PEAK VS. ROOT-MEAN-SQUARE (RMS) ACCELERATION AS A RESPONSE PARAMETER

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SUMMARY

This paper addresses whether the two-parameter description of expected structural response, namely root-means-square (rms) acceleration, coupled with response duration, improves present response spectrum techniques. Response duration spectra computed for a linear single-degree-of-freedom oscillator using four investigated definitions of response duration show considerable variation in magnitude and are not necessarily amplitude or frequency dependent. The corresponding rms acceleration spectra resemble the shape of traditional peak acceleration spectra but do not describe amplitude levels corresponding to a consistent number of cycles for all frequencies.

INTRODUCTION

A current problem in seismic design is establishing an effective measure of expected structural response. Present design response spectra display the maximum value only of the response of a linear single-degree-of-freedom (SDOF) oscillator and hence ignore information on the duration of the response and the effect of the amplitudes of the lesser but near maximum peak values of the response time history. To date, no definition of duration has been developed for characterizing structural response to strong ground motion, but it would seem that response duration should be amplitude and frequency dependent.

DURATION AND ROOT-MEAN-SQUARE ACCELERATION OF STRONG MOTION

Definitions of duration proposed for strong ground motion (Ref. 1-4) gave impetus to the development of the two-parameter description, root-mean-square (rms) acceleration, which by its definition is coupled with duration, as a measure of the effective acceleration of a ground motion time history (Ref. 3 and 5). The rms acceleration, a_{rms}, is defined over a duration T from an initial time T_1 to end time T_2, where $T = T_2 - T_1$, as

$$a_{rms} = \{\frac{1}{T}\int_{T_1}^{T_2} [a(t)]^2 dt\}^{\frac{1}{2}} \qquad (1)$$

As a measure of the effective acceleration of response which incorporates duration, Ref. 6 developed rms acceleration spectra to represent a summary of the peak amplitudes of a response time history based on a definition of response duration in which the duration was arbitrarily terminated when the response acceleration amplitude reached 10% of the largest response peak and

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thereafter did not exceed that value. As a ground motion description, rms acceleration has been shown to be dependent on the definition of duration used in equation (1) (Ref. 3). Likewise, as a response parameter, it is expected that rms acceleration would also be dependent on the characterization of response duration.

DURATION AND RMS ACCELERATION AS RESPONSE PARAMETERS

Because rms acceleration is closely coupled with duration, the sensitivity of response rms acceleration to the definition of duration assumed is illustrated in Figure 1 for the response of a SDOF oscillator for 2%, 5%, and 10% damping and for frequencies ranging from 0.2 Hz to 34 Hz subject to the 1940 El Centro, California, earthquake component S00E (A001). Four definitions of proposed strong ground motion duration (Ref. 1-4) are investigated in this study as possible response durations. The cutoff level for Ref. 1 was arbitrarily chosen to be 0.05g. Ref. 1-4 are denoted in Figure 1 and in all subsequent figures as Bolt, T&B, M&S, and V&L, respectively.

In Figure 1, the duration spectra for response durations defined by Ref. 1 and 4 are amplitude dependent since these durations decrease with increasing damping and hence decreasing amplitudes. The duration spectra for the response durations based on Ref. 2 and 3 are similar in shape and magnitude but are independent of amplitude. While there is considerable variation in the magnitudes of the response durations among the four definitions, the corresponding rms acceleration spectra also shown in Figure 1 are similar in shape and resemble traditional peak acceleration spectra. The latter observation was also noted in Ref. 6.

The coupling of response rms acceleration with response duration is further investigated for a linear SDOF oscillator for frequencies between 0.2 Hz and 34 Hz and for 2% damping subject to eight representative ground motion time histories listed in Table 1. Investigated for the SDOF oscillator response due to each input ground motion using the four definitions of response duration as in Figure 1 are, as a function of frequency, the response duration, the response rms acceleration, and the kth largest peak in the response time history corresponding to the amplitude level of the computed rms acceleration. A peak is defined as the maximum amplitude between two zero crossings of the response time history. The kth largest peak is the kth peak in the response time history where the peaks are arranged in descending order from the largest (k=1) to smallest peak.

For the response to each of the eight input motions, the response duration spectra shown in Figure 2 based on the different definitions of duration have considerable variation in magnitude but indicate an overall trend of decreasing duration with increasing oscillator frequency. The responses to several input records, however, produced spurious large durations near the 10 Hz to 20 Hz frequency range. Despite the differences in the computed response duration, the corresponding rms acceleration spectra illustrated in Figure 3, which were computed using the durations in Figure 2, show similarity to each other in shape and magnitude levels and agree with the trends noted in Figure 1. Because the response durations computed from Ref. 1 with a 0.05g cutoff level typically are the largest durations, the resulting rms acceleration spectra computed from equation (1) are the smallest. Figure 4 shows that regardless of the definition of response duration used, the kth largest acceleration peak in the response time history corresponding to the amplitude level of the rms acceleration increases with increasing oscillator frequency between 0.2 Hz and about 20 Hz but beyond 20 Hz decreases with increasing frequency. The corresponding kth largest peak ranges from the first peak for very small durations at low frequencies to more than the 200th peak at higher frequencies. This indicates that the rms acceleration spectra do not consistently summarize the same number of cycles of response for all frequencies. Consequently, a kth peak acceleration spectra, as proposed by Ref. 7 and 8, may be more informative for seismic design, fatigue calculations, and liquefaction studies as a way of incorporating the response duration.

RMS ACCELERATION OF RECORDED BUILDING RESPONSE

Using the above four definitions of response duration, the resulting rms acceleration and the kth largest peak corresponding to the rms acceleration level are shown in Table 2 for the response records obtained in the Imperial County Services Building during the October 15, 1979 Imperial Valley, California, earthquake. As a summary of the amplitude levels of actual recorded response, the rms accelerations of the horizontal records describe amplitude levels ranging from the 20th to 30th largest peaks.

CONCLUSIONS

While initially rms acceleration seems attractive as a response desciption since it incorporates the duration of response, it nonetheless requires an explicit definition of response duration. Application of the durations proposed for strong ground motion as possible response durations indicated considerable differences in the duration spectra and not all definitions were amplitude and frequency dependent. As a function of amplitude, duration would be useful in characterizing the expected damage of structures. The corresponding rms acceleration spectra are similar in shape to traditional acceleration spectra and to each other regardless of the definition of duration. The peak number in the response time history which is summarized by the rms acceleration value is not consistent for all frequencies. Therefore, kth peak acceleration spectra which have been proposed appear to be an improvement over rms acceleration spectra since the kth peak spectra incorporate duration without having to explicitly define duration and give amplitude levels corresponding to a consistent number of cycles for all frequencies.

ACKNOWLEDGEMENTS

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Table 1 Earthquake Time Histories Analyzed

No.	Year	Earthquake	Recording Station	Component	PGA(g)
A001	1940	Imperial Valley, CA	El Centro	S00E	0.35
A004	1952	Kern County, CA	Taft	S69E	0.18
A015	1957	San Francisco, CA	Golden Gate Park	S80E	0.10
B029	1949	Western Washington	Olympia	N86E	0.28
B034	1966	Parkfield, CA	Cholame, Station 5	N85E	0.43
C041	1971	San Fernando, CA	Pacoima Dam	S16E	1.17
C048	1971	San Fernando, CA	8244 Orion Boulevard	N00W	0.25
—	1979	Imperial Valley, CA	Free Field, Imperial County Services Building	092°	0.24

Table 2 Root-Mean-Square (RMS) Acceleration of Imperial County Services Building Records of October 15, 1979

		RMS (cm/sec/sec)				kth Largest Peak in Response Time History Corresponding to RMS Acceleration			
Trace	Peak Acceleration (cm/sec/sec)	Bolt	Trifunac-Brady	McCann-Shah	VanMarcke-Lai	Bolt	Trifunac-Brady	McCann-Shah	VanMarcke-Lai
FF 092	231.44	60.2	51.7	59.1	91.2	22	26	23	12
FF UP	230.90	60.4	59.6	56.4	77.0	68	71	72	50
FF 002	209.02	62.6	59.4	63.6	71.5	25	26	25	20
N/R/W	531.34	109.9	169.2	186.9	197.8	29	17	16	15
N/R/C	551.56	104.6	151.7	213.3	200.6	29	19	16	16
N/R/E	569.38	91.7	210.7	158.7	213.5	34	25	19	16
E/R/C	443.90	116.1	124.4	117.6	212.3	16	16	16	12
E/4/C	258.21	82.9	86.8	89.9	89.6	17	16	16	16
E/2/C	268.54	75.2	80.8	103.5	90.6	26	25	20	21
N/2/W	355.80	85.9	92.8	103.6	124.4	30	30	25	20
N/2/C	307.44	77.1	92.3	90.5	103.0	28	25	26	24
N/2/E	641.95	98.3	106.5	107.5	270.0	32	28	27	6
N/G/W	330.57	86.5	98.9	118.0	116.3	27	25	19	19
N/G/E	284.03	74.6	90.0	87.8	95.8	26	23	24	23
E/G/E	324.96	69.6	68.4	84.4	141.8	21	21	14	9
U/G/E	174.26	39.3	25.2	31.8	59.5	53	90	71	28

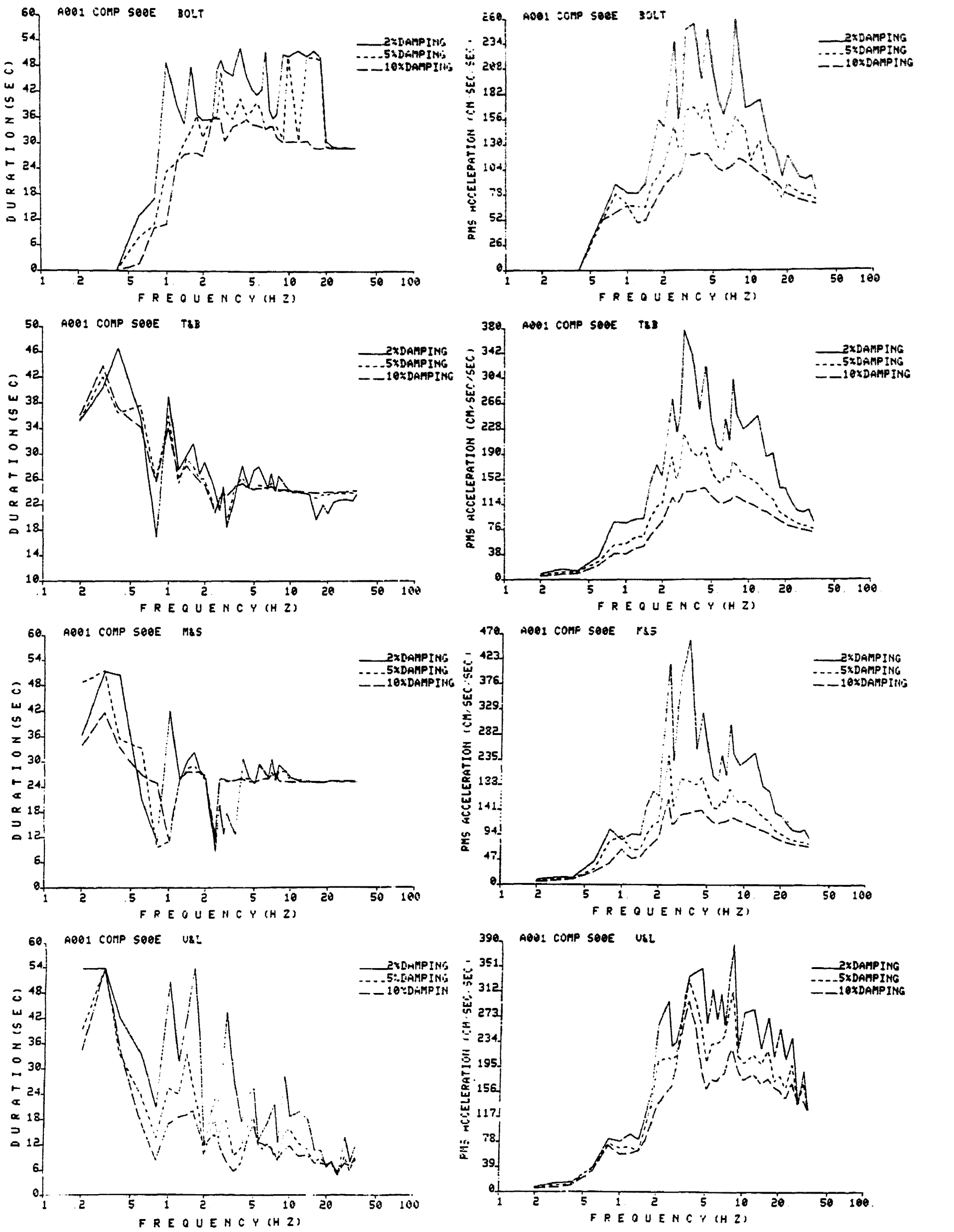

Figure 1. Duration and RMS Acceleration Spectra for the Response of a Single Degree of Freedom Oscillator Subject to the 1940 El Centro, California, SOOE Component

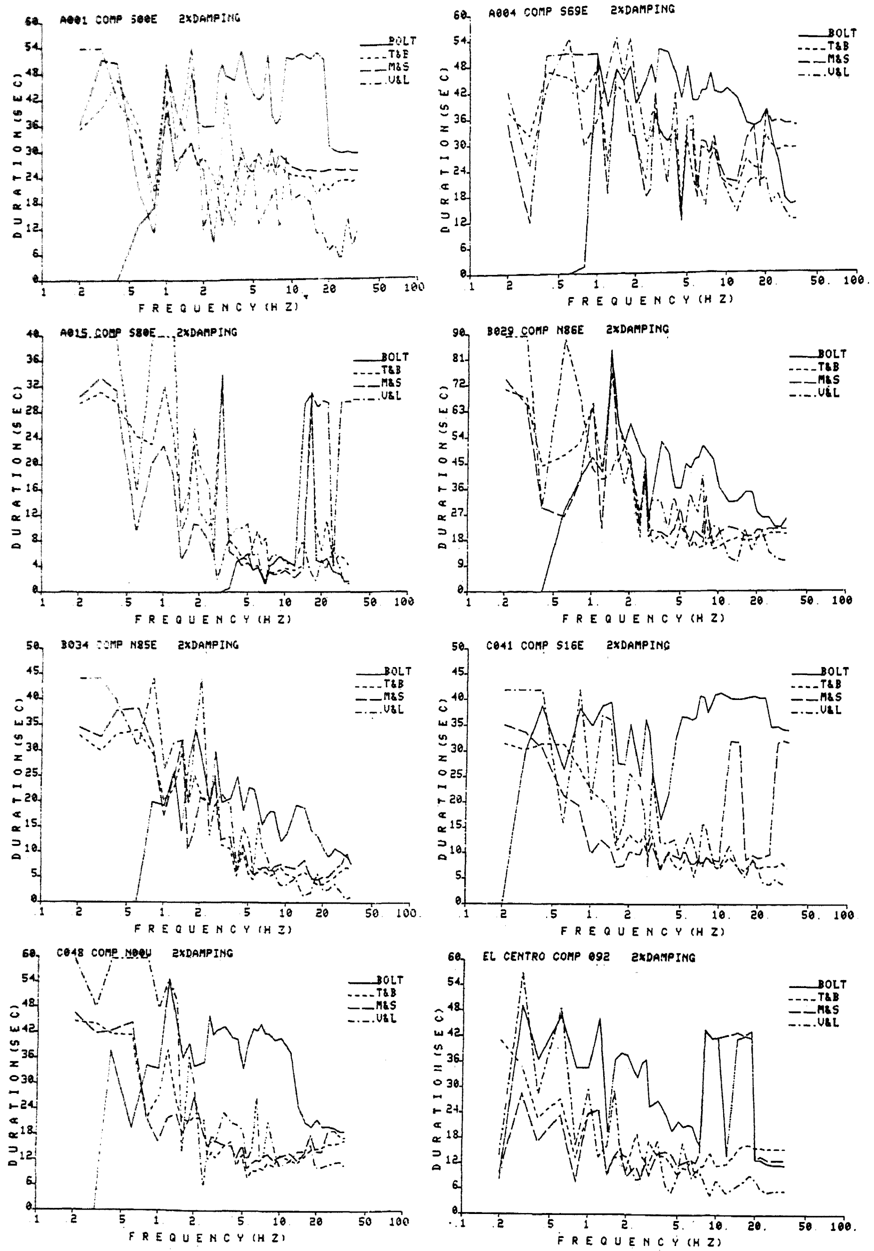

Figure 2. Duration Spectra for the Response of a Single Degree of Freedom Oscillator with 2% Damping Subject to Eight Representative Ground Motions

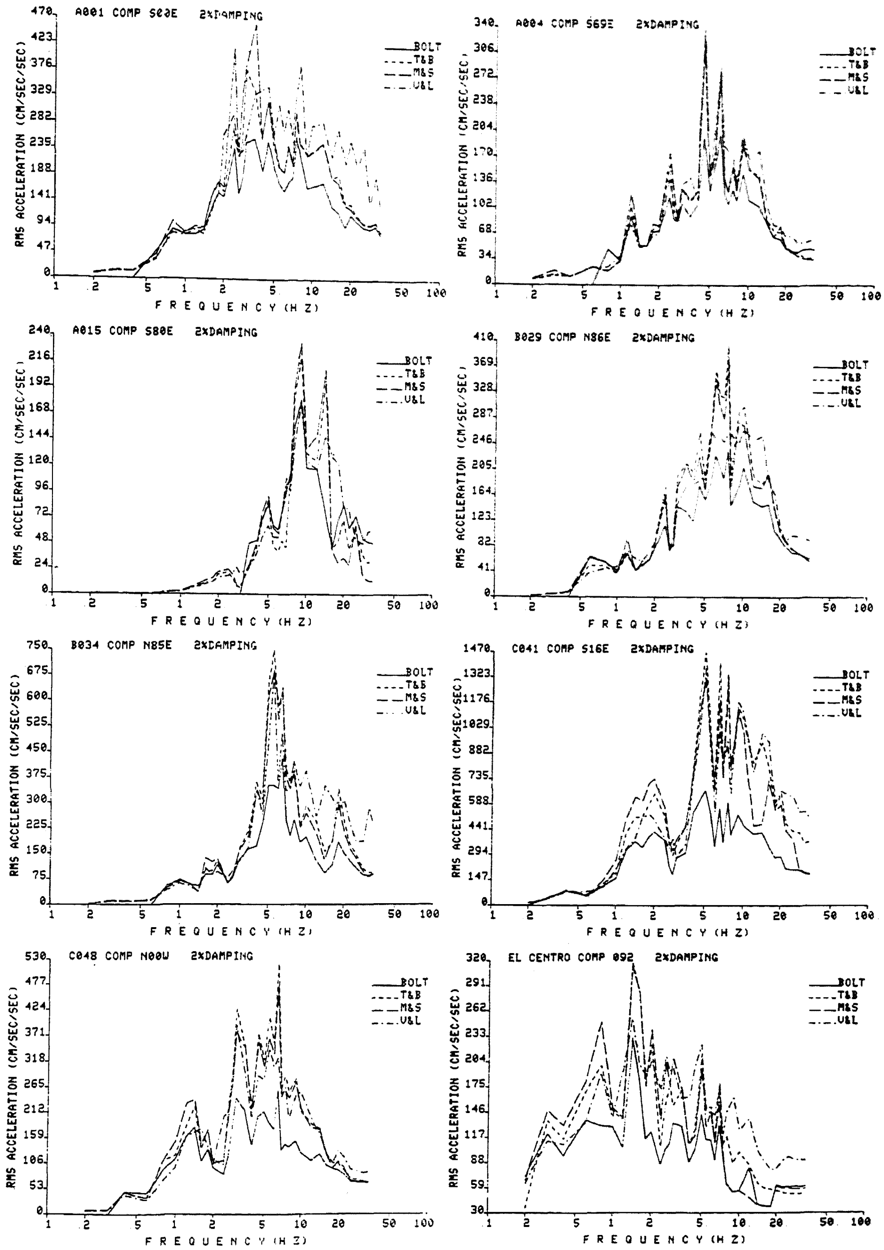

Figure 3. RMS Acceleration Spectra for the Response of a Single Degree of Freedom Oscillator with 2% Damping Subject to Eight Representative Ground Motions

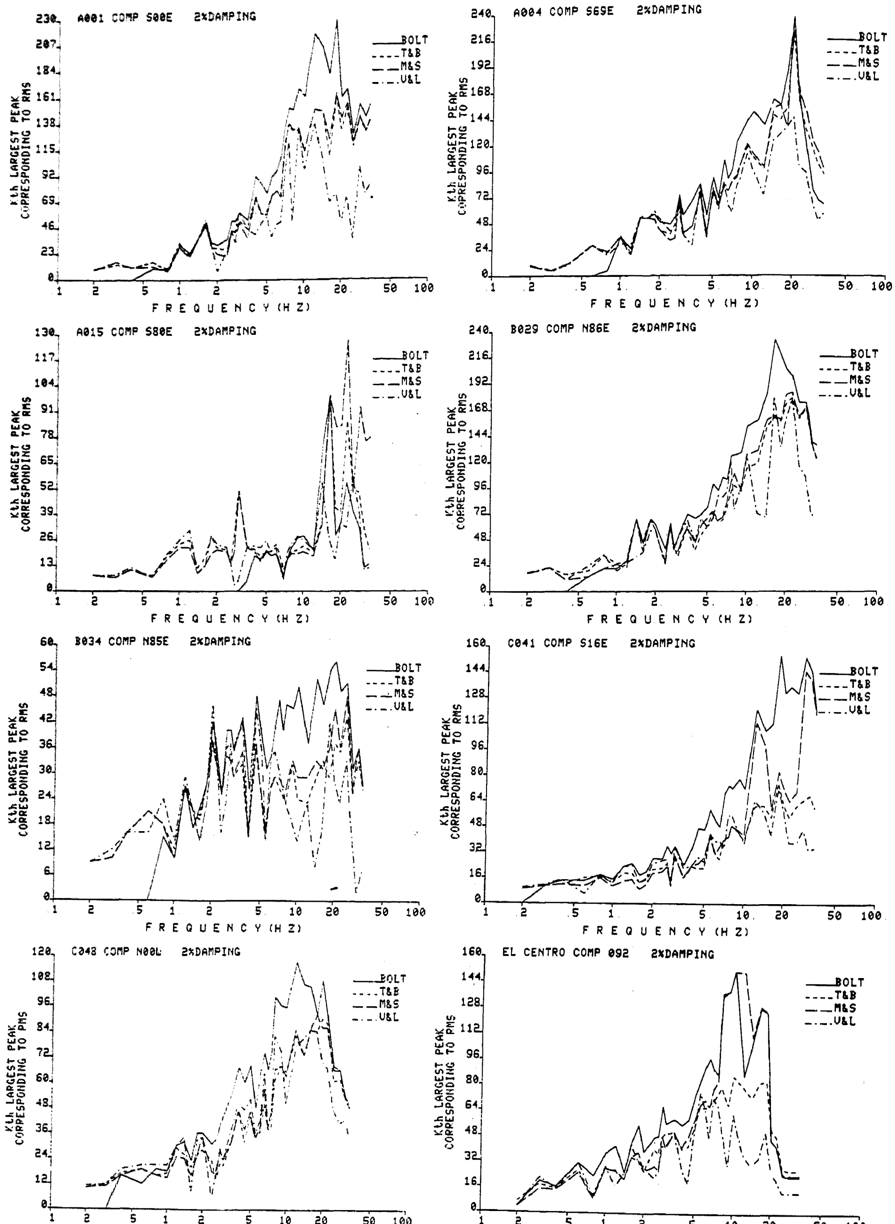

Figure 4. kth Largest Peak in the Response Time History Corresponding to the RMS Acceleration Amplitude of the Response of a Single Degree of Freedom Oscillator with 2% Damping Subject to Eight Representative Ground Motions