

## INFLUENCE OF MOTION DURATION ON INELASTIC STRUCTURAL RESPONSE

K. Meskouris (I)

### SUMMARY

Shear beam models of a 5- and 10-story high moment resisting frame were subjected to 12 artificial accelerograms matching the same NEWMARK/HALL design spectrum. Model parameters varied were spring hysteretic laws and target ductilities. Maximum and cumulative ductilities as well as energy-based damage indicators were computed and correlated with the ARIAS intensities of the motions.

### INTRODUCTION

Seismic design methods which explicitly consider inelastic structural behavior are of great practical importance for construction in high seismicity areas. Some parameters of the ground motion, such as duration and the time variability of its frequency content, which cannot be readily considered in the standard response spectrum-modal analysis approach, acquire special significance when the structure responds inelastically. In this paper, results of an investigation on the influence of motion duration on the inelastic response of tall buildings are reported.

### SCOPE OF THE INVESTIGATION

Three plane, moment resisting frames (3, 5 and 10 stories high) were designed for target ductilities of 2 and 4 by means of the NEWMARK/HALL inelastic spectrum approach. Both point hinge member models and shear beam models were utilized, the former, however, on a limited scale, due to their expensive use. Herein, only shear beam model results for the 5- and 10-story frames are presented.

The following tables summarize the shear beam model properties, that is, story masses, spring stiffnesses and ultimate elastic spring elongations:

Story	1	2	3	4	5	6	7	8	9	10
$k_i$ [kN/m]	18300	17600	16900	16200	15500	14800	14100	13400	12700	12000
$m_i$ [kg]	50000	50000	50000	50000	50000	50000	50000	50000	50000	45000
$x_{ei}$ [cm] $\mu=2$	3.76	3.71	3.62	3.52	3.40	3.23	3.00	2.70	2.26	1.44
$x_{ei}$ [cm] $\mu=4$	1.88	1.85	1.81	1.77	1.70	1.62	1.51	1.36	1.14	0.75

(I) Dr.-Ing. Privatdozent, Lehrstuhl KIB 3, Ruhr-Universität Bochum,  
W. Germany

Story	1	2	3	4	5
$k_i$ [kN/m]	13305	14098	10496	10495	8431
$m_i$ [kg]	55000	55000	55000	55000	50000
$x_{el}$ [cm] $\mu=2$	4.52	3.75	4.32	3.44	2.72
$x_{el}$ [cm] $\mu=4$	2.27	1.88	2.18	1.72	1.41

Story stiffnesses were computed by the expression

$$k_i = \frac{24E}{h_i^2} \left[ \frac{2}{J_s} + \frac{1}{J_{R,o}} + \frac{1}{J_{R,u}} \right]^{-1}$$

Herein, E is Young's modulus,  $h_i$  stands for story height,  $J_s$ ,  $J_{R,o}$  and  $J_{R,u}$  are moments of inertia of columns and girders in the upper and lower story, and  $l_s$ ,  $l_R$  denote column and girder lengths. The ultimate elastic spring elongations were evaluated as RMS values of the relative story displacements corresponding to the inelastic response spectra.

Two different hysteretic laws were utilized for the nonlinear story springs, namely, the elastoplastic idealization of Fig. 1a and an origin-oriented, UMEMURA-type law (Fig. 1b). In both cases, the models are completely defined by their elastic stiffnesses and their maximum elastic displacements  $x_{el}$ . In comparison to the elastoplastic law, the origin-oriented model exhibits marked stiffness degradation and dissipates significantly less work.

Based on the NEWMARK/HALL design spectrum for 0.33g ground acceleration and 2% damping, twelve artificial motions were generated with nominal durations of 6, 8, 12, ... 28s. Their ARIAS intensities, defined as the definite time integrals of squared acceleration over the entire motion duration, were utilized as characteristic motion duration parameters, since they are directly connected with the energy content of the accelerograms. The following table lists the ARIAS intensities  $I_o$  of the twelve motions:

Motion [sec]	6	8	10	12	14	16	18	20	22	24	26	28
$I_o$ [m <sup>2</sup> /s <sup>3</sup> ]	11.96	13.76	17.55	18.69	19.88	20.82	23.09	24.29	25.66	27.28	28.29	29.33

Time histories of relevant response parameters were calculated by Direct Integration (NEWMARK  $\beta$ - $\gamma$  method). A stiffness proportional modal damping of 2% for the ground mode was assumed in all cases. Following damage indicators were evaluated:

- a) Maximum ductility demands of the story springs, defined as ratios of maximum elastoplastic deformation to ultimate elastic deformation  $x_{el}$ .
- b) Cumulative ductility demands, defined as sums of the absolute values of plastic deformation normalized by  $x_{el}$ .
- c) Number N of plastic excursions.
- d) Maxima of the total seismic work absorbed by the building (seismic input energy). The total seismic work equals the sum of kinetic energy, elastically stored energy, energy dissipated by viscous damping, and, finally, hysteretically dissipated energy.
- e) Total energy dissipated by hysteretic action.

#### RESULTS

Tables in the Appendix summarize the results obtained, with energy quantities expressed in [kNm]. These values were correlated with the ARIAS intensities of the motions, furnishing the correlation coefficients given in the last column. To aid visualization, Figs. 2 and 3 depict mean values plus/minus one standard deviation of both maximum and cumulative ductilities for all cases considered.

Results show considerable variation in ductility demands and energy indicators with motion duration; however, no all-encompassing rule can be stated at the moment. Maximum ductility demands determine the risk of sudden failure, whereas cumulative ductilities characterize the risk of failure through gradual strength degradation. Their dependence on motion duration in the nonlinear range underlines the importance of including in the design process analysis methods that explicitly consider this parameter, e.g. time history calculations.

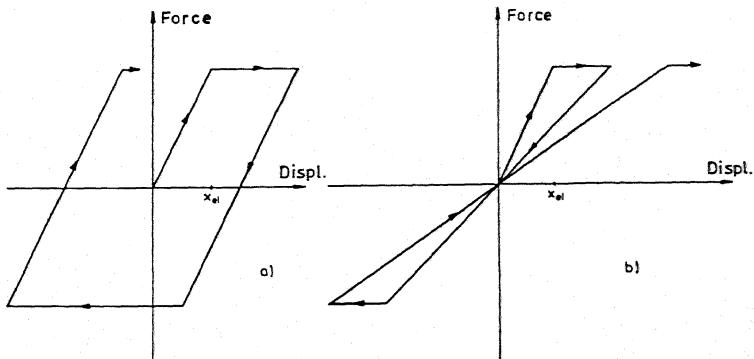


Fig. 1: Nonlinear spring laws

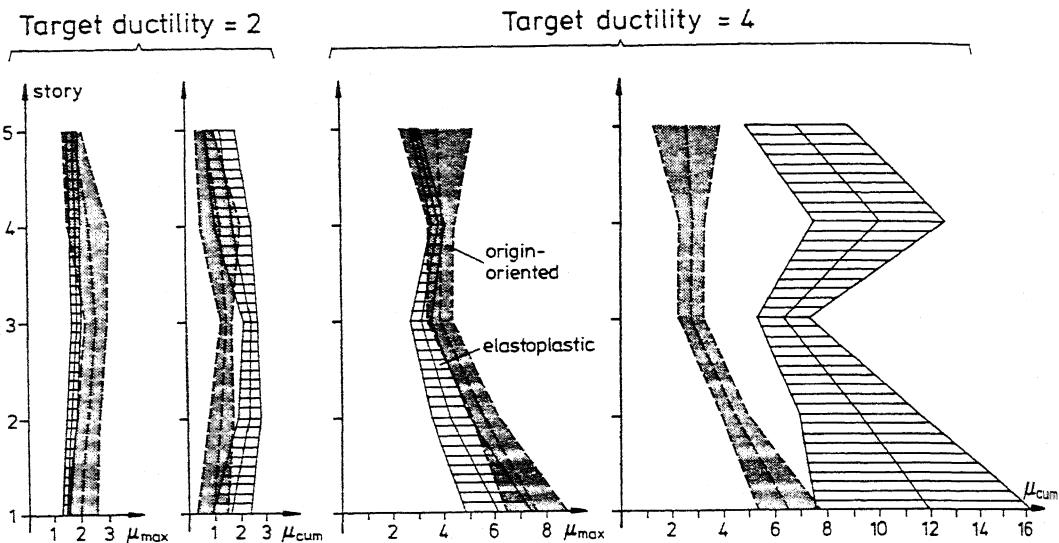


Fig. 2: Ductility demands, 5-story frame

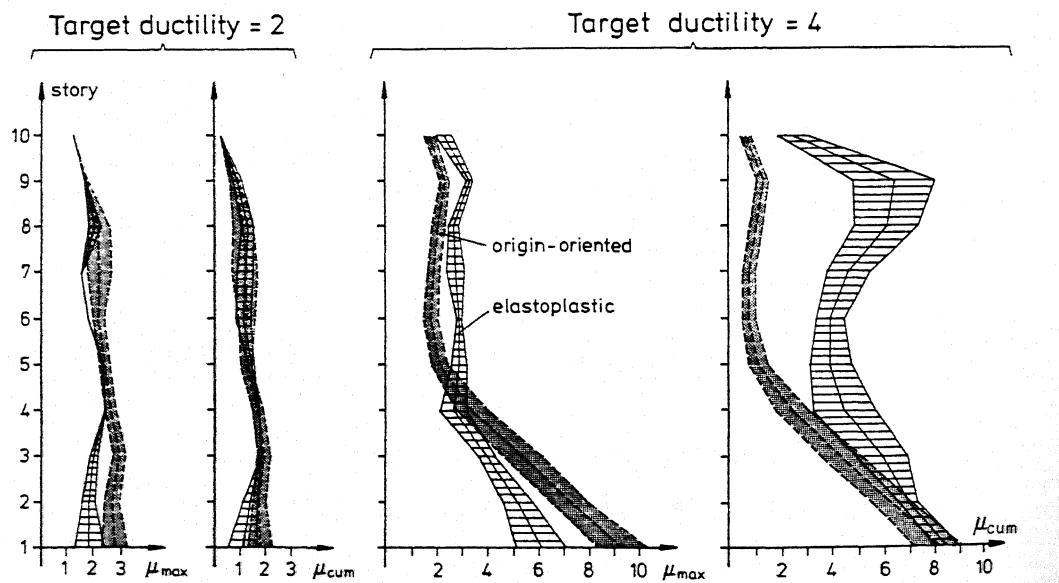


Fig. 3: Ductility demands, 10-story frame

10 - story frame, Target ductility 2, elastoplastic model

		Nominal duration																							
		6	8	10	12	14	16	18	20	22	24	26	28	29	30	31	32	33	34	35	36	37	38	39	
Nominal duration		6	8	10	12	14	16	18	20	22	24	26	28	29	30	31	32	33	34	35	36	37	38	39	
Hox input energy		390.7	460.4	431.0	410.1	419.1	467.7	467.6	479.3	510.4	541.1	542.7	0.95												
Hyst. dissip energy		259.4	255.4	255.2	238.7	210.6	206.9	211.6	207.9	205.6	205.1	205.0	-0.80												
$\bar{\mu}_{\text{max}}$	1	2.27	2.27	1.81	1.89	1.20	1.54	1.65	1.65	1.70	1.76	1.76	-0.63												
$\bar{\mu}_{\text{cum}}$	1	2.23	2.25	1.37	0.98	0.64	0.76	0.83	0.82	0.85	0.86	0.82	-0.76												
N	1	1	1	1	1	1	1	1	1	1	1	1	0.78												
$\bar{\mu}_{\text{max}}$	2	2.07	2.11	1.65	1.50	1.40	1.60	1.79	1.86	1.99	1.99	1.99	0.65												
$\bar{\mu}_{\text{cum}}$	2	1.81	1.80	1.89	1.56	1.31	1.12	1.09	1.19	1.16	1.24	1.26	-0.14												
N	2	2	2	2	3	3	3	5	5	5	5	5	0.06												
$\bar{\mu}_{\text{max}}$	3	1.85	1.86	2.04	1.89	1.85	2.11	2.17	2.27	2.25	2.27	2.27	0.71												
$\bar{\mu}_{\text{cum}}$	3	1.78	1.78	1.81	1.83	1.77	1.82	1.92	1.86	1.91	1.73	1.89	0.74												
N	3	3	3	2	2	2	3	3	3	3	3	3	0.15												
$\bar{\mu}_{\text{max}}$	4	2.46	2.47	2.55	2.42	2.36	2.37	2.47	2.49	2.46	2.42	2.42	-0.53												
$\bar{\mu}_{\text{cum}}$	4	2.32	1.82	1.82	1.78	1.86	1.85	1.87	1.87	1.80	1.77	1.74	0.52												
N	3	3	3	3	3	2	2	2	2	2	2	2	-0.81												
$\bar{\mu}_{\text{max}}$	5	2.65	2.65	2.43	2.43	2.38	2.47	2.41	2.42	2.43	2.41	2.41	-0.87												
$\bar{\mu}_{\text{cum}}$	5	1.94	1.94	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95												
N	2	2	3	2	2	1	1	1	1	1	1	1	-0.60												
$\bar{\mu}_{\text{max}}$	6	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	-0.87												
$\bar{\mu}_{\text{cum}}$	6	2.12	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	0.92												
N	2	1	1	1	1	1	1	1	1	1	1	1	-0.04												
$\bar{\mu}_{\text{max}}$	7	0.74	0.66	1.40	1.71	1.63	1.49	1.26	1.18	1.09	0.97	0.87	-0.14												
$\bar{\mu}_{\text{cum}}$	7	1	1	1	1	1	1	1	1	1	1	1	0.79												
N	1	1	1	1	1	1	1	1	1	1	1	1	0.87												
$\bar{\mu}_{\text{max}}$	8	1.12	1.16	1.29	1.65	2.37	2.20	2.06	2.03	2.04	1.96	1.91	1.87	-0.06											
$\bar{\mu}_{\text{cum}}$	8	0.74	0.78	1.25	1.65	1.42	1.34	1.31	1.37	1.44	1.49	1.39	0.71												
N	1	1	1	2	4	3	2	1	2	1	2	1	0.05												
$\bar{\mu}_{\text{max}}$	10	1.26	1.19	1.19	1.23	1.25	1.28	1.27	1.27	1.27	1.27	1.27	0.42												
$\bar{\mu}_{\text{cum}}$	10	0.44	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49												
N	1	1	1	2	1	2	2	2	2	2	2	2	0.46												

10 - story frame, Target ductility 4, elastoplastic model

		Nominal duration																							
		6	8	10	12	14	16	18	20	22	24	26	28	29	30	31	32	33	34	35	36	37	38	39	
Nominal duration		6	8	10	12	14	16	18	20	22	24	26	28	29	30	31	32	33	34	35	36	37	38	39	
Hox input energy		390.7	460.4	431.0	410.1	419.1	467.7	467.6	479.3	510.4	541.1	542.7	0.95												
Hyst. dissip energy		259.4	255.4	255.2	238.7	210.6	206.9	211.6	207.9	205.6	205.1	205.0	-0.80												
$\bar{\mu}_{\text{max}}$	1	2.27	2.27	1.81	1.89	1.20	1.54	1.65	1.65	1.70	1.76	1.76	-0.63												
$\bar{\mu}_{\text{cum}}$	1	2.23	2.25	1.37	0.98	0.64	0.76	0.83	0.82	0.85	0.86	0.82	-0.76												
N	1	1	1	1	1	1	1	1	1	1	1	1	0.78												
$\bar{\mu}_{\text{max}}$	2	2.07	2.11	1.65	1.50	1.40	1.60	1.79	1.86	1.99	1.99	1.99	0.65												
$\bar{\mu}_{\text{cum}}$	2	1.81	1.80	1.89	1.56	1.31	1.12	1.09	1.19	1.16	1.24	1.26	-0.14												
N	2	2	2	3	3	5	5	5	5	5	5	5	0.06												
$\bar{\mu}_{\text{max}}$	3	2.08	2.08	2.04	1.89	1.85	2.11	2.17	2.27	2.25	2.27	2.27	0.71												
$\bar{\mu}_{\text{cum}}$	3	1.78	1.78	1.81	1.83	1.77	1.82	1.92	1.86	1.91	1.73	1.89	0.74												
N	3	3	3	3	2	2	2	2	2	2	2	2	-0.81												
$\bar{\mu}_{\text{max}}$	4	2.65	2.65	2.43	2.43	2.42	2.42	2.42	2.42	2.42	2.42	2.42	-0.87												
$\bar{\mu}_{\text{cum}}$	4	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	0.71												
N	3	3	3	3	2	2	2	2	2	2	2	2	-0.81												
$\bar{\mu}_{\text{max}}$	5	2.65	2.65	2.43	2.43	2.42	2.42	2.42	2.42	2.42	2.42	2.42	-0.87												
$\bar{\mu}_{\text{cum}}$	5	1.94	1.94	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	0.74												
N	2	2	3	3	3	3	3	3	3	3	3	3	-0.04												
$\bar{\mu}_{\text{max}}$	6	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92	-0.87												
$\bar{\mu}_{\text{cum}}$	6	2.12	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	0.92												
N	2	1	1	1	1	1	1	1	1	1	1	1	-0.04												
$\bar{\mu}_{\text{max}}$	7	0.74	0.66	1.40	1.71	1.63	1.49	1.26	1.18	1.09	0.97	0.87	-0.14												
$\bar{\mu}_{\text{cum}}$	7	1	1	1	1	1	1	1	1	1	1	1	0.79												
N	1	1	1	1	1	1	1	1	1	1	1	1	0.87												
$\bar{\mu}_{\text{max}}$	8	1.12	1.16	1.29	1.65	2.37	2.20	2.06	2.03	2.04	1.96	1.91	1.87	-0.06											
$\bar{\mu}_{\text{cum}}$	8	0.74	0.78	1.25	1.65	1.42	1.34	1.31	1.37	1.44															

10 - story frame; Target ductility 4; origin-oriented model															
Nominal duration	6	8	10	12	14	16	18	20	22	24	26	28	ρ		
Max input energy	146.3	155.2	165.3	175.2	185.3	195.2	205.2	215.2	225.2	235.2	245.2	255.2	265.2	275.2	285.2
Hydrodamp energy	115.6	108.6	100.6	96.7	101.7	107.3	114.6	119.1	145.9	142.4	138.5	135.6	0.74	0.84	0.68
$\mu_{\text{max}}$	2.08	3.19	2.76	1.71	1.92	3.29	3.10	3.13	3.21	3.16	3.01	0.24			
$\mu_{\text{cum}}$	1.88	2.14	2.14	1.19	0.67	0.68	2.20	2.06	2.05	2.19	2.14	1.98	0.25		
N	3	3	2	4	6	6	5	6	6	5	6	5	0.64		
$\mu_{\text{max}}$	2.85	2.84	2.95	2.68	2.29	2.29	2.03	2.56	2.04	2.90	2.32	2.93	0.20		
$\mu_{\text{cum}}$	1.81	1.80	1.82	1.67	1.25	1.25	1.02	1.82	1.90	1.80	1.87	1.85	0.17		
N	2	2	2	2	4	5	5	4	5	4	5	4	0.82		
$\mu_{\text{max}}$	2.75	2.65	2.74	2.94	2.83	2.65	3.14	2.35	3.17	3.23	2.25	3.22	0.16		
$\mu_{\text{cum}}$	1.73	1.61	1.71	1.51	1.79	1.51	2.10	2.29	2.06	2.17	2.22	2.27	0.84		
N	3	3	2	2	3	4	4	4	4	4	4	4	0.68		
$\mu_{\text{max}}$	2.50	2.33	2.37	2.65	2.70	2.62	2.76	2.96	2.87	2.34	2.53	2.98	0.91		
$\mu_{\text{cum}}$	1.48	1.30	1.37	1.62	1.68	1.51	1.17	1.91	1.84	1.87	1.83	1.95	0.91		
N	3	3	3	2	2	3	3	3	3	3	3	3	0.21		
$\mu_{\text{max}}$	2.36	2.16	2.18	2.33	2.48	2.49	2.59	2.67	2.66	2.58	2.54	2.51	0.74		
$\mu_{\text{cum}}$	1.24	1.15	1.13	1.32	1.40	1.47	1.58	1.59	1.67	1.51	1.51	1.51	0.74		
N	2	2	2	2	2	2	2	2	2	2	2	2	0.21		
$\mu_{\text{max}}$	2.09	1.83	1.77	1.97	2.32	2.44	2.56	2.57	2.55	2.31	2.20	2.11	0.51		
$\mu_{\text{cum}}$	1.07	0.79	0.78	0.94	1.20	1.41	1.55	1.57	1.55	1.29	1.16	1.10	0.52		
N	2	2	2	2	2	2	2	2	2	2	2	2	0.00		
$\mu_{\text{max}}$	1.82	1.46	1.38	1.82	2.36	2.64	2.82	2.80	2.79	2.43	2.16	1.64	0.64		
$\mu_{\text{cum}}$	0.79	0.46	0.37	0.29	1.34	1.60	1.60	1.71	1.74	1.42	1.25	1.15	0.53		
N	2	2	2	2	2	2	2	2	2	2	2	2	0.00		
$\mu_{\text{max}}$	1.52	1.47	1.41	2.22	2.50	2.67	2.68	2.69	2.47	2.33	2.22	2.11	0.71		
$\mu_{\text{cum}}$	0.41	0.43	0.43	0.17	1.14	1.41	1.59	1.60	1.62	1.41	1.39	1.18	0.22		
N	1	1	2	2	2	2	2	2	2	2	2	2	0.51		
$\mu_{\text{max}}$	1.48	1.54	1.50	1.61	1.61	1.76	1.80	1.80	1.81	1.75	1.70	1.67	0.53		
$\mu_{\text{cum}}$	0.42	0.48	0.44	0.55	0.65	0.73	0.76	0.78	0.80	0.74	0.69	0.66	0.55		
N	1	1	1	1	1	2	2	2	2	1	1	1	0.63		
$\mu_{\text{max}}$	1.19	1.18	1.18	1.21	1.25	1.27	1.27	1.27	1.27	1.24	1.23	1.22	0.29		
$\mu_{\text{cum}}$	0.24	0.19	0.18	0.17	0.22	0.25	0.25	0.25	0.25	0.24	0.24	0.16	0.18		
N	1	1	1	1	1	1	1	1	1	1	1	1	0.00		

Nominal duration	6	8	10	12	14	16	18	20	22	24	26	28	ρ		
Max input energy	146.3	155.2	165.3	175.2	185.3	195.2	205.2	215.2	225.2	235.2	245.2	255.2	265.2	275.2	285.2
Hydrodamp energy	115.6	108.6	100.6	96.7	101.7	107.3	114.6	119.1	145.9	142.4	138.5	135.6	0.74	0.84	0.68
$\mu_{\text{max}}$	2.08	3.19	2.76	1.71	1.92	3.29	3.10	3.13	3.21	3.16	3.01	0.24			
$\mu_{\text{cum}}$	1.88	2.14	2.14	1.19	0.67	0.68	2.20	2.06	2.05	2.19	2.14	1.98	0.25		
N	3	3	2	4	6	6	5	6	6	5	6	5	0.64		
$\mu_{\text{max}}$	2.85	2.84	2.95	2.68	2.29	2.29	2.03	2.56	2.04	2.90	2.32	2.93	0.20		
$\mu_{\text{cum}}$	1.81	1.80	1.82	1.67	1.25	1.25	1.02	1.82	1.90	1.80	1.87	1.85	0.17		
N	2	2	2	2	4	5	5	4	5	4	5	4	0.82		
$\mu_{\text{max}}$	2.75	2.65	2.74	2.94	2.83	2.65	3.14	2.35	3.17	3.23	2.25	3.22	0.16		
$\mu_{\text{cum}}$	1.73	1.61	1.71	1.51	1.79	1.51	2.10	2.29	2.06	2.17	2.22	2.27	0.84		
N	3	3	2	2	3	4	4	4	4	4	4	4	0.68		
$\mu_{\text{max}}$	2.50	2.33	2.37	2.65	2.70	2.62	2.76	2.96	2.87	2.34	2.53	2.98	0.91		
$\mu_{\text{cum}}$	1.48	1.30	1.37	1.62	1.68	1.51	1.17	1.91	1.84	1.87	1.83	1.95	0.91		
N	2	2	2	2	2	2	3	3	3	3	3	3	0.21		
$\mu_{\text{max}}$	2.36	2.16	2.18	2.33	2.48	2.49	2.59	2.67	2.66	2.58	2.54	2.51	0.74		
$\mu_{\text{cum}}$	1.24	1.15	1.13	1.32	1.40	1.47	1.58	1.59	1.67	1.51	1.51	1.51	0.74		
N	2	2	2	2	2	2	2	2	2	2	2	2	0.21		
$\mu_{\text{max}}$	2.09	1.83	1.77	1.97	2.32	2.44	2.56	2.57	2.55	2.31	2.20	2.11	0.51		
$\mu_{\text{cum}}$	1.07	0.79	0.78	0.94	1.20	1.41	1.55	1.57	1.55	1.29	1.16	1.10	0.52		
N	2	2	2	2	2	2	2	2	2	2	2	2	0.00		
$\mu_{\text{max}}$	1.82	1.46	1.38	1.82	2.36	2.64	2.82	2.80	2.79	2.43	2.16	1.79	0.64		
$\mu_{\text{cum}}$	0.79	0.46	0.37	0.29	1.34	1.60	1.60	1.71	1.74	1.42	1.25	1.15	0.53		
N	2	2	2	2	2	2	2	2	2	2	2	2	0.00		
$\mu_{\text{max}}$	1.52	1.47	1.41	2.22	2.50	2.67	2.68	2.69	2.47	2.33	2.22	2.11	0.71		
$\mu_{\text{cum}}$	1.01	0.43	0.43	0.17	1.14	1.41	1.59	1.60	1.62	1.41	1.39	1.18	0.22		
N	1	1	2	2	2	2	2	2	2	2	2	2	0.51		
$\mu_{\text{max}}$	1.48	1.54	1.50	1.61	1.61	1.76	1.80	1.80	1.81	1.75	1.70	1.67	0.53		
$\mu_{\text{cum}}$	0.42	0.48	0.44	0.55	0.65	0.73	0.76	0.78	0.80	0.74	0.69	0.66	0.55		
N	1	1	1	1	1	2	2	2	2	1	1	1	0.63		
$\mu_{\text{max}}$	1.26	1.19	1.18	1.21	1.25	1.27	1.27	1.27	1.27	1.24	1.23	1.22	0.29		
$\mu_{\text{cum}}$	0.24	0.19	0.18	0.17	0.22	0.25	0.25	0.25	0.25	0.24	0.24	0.16	0.18		
N	1	1	1	1	1	1	1	1	1	1	1	1	0.00		

Nominal duration	6	8	10	12	14	16	18	20	22	24	26	28	ρ		
Max input energy	146.3	155.2	165.3	175.2	185.3	195.2	205.2	215.2	225.2	235.2	245.2	255.2	265.2	275.2	285.2
Hydrodamp energy	115.6	108.6	100.6	96.7	101.7	107.3	114.6	119.1	145.9	142.4	138.5	135.6	0.74	0.84	0.68
$\mu_{\text{max}}$	2.08	3.19	2.76	1.71	1.92	3.29	3.10	3.13	3.21	3.16	3.01	0.24			
$\mu_{\text{cum}}$	1.88	2.14	2.14	1.19	0.67	0.68	2.20	2.06	2.05	2.19	2.14	1.98	0.25		
N	3	3	2	4	6	6	5	6	6	5	6	5	0.64		
$\mu_{\text{max}}$	2.85	2.84	2.95	2.68	2.29	2.29	2.03	2.56	2.04	2.90	2.32	2.93	0.20		
$\mu_{\text{cum}}$	1.81	1.80	1.82	1.67	1.25	1.25	1.02	1.82	1.90	1.80	1.87	1.85	0.17		
N	2	2	2	2	4	5	5	4	5	4	5	4	0.82		
$\mu_{\text{max}}$	2.75	2.65	2.74	2.94	2.83	2.65	3.14	2.35	3.17	3.23	2.25	3.22	0.16		
$\mu_{\text{cum}}$	1.73	1.61	1.71	1.51	1.79	1.51	2.10	2.29	2.06	2.17	2.22	2.27	0.84		
N	3	3	2	2	3	3	3	3	3	3	3	3	0.2		

5 - story frame; Target ductility 2 ; elastoplastic model													
Nominal duration	6	8	10	12	14	16	18	20	22	24	26	28	0
Max.input energy	231.9	235.2	281.1	259.2	266.5	323.2	380.4	415.9	436.0	465.7	468.3	482.6	0.96
Hyst.dissip.energy	114.0	126.8	149.2	139.3	133.9	136.6	188.5	213.2	232.3	231.9	227.6	224.9	0.92
1	$\mu_{\max}$	1.70	1.61	1.63	1.30	1.31	1.25	1.43	1.46	1.47	1.44	1.43	1.48
	$\mu_{\text{cum}}$	0.95	1.09	1.23	0.82	0.66	0.67	1.46	1.90	2.23	2.60	2.65	2.66
	N	4	5	5	5	7	11	12	12	11	11	12	0.90
2	$\mu_{\max}$	2.11	1.94	1.88	1.65	1.46	1.45	1.46	1.46	1.54	1.69	1.57	1.49
	$\mu_{\text{cum}}$	1.71	1.97	2.32	2.06	1.94	1.91	2.49	2.85	3.15	2.85	2.69	2.46
	N	4	5	7	6	6	7	10	11	11	11	10	0.93
3	$\mu_{\max}$	1.81	1.57	1.80	1.98	2.0	1.95	2.07	2.06	2.05	1.90	1.84	1.78
	$\mu_{\text{cum}}$	1.81	1.95	2.38	2.64	2.61	2.53	2.64	2.76	2.78	2.49	2.48	2.42
	N	4	4	8	6	5	6	8	8	10	10	10	0.85
4	$\mu_{\max}$	1.52	1.48	1.61	1.78	1.82	1.90	2.02	2.05	2.08	2.05	2.02	1.98
	$\mu_{\text{cum}}$	0.94	1.0	1.08	1.08	1.14	1.34	2.23	2.42	2.52	2.51	2.61	2.66
	N	3	3	5	5	5	6	9	9	9	8	9	0.95
5	$\mu_{\max}$	1.35	1.38	1.62	1.71	1.68	1.72	1.87	1.93	1.96	1.96	1.93	1.93
	$\mu_{\text{cum}}$	0.48	0.39	0.63	0.81	1.05	1.19	1.60	1.72	1.84	2.02	1.98	1.99
	N	4	3	5	4	4	4	8	8	8	8	8	0.87

5 - story frame; Target ductility 4 ; elastoplastic model													
Nominal duration	6	8	10	12	14	16	18	20	22	24	26	28	0
Max.input energy	151.8	187.2	256.1	239.9	254.8	280.9	312.7	333.8	361.1	386.5	390.6	401.0	0.99
Hyst.dissip.energy	101.2	138.6	176.1	167.0	173.0	193.1	228.2	242.5	258.3	269.4	271.7	274.9	0.99
1	$\mu_{\max}$	4.65	4.29	4.40	4.66	5.38	5.98	6.97	7.28	7.35	7.46	7.39	7.37
	$\mu_{\text{cum}}$	6.00	6.73	7.98	7.39	8.52	10.38	13.46	14.64	15.85	17.45	17.51	17.64
	N	7	10	13	10	14	15	15	15	16	16	17	16
2	$\mu_{\max}$	3.17	2.83	3.13	4.28	5.07	4.96	4.68	4.80	4.84	4.43	4.29	4.28
	$\mu_{\text{cum}}$	4.67	6.48	7.55	7.72	7.82	8.67	10.88	11.51	11.98	11.51	11.29	10.90
	N	5	9	13	8	14	15	15	16	17	17	17	0.90
3	$\mu_{\max}$	3.36	3.38	3.33	3.40	3.76	3.47	2.87	2.83	2.77	2.68	2.71	2.68
	$\mu_{\text{cum}}$	3.58	6.08	7.90	7.02	6.03	6.07	6.06	6.40	6.99	6.48	6.61	6.99
	N	3	7	11	10	13	16	15	14	15	17	17	0.94
4	$\mu_{\max}$	3.78	4.22	4.24	3.81	3.77	3.89	3.78	3.67	3.67	3.50	3.45	3.41
	$\mu_{\text{cum}}$	3.95	6.86	9.97	9.00	9.30	10.09	10.31	10.70	11.18	12.37	13.23	13.57
	N	4	9	11	9	12	14	13	15	16	21	21	0.96
5	$\mu_{\max}$	2.66	2.77	2.74	2.88	3.17	3.17	2.97	2.94	2.92	2.82	2.76	2.73
	$\mu_{\text{cum}}$	2.54	3.59	5.21	5.84	7.05	7.31	7.73	8.10	8.27	8.38	8.65	8.83
	N	4	8	11	12	12	15	18	18	18	22	24	0.99

5-story frame; Target ductility 2; origin-oriented model													
Nominal duration	6	8	10	12	14	16	18	20	22	24	26	28	$\varphi$
Max. input energy	195.6	195.6	201.4	234.7	268.7	305.0	375.0	391.9	394.0	405.0	401.5	365.0	0.92
Hyst. dissip. energy	41.2	35.9	34.1	42.7	44.7	49.2	70.7	73.8	76.7	73.9	66.3	53.4	0.77
1	$\mu_{\max}$	1.89	1.69	1.62	1.27	1.14	1.36	2.84	2.92	3.08	2.37	2.04	1.57
	$\mu_{\text{cum}}$	0.86	0.69	0.59	0.25	0.13	0.35	1.80	1.85	1.99	1.32	1.01	0.57
	N	4	2	2	2	3	3	5	5	5	5	5	0.74
2	$\mu_{\max}$	2.41	2.47	2.52	1.73	1.52	1.62	2.64	2.78	2.87	2.69	2.16	1.86
	$\mu_{\text{cum}}$	1.37	1.43	1.48	0.73	0.50	0.61	1.61	1.73	1.82	1.62	1.15	0.82
	N	5	3	4	3	3	3	5	5	5	7	6	0.52
3	$\mu_{\max}$	2.02	1.96	1.79	2.68	2.95	3.09	2.79	2.74	2.75	2.58	2.84	2.85
	$\mu_{\text{cum}}$	0.98	0.94	0.74	1.58	1.86	1.99	1.76	1.68	1.70	1.52	1.79	1.77
	N	4	3	3	4	4	4	4	4	4	5	6	0.75
4	$\mu_{\max}$	1.30	1.17	1.09	2.77	3.09	2.94	2.21	2.22	2.13	3.43	3.44	2.99
	$\mu_{\text{cum}}$	0.26	0.15	0.08	1.65	1.98	1.84	1.11	1.10	1.02	2.22	2.23	1.85
	N	2	2	2	4	5	5	4	4	4	7	7	0.87
5	$\mu_{\max}$	1.41	1.25	1.18	1.69	2.03	2.15	1.71	1.72	1.72	2.25	2.27	2.22
	$\mu_{\text{cum}}$	0.37	0.25	0.16	0.60	0.96	1.09	0.66	0.65	0.65	1.16	1.08	1.10
	N	3	2	2	4	5	5	2	2	2	4	4	0.21

5-story frame; Target ductility 4; origin-oriented model													
Nominal duration	6	8	10	12	14	16	18	20	22	24	26	28	$\varphi$
Max. input energy	158.3	140.7	163.2	147.8	150.2	182.3	241.1	253.3	245.6	262.8	253.8	248.9	0.89
Hyst. dissip. energy	49.4	47.8	47.8	42.1	41.9	41.2	53.2	54.1	54.7	52.2	51.5	49.1	0.43
1	$\mu_{\max}$	6.80	6.82	7.17	5.95	5.99	6.18	8.60	9.05	9.15	8.64	8.46	8.34
	$\mu_{\text{cum}}$	5.53	5.64	5.98	4.86	4.95	4.99	7.56	8.00	8.07	7.48	7.26	7.27
	N	4	4	4	4	3	3	5	4	4	4	5	4
2	$\mu_{\max}$	6.36	6.09	6.13	5.74	4.83	4.47	5.27	5.15	5.20	5.44	5.72	5.80
	$\mu_{\text{cum}}$	5.29	4.96	5.02	4.67	3.79	3.44	4.23	4.10	4.15	4.41	4.66	4.79
	N	3	3	3	2	2	1	4	2	3	4	2	-0.06
3	$\mu_{\max}$	4.76	4.70	4.33	4.07	3.86	3.40	3.81	3.54	3.55	3.47	3.33	3.06
	$\mu_{\text{cum}}$	3.63	3.59	3.27	2.97	2.77	2.38	2.77	2.51	2.54	2.43	2.27	2.05
	N	3	3	3	3	3	4	3	3	3	3	3	-0.05
4	$\mu_{\max}$	3.90	3.64	3.41	2.88	3.74	4.03	4.50	4.55	4.63	4.15	3.84	3.56
	$\mu_{\text{cum}}$	2.81	2.60	2.28	1.78	2.63	2.96	3.39	3.46	3.51	3.02	2.69	2.50
	N	3	3	3	3	3	4	4	3	3	3	4	0.25
5	$\mu_{\max}$	1.77	1.53	1.53	2.89	4.64	5.15	4.99	5.07	5.15	4.39	4.08	3.84
	$\mu_{\text{cum}}$	0.75	0.49	0.43	1.68	3.48	3.90	3.67	3.66	4.00	3.27	2.99	2.72
	N	3	2	2	3	3	4	4	4	4	3	3	0.43