NATIONAL CENTER FOR EARTHQUAKE
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State University of New York at Buffalo

STATISTICAL EVALUATION OF DEFLECTION AMPLIFICATION FACTORS FOR REINFORCED CONCRETE STRUCTURES

by

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Technical Report NCEER-89-0028

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PREFACE

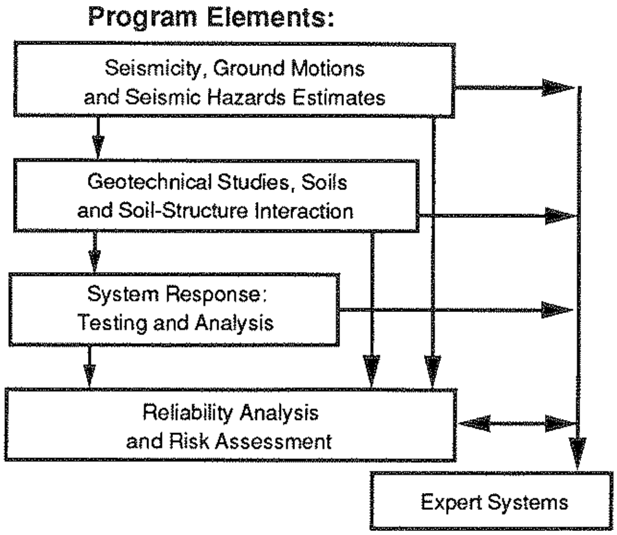
The National Center for Earthquake Engineering Research (NCEER) is devoted to the expansion and dissemination of knowledge about earthquakes, the improvement of earthquake-resistant design, and the implementation of seismic hazard mitigation procedures to minimize loss of lives and property. The emphasis is on structures and lifelines that are found in zones of moderate to high seismicity throughout the United States.

NCEER's research is being carried out in an integrated and coordinated manner following a structured program. The current research program comprises four main areas:

- Existing and New Structures
- Secondary and Protective Systems
- Lifeline Systems
- Disaster Research and Planning

This technical report pertains to Program 1, Existing and New Structures, and more specifically to reliability analysis and risk assessment.

The long term goal of research in Existing and New Structures is to develop seismic hazard mitigation procedures through rational probabilistic risk assessment for damage or collapse of structures, mainly existing buildings, in regions of moderate to high seismicity. This work relies on improved definitions of seismicity and site response, experimental and analytical evaluations of systems response, and more accurate assessment of risk factors. This technology will be incorporated in expert systems tools and improved code formats for existing and new structures. Methods of retrofit will also be developed. When this work is completed, it should be possible to characterize and quantify societal impact of seismic risk in various geographical regions and large municipalities. Toward this goal, the program has been divided into five components, as shown in the figure below:



Tasks:

Earthquake Hazards Estimates,
Ground Motion Estimates,
New Ground Motion Instrumentation,
Earthquake & Ground Motion Data Base.

Site Response Estimates,
Large Ground Deformation Estimates,
Soil-Structure Interaction.

Typical Structures and Critical Structural Components:
Testing and Analysis;
Modern Analytical Tools.

Vulnerability Analysis,
Reliability Analysis,
Risk Assessment,
Code Upgrading.

Architectural and Structural Design,
Evaluation of Existing Buildings.

Reliability analysis and risk assessment research constitutes one of the important areas of Existing and New Structures. Current research addresses, among others, the following issues:

1. Code issues - Development of a probabilistic procedure to determine load and resistance factors. Load Resistance Factor Design (LRFD) includes the investigation of wind vs. seismic issues, and of estimating design seismic loads for areas of moderate to high seismicity.
2. Response modification factors - Evaluation of RMFs for buildings and bridges which combine the effect of shear and bending.
3. Seismic damage - Development of damage estimation procedures which include a global and local damage index, and damage control by design; and development of computer codes for identification of the degree of building damage and automated damage-based design procedures.
4. Seismic reliability analysis of building structures - Development of procedures to evaluate the seismic safety of buildings which includes limit states corresponding to serviceability and collapse.
5. Retrofit procedures and restoration strategies.
6. Risk assessment and societal impact.

Research projects concerned with reliability analysis and risk assessment are carried out to provide practical tools for engineers to assess seismic risk to structures for the ultimate purpose of mitigating societal impact.

This study addresses the issues of determining deflection amplification factors for reinforced concrete structures. Statistical modeling techniques are used to produce structural response data. From these results, deflection amplification factors are determined and compared with those specified in NEHRP. Results indicate that the NEHRP recommendations are too large and overestimate the design story drifts.

ABSTRACT

This report presents a statistical evaluation of the deflection amplification factors C_d for reinforced concrete structures. Twelve multi-degree-of-freedom structural models with various dynamic characteristics are first constructed. Next, ninety synthetic earthquakes are generated from three power spectra representing different soil conditions. Then, the nonlinear and corresponding linear time history analyses are performed to produce structural response data. These data are used to derive an empirical formula for the C_d factor by the regression analysis. On the basis of this empirical formula, the C_d factors for the design of building structures are recommended. From the comparison of the proposed C_d factors with those specified in NEHRP Recommended Provisions, it appears that most of the C_d factors specified in the NEHRP Provisions are too large and consequently the design story drifts of structures are overestimated.

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SECTION 1
INTRODUCTION

The current seismic design criteria for building structures such as the NEHRP Recommended Provisions [1] allow structures to undergo inelastic deformations under a specified design earthquake. In addition, the equivalent linear design procedure is also stipulated to facilitate the design process. The effects of inelastic deformation are included in the equivalent linear design procedure by introducing the response modification factor R and the deflection amplification factor C_d. The response modification factor is used to reduce the design base shear from an elastic response level to an equivalent nonlinear level, while the deflection amplification factor C_d is used to convert the linear interstory displacement to a corresponding nonlinear value.

In the NEHRP Recommended Provisions, a constant value of the response modification factor R is assigned to each type of structure depending on the construction material and seismic resisting system. The recommended R values reflect the experience of code committees on the performance of different structural systems and implicitly account for both damping and ductility in the structural systems. Recently, a statistical evaluation of the R factors for reinforced concrete structures has been carried out [2]. From a multivariate nonlinear regression analysis, an empirical formula for the R factor is established. It is found that the R factor is not a constant value. Rather, it is a function of the maximum story ductility ratio, viscous damping ratio, fundamental period of structure and dominant period of earthquake motion. Furthermore, it is also found that the R factors specified in the NEHRP Provisions are too large and unconservative.

In the NEHRP Recommended Provisions, the deflection amplification factor C_d is also specified for each type of structure. In establishing C_d values, the allowable ductility expected for each type of structure has not been taken into consideration explicitly; thus the justification for the recommended C_d values in the Provision is not clear. In this report, a statistical evaluation of the deflection amplification factor is presented. The deflection amplification factor of a structure is defined as the largest story deflection amplification factor, which is the ratio of the absolute maximum interstory displacement obtained from a nonlinear time history analysis to the corresponding value from a linear time history analysis. In this study, twelve multi-degree-of-freedom (MDF) structural models with various dynamic characteristics are first constructed, next, 90 synthetic earthquakes are generated from three power spectra representing different soil conditions. Then, the nonlinear and corresponding linear analyses are performed to produce structural response data. On the basis of these data, an empirical formula for the deflection amplification factor is established from a regression analysis. The C_d factors obtained from the empirical formula are compared to those specified in the NEHRP Recommended Provisions.

SECTION 2

GENERATION OF RESPONSE DATA

To generate response data, the analytical structural models and synthetic earthquake acceleration time histories are first established. Then, the nonlinear and corresponding linear time history analyses are carried out. A brief summary of the response analysis is described below. Detail is given in Ref. 2.

Twelve structural models, which represent reinforced concrete buildings, are considered in this study. These structures were constructed from the combination of number of story, fundamental period and viscous damping ratio as shown in table 2-I. The structures are idealized as multi-degree-of-freedom stick models. The nonlinear behavior of structure is described by using the modified Takeda hysteretic model. The parameters defining the stick and hysteretic models are given in Ref. 2.

In this study, 90 synthetic earthquake time histories are generated from appropriate power spectra. The scheme of generating synthetic earthquakes is described in Ref. 2. The parameters selected for simulating earthquake motion are presented in table 2-II. The parameters for the Kanai-Tajimi (K-T) power spectrum ω_g and ζ_g are selected so that each power spectrum represents a site condition such as rock, stiff or soft soils. Three levels of peak ground acceleration (PGA) 0.1g, 0.15g and 0.2g are used so that the nonlinear responses are distributed in a wide range.

The Newmark's beta method with beta equal to 1/4 is used to perform step-by-step integration of the equations of motion. The time history analyses are carried out for all 12 structural models subject to 90 synthetic earthquakes to produce the nonlinear and linear response data. Thus, 1080 response data are obtained and shown in Appendix A.

TABLE 2-I Structural Parameters

Structure	Stick Model	Number of Stories	Fundamental Period (sec.)	Viscous Damping Ratio (%)
1	A	4	0.3	3
2	A	4	0.3	5
3	A	4	0.3	7
4	B	4	0.6	3
5	B	4	0.6	5
6	B	4	0.6	7
7	C	10	0.9	3
8	C	10	0.9	5
9	C	10	0.9	7
10	D	10	1.2	3
11	D	10	1.2	5
12	D	10	1.2	7

TABLE 2-II Earthquake Parameters

Earthquake	PGA (g)	Soil Type	ω_g (rad/sec)	ζ_g	d_E (sec)
1-10	0.1	Rock	8π	0.6	10
11-20	0.15				
21-30	0.2				
31-40	0.1	Stiff	5π	0.6	15
41-50	0.15				
51-60	0.2				
61-70	0.1	Soft	2.4π	0.85	20
71-80	0.15				
81-90	0.2				

SECTION 3
DETERMINATION OF EMPIRICAL FORMULA

The deflection amplification factor for i-th story, i.e., $C_{d,i}$, is defined as

$$C_{d,i} = \frac{U_{n,i}}{U_{l,i}} \tag{3.1}$$

where $U_{n,i}$ is the absolute maximum interstory displacement obtained from a nonlinear time history analysis and $U_{l,i}$ is the corresponding value from a linear time history analysis. The deflection amplification factor of a structure C_d is the largest value among all the story deflection amplification factors, that is,

$$C_d = max(C_{d,i}) \tag{3.2}$$

From the statistical analysis of the response modification factor R [2], it has been found that the maximum story ductility ratio, viscous damping ratio and earthquake-structure period ratio have significant effect on the R factor. However, there is no apparent trend observed for the C_d factor due to viscous damping ratio and earthquake-structure period ratio. Thus, in this study the C_d factor is assumed to be only a function of the maximum story ductility ratio μ_m. It is to be noted that C_d and μ_m do not necessarily occur at the same story. The data with μ_m or C_d less than one are excluded from the 1080 data base; thus only 1034 data are used in the analysis and these data are plotted in figure 3-1. From this figure, it is observed that lnC_d and $ln\mu_m$ may follow a linear relationship, while the conditional variance of lnC_d on $ln\mu_m$ is not constant. Thus, the following form is used for regression analysis.

$$lnC_d = a(ln\mu_m) \tag{3.3}$$

$$Var(lnC_d/ln\mu_m) = s(ln\mu_m)^2 \tag{3.4}$$

where a and s are two consonants to be determined. Using the IMSL subroutines DRONE and DRNLIN [3], the unknown regression coefficients a and s are determined as

$$a = 0.414$$
$$s = 0.0158$$

Thus, the empirical formula for the deflection amplification factor C_d is

$$\ell n C_d = 0.414 \ \ell n \mu_m \tag{3.5}$$

$$Var(\ell n C_d | \ell n \mu_m) = 0.0158 (\ell n \mu_m)^2 \tag{3.6}$$

From Eq. (3.6), the conditional standard deviation σ is equal to 0.126 $ln \mu_m$. The mean curve, mean ± σ curve and mean ± 2σ curve are also plotted in figure 3-1.

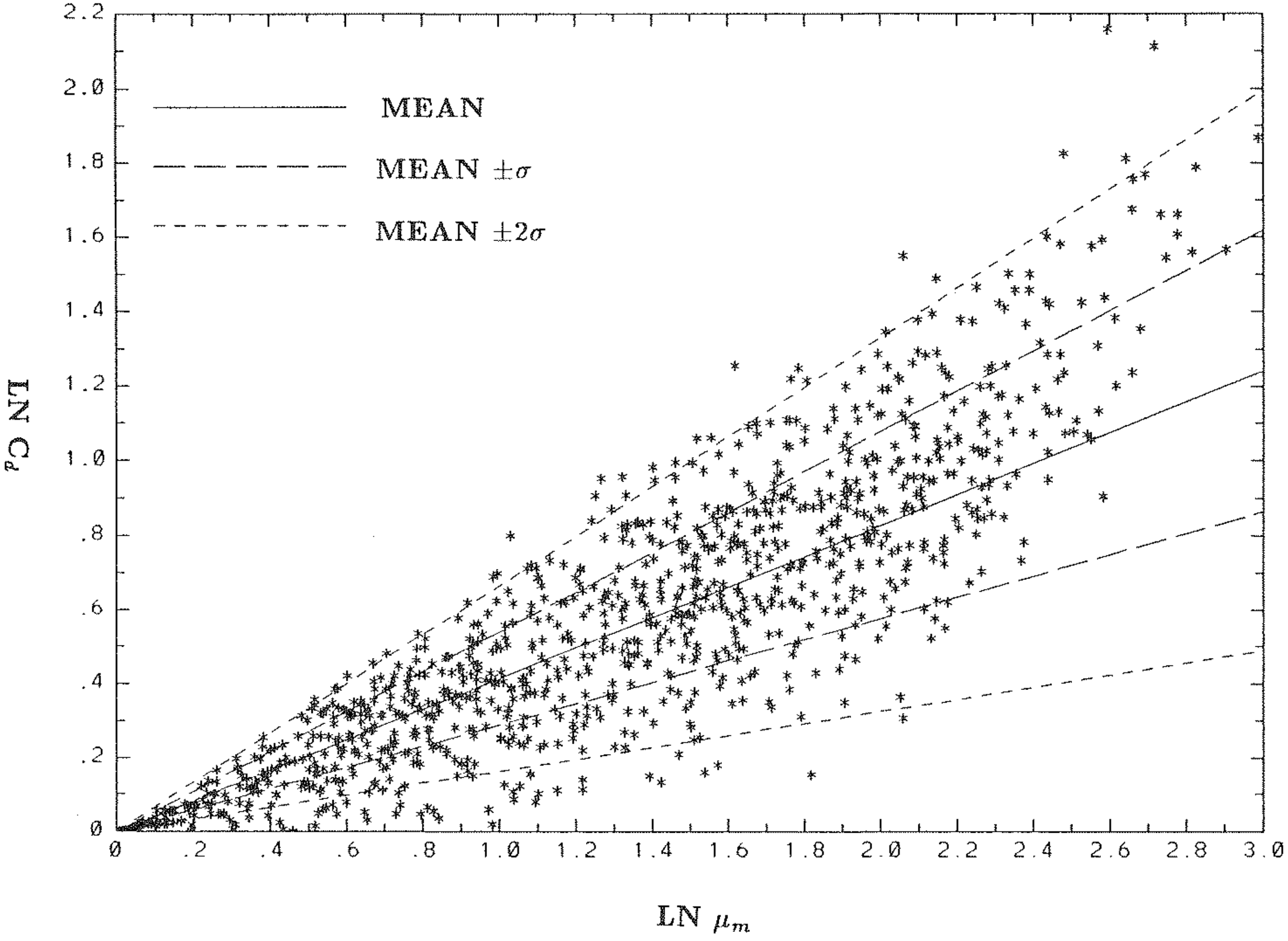

FIGURE 3-1 Deflection Amplification Data

SECTION 4

RECOMMENDATION FOR EARTHQUAKE RESISTANT DESIGN

In the NEHRP Recommended Provisions, the elastic story drift (or interstory displacement) is multiplied by the C_d factor to obtain an equivalent nonlinear story drift which should be less than the allowable story drift. Table 4-I gives the deflection amplification factors C_d specified in the NEHRP Provisions for reinforced concrete structures. Notice that a constant value is assigned to each type of structure. In establishing C_d values, the deformation capability of each type of structure has been recognized and considered implicitly in the Provisions. The deformation capability is resulted from the detailing requirements for structures. However, the allowable ductility ratio for each type of structure is unspecified in the Provisions.

In this study, the empirical formula for the C_d factor, as a function of the maximum story ductility ratio μ_m, has been established in Eqs. (3.5) and (3.6). The mean plus one standard deviation value vs. μ_m are shown in table 4-II. These values are recommended for use in the earthquake-resistant design of buildings. The mean plus one standard deviation value is recommended so that the variation of C_d is taken into consideration.

To compare the recommended C_d values with those specified in the NEHRP Provisions, one must first determine the allowable ductility ratio implied in the NEHRP Provision. For example, if the maximum story ductility ratio for concrete shear wall structure is 4, then the proposed C_d factor is 2.1 instead of 5 as specified in the NEHRP Provisions. From the comparison of table 4-I and 4-II, it appears that the C_d factors specified in the NEHRP Provisions seems too large and consequently the design story drifts are overestimated.

TABLE 4-I NEHRP Deflection Amplification Factors

Structural System	Seismic Resisting System	C_d
Bearing Wall System	Reinforced Concrete Shear Walls	4
Building Frame System	Reinforced Concrete Shear Walls	5
Moment Resisting Frame System	Special Moment Frames of Reinforced Concrete	5-1/2
	Ordinary Moment Frames of Reinforced Concrete	2
	Intermediate Moment Frames of Reinforced Concrete	3-1/2
Dual System	A Special Moment Frame and Reinforced Concrete Shear Walls	6-1/2
	Intermediate Moment Frame and Reinforced Concrete Shear Walls	5

Table 4-II Recommended Deflection Amplification Factors

μ_m	C_d
2	1.5
3	1.8
4	2.1
5	2.4
6	2.6
7	2.9
8	3.1

SECTION 5
CONCLUSIONS

This report presents a statistical evaluation of the deflection amplification factor C_d for reinforced concrete structures. Twelve structural models with various dynamic characteristics are first constructed. Next, ninety synthetic earthquakes are generated from three power spectra representing different soil conditions. Then, the nonlinear and corresponding linear time history analyses are performed to produce structural response data. These data are used to derive an empirical formula for the C_d factor by the regression analysis. The empirical formula expresses the deflection amplification factor as a function of the maximum story ductility ratio. On the basis of this empirical formula, the appropriate C_d factors for the design of building structures are recommended. From the comparison of the proposed C_d factors with those specified in NEHRP Provisions, it appears that most of the C_d factors specified in the NEHRP Provisions are too large and consequently the design story drifts of the structure are overestimated.

SECTION 6
REFERENCES

1. Building Seismic Safety Council, "NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings," 1988 Edition, Washington, D.C., October 1988.

2. Hwang, H. and Jaw, J. -W., "Statistical Evaluation of Response Modification Factors for Reinforced Concrete Structures," Technical Report NCEER-89-0002, National Center for Earthquake Engineering Research, SUNY, Buffalo, New York, February 1989.

3. "User's Manual of FORTRAN subroutines for statistical analysis," Version 1.0, International Mathematical and Statistical Libraries, Inc., Houston, Texas, April 1987.

APPENDIX A

STRUCTURAL RESPONSE DATA

Structure 1 ($T_s = 0.3$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.25$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	2.513	1.319	16	5.077	1.592
2	1.977	0.960	17	4.442	1.698
3	2.239	1.528	18	2.946	1.169
4	2.319	1.036	19	7.130	2.700
5	2.569	1.568	20	6.738	2.213
6	2.804	1.268	21	10.745	2.190
7	2.288	1.056	22	6.703	2.500
8	1.383	0.872	23	4.518	1.282
9	3.388	1.606	24	6.979	2.072
10	2.814	1.433	25	9.470	2.234
11	5.225	2.554	26	4.666	1.885
12	4.882	1.516	27	6.126	1.746
13	2.816	1.112	28	4.844	1.484
14	4.063	1.342	29	6.672	1.696
15	5.010	1.790	30	4.593	1.291

Structure 1 ($T_s = 0.3$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	2.980	1.455	46	5.643	2.155
32	2.789	1.327	47	5.822	2.050
33	3.640	2.387	48	5.701	1.849
34	2.351	1.450	49	6.475	2.200
35	2.072	1.275	50	4.526	1.858
36	2.266	1.318	51	8.462	2.095
37	1.966	1.141	52	8.107	2.740
38	2.895	1.362	53	8.731	1.734
39	3.161	1.545	54	10.058	2.725
40	2.090	1.108	55	7.916	2.074
41	6.650	2.012	56	11.983	2.926
42	4.909	1.635	57	12.348	3.030
43	4.339	1.456	58	12.798	2.881
44	9.864	2.359	59	9.744	2.927
45	7.117	2.194	60	9.054	2.276

Structure 1 ($T_s = 0.3$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	2.090	1.561	76	4.069	2.094
62	2.323	1.386	77	7.890	3.039
63	1.783	1.397	78	6.531	2.147
64	2.093	1.373	79	6.426	2.963
65	1.713	1.183	80	7.727	3.402
66	2.699	1.642	81	8.935	3.106
67	1.353	0.882	82	11.504	4.139
68	3.749	2.606	83	15.580	4.683
69	2.060	1.214	84	9.386	3.957
70	1.757	1.074	85	10.917	4.483
71	3.871	1.969	86	15.373	5.264
72	6.986	2.493	87	11.831	3.621
73	6.738	2.574	88	8.794	2.973
74	6.321	2.438	89	9.182	3.190
75	9.102	3.973	90	7.619	2.648

Structure 2 ($T_s = 0.3$ sec, $\zeta = 5\%$); Earthquakes ($T_g = 0.25$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.457	0.986	16	3.299	1.315
2	1.924	1.267	17	3.803	1.571
3	1.554	1.203	18	2.122	0.991
4	2.744	1.500	19	5.772	3.032
5	1.362	1.017	20	6.348	2.268
6	1.897	1.292	21	6.618	1.811
7	2.285	1.256	22	4.989	2.196
8	1.342	1.031	23	4.251	1.469
9	1.645	1.141	24	4.426	1.397
10	1.564	0.987	25	6.641	2.123
11	3.314	1.988	26	3.578	1.692
12	4.314	1.805	27	5.627	1.993
13	2.947	1.543	28	5.177	1.835
14	3.376	1.248	29	5.886	1.859
15	3.991	1.775	30	4.385	1.598

Structure 2 ($T_s = 0.3$ sec, $\zeta = 5\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	2.524	1.531	46	5.063	2.174
32	2.660	1.506	47	5.207	2.380
33	2.045	1.403	48	4.850	1.912
34	1.858	1.373	49	5.090	2.183
35	2.065	1.522	50	4.024	1.800
36	1.891	1.409	51	5.146	1.427
37	1.852	1.167	52	7.253	2.613
38	2.288	1.361	53	6.230	1.535
39	1.711	1.063	54	10.616	3.209
40	1.580	1.000	55	6.975	2.048
41	4.261	1.780	56	10.045	3.235
42	4.377	1.800	57	7.894	2.416
43	4.198	1.725	58	8.693	2.167
44	8.472	2.580	59	8.714	3.233
45	4.757	1.836	60	9.742	2.449

Structure 2 ($T_s = 0.3$ sec, $\zeta = 5\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	1.269	1.145	76	2.815	1.759
62	1.673	1.203	77	6.532	3.126
63	1.506	1.254	78	5.525	2.365
64	1.675	1.407	79	5.951	3.488
65	1.286	1.105	80	5.343	2.922
66	1.729	1.393	81	7.420	3.297
67	1.312	1.048	82	8.555	3.638
68	2.795	2.226	83	12.835	4.832
69	1.958	1.426	84	8.533	4.432
70	1.552	1.222	85	9.492	4.333
71	4.035	2.314	86	14.036	6.124
72	5.779	2.478	87	10.901	4.296
73	5.562	2.446	88	8.139	3.645
74	5.276	2.500	89	8.026	3.536
75	7.486	3.844	90	6.781	2.715

Structure 3 ($T_s = 0.3$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.25$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.303	1.049	16	2.252	1.067
2	1.272	1.068	17	3.203	1.436
3	1.250	1.088	18	1.731	0.934
4	1.482	1.044	19	4.556	2.885
5	1.136	1.037	20	3.505	1.395
6	1.216	1.017	21	3.670	1.259
7	2.030	1.250	22	3.222	1.590
8	1.042	1.000	23	3.815	1.567
9	1.494	1.072	24	3.770	1.310
10	1.375	1.079	25	3.992	1.576
11	1.766	1.192	26	3.385	1.796
12	4.444	2.168	27	4.857	1.882
13	2.470	1.525	28	5.387	2.274
14	2.927	1.286	29	4.874	1.846
15	2.561	1.465	30	4.703	2.148

Structure 3 ($T_s = 0.3$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	2.023	1.471	46	4.910	2.350
32	2.444	1.558	47	4.299	2.280
33	1.963	1.470	48	3.977	1.849
34	1.325	1.102	49	4.387	2.139
35	1.710	1.377	50	3.583	1.752
36	1.202	1.073	51	5.249	1.524
37	1.616	1.127	52	6.767	2.530
38	2.047	1.443	53	6.384	1.821
39	1.515	1.103	54	9.877	3.504
40	1.291	0.970	55	5.596	1.928
41	3.663	1.448	56	8.839	3.406
42	3.742	1.822	57	5.973	2.042
43	3.922	1.874	58	7.365	2.074
44	4.557	1.654	59	7.807	3.080
45	2.546	1.200	60	8.937	2.625

Structure 3 ($T_s = 0.3$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	1.019	1.000	76	1.770	1.279
62	1.603	1.295	77	6.081	3.371
63	1.296	1.143	78	3.246	1.684
64	1.072	1.019	79	5.044	3.507
65	1.155	1.056	80	4.510	2.707
66	1.093	1.019	81	7.339	3.620
67	1.065	1.019	82	7.520	3.500
68	1.952	1.574	83	11.835	4.858
69	1.432	1.224	84	7.836	4.707
70	1.148	1.056	85	8.134	3.970
71	3.033	1.948	86	11.939	6.200
72	4.760	2.350	87	6.914	3.128
73	4.563	2.273	88	6.738	3.320
74	5.028	2.638	89	7.752	3.381
75	5.836	3.388	90	5.448	2.445

Structure 4 ($T_s = 0.6$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.25$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	2.239	1.684	16	4.625	2.222
2	2.379	1.462	17	6.574	1.887
3	1.833	1.298	18	1.652	0.672
4	2.915	1.489	19	2.784	1.266
5	2.191	1.639	20	2.984	1.083
6	1.434	1.143	21	6.722	1.419
7	2.514	1.685	22	5.772	2.837
8	1.958	1.136	23	6.005	1.949
9	2.520	1.443	24	5.786	2.036
10	4.417	2.048	25	5.505	1.422
11	2.897	1.443	26	4.473	1.338
12	4.170	1.424	27	5.831	2.061
13	2.316	0.946	28	3.329	0.945
14	5.629	2.702	29	5.998	2.076
15	2.866	1.130	30	4.828	2.390

Structure 4 ($T_s = 0.6$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	4.444	1.804	46	8.711	2.067
32	4.525	2.109	47	4.437	1.661
33	2.558	1.508	48	7.031	1.914
34	4.662	2.406	49	4.653	1.174
35	2.500	1.214	50	4.778	2.166
36	4.152	1.875	51	9.302	1.961
37	4.221	1.534	52	9.812	2.583
38	3.231	1.861	53	5.811	1.469
39	2.623	1.329	54	7.824	1.359
40	1.901	0.780	55	7.667	1.931
41	5.771	1.525	56	8.265	1.829
42	5.648	1.923	57	9.517	2.331
43	2.668	1.018	58	8.790	1.861
44	6.231	2.137	59	6.149	1.166
45	4.485	1.327	60	7.771	1.439

Structure 4 ($T_s = 0.6$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	2.434	1.162	76	5.648	2.288
62	5.579	2.505	77	9.497	2.391
63	2.997	1.347	78	7.440	1.883
64	5.571	2.282	79	7.961	2.169
65	3.055	1.266	80	9.619	2.762
66	3.321	1.377	81	9.376	2.369
67	4.511	2.057	82	8.500	1.779
68	5.684	2.633	83	8.421	1.686
69	2.536	1.161	84	9.613	2.535
70	3.184	1.367	85	9.602	2.023
71	5.203	1.762	86	11.451	2.586
72	6.824	2.166	87	10.660	2.084
73	7.266	2.247	88	8.264	2.186
74	6.721	1.826	89	8.713	2.204
75	10.052	2.853	90	9.799	2.551

Structure 5 (T_s = 0.6 sec, ζ = 5%); Earthquakes (T_g = 0.25 sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.701	1.380	16	3.906	2.310
2	1.646	1.265	17	5.250	2.008
3	1.413	1.120	18	2.100	1.074
4	2.025	1.190	19	1.658	0.857
5	1.265	1.109	20	2.726	1.291
6	1.132	1.019	21	5.866	1.615
7	1.840	1.296	22	5.220	2.980
8	1.483	1.138	23	4.979	2.155
9	1.849	1.282	24	4.889	1.953
10	3.039	1.677	25	5.047	1.698
11	2.529	1.646	26	3.829	1.492
12	2.887	1.330	27	4.697	2.162
13	1.528	1.023	28	3.159	1.117
14	3.877	2.303	29	4.645	2.167
15	2.461	1.198	30	4.634	2.228

Structure 5 ($T_s = 0.6$ sec, $\zeta = 5\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	3.712	2.046	46	7.074	2.359
32	4.053	2.202	47	3.242	1.551
33	1.410	1.079	48	5.376	1.848
34	3.572	2.214	49	3.380	1.119
35	2.188	1.294	50	3.840	2.184
36	2.761	1.688	51	6.877	1.928
37	4.873	2.086	52	8.381	2.574
38	3.455	2.319	53	5.158	1.637
39	1.932	1.223	54	6.626	1.550
40	2.076	1.049	55	7.189	2.189
41	4.754	1.541	56	5.946	1.671
42	4.332	1.892	57	7.607	2.129
43	3.295	1.339	58	7.883	2.045
44	5.698	2.387	59	4.815	1.197
45	1.956	0.743	60	7.874	1.966

Structure 5 ($T_s = 0.6$ sec, $\zeta = 5\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	2.209	1.199	76	4.101	1.755
62	2.958	1.663	77	7.356	2.387
63	2.195	1.233	78	7.197	2.330
64	2.420	1.325	79	5.509	1.704
65	2.500	1.179	80	6.748	2.466
66	2.687	1.489	81	8.546	2.778
67	3.358	2.029	82	7.561	1.968
68	4.310	2.706	83	7.333	1.685
69	2.426	1.449	84	7.441	2.377
70	2.658	1.426	85	7.233	2.275
71	4.616	1.828	86	7.891	2.043
72	6.765	2.911	87	9.249	2.416
73	5.519	2.100	88	7.257	2.517
74	6.027	2.071	89	9.112	2.718
75	8.079	2.980	90	8.103	2.489

Structure 6 (T_s = 0.6 sec, ζ = 7%); Earthquakes (T_g = 0.25 sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.246	1.131	16	3.007	1.991
2	1.086	1.026	17	4.143	1.970
3	1.159	1.024	18	1.511	0.913
4	1.731	1.146	19	1.541	1.005
5	1.010	1.000	20	2.446	1.403
6	0.991	1.000	21	4.789	1.614
7	1.444	1.112	22	4.281	2.445
8	1.052	1.007	23	3.962	1.949
9	1.336	1.084	24	4.148	1.899
10	2.126	1.357	25	3.904	1.617
11	1.760	1.364	26	3.474	1.605
12	2.890	1.491	27	3.673	1.974
13	1.320	1.049	28	3.768	1.578
14	2.124	1.433	29	3.986	2.064
15	2.252	1.319	30	4.330	2.352

Structure 6 ($T_s = 0.6$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	3.216	2.062	46	5.847	2.531
32	1.961	1.333	47	2.559	1.432
33	1.138	1.051	48	3.868	1.607
34	1.674	1.168	49	2.642	1.061
35	1.912	1.313	50	2.817	1.855
36	1.786	1.289	51	5.437	1.820
37	2.915	1.459	52	6.957	2.461
38	2.702	2.010	53	3.646	1.427
39	1.465	1.171	54	5.305	1.541
40	1.725	1.065	55	6.590	2.301
41	4.003	1.572	56	5.101	1.640
42	2.945	1.457	57	6.199	1.901
43	3.053	1.448	58	9.722	3.059
44	4.232	2.013	59	4.023	1.161
45	1.992	0.960	60	7.502	2.230

Structure 6 ($T_s = 0.6$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	2.050	1.227	76	3.747	1.780
62	1.681	1.185	77	5.594	2.192
63	1.338	0.937	78	6.185	2.405
64	2.260	1.420	79	4.520	1.586
65	1.792	1.111	80	4.561	1.967
66	1.996	1.246	81	7.089	2.727
67	2.067	1.304	82	6.305	2.257
68	2.922	2.038	83	6.905	1.750
69	1.929	1.393	84	6.828	2.513
70	2.183	1.315	85	6.319	2.404
71	4.563	2.102	86	5.853	1.870
72	5.925	3.025	87	8.242	2.603
73	5.037	2.226	88	6.697	2.831
74	5.433	2.183	89	8.823	2.842
75	5.088	2.299	90	6.279	2.500

Structure 7 ($T_s = 0.9$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.25$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.689	1.050	16	2.367	1.236
2	1.540	1.265	17	2.896	1.264
3	1.420	1.128	18	2.534	1.319
4	2.262	1.283	19	3.645	1.845
5	1.779	1.473	20	2.776	1.376
6	1.767	0.991	21	4.555	1.628
7	2.148	1.511	22	2.726	1.285
8	1.182	1.028	23	4.537	1.975
9	2.708	1.394	24	3.571	1.808
10	2.574	1.753	25	4.690	1.927
11	2.539	1.575	26	8.068	2.985
12	4.382	1.792	27	4.037	1.752
13	2.893	1.333	28	3.813	1.615
14	2.688	1.500	29	5.540	1.852
15	3.537	1.363	30	6.804	2.785

Structure 7 ($T_s = 0.9$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	1.711	0.914	46	14.571	3.878
32	3.300	1.885	47	5.088	1.924
33	1.629	1.141	48	2.948	1.166
34	2.198	1.393	49	4.771	1.960
35	3.780	2.481	50	3.053	1.881
36	2.064	1.261	51	19.832	6.471
37	3.566	1.660	52	11.019	2.925
38	2.779	1.917	53	18.229	4.788
39	2.571	1.670	54	11.777	3.100
40	4.734	2.892	55	11.432	4.958
41	5.031	1.729	56	13.678	3.325
42	5.466	2.387	57	5.989	1.366
43	3.009	1.107	58	10.196	2.341
44	5.337	2.364	59	13.031	3.706
45	5.151	1.879	60	9.028	2.899

Structure 7 ($T_s = 0.9$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	3.770	1.835	76	10.070	4.150
62	2.710	0.991	77	8.196	2.519
63	1.903	0.937	78	11.759	3.383
64	5.318	2.257	79	8.599	2.819
65	4.142	1.696	80	7.017	1.790
66	4.353	2.186	81	8.970	2.331
67	3.416	1.368	82	11.386	3.138
68	4.936	1.821	83	12.683	2.918
69	4.382	2.190	84	8.533	1.866
70	4.513	1.942	85	10.285	2.545
71	16.065	5.270	86	9.376	2.579
72	7.918	2.605	87	13.214	2.472
73	5.992	1.840	88	7.732	2.150
74	7.405	3.081	89	16.682	4.756
75	11.100	3.300	90	7.491	1.743

Structure 8 ($T_s = 0.9$ sec, $\zeta = 5\%$); Earthquakes ($T_g = 0.25$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.459	1.160	16	1.809	1.391
2	1.140	1.022	17	1.931	1.112
3	0.990	1.000	18	2.210	1.398
4	1.828	1.367	19	2.307	1.416
5	1.106	1.015	20	1.653	1.228
6	1.669	1.131	21	4.638	2.650
7	1.107	1.038	22	2.464	1.445
8	0.909	1.000	23	3.035	1.600
9	1.768	1.190	24	3.353	1.953
10	1.491	1.250	25	2.891	1.517
11	1.643	1.351	26	3.751	2.207
12	3.205	1.689	27	2.956	1.844
13	2.408	1.424	28	2.362	1.601
14	2.006	1.186	29	4.257	1.526
15	2.401	1.536	30	6.055	2.968

Structure 8 ($T_s = 0.9$ sec, $\zeta = 5\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	1.411	1.037	46	8.620	2.734
32	2.282	1.572	47	3.171	1.517
33	1.213	1.000	48	3.280	1.675
34	1.819	1.387	49	3.746	1.628
35	1.995	1.515	50	2.310	1.408
36	1.519	1.182	51	14.748	5.862
37	2.379	1.603	52	13.257	4.215
38	2.200	1.706	53	16.850	5.986
39	1.856	1.420	54	8.243	2.405
40	1.892	1.374	55	15.144	8.273
41	3.652	1.640	56	12.505	4.158
42	3.381	1.922	57	5.653	1.710
43	1.910	1.053	58	6.573	1.978
44	3.710	1.897	59	7.321	2.727
45	2.122	1.129	60	7.667	2.830

Structure 8 ($T_s = 0.9$ sec, $\zeta = 5\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	3.788	2.260	76	5.197	2.091
62	1.921	0.801	77	7.120	2.253
63	1.987	1.206	78	3.802	1.385
64	3.398	1.664	79	8.219	2.461
65	3.163	1.750	80	5.547	1.880
66	2.328	1.257	81	7.850	2.386
67	2.802	1.475	82	9.579	3.318
68	3.955	1.899	83	9.666	2.337
69	2.761	1.745	84	6.863	1.879
70	4.613	2.234	85	9.046	2.870
71	5.872	2.451	86	10.262	3.514
72	4.550	1.602	87	12.256	2.940
73	5.330	1.883	88	6.493	2.307
74	4.376	1.752	89	10.810	3.930
75	8.091	2.899	90	8.015	2.389

Structure 9 (T_s = 0.9 sec, ζ = 7%); Earthquakes (T_g = 0.25 sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.040	1.008	16	1.367	1.182
2	0.943	1.000	17	1.652	1.124
3	0.843	1.000	18	1.701	1.294
4	1.461	1.257	19	1.802	1.144
5	0.976	1.000	20	1.382	1.160
6	1.479	1.173	21	3.437	1.836
7	0.901	1.000	22	2.145	1.462
8	0.752	1.000	23	2.567	1.544
9	1.400	1.152	24	2.599	1.704
10	1.005	1.000	25	2.016	1.250
11	1.110	1.022	26	3.003	1.988
12	2.513	1.608	27	2.441	1.782
13	1.807	1.251	28	1.669	1.294
14	1.944	1.317	29	4.108	1.669
15	1.893	1.424	30	5.331	3.005

Structure 9 ($T_s = 0.9$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	1.402	1.125	46	4.384	1.936
32	1.757	1.416	47	3.076	1.574
33	1.062	1.016	48	2.381	1.446
34	1.223	1.043	49	3.071	1.471
35	1.464	1.291	50	2.003	1.370
36	1.619	1.367	51	10.325	4.491
37	2.139	1.514	52	11.402	4.171
38	1.767	1.470	53	10.500	4.297
39	1.297	1.180	54	6.458	2.064
40	1.369	1.189	55	13.384	8.646
41	2.492	1.436	56	8.752	3.444
42	3.011	1.984	57	6.651	2.419
43	1.677	1.015	58	5.113	1.811
44	2.655	1.534	59	5.584	2.563
45	1.771	1.152	60	7.327	3.071

Structure 9 ($T_s = 0.9$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	2.953	2.056	76	4.138	1.929
62	1.950	0.896	77	5.343	2.118
63	1.841	1.365	78	3.903	1.669
64	2.169	1.300	79	6.929	2.373
65	2.542	1.750	80	3.867	1.611
66	1.821	1.081	81	9.593	3.005
67	2.348	1.470	82	8.034	2.982
68	3.478	1.941	83	8.258	2.151
69	1.907	1.405	84	7.073	2.220
70	4.210	2.310	85	8.365	2.715
71	6.043	2.870	86	14.303	5.797
72	4.316	1.832	87	10.457	2.941
73	5.198	2.129	88	5.750	2.180
74	4.328	1.884	89	7.952	3.194
75	6.463	2.626	90	7.780	2.718

Structure 10 (T_s = 1.2 sec, ζ = 3%); Earthquakes (T_g = 0.25 sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.279	1.079	16	2.540	1.296
2	1.352	1.005	17	2.774	1.656
3	1.763	1.339	18	1.404	1.064
4	1.623	1.218	19	2.003	1.118
5	1.860	1.247	20	4.139	2.177
6	1.547	1.134	21	4.814	2.294
7	1.937	1.367	22	2.590	1.381
8	0.880	1.000	23	3.188	1.858
9	1.719	1.234	24	3.100	2.084
10	1.012	1.000	25	10.219	4.100
11	1.775	0.994	26	2.184	0.841
12	6.546	3.043	27	7.531	3.295
13	1.796	1.230	28	4.076	2.580
14	2.075	1.378	29	3.607	1.450
15	2.114	1.369	30	3.375	1.150

Structure 10 ($T_s = 1.2$ sec, $\zeta = 3\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	5.095	2.841	46	5.014	2.378
32	2.697	1.661	47	3.866	1.300
33	1.479	1.153	48	3.412	1.402
34	2.726	1.639	49	8.306	3.610
35	2.991	2.039	50	3.582	1.888
36	2.698	1.867	51	5.343	2.055
37	2.189	1.586	52	6.249	2.097
38	2.673	1.992	53	7.229	2.757
39	2.782	1.398	54	5.544	1.401
40	2.191	1.205	55	4.814	1.588
41	5.072	1.916	56	11.437	3.618
42	5.453	2.441	57	4.470	1.809
43	2.821	1.090	58	5.134	1.504
44	5.169	1.773	59	4.146	1.143
45	3.791	1.667	60	7.257	2.609

Structure 10 (T_s = 1.2 sec, ζ = 3%); Earthquakes (T_g = 0.83 sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	3.392	1.335	76	4.526	1.791
62	2.737	0.992	77	3.774	1.256
63	2.165	1.412	78	6.719	1.607
64	3.024	1.256	79	9.542	2.799
65	3.143	1.392	80	13.191	4.915
66	4.831	2.766	81	10.533	2.623
67	4.117	1.632	82	14.265	3.446
68	3.796	1.670	83	7.588	1.823
69	2.858	1.269	84	7.404	2.175
70	3.565	1.634	85	9.421	2.810
71	5.685	2.465	86	8.685	2.130
72	14.268	5.337	87	13.050	3.106
73	8.565	2.875	88	16.057	4.990
74	9.653	3.079	89	11.448	2.783
75	13.629	3.991	90	6.918	1.593

Structure 11 (T_s = 1.2 sec, ζ = 5%); Earthquakes (T_g = 0.25 sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.087	1.020	16	1.847	1.373
2	0.997	1.000	17	1.785	1.144
3	1.109	1.059	18	1.514	1.102
4	1.016	1.000	19	1.771	1.148
5	1.203	1.069	20	2.236	1.643
6	1.193	1.075	21	3.362	2.041
7	1.229	1.070	22	1.880	1.232
8	0.731	1.000	23	1.995	1.370
9	1.375	1.128	24	1.959	1.500
10	0.783	1.000	25	5.527	3.014
11	1.696	1.112	26	2.369	1.246
12	2.284	1.260	27	2.625	1.506
13	1.365	1.218	28	1.826	1.522
14	1.227	1.077	29	2.883	1.507
15	2.205	1.527	30	3.291	1.288

Structure 11 (T_s = 1.2 sec, ζ = 5%); Earthquakes (T_g = 0.4 sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	2.246	1.370	46	4.309	2.600
32	1.590	1.209	47	2.751	1.134
33	1.221	1.073	48	2.565	1.390
34	2.156	1.546	49	3.797	2.298
35	2.502	1.858	50	2.947	1.806
36	1.846	1.187	51	3.428	1.540
37	1.278	1.048	52	5.976	2.397
38	1.452	1.217	53	4.937	2.401
39	1.953	1.318	54	4.343	1.233
40	1.864	1.241	55	3.869	1.675
41	3.613	1.910	56	6.951	3.036
42	4.019	2.223	57	3.416	1.558
43	1.924	1.031	58	5.079	1.922
44	3.652	1.493	59	4.482	1.419
45	3.575	1.906	60	6.050	2.413

Structure 11 ($T_s = 1.2$ sec, $\zeta = 5\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	3.167	1.270	76	2.770	1.365
62	2.463	1.203	77	3.961	1.386
63	1.702	1.119	78	5.000	1.415
64	2.214	1.047	79	7.834	2.541
65	2.730	1.536	80	7.181	3.150
66	4.058	2.672	81	8.798	2.628
67	3.253	1.707	82	11.495	3.089
68	3.957	2.294	83	6.524	2.071
69	2.420	1.216	84	6.930	2.573
70	1.777	1.049	85	7.726	2.711
71	4.553	1.894	86	9.843	3.322
72	7.021	3.474	87	11.944	3.445
73	8.445	4.035	88	10.147	3.242
74	4.830	2.080	89	9.744	2.791
75	6.765	2.405	90	5.889	1.653

Structure 12 ($T_s = 1.2$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.25$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
1	1.006	1.000	16	1.386	1.161
2	0.813	1.000	17	1.631	1.129
3	0.872	1.000	18	1.424	1.115
4	0.810	1.000	19	1.460	1.170
5	0.967	1.000	20	1.674	1.429
6	0.998	1.000	21	2.474	1.500
7	0.980	1.000	22	1.496	1.184
8	0.646	1.000	23	1.738	1.293
9	1.161	1.057	24	1.662	1.396
10	0.637	1.000	25	2.183	1.457
11	1.624	1.218	26	2.047	1.274
12	1.683	1.168	27	2.281	1.375
13	1.066	1.020	28	1.920	1.375
14	1.025	1.000	29	2.961	1.641
15	2.055	1.492	30	3.143	1.392

Structure 12 ($T_s = 1.2$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.4$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
31	1.837	1.376	46	3.493	2.478
32	1.292	1.107	47	2.779	1.276
33	1.069	1.020	48	2.338	1.539
34	1.494	1.247	49	2.637	1.805
35	2.024	1.616	50	2.134	1.493
36	1.649	1.182	51	5.817	2.822
37	1.209	1.050	52	5.632	2.619
38	1.133	1.058	53	3.097	1.785
39	1.267	1.075	54	4.531	1.458
40	1.529	1.204	55	3.558	1.867
41	3.002	1.771	56	5.812	3.032
42	2.668	1.630	57	3.082	1.506
43	1.784	1.255	58	4.865	2.236
44	3.343	1.525	59	4.558	2.037
45	2.457	1.559	60	4.578	1.967

Structure 12 ($T_s = 1.2$ sec, $\zeta = 7\%$); Earthquakes ($T_g = 0.83$ sec)

EQ	μ_m	C_d	EQ	μ_m	C_d
61	2.818	1.295	76	2.171	1.204
62	2.126	1.235	77	4.254	1.672
63	1.441	1.139	78	4.960	1.611
64	2.145	1.240	79	6.598	2.340
65	2.179	1.437	80	3.402	1.450
66	3.546	2.591	81	7.119	2.216
67	2.539	1.661	82	10.300	3.073
68	3.740	2.285	83	4.485	1.722
69	2.040	1.152	84	5.162	2.179
70	1.894	1.346	85	6.489	2.469
71	3.778	1.855	86	8.661	3.491
72	5.734	2.477	87	11.213	3.731
73	4.975	2.394	88	9.786	3.479
74	3.879	1.945	89	8.053	2.599
75	5.292	2.386	90	5.052	1.664

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