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INFLUENCE OF MODELING PARAMETERS ON STEEL FRAME BUILDING RESPONSE

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SUMMARY

The purpose of this paper is to quantify the sensitivity of building response to variations in modeling parameters and assumptions for the mid-rise building in this study. Three levels of seismic hazard levels are used as input ground motion. The study shows:

1. Approximate models of the beam-column joint region, such as the Centerline, Rigid End Zone, and Scissors Models, can have a significant impact on system response quantities.
2. Component responses such as beam plastic rotation and panel-zone plastic rotation are significantly affected by modeling assumptions.
3. For all seismic hazard levels, the analysis shows similar normalized global response and in general, the benchmark model yields conservative results.

INTRODUCTION

Nonlinear time-history analysis is often used to assess the performance of buildings subjected to strong earthquake ground motions. Such an analysis requires a detailed analytical computer model of the structure and involves the selection of various modeling parameters and techniques. Engineers will oftentimes have different approaches to the same problem or make simplifying assumptions to reduce the effort associated with obtaining the results. Thus, due to the uncertainty and variability associated with analytical modeling, the results of any analysis should be carefully considered.

BUILDING DESCRIPTION

A six-story building with four levels of subterranean parking located in Southern California was selected for this study. The lateral force resisting system consists of a pair of two-bay welded steel moment-resisting frames in each of the principal directions of the building and perimeter concrete walls at the parking levels. The design of this building specified A36 steel for the beams and A572, Gr. 50 steel for the columns and doubler plates. The typical floor system is composed of an 18 gauge 3 inches deep metal deck with 2-1/2” of hard rock concrete fill.

DRAIN-2DX MODELS

The two-dimensional nonlinear computer program DRAIN-2DX was selected as the analytical tool for this study. All computer models used in the analysis and their initial elastic fundamental period are described below.

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A nonlinear model of one of the building frames, shown in Figure 1, was created and is referred to as the *Benchmark* model (T_1=1.41 sec). This model is considered by the authors to be the most appropriate representation of the building frame for a nonlinear analysis. The floor levels are modeled as rigid diaphragms and the levels including and below the first floor are laterally restrained. A bilinear moment-curvature relation with a modulus of elasticity of 29000 ksi and a post-yield stiffness ratio of 3% is used to represent the stiffness of the beams and columns. The strength of the elements is represented by a failure surface that can account for moment and axial force interaction. Composite slab-beam behavior is not considered. The beam-column panel zone is modeled using the approach employed by Krawinkler [Krawinkler, et. al. 1998] and is shown in Figure 2c. Rigid elements are used to model the rectangular boundaries of the panel zone such that the region may deform into a parallelogram. Two bilinear springs in parallel are used to model the trilinear stiffness and strength behavior as suggested by Krawinkler [Krawinkler, et. al. 1975]. Expected yield strengths of the steel were assumed using the values from tensile tests on wide flange structural shapes [SSPC, 1994]. Mass and stiffness proportional damping of 2% was specified for the fundamental mode and a frequency of 2 Hz. For steel frame buildings with few internal walls, a damping ratio between 0.5% and 2.5% [Cook, 1985] is typically used to account for the structural damping provided by partitions, connections, and other items not explicitly modeled. One-half of the building mass is lumped at the column locations at each level of the frame and tributary dead loads are applied to the beams and columns. The P-Delta induced shear is accounted for by including a fictitious column with geometric stiffness only and applying one-half of the building dead load as nodal loads at each floor level

Seven sensitivity models were created in order to investigate the sensitivity of the building response to a number of parameters and assumptions associated with analytical nonlinear computer modeling. Each model is identical to the Benchmark model, except for one variation. The Centerline model (T_1=1.50 sec) completely ignores the strength and stiffness of the panel zones, see Figure 2a. The Rigid End Zone model (T_1=1.27 sec) is similar to the Centerline model but includes rigid end offsets in the beams and columns. The Scissors model (T_1=1.53 sec) is similar to the Rigid End Zone model but includes a pair of bilinear rotational springs [Krawinkler et al., 1975] connected at the centerline of the beam-column intersection. This is to account for the strength and stiffness of the beam-column panel zone, see Figure 2b. The Design Strength model (T_1=1.41 sec) uses the design steel strengths for the beam, column, and panel zone properties. The 5% Damping model (T_1=1.41 sec) employs 5% damping in the fundamental mode and 2 Hz frequency. The Basement model (T_1=1.38 sec) completely restrains the columns at twenty feet below the first floor and the No P-Delta model (T_1=1.39 sec) ignores the effect of the P-Delta induced shear.

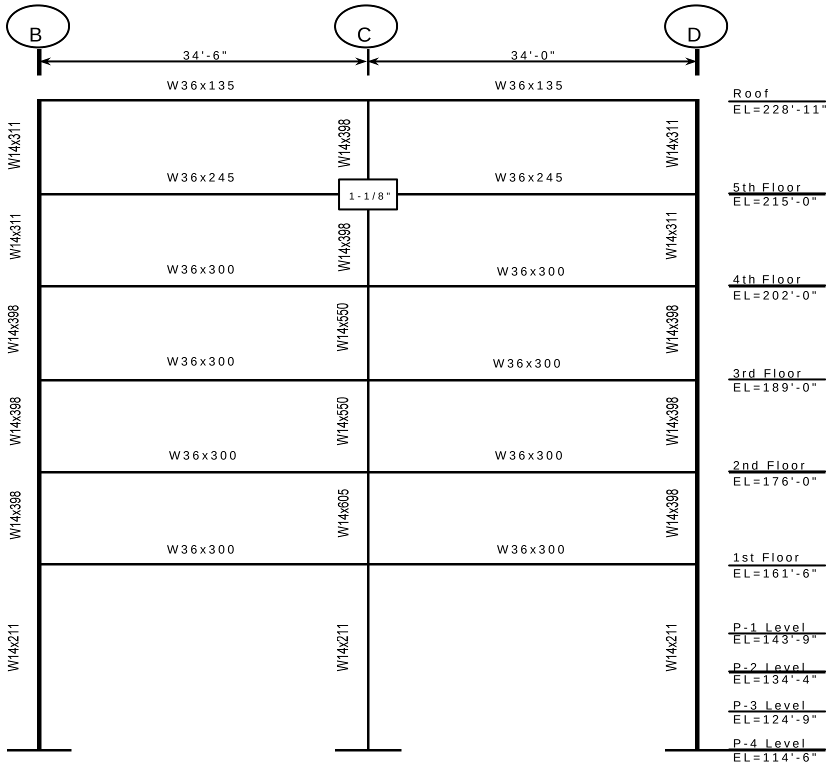
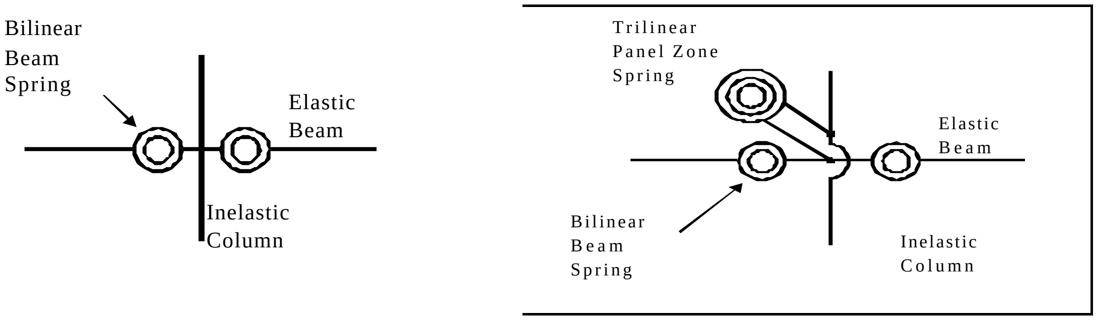
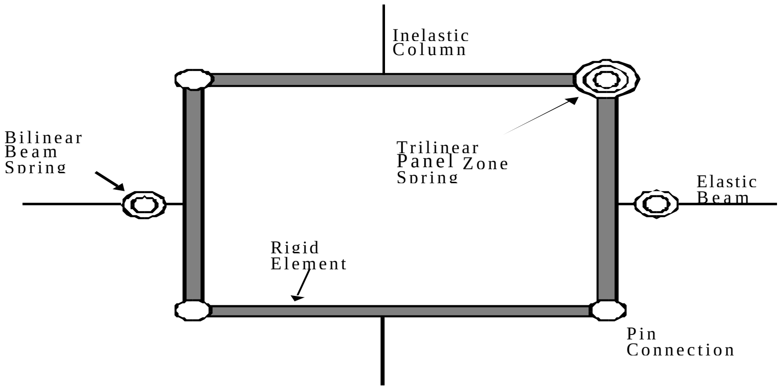


Figure 1 - Elevation view of model frame



(a) Centerline model **(b) Scissors model**



(c) Benchmark model

Figure 2 - Beam-column joint models

EARTHQUAKE GROUND MOTION

The earthquake ground motion time histories selected for this study were obtained from the ground motions developed as part of Phase 2 of the FEMA/SAC Steel Project (Somerville et al., 1997). A total of sixty time histories were selected, twenty from each of three seismic hazard levels with exceedance probabilities of 50% in 50 years, 10% in 50 years, and 2% in 50 years. The mean, mean plus one standard deviation, and mean minus one standard deviation of the 2% damped response spectra for each risk level are shown in Figures 3 through 5

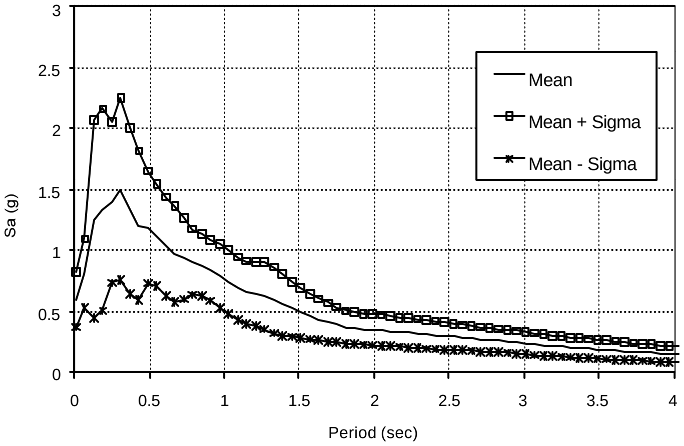


Figure 3 - 2% damped response spectra for 50% in 50 year ground motions

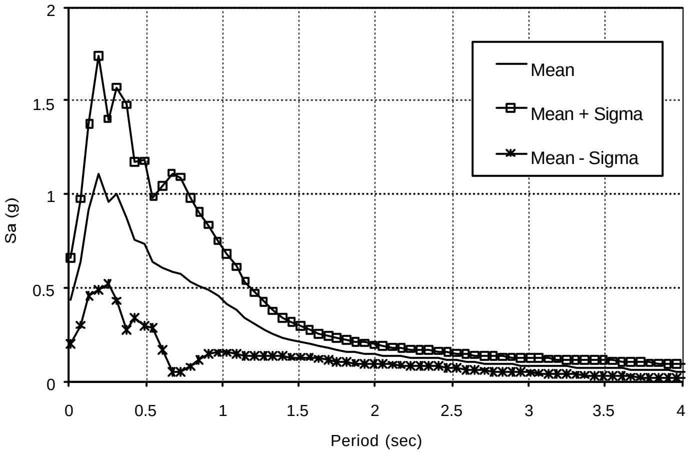


Figure 4 - 2% damped response spectra for 10% in 50 year ground motions

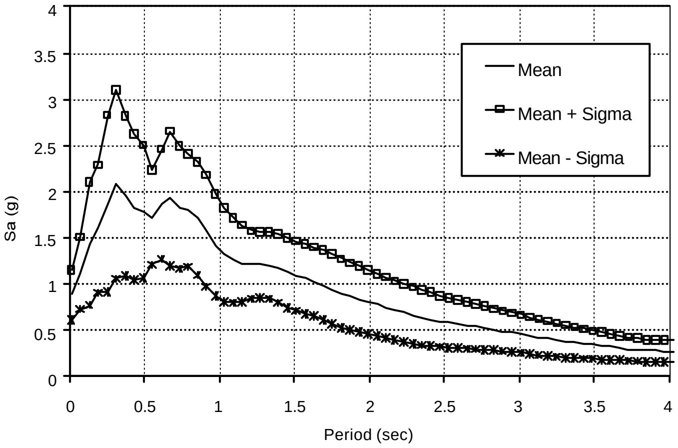


Figure 5 - 2% damped response spectra for 2% in 50 year ground motions

RESULTS

The nonlinear DRAIN-2DX computer models were subjected to sixty earthquake ground motion time histories and both system and component response quantities were tabulated, including: 1) base shear coefficient (base shear/model weight), 2) roof displacement angle, 3) interstory drift angle, 4) beam plastic rotation angle, and 5) panel zone plastic rotation angle. The sample statistics for the response quantity results from all eight computer models are presented in Table 1. Table 2 provides the sample statistics for the normalized response quantity results. The response quantity results are normalized by taking the Benchmark model result and dividing by the result from the Sensitivity model. The mean and coefficient of variation of the normalized results are tabulated for each risk level of ground motion. Figures 6 through 8 show the mean, mean plus one standard deviation, and mean minus one standard deviation normalized roof displacement, interstory drift angle, and base shear coefficient results, respectively.

CONCLUSIONS

It is important to realize that engineers may approach the analytical model of a building in many different ways. The purpose of this paper is to quantify the sensitivity of building response to variations in modeling parameters and assumptions for the mid-rise building in this study.

1. Approximate models of the beam-column joint region, such as the Centerline, Rigid End Zone, and Scissors models, can have a significant impact on system response quantities. It is important to accurately model the joint region in order to obtain realistic system demands.
2. Component responses such as beam plastic rotation and panel-zone plastic rotation are significantly affected by modeling assumptions.
3. For the mid-rise building in this study, the response quantity results are insensitive to P-delta modeling and the modeling of the structure below grade. However, for taller buildings with large column axial loads and significant overturning effects, these modeling assumptions may have considerable influence on building response.
4. The normalized results from all three seismic hazard levels of ground motion shows similar behavior.
5. Global response parameters, roof displacement angle, interstory drift angle and maximum base shear, were studied and the benchmark model generally yields conservative results.

The 1997 Uniform Building Code, UBC, [ICBO, 1997] permits the use of both linear and nonlinear time history analyses for the design of buildings. In such cases, a minimum of three earthquake time-history records, scaled to the appropriate seismic hazard level, are required to perform a time history analysis. For a given parameter of interest, the demand is specified to be the maximum response if three ground motion time histories are used or the average response if using seven or more ground motions. In future work, the validity of this design approach will be studied.

Table 1 - Sample statistics for response quantities

Model	50% in 50 years									
	RDA		IDA		BSC		BPR		PZPR	
	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)
Benchmark	0.007	32.9	0.020	33.7	0.27	22.9	0.00001	216.4	0.00223	126.6
Rigid End Zone	0.007	42.5	0.011	44.5	0.29	25.6	0.00292	152.2	0.00000	0.0
Centerline	0.007	32.9	0.013	27.0	0.27	22.0	0.00147	141.4	0.00000	0.0
Scissors	0.006	27.3	0.011	27.2	0.20	13.6	0.00000	0.0	0.00327	70.2
Design Strength	0.007	32.0	0.020	33.6	0.26	19.9	0.00003	154.2	0.00292	105.9
5% Damping	0.006	39.7	0.016	41.8	0.22	28.0	0.00001	117.9	0.00109	215.8
Basement	0.007	34.9	0.020	36.0	0.27	21.1	0.00001	204.9	0.00237	126.6
No P-Delta	0.007	35.0	0.020	36.2	0.27	22.9	0.00001	222.7	0.00220	137.5

Model	10% in 50 years									
	RDA		IDA		BSC		BPR		PZPR	
	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)
Benchmark	0.013	40.3	0.035	36.3	0.39	17.3	0.00033	159.2	0.01340	83.1
Rigid End Zone	0.013	40.8	0.025	56.1	0.40	13.6	0.01762	91.0	0.00000	0.0
Centerline	0.017	82.1	0.043	127.2	0.35	11.9	0.02159	142.5	0.00000	0.0
Scissors	0.013	55.6	0.023	47.8	0.28	14.4	0.00078	435.9	0.01393	74.2
Design Strength	0.013	45.9	0.036	45.9	0.35	16.2	0.00067	159.1	0.01435	86.0
5% Damping	0.012	39.3	0.032	34.8	0.36	20.2	0.00011	172.5	0.01054	90.9
Basement	0.013	41.2	0.035	36.4	0.39	16.8	0.00033	156.8	0.01384	80.9
No P-Delta	0.013	38.3	0.035	33.9	0.38	16.9	0.00028	152.3	0.01276	77.0

Model	2% in 50 years									
	RDA		IDA		BSC		BPR		PZPR	
	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)
Benchmark	0.025	36.7	0.067	35.0	0.47	9.8	0.00078	78.6	0.03956	56.6
Rigid End Zone	0.023	37.5	0.048	46.2	0.45	5.3	0.04393	60.2	0.00000	0.0
Centerline	0.027	39.3	0.065	52.5	0.38	6.3	0.03955	58.9	0.00000	0.0
Scissors	0.028	41.2	0.047	36.0	0.35	11.6	0.00905	86.1	0.03611	44.1
Design Strength	0.025	36.6	0.067	37.8	0.42	10.1	0.00119	80.1	0.03895	51.9
5% Damping	0.023	35.4	0.060	32.0	0.46	10.6	0.00027	71.2	0.03473	59.6
Basement	0.025	36.8	0.066	35.6	0.47	9.5	0.00076	77.1	0.03956	55.7
No P-Delta	0.025	37.5	0.066	31.5	0.46	9.1	0.00067	69.4	0.03890	58.1

RDA - Roof Displacement Angle
IDA - Interstory Drift Angle
BSC - Base Shear Coefficient
BPR - Beam Plastic Rotation
PZPR - Panel Zone Plastic Rotation

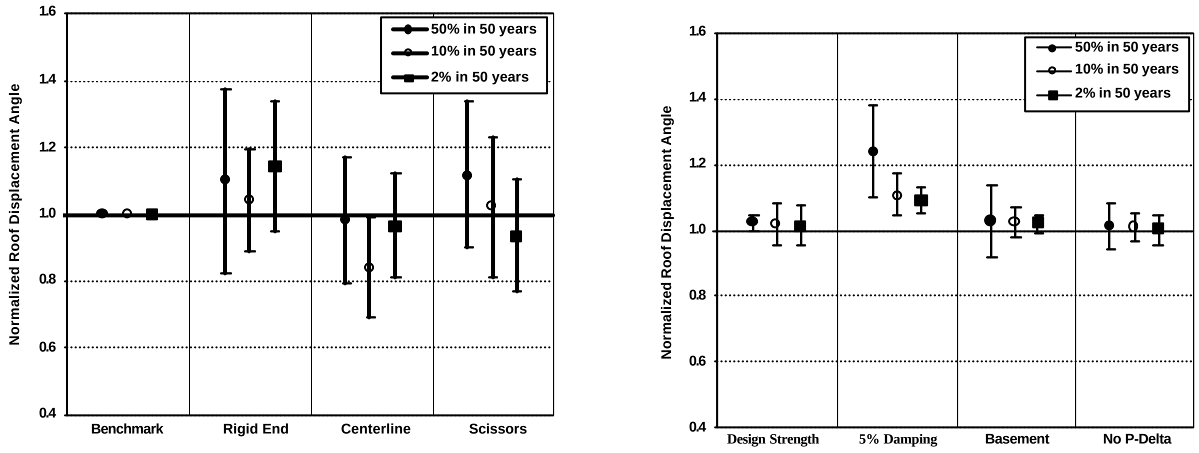


Figure 6 - Normalized maximum roof displacement results (Benchmark/Sensitivity)

Table 2 - Sample statistics for normalized response quantities (Benchmark/Sensitivity)

Model	50% in 50 years					
	RDA		IDA		BSC	
	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)
Benchmark	1.00	0.0	1.00	0.0	1.00	0.0
Rigid End Zone	1.10	25.1	1.90	25.1	0.94	19.3
Centerline	0.98	19.2	1.53	23.9	1.00	13.7
Scissors	1.12	19.3	1.82	20.1	1.35	14.0
Design Strength	1.02	2.5	1.01	2.3	1.05	4.4
5% Damping	1.24	11.4	1.26	11.2	1.23	8.3
Basement	1.03	10.6	1.02	8.4	0.99	4.9
No P-Delta	1.01	7.0	1.02	6.1	1.01	4.3

Model	10% in 50 years					
	RDA		IDA		BSC	
	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)
Benchmark	1.00	0.0	1.00	0.0	1.00	0.0
Rigid End Zone	1.04	14.8	1.53	26.2	0.97	7.4
Centerline	0.84	17.7	1.13	27.9	1.09	11.1
Scissors	1.02	20.5	1.60	25.5	1.37	11.2
Design Strength	1.02	6.5	1.00	8.5	1.09	3.8
5% Damping	1.11	5.8	1.11	6.5	1.07	5.0
Basement	1.02	4.3	1.01	2.8	0.99	1.3
No P-Delta	1.01	4.3	1.02	7.6	1.01	1.8

Model	2% in 50 years					
	RDA		IDA		BSC	
	Mean	COV(%)	Mean	COV(%)	Mean	COV(%)
Benchmark	1.00	0.0	1.00	0.0	1.00	0.0
Rigid End Zone	1.14	16.9	1.48	24.0	1.05	5.7
Centerline	0.97	16.0	1.14	28.7	1.24	5.8
Scissors	0.94	17.9	1.46	20.4	1.34	8.5
Design Strength	1.02	6.0	1.01	5.2	1.11	2.1
5% Damping	1.09	3.5	1.12	5.1	1.02	2.4
Basement	1.02	2.7	1.02	2.6	1.00	0.9
No P-Delta	1.00	4.5	1.02	5.7	1.01	1.6

RDA - Roof Displacement Angle
IDA - Interstory Drift Angle
BSC - Base Shear Coefficient

BPR - Beam Plastic Rotation
PZPR - Panel Zone Plastic Rotation

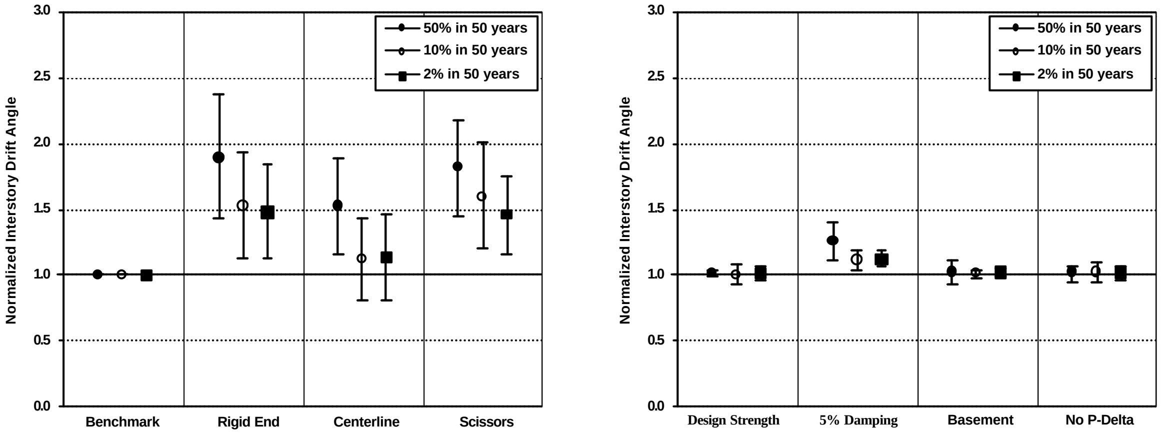


Figure 7 - Normalized maximum interstory drift results (Benchmark/Sensitivity)

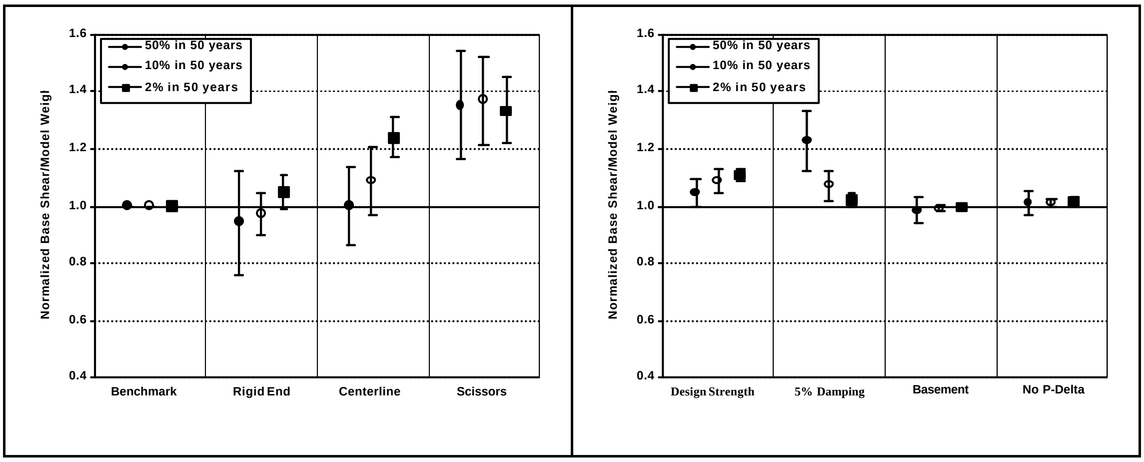


Figure 8 - Normalized maximum base shear coefficient results (Benchmark/Sensitivity)

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