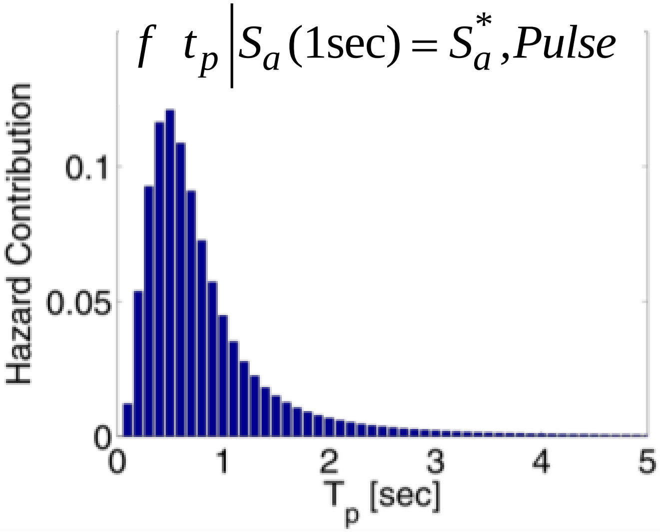
$$\frac{\nu\cdot P\big[x=x_0\,\big|\,Pulse,m,l,p,e,\varepsilon\big]\cdot P\;\;Pulse\,\big|\,l,p,e\;\;\cdot f\;\;m,l,p,e,\varepsilon}{\lambda_{x_0}}+\frac{\nu\cdot I\big[x=x_0\,\big|\,NoPulse,m,l,p,e,\varepsilon\big]\cdot P\;\;NoPulse\,\big|\,l,p,e\;\;\cdot f\;\;m,l,p,e,\varepsilon}{\lambda_{x_0}}$$

DESIGN EARTHQUAKES

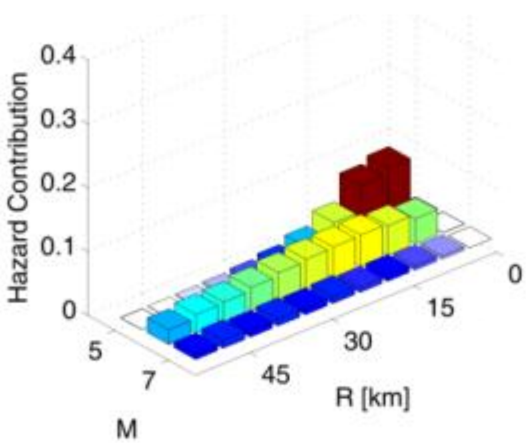
A procedure for identification of design spectra scenarios was proposed



$f\ \ m,r \,\big|\, S_a(1\text{sec}) = S_a^*, Pulse$



$f\ \ t_p \,\big|\, S_a(1\text{sec}) = S_a^*, Pulse$

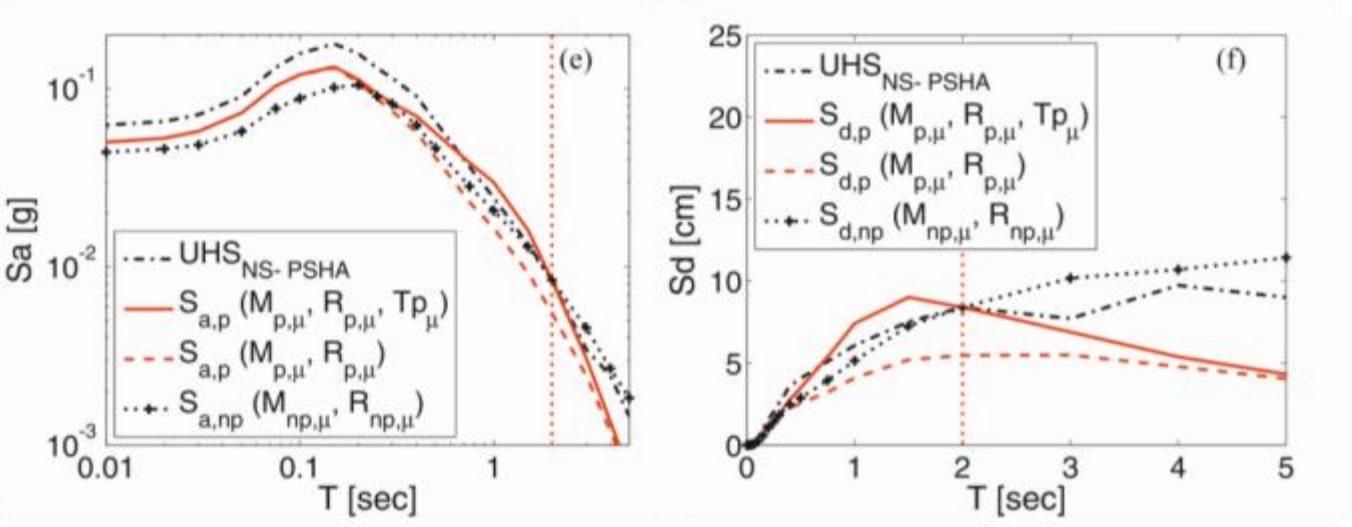


$f\ \ m,r \,\big|\, S_a(1\text{sec}) = S_a^*, NoPulse$

Chioccarelli, E., Iervolino, I. (2012). Near-Source Seismic Hazard and Design Scenarios, Earthquake Engineering and Structural Dynamic, 42(4), 603-622. DOI: 10.1002/eqe.2232.

DESIGN EARTHQUAKES

Different design spectra are dependent on the fundamental period of the considered structure:



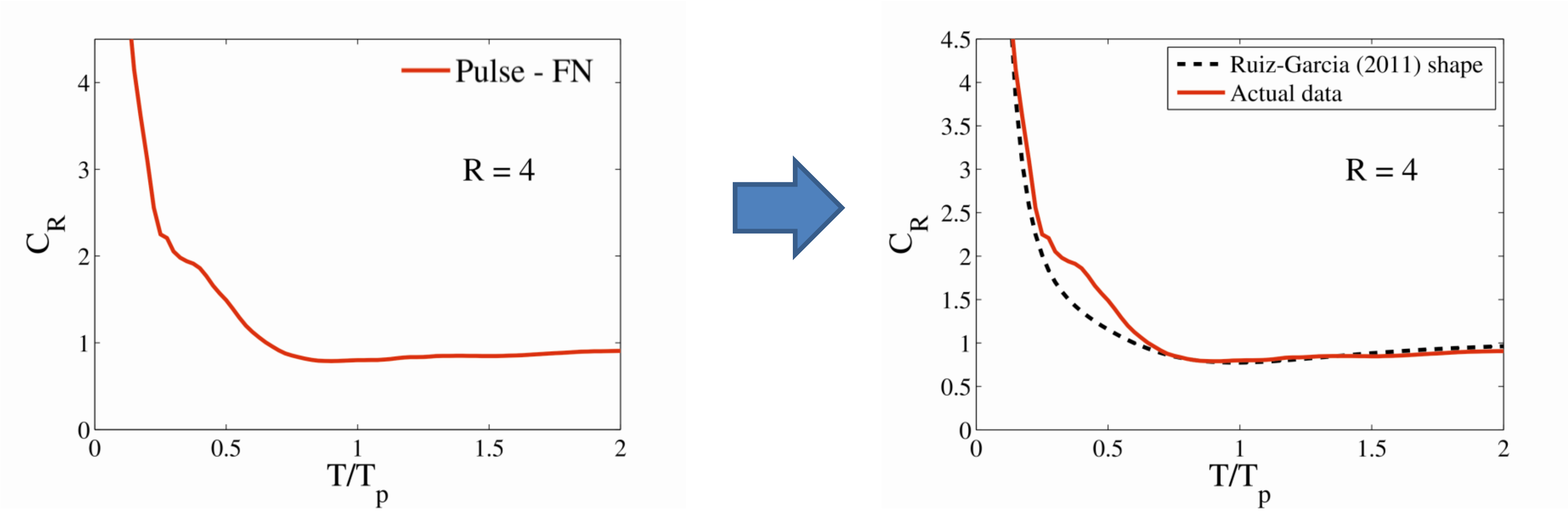
Marginal pulse occurrence probability disaggregation and its complementary part can be used to weight expected values of structural response (measured by engineering demand parameter or EDP) for pulse-like and non pulse-like scenarios:

$$E\left[EDP\middle|s_a = s_a^*\right] = E\left[EDP\middle|s_a = s_a^*, Pulse\right]\cdot P\left[Pulse\,|\,s_a = s_a^*\right] + E\left[EDP\middle|s_a = s_a^*, NoPulse\right]\cdot P\left[NoPulse\,|\,s_a = s_a^*\right]$$

Chioccarelli, E., Iervolino, I. (2012). Near-Source Seismic Hazard and Design Scenarios, Earthquake Engineering and Structural Dynamic, 42(4), 603-622, DOI: 10.1002/eqe.2232.

INELASTIC DEMAND

Ruiz-Garcia, basing on empirical evidence, proposed a functional form of C_R of pulse-like records in order to account for the dominant frequency in ground motion (T_p). In the same work it was noted that the model is able to capture the shape of C_R around $T/T_p=1$ while it is not able to capture the bump in the low T/T_p range. Such model has been fitted on our data.



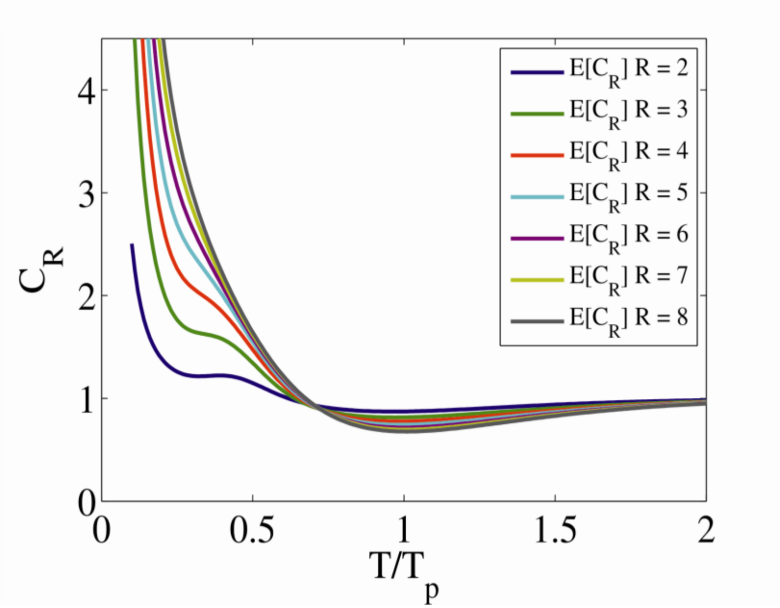
$$C_R = 1 + \theta_1 \cdot (T_p/T)^2 \cdot (R-1) + \theta_2 \cdot (T_p/T) \cdot \exp\{\theta_3 \cdot [\ln(T/T_p - 0.08)^2]\}$$

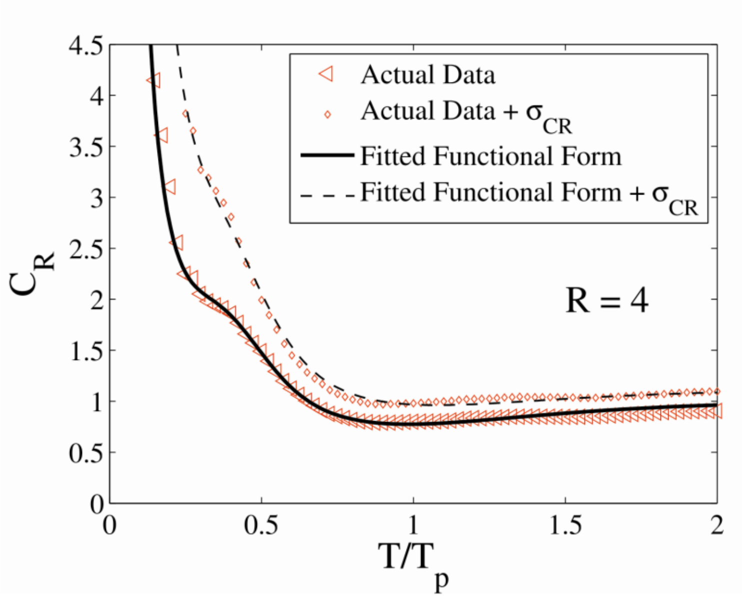
Ruiz-Garcìa J. Inelastic displacement ratios for seismic assessment of structures subjected to forward-directivity near-fault ground motions. *Journal of Earthquake Engineering* 2011; **15**(3):449–468.

INELASTIC DEMAND

Following equation consists of adding another term to reflect the C_R trend in the low T/T_p range. The resulting relationship has another bump shifted and representing a peak rather than a valley. This equation has the same analytical form of that proposed by Baez and Miranda for C_R in the case of soft soil sites. In fact, in that case, the SDoF response also is dominated by specific frequencies of ground motion, yet of different nature.

$$C_R = 1 + \theta_1 \cdot (T_p/T)^2 \cdot (R-1) + \theta_2 \cdot (T_p/T) \cdot \exp\left\{\theta_3 \cdot \left[\ln(T/T_p - 0.08)\right]^2\right\} + \boxed{\theta_4 \cdot (T_p/T) \cdot \exp\left\{\theta_5 \cdot \left[\ln(T/T_p + 0.5 + 0.02 \cdot R)\right]^2\right\}}$$





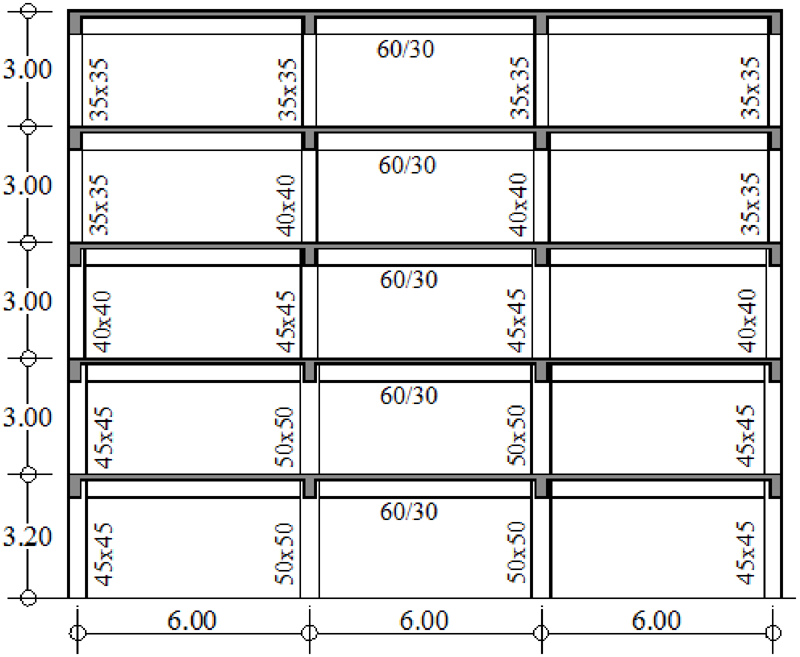
Chioccarelli, E., Iervolino, I., Baltzopoulos, G. (2012). Inelastic Spectral Amplification of Near-Source Pulse-Like Ground Motions, Earthquake Engineering and Structural Dynamic, , 41(15), pp 2351-2357. DOI: 10.1002/eqe.2167.

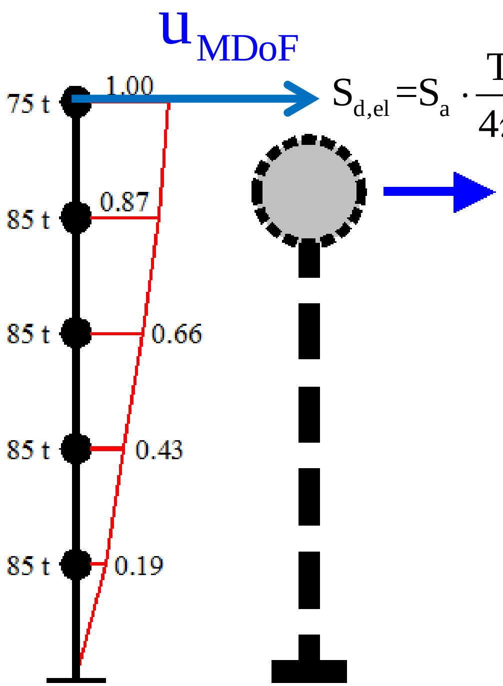
DISPLACEMENT COEFFICIENT METHOD

FEMA 440 (2005)

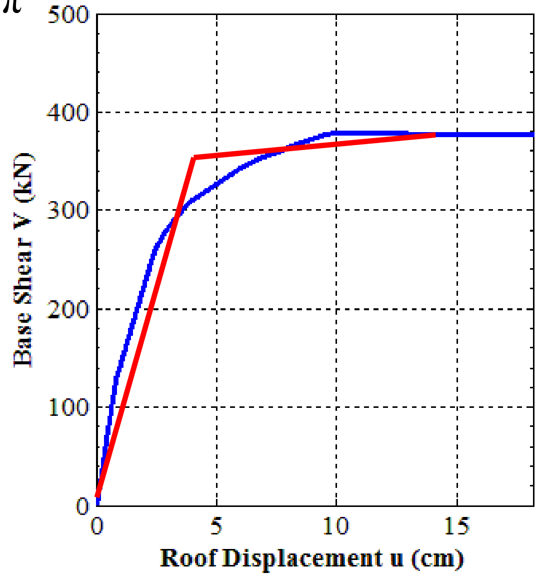
- Static non-linear procedures seek to estimate inelastic demand of the MDoF structure given the **expected inelastic displacement** of an equivalent SDoF system.
- A “pushover” force-displacement curve is used to determine the inelastic properties of the SDoF.
- SDoF inelastic displacement can be estimated by using inelastic spectra, given elastic demand.
- Inelastic spectra are usually provided in the form of R-μ-T relations or **inelastic displacement ratios**.

$$C_R = \frac{S_{d,inel}}{S_{d,e}}$$





$$S_{d,el} = S_a \cdot \frac{T^2}{4\pi^2}$$



DISPLACEMENT COEFFICIENT METHOD

FEMA 440 (2005)

$$C_0 = \frac{\varphi^T M r}{\varphi^T M \varphi}$$

Convert SDoF to MDoF displacement.

$$C_1 = \frac{S_{d,inel}}{S_a \cdot T^2/4\pi^2}$$

Inelastic Displacement Ratio.

Account for shape of hysteresis loops.

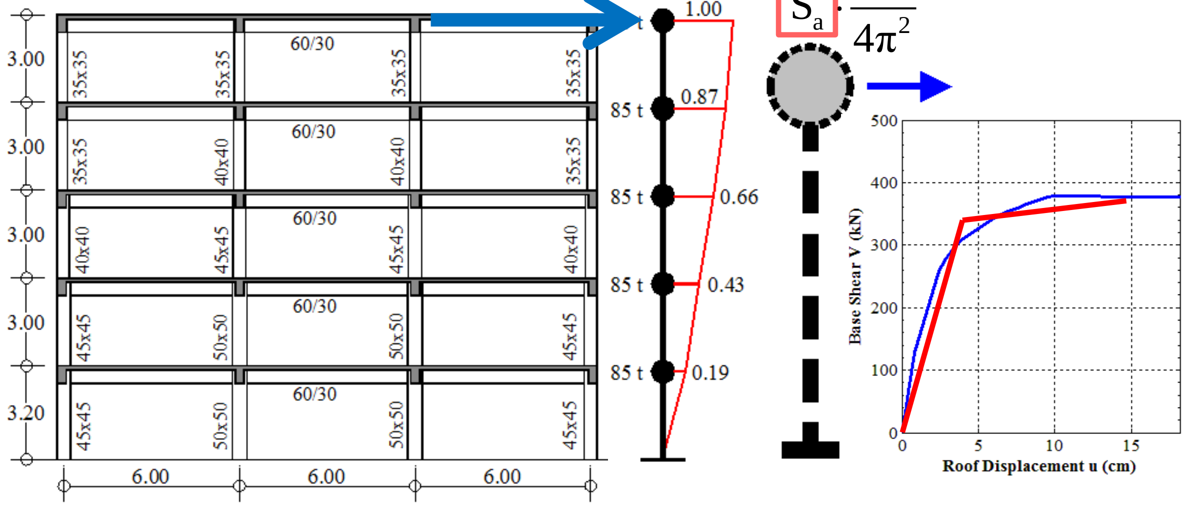
Account for 2nd order effects.

$$\delta_t = \boxed{C_0}\cdot\boxed{C_1}\cdot\boxed{C_2}\cdot\boxed{C_3}\cdot S_a \cdot \frac{T^2}{4\pi^2}$$

target displacement δ_t

PSHA

$$\boxed{S_a}\cdot\frac{T^2}{4\pi^2}$$



The Displacement Coefficient Method employs a relation for mean inelastic displacement ratio.

$$C_1 = 1 + \frac{R-1}{\alpha \cdot T^2}$$

$$R = \frac{S_a/g}{V_y/W}\cdot C_m$$

The relation proposed in FEMA 440 cannot capture the particular response of near-source pulse-like ground motions.

DISPLACEMENT COEFFICIENT METHOD

Theorem of conditional mean:

$$\delta_{t-NS} = \boxed{\delta_{t|pulse}} \cdot \boxed{P\ \ pulse\,|\,S_a = s_a} + \boxed{\delta_{t|no\ pulse}} \cdot \boxed{1 - P\ \ pulse\,|\,S_a = s_a}$$

$f\ \ C_R\,|Pulse$

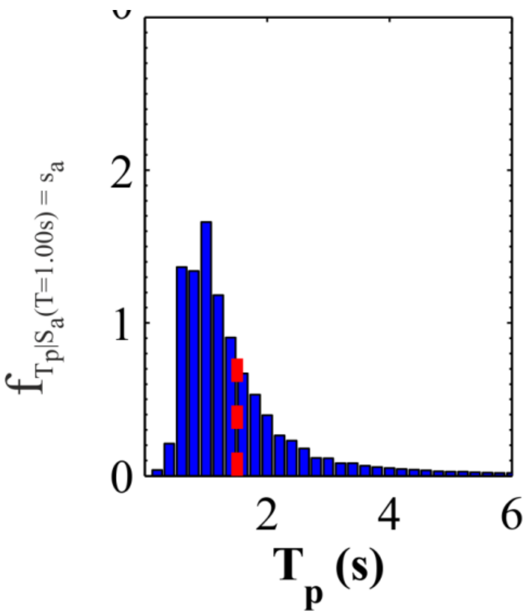
Ordinary (Fema 440, 2005)

Disaggregation of seismic hazard

- Disaggregation of near-source hazard can provide the conditional probability density of pulse period, given occurrence of the hazard threshold.
- Such a PDF of T_p can be used to compute the expectation of **inelastic displacement ratio**.

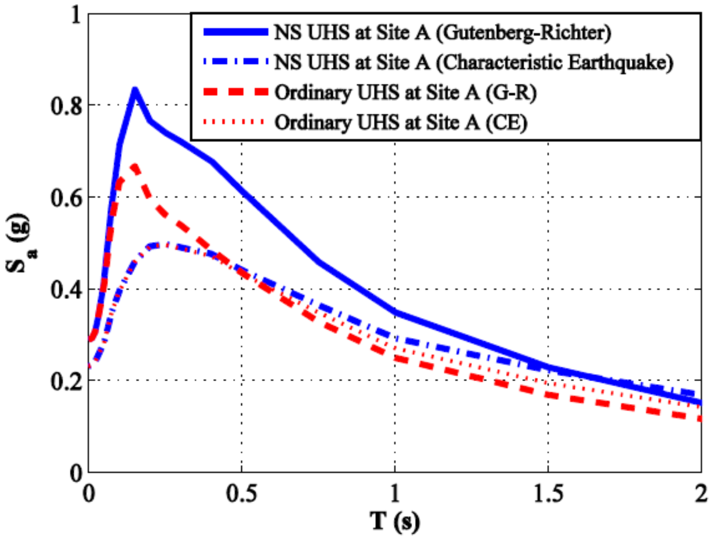
$$E\ \ C_R\,|\,S_a(T) = s_a\ \ = \int_{t_p} E\left[C_R\,|\,S_a\ \ T\ \ = s_a, T_P = x\right] \cdot f_{T_P|S_a\ \ T\ \ =s_a}\ \ x\ \ \cdot dx$$

$$E\ \ C_R\,|\,S_a(T) = s_a\ \ \approx E\left[C_R\,|\,T_P = E\left[T_p\middle|S_a\ \ T\ \ = s_a\right]\right]$$



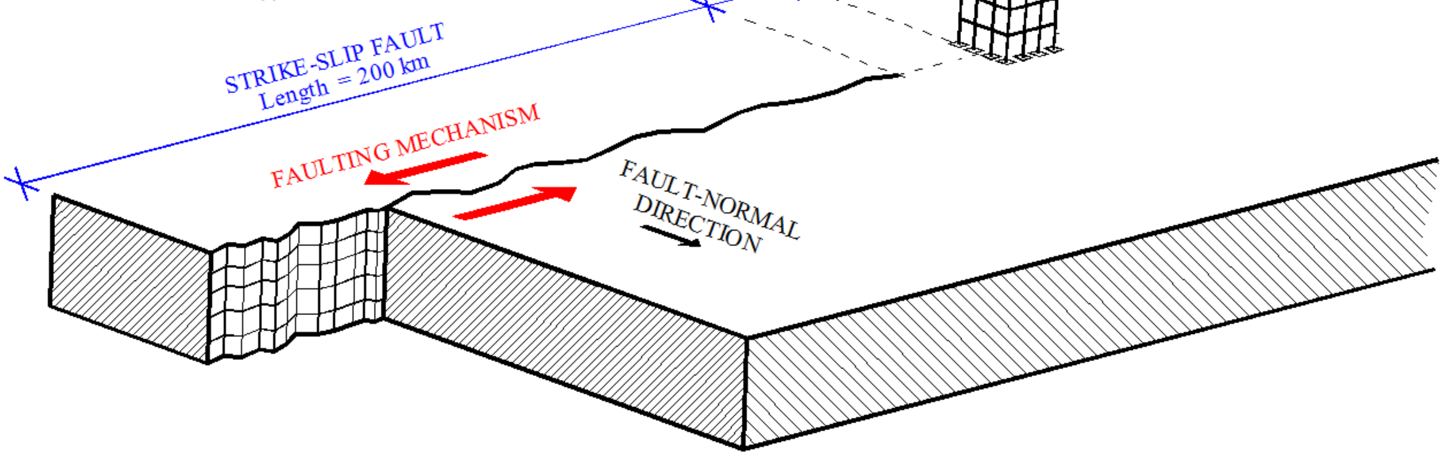
Baltzopoulos, G., Chioccarelli, E., Iervolino, I. (2013). Nonlinear static procedures in near-source conditions, Earthquake Engineering and Structural Dynamic, proposed for publication.

DISPLACEMENT COEFFICIENT METHOD

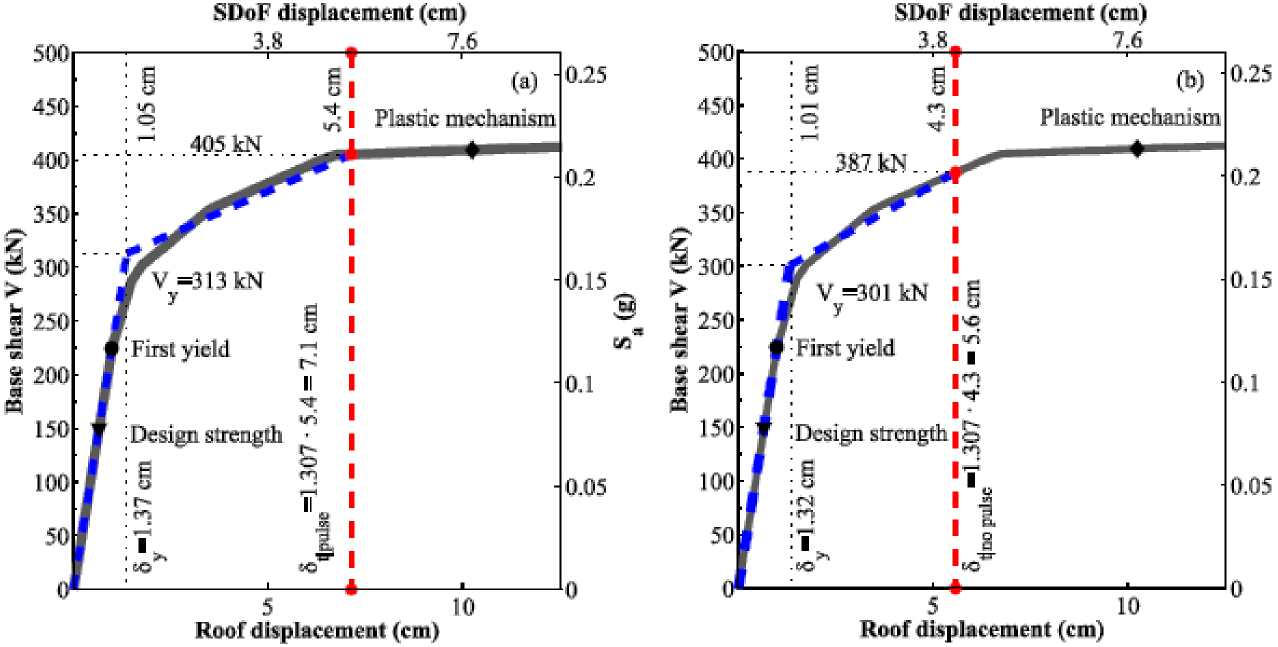


APPLICATION

- Various single-fault near-source design scenarios were developed, in order to provide an illustrative application.
- Near-source hazard was computed for each site, considering various performance levels, with their corresponding return periods.



DISPLACEMENT COEFFICIENT METHOD



APPLICATION

- Target displacement conditional on pulse occurrence is computed using the PDF of T_p and the predictive model for inelastic displacement ratio of impulsive records.
- Target displacement for the non-impulsive case is computed using the displacement coefficient method in its traditional format.
- The two estimates of mean inelastic demand are combined using the conditional probability of pulse occurrence.
- The procedure is repeated for various performance levels, corresponding to various return periods.

Baltzopoulos, G., Chioccarelli, E., Iervolino, I. (2013). Nonlinear static procedures in near-source conditions, Earthquake Engineering and Structural Dynamic, proposed for publication.

DISPLACEMENT COEFFICIENT METHOD

		First mode period	C_R	$E\ T_p$ (s)	$\delta_{t\|pulse}$ (mm)	$\delta_{t\|no\ pulse}$ (mm)	$P[pulse\|S_a = s_a]$	δ_{t-NS} (mm)	δ_{t-ord} (mm)	$\frac{\delta_{t-NS} - \delta_{t-ord}}{\delta_{t-ord}}$
SITE A Gutenberg-Richter seismicity model	T_R=2475yr	0.50s	1.44	0.96	71	56	0.741	67	38	77%
		0.75s	1.31	1.24	111	90	0.673	104	63	65%
		1.00s	1.21	1.51	137	118	0.629	130	83	57%
	T_R=975yr	0.50s	1.17	0.85	40	37	0.687	39	24	63%
		0.75s	1.09	1.03	60	56	0.602	58	40	46%
		1.00s	1.04	1.23	72	70	0.513	71	53	34%

		First mode period	C_R	$E\ T_p$	$\delta_{t\|pulse}$	$\delta_{t\|no\ pulse}$	$P[pulse\|S_a = s_a]$	δ_{t-NS}	δ_{t-ord}	$\frac{\delta_{t-NS} - \delta_{t-ord}}{\delta_{t-ord}}$
SITE A Characteristic Earthquake seismicity model	T_R=2475yr	0.50s	3.77	4.48	143	40	0.170	58	39	47%
		0.75s	3.10	4.37	218	73	0.166	97	71	37%
		1.00s	2.51	4.45	248	101	0.165	125	96	30%
	T_R=975yr	0.50s	3.13	4.51	75	25	0.100	30	24	25%
		0.75s	2.03	4.71	83	42	0.073	45	40	12%
		1.00s	1.72	4.98	94	55	0.060	57	53	8%

EVALUATION OF RESULTS

➡ Each resulting estimate for near-source target displacement can be compared to an ***ordinary*** estimate, where no near-source effects have been taken into account during hazard computations or implementation of the non-linear static procedure.

➡ Substantial percentile increment of displacement demand was observed for the directivity-prone sites examined.

➡ Directivity effects on displacement demand were consistently more pronounced for performance levels corresponding to longer return periods..

➡ There were cases where directivity had negligible impact on elastic demand within a given spectral region and yet had significant influence on inelastic demand.

GRAZIE PER L’ATTENZIONE