ANALYSIS OF 2/3-g HOUSNER REANALYSIS DESIGN SPECTRUM

FOR SAN ONOFRE NUCLEAR GENERATING STATION

23 February 1982

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1.0 INTRODUCTION

1.1 Historical Background

San Onofre Nuclear Generating Station Unit 1 (SONGS-1) was designed and built for a design peak ground acceleration (DPGA) of 0.5 g. Although that is still the appropriate value (Refs. 1, 2, and 4) for a confidence level greater than the 84th-percentile for the maximum hypothesized earthquake, events have led to consideration of higher DPGA values. The DPGA was amplified as a function of period according to the Housner response spectrum (Ref. 3). Construction was completed and the plant went into operation in 1968.

Subsequent to that time, Southern California Edison (SCE) agreed to a DPGA of 0.67 g for the design of San Onofre Units 2 and 3 (Refs. 5, 6, and 7). SCE also agreed to use this same value for the DPGA for the seismic reevaluation of San Onofre Unit 1 (Ref. 8).

Since that time, several large earthquakes have been recorded, and the number of close-in strong-motion data has more than doubled. This more recent data demonstrates the conservatism of this DPGA.

In addition, numerous special investigations have refined and improved the ground motion predictions for the San Onofre site. These studies include:

- A careful examination of a well recorded large-magnitude earthquake in Southern California (IV-79);

- An identification and evaluation of exceptionally strong recordings written during recent large earthquakes;

- Two regression analyses of instrumental peak ground acceleration (IPGA) data to define the appropriate IPGA for the site;

- Regression analyses of instrumental spectral-ordinate data to define the appropriate instrumental ground-motion spectrum for the site;

- Detailed source-modeling studies to define the appropriate instrumental ground-motion spectrum for the site;

- Recent work leading to proposed new regulatory spectra;

- Two probability studies, one of which used three different methodologies on peak acceleration, and the other of which developed equal-probability spectra;

- Comparison to other parts of the SEP program;

- Comparison with design practices for dams in California.

In addition to these studies, the SONGS 2 and 3 Design Basis Earthquake (DBE) was extensively litigated in the latter half of 1981 before the Atomic Safety and Licensing Board. Those hearings elicited testimony from numerous experts in geology, seismology, and earthquake engineering. The transcript embodies almost 7,000 pages and provides an exceptionally thorough and detailed review of the matter. The Board issued its Partial Initial Decision on 11 January 1982. The Decision is 240 pages and is consistent with the thoroughness and completeness of the Hearings and of SCE's studies of the site. The Decision supports SCE's work in all essential points. Furthermore, the margin inherent in the Units 2 and 3 DBE was noted by the ASLB in reiterating Dr. R. L. McNeill's statement that: "Events since the design was established indicate, in his opinion, that the spectra, the time history, and the duration of the time history are extreme; he further stated that, if he were to do the design again, with the many more records for guidance, the design constraints would be much less severe than they are" (Ref. 9).

This report considers the same data which was considered by the Board in its evaluation of the Units 2 and 3 DBE. This report also provides additional evidence which is available in the form of peak ground accelerations, spectra, and probabilities. These will be presented in several forms for comparison to the 0.67-g Housner spectrum. If the comparative strong ground-motion data, appropriately corrected for the effects of site conditions and the presence of structures, exceed the 0.67-g Housner design spectrum then that spectrum must be reassessed. On the other hand, if the comparative data are less than the 0.67-g Housner spectrum in most or all cases, then the 0.67-g Housner spectrum should be taken as appropriately conservative for the reanalysis.

1.2 Objectives and Organization

The objective of this report is to display the conservatism of the Unit 1 reanalysis spectrum. This will be done by presenting all recent relevant close-in strong-motion data and studies which SCE has been able to accumulate, and by comparing those data and studies to the reanalysis spectrum.

When making spectral comparisons, it is best to place most reliance on comparisons of like quantities. Specifically, comparisons of spectra are valid only if, among other things (Ref. 10), all parameters are free-field instrumental, or alternatively if all parameters are structure-specific. Such comparisons are made below in Section 2.

At a meeting on 16 February 1982, the Staff requested that comparisons be made between the design form of the reanalysis spectrum and the free-field instrumental forms of spectra for the information SCE has developed. We recognize that such comparisons are important from the standpoint of utilizing past experience and understanding. We also understand that such comparisons will be used only as a guide to judgement, and not for strict quantitative purposes. The requested comparisons are given in Section 3.

The final Section 4 summarizes and concludes that by all reasonable comparisons which adhere to the physical principles applicable to the situation, the proposed 2/3 g Housner design form of the reanalysis spectrum lies above the 84th percentile of available data, and is therefore appropriately conservative for the reanalysis of San Onofre Unit 1.

2.0 EVALUATION OF REANALYSIS SPECTRUM BY COMPARING ITS INSTRUMENTAL FORM TO INSTRUMENTAL INFORMATION

2.1 Instrumental Reanalysis Spectrum

Many workers prefer to use low values of damping when comparing spectra, because low-damping spectra tend to be crisp and robust, showing the details of the information to be compared. On the other hand, other workers prefer to use higher values of damping, values more nearly equal to those operative in the structures. It is expected that various elements to be reevaluated will have various dampings, and that those damping values will likely lie in the range of 2 to 10 percent. For this reason, all of the comparisons will be given for 2 percent damping, and several (where the values were already available or readily calculable) will also be given for 10 percent damping.

For reference, Figure 1 presents the design forms of the reanalysis spectrum at 2 and 10 percent dampings.

The 0.67-g Housner spectrum has been used directly for the design reevaluation, and its instrumental free-field form has not been previously derived. All of the data to be used for comparison are of the instrumental free-field form, so the instrumental free-field form of the design 0.67-g Housner must be constructed in order to make meaningful comparisons (Refs. 10, 11, and 12). The constructed instrumental form in this case does not have to be of high precision, because it is to be used only for comparisons to evaluate its reasonableness and conservatism.

The construction of the instrumental spectrum from the design spectrum involves two considerations: the effects of small departures from linear behavior of structural components; and the effects of soil-structure interaction. Both of these considerations will be handled on a reasonable but approximate basis for these comparisons, as will now be developed.

A convenient way to account for departures from linearity is to call upon the concept of ductility, using a numerically small value, well below the classical ductile and yielding behavior. For facilities which must remain elastic or nearly elastic, and which perform a vital safety-related function and must remain functional without repair, ductilities of about 1.3 are recommended (Ref. 13).

The value of ductility D = 1.3 is extremely small and will be used here. The value is utilized to multiply the amplified acceleration part (0.1 - 0.6 sec.) of the 0.67-g Housner design spectrum by $\sqrt{2D-1}$, and the amplified velocity part of the design spectrum (0.6 - 1.0 sec.) by D (Ref. 14). The zero-period acceleration (ZPA) part of the spectrum (less than 0.1 sec.) is conservatively left unaltered. The resulting spectrum is smoothed at the transitions between the ZPA and the acceleration and velocity parts.

The effects of soil-structure interaction are presently best handled by reference to data in the literature, comparing free-field recordings to those in structures. When this is done, the results indicate that the ratio of instrumental free-field to building recordings is from about 1-1/2 to about 4-1/2, at short periods (Ref. 15). For conservatism, these ratios are taken as 1-1/4 to 2, the lower values taken to apply to small, shallow structures, and the higher values to large, deeply embedded structures.

The resulting instrumental spectra are compared to the design reanalysis spectra in Figure 2. That instrumental spectrum will now be used for several comparisons.

2.2 Comparison to Recent Instrumental Data

The Imperial Valley earthquake of October 1979 (IV-79) was about the right magnitude, and had instrument arrays close-in at about the right distances. Thus, the horizontal components constitute an important data set for studying the SONGS situation, although the vertical components are inapplicable to the SONGS site conditions (Refs. 16 and 8).

For the SONGS conditions, at 8 km from the fault, IV-79 recordings from stations at 6 to 10 km could be used to obtain an estimate of the SONGS IPGA. However, station 5058 at 13 km recorded an exceptionally high acceleration which should be included in the analysis to be conservative. The statistics of the spectra of all recordings from 6 to 13 km were calculated. The resulting 84th-percentile spectrum is shown, compared to the reanalysis spectrum for 2 percent damping, in Figure 3 (Ref. 25). The results for 10 percent damping are given in Figure 4.

The comparisons of Figure 3 show that, when compared to the 84th-percentile spectrum of an appropriate IV-79 records, the reanalysis spectrum is conservative, substantially exceeding the 84th-percentile spectrum for IV-79.

Although IV-79 is particularly attractive because it is directly comparable and very well instrumented, it turns out that there is a large body of diverse close-in strong-motion data which can also be used for comparison. The SONGS conditions are $M_s 7$, R=8 km, where R is the closest distance to the fault. Thus, it seems that a reasonable data set might result if attention were restricted to recordings which meet the following selection criteria:

(1) Magnitude greater than 6;

(2) Distance to fault less than 20 km, and known;

(3) Free-field or small-building, level-ground instrument station;

For purposes of comparison with the reanalysis spectrum, attention can be focussed on the most severe recordings by limiting the analysis to recordings that exceed the 84th percentile of the TERA regression of PGA. The results of this data survey of exceptional events for data since 1973 is given in Table 1. In that table, there are 14 pairs (counting 09 June 1980 Victoria as a pair for this count). This is a substantial data set of exceptional recordings: there are 14 pairs representing a total of 27 strong-motion, close-in components from 6 earthquakes. Of the 27 components, all were of adequate quality to pick off a PGA, and 23 were of adequate quality to calculate the instrumental spectrum.

To put these exceptional records consistently on a common basis for conditions similar to the SONGS site, the reported IPGA for each record was multiplied by the ratio of 84th percentile IPGA calculated for M7, R8 to the 84th percentile IPGA calculated for the reported magnitude and distance for that event, using the TERA equation. If a record qualified as an exceptional recording, all of its components were studied.

The resulting scaled horizontal components of the exceptional recordings are given in Col. 8 of Table 1. The IPGA values range from 0.30 to 0.98 g, and they average 0.51 g. The individual values, and thus the average, do not exceed the IPGA (0.84 to 1.34 g) of the reanalysis spectrum.

Similar calculations have been performed period by period for those 23 components of adequate quality to calculate the instrumental spectrum. Only one exceptional horizontal spectrum exceeds the reanalysis spectrum, but this is slight, and only over a narrow range of periods. The average spectrum of the exceptional horizontal recordings is shown, compared to the reanalysis spectrum, in Figure 5. That average spectrum of the exceptional events lies at all points below the reanalysis spectrum.

The data in Table 1 were presented to the Staff at the meeting of 16 February 1982. At that meeting, the Staff suggested that the work be repeated using another regression of PGA recently published (Ref. 17). This has been done using Ref. 17 to scale from the actual conditions to M7, R8. The results are given in Table 1-U. The average values in Tables 1 and 1-U are quite similar: 0.51 g and 0.53 g, compared to the instrumental range of 0.84 g to 1.34 g.

These comparisons indicate that it is possible to find records for which one component exceeds the reanalysis spectrum at some periods. They also show that it has not been possible to find an exceptional record for which more than one component exceeds the reanalysis spectrum.

Finally, these comparisons show that the reanalysis IPGA and spectrum are very conservative, being well above the 84th percentile, and probably above the 95th percentile of earthquake spectra.

2.3 Comparisons to Calculated Instrumental Values

Three sophisticated and detailed studies have been done to calculate PGA and spectra for the SONGS site.

One of these studies, done by TERA (Refs. 18 and 19), regressed world-wide data to estimate IPGA as a function of magnitude and distance. A summary of the key points is given in App. A. The data were selected to be within 50 km of the fault to avoid the unrelated trends which may arise when distant data are used to estimate close-in motions. The selection yielded a very large data set: 229 components from 27 earthquakes. The results of the regression for SONGS conditions are as follows:

Level	IPGA, M7, R8
Median	0.32 g
84th Pctl	0.49 g

These results show that the reanalysis IPGA (0.84 to 1.34 g) lies several standard deviations above the median, and is therefore quite conservative.

TERA has also performed regression analyses on the vertical accelerations similar to the analyses performed on the horizontal accelerations. The results of this study show that the 84th-percentile vertical acceleration for $M_S 7$ at 8 km is 0.42 g, which would lie well below the corresponding reanalysis IPGA.

Another of the studies, done by Woodward-Clyde Consultants (WCC) (Ref. 20), regressed instrumental spectra of selected data to estimate the site instrumental spectrum for magnitude M6.5. That spectrum was then raised to accommodate M7. A summary of the key points is given in App. B. All elements of the data screening were taken to be conservative, with some being very conservative. Further, recordings from earthquakes since the closing of the WCC data base in mid-1978 provide independent data which can be used to estimate how the WCC spectrum should be revised to represent the 84th percentile. Those data have been applied (App. B), and the resulting revised WCC spectrum is given, for 2 percent damping, in Figure 6, compared to the initial spectrum.

The comparisons to the reanalysis spectrum are shown in Figure 7 for 2 percent damping, and in Figures 8 for 10 percent damping.

The third study is the DELTA source-modeling study (Ref. 21), which considered all three components. A summary of the key points in the derivation, testing, and application of this method is given in App. C. The DELTA results were presented to the Staff at the meeting of 16 February 1982. At that meeting, the Staff requested that the worst-case rupture configuration be treated in some way for direct comparison to 84th-percentile instrumental spectra. To comply with this request, the mean of the worst-case calculated spectrum was multiplied by 1.5 to account for scatter in observed data (See App. C). The results are compared to the reanalysis spectrum in Figure 7.

All of these sophisticated calculations--the 84th percentile TERA IPGA regression, the 84th percentile WCC instrumental spectrum regression, and the worst case of the DELTA source-modeling instrumental spectrum calculations--lie below the reanalysis spectrum and accordingly, demonstrate the conservatism of the reanalysis spectrum, indicating that it is well above the 84th percentile of earthquake data and calculations.

2.4 Comparisons to Regulatory Spectra

These results are presented here for comparison with past and current regulatory thinking. The spectra included in these com arisons are the SONGS Units 2 and 3 DBE spectrum, and the site-specific spectrum calculated by the methods of NUREG/CR-0098 (NR-98) (Ref. 22).

The derivation of the design form of the DBE spectrum, and the calculation of its instrumental form have been described (Ref. 23). The NR-98 spectrum was developed as recommended by Dr. N. M. Newmark. That spectrum has been anchored to the TERA IPGA (0.49 g) , and was calculated using a ground velocity of 36 ips/g because of the stiffness of the site. The results are given in Figure 9.

It has already been pointed out that the Units 2 and 3 DBE spectrum is conservative by any reasonable measure. The reanalysis spectrum is but little less than the DBE, except at long periods. Both lie above the NR-98 spectrum at all periods.

Figure 9 is for 2 percent damping. Similar comparisons for 10 percent damping are given in Figure 10.

The comparison to the site-specific instrumental form of NR-98 is a particularly convincing demonstration of the conservatism of the reanalysis spectrum. It is anchored to the most applicable and most reviewed PGA available, and it uses the spectral shape of the latest broadly applicable spectral method. That method was intentionally structured for conservative application to a wide range of conditions. Thus, the construction of the site-specific spectrum by these methods is a multiply conservative process. Notwithstanding these conservatisms, the reanalysis spectrum lies at all points above the site-specific NR-98 spectrum.

2.5 Comparison to Equal-Probability nstrumental Spectra

All of the probability studies reported herein used the basic seismicity of the site compiled by Sierra Geophysics, as summarized in App. D.

Equal-probability spectra have been calculated by Woodward-Clyde Consultants, as summarized in App. F. The calculation was a conventional probability study, using the updated spectral values of Figure 6. The resulting equal-probability spectra are shown, compared to the reanalysis spectrum, in Figure 11 for 2 percent damping, and in Figure 12 for 10 percent damping.

The results show that the greatest annual probability of exceeding the reanalysis spectrum instrumentally is about 10^{-5}; while an average value would be nearer 10^{-6}.

2.6 Comparison to California Dam-Design Practice

This comparison of the reanalysis IPGA to the catalogue of IPGA used for the recent analyses and reanalyses of dams is given to provide an evaluation of the relative conservatism of the reanalysis IPGA. This may provide information about how the reanalysis IPGA compares to the requirements of a California regulatory agency dealing with a different type of structure related to public health and safety. The IPGAs used for recent analyses and reanalyses are given as a function of distance from the causative fault in Figure 13 (Ref. 24). Also shown on the figure are the median and the 84th percentile from the TERA regression (Ref. 18). From the data on Figure 13 the conservatism of the California dam-design practice becomes clear: within 30 km, only one IPGA falls below the median; and most of the IPGAs are greater than the 84th percentile.

The IPGA for reanalysis is shown in Figure 13. It ranges from 0.84 to 1.34 g, approximately twice the corresponding instrumental values used for California dams. Thus, compared to California dam-design practice, which generally exceeds 84th percentile instrumental values, the reanalysis IZPA is conservative.

3.0 EVALUATION OF REANALYSIS SPECTRUM BY COMPARING ITS DESIGN FORM TO INSTRUMENTAL INFORMATION

These comparisons were specifically requested by the Staff, and are furnished in that spirit. Specifically, it is recognized that these comparisons are important from the standpoint of past experience and understanding. Further, it is understood that they will not be misused by making strict quantitative interpretations but rather as a guide for judging the conservatism of the design spectrum.

3.1 Comparison to Recent Instrumental Data

The comparison of the reanalysis design form to the IV-79 84th-percentile instrumental spectra are given in Figures 14 and 15 for 2 and 10 percent damping, respectively. The IV-79 instrumental data are below the design spectra except at the mid-period range around 0.2 seconds, where the instrumental values lie above the design spectra by a percent or so. The comparison of the reanalysis design form to the instrumental spectrum of the exceptional events (by Table 1) is given in Figure 16, for 2 percent damping.

The instrumental spectrum of the exceptional records lies well below the design spectrum at short and long periods, and lies above the design spectrum by about 30 percent in the mid-period range. These small exceedances over a narrow range of periods are not considered significant, especially considering the large margins reflected by the instrumental comparisons, as described in Section 2.

3.2 Comparisons to Calculated Instrumental Values

The comparisons of the reanalysis design form to the revised WCC 84th-percentile instrumental, the DELTA 84th-percentile, and the DELTA meanx1.5 instrumental spectra are given in Figure 17. The revised WCC 84th-percentile instrumental spectrum is given for 10 percent damping in Figure 18. For reference, the TERA 84th-percentile instrumental PGA is also drawn in Figure 17. For both 2 and 10 percent damping, the revised WCC 84th-percentile spectra are about 80 percent of the corresponding design spectra at short and long periods and exceed the design spectra by a maximum of only 10 to 15 percent at a period of about 0.15 seconds. The instrumental values of the DELTA 84th-percentile spectrum lie below the design spectra at all points. The values of the DELTA meanx1.5 lie well below the design except in the mid-period range, where the maximum exceedance is about 10 percent.

3.3 Comparisons to Regulatory Instrumental Spectra

The comparisons of the Unit 1 reanalysis spectrum to the Units 2 and 3 DBE are given in Figures 19 and 20 for 2 and 10 percent damping, respectively. These figures demonstrate the Units 2 and 3 spectra exhibit slightly more margin, as discussed in Section 1.1, than the Unit 1 reanalysis spectrum. These differences not withstanding, Figures 9 and 10 show that these spectra contain substantial margin relative to the guidelines of NR-98.

3.4 Comparisons to Site-Specific Spectra

From late 1978 until his death in 1981, Dr. N. M. Newmark worked with Dr. R. L. McNeill to: (1) define a site-specific instrumental spectrum; and (2) define a comparative design spectrum (Newmark-McNeill) for purposes of comparisons to any spectrum proposed for design at the SONGS site.

The purpose of the site-specific instrumental spectrum was to tie together the various efforts on Unit 1 and Units 2 and 3, and to provide a common basis for evaluating and studying instrumental spectra as they might be applicable to the site. Those spectra have been presented in Figures 9 and 10, for 2 and 10 percent damping, respectively.

The purpose of the Newmark-McNeill spectrum was to provide a common basis for evaluating proposed design spectra for the site: any design spectrum which lies above the Newmark-McNeill spectrum is above the 84th percentile of effective spectral motions for the site; a design spectrum which lies below the Newmark-McNeill spectrum should be studied in further detail to evaluate its conservatism.

The Newmark-McNeill spectra are related to and derived from the site-specific instrumental spectra of Figures 9 and 10. A very small ductility of 1.3 is applied to the mid- and long-period parts of the spectrum according to the methods of NR-98. A total site and soil-structure-interaction factor of 0.8 is applied to the short- and mid-period parts of the spectrum. The resulting Newmark-McNeill spectra are given in Figures 19 and 20, for 2 and 10 percent damping, respectively.

The comparisons of the reanalysis design spectra to the Newmark-McNeill spectra in Figures 19 and 20 show the reanalysis spectrum to be conservative, lying at all points above the 84th percentile of effective spectral motion for the site.

3.5 <u>Comparisons to Equal-Probability Instrumental Spectra</u>

The comparisons of the reanalysis design form to the instrumental equal-probability spectra are given in Figures 21 and 22 for 2 and 10 percent damping, respectively.

Comparison of the design spectrum for each damping to the instrumental equal-probability spectra indicate that the Housner spectral shape coincides rather well with the the 10^{-4} to 10^{-5} contours of equal hazard.

3.6 Comparison to Other SEP Plants

As described in Appendix G, TERA has contrasted the methods for evaluating the seismic hazard of the eastern SEP plants against the seismic hazard at SONGS 1. In applying the three evaluation criteria developed for the eastern SEP plants and described in NUREG/CR-1582 to SONGS 1, it is concluded that there is much greater confidence in the SONGS 1 ground-motion prediction and furthermore, that the SONGS 1 seismic reanalysis ZPA is conservative with respect to accepted reanalysis criteria for other SEP plants. From these results we can conclude with confidence that there is an appropriate level of conservatism in the SONGS 1 reanalysis ZPA.

For purposes of these SEP comparisons, TERA has done probabilistic studies in two ways (App. E). A conventional analysis uses tectonic and seismicity models of major faults of the region with the TERA attenuation relationship based on fault distance (Refs. 18, 19, and App. A) to probabilistically estimate peak acceleration at the SONGS site. A second analysis uses historical earthquakes of fixed location and magnitude together with an attenuation relationship based on hypocentral distance to probabilistically estimate peak accelerations at the site. This second approach, being independent of source and seismicity models, was used as a basis for judging the relative conservatism of using source and seismicity models to evaluate the hazard for SONGS. Appendix G contrasts the confidence within each step in those analyses between the eastern plants and a SONGS 1 application, where it is found that there is much greater confidence in the SONGS 1 prediction compared to the eastern plants for the reasons summarized in Table 2. The comparison of results between the eastern SEP plants and SONGS in Table 3 shows that the SONGS 1 seismic reanalysis PGA is approximately 10-100 times less likely to be exceeded than the seismic criteria for eastern SEP plants. It is therefore apparent that the SONGS seismic design criteria are at least as conservative as the eastern SEP plants.

A final and interesting comparison is given in Table 4 where the deterministic 10CFR100 Appendix A results are given. Again, study of Table 4 leaves the flavor that the SONGS seismic basis is very reliable and relatively conservative with respect to the basis for the other SEP plants.

3.7 Conclusions From These Comparisons

These comparisons of design and instrumental spectra show that it is possible to find combinations where the instrumental spectra exceed the design, as might be expected. In these cases, however, the exceedances are small and the period ranges are narrow. Careful considerations of the effects of structure on the free-field response and of the dynamic behavior of the structure, as discussed in Section 2, lead to the conclusion that these minor exceedances are not significant. These comparisons are consistent with the conclusion of Section 2, namely that the reanalysis design spectrum is quite conservative by any reasonable comparison criterion.

4.0 SUMMARY AND CONCLUSIONS

The instrumental form of the reanalysis spectrum has been compared to significant instrumental information with the following results:

- the reanalysis spectrum exceeds the 84th percentile of the appropriate Imperial Valley 1979 earthquake data by at least 30 percent (Figures 3 and 4).

- the reanalysis spectrum exceeds the average spectrum of identified exceptional records by at least 15 percent (Table 1, Figure 5).

- the reanalysis spectrum exceeds the 84th percentile spectra calculated for the SONGS site by two very different methods by at least 35 percent (Figures 7 and 8).

- the reanalysis spectrum exceeds the NR-98 84th percentile site-specific instrumental spectrum by at least 30 percent (Figures 9 and 10).

- the reanalysis spectrum has an annual probability of exceedance of about 10^{-5} (Figures 11 and 12).

- the reanalysis PGA is at least as conservative as other SEP plants; and greater confidence is placed on the basic data and the analysis resulting therefrom (Tables 2, 3, and 4).

- the reanalysis PGA is roughly twice that which would be used for modern dam design in California.

In addition to those instrumental-motion comparisons, comparisons between the design form of the reanalysis spectra and the Newmark-McNeill spectra show that the reanalysis spectrum lies at all points above the Newmark-McNeill form.

If comparisons of the design form of the reanalysis spectrum are made to the instrumental forms of other spectra, then cases can be found where the instrumental spectra exceed the design reanalysis spectrum. The exceedances are small, and occur only over narrow period ranges. These comparisons speak for the conservatism of the reanalysis spectrum, because if that spectrum were unconservatively low, one would expect comparable instrumental spectra to exceed it by appreciable amounts over broad period ranges.

The comparisons presented show without exception that the reanalysis spectrum exceeds the 84th percentile of comparable actual and calculated earthquake spectra.

REFERENCE LIST

Abbreviations

Cx: Contention Number.

WTxx: Written Testimony submitted for ASLB Hearings, SONGS Units 2 and 3, at page xx.

TRxx: Transcripts of Testimony for ASLB Hearings, SONGS Units 2 and 3, at page xx.

Lyy: Line number yy.

pzz: Page number zz.

PIDxx: Partial Initial Decision issued 11 January 1982 by ASLB for Units 2 and 3, at page xx.

1. R. L. McNeill, C4, WT18,L12 to L15.
2. L. H. Wight, C4, WT, Exhibit LHW-1, p. 1-2.
3. Housner, G. W., 1979, "Design Spectrum," Chapter 5 in Earthquake Engineering, R. L. Wiegel, Editor, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, pp. 93-106.
4. Tera Corporation, "Estimation of Peak Horizontal Ground Acceleration at San Onofre Nuclear Generating Station," 19 February 1982.
5. R. L. McNeill, C4, WT18, L01 to L22.
6. R. L. McNeill, C4, WT19, L04, to L10.
7. PID 134 to 136.
8. Letter from K. P. Baskin (SCE) to D. M. Crutchfield (NRC) dated May 11, 1981, Seismic Reanalysis Systematic Evaluation Program, San Onofre Nuclear Generating Station, Unit 1.
9. PID 140.
10. R. L. McNeill, C4, WT15, L20 to TR16 L26.
11. I. M. Idriss, WT13, L25-26, WT14, L01-02.

12. PID 115.

13. USNRC: "Development of Criteria for Seismic Review of Selected Nuclear Power Plants," by N. M. Newmark and W. J. Hall, NUREG/CR-0098, May 1978 (Table 4)

14. Ibid, (p. 27)

15. R. L. McNeill, C4, WT23 L01 to L02

16. G. A. Frazier, C1, WT (entire).

17. Joyner, W. B. and D. M. Boore: "Peak Horizontal Acceleration and Velocity from Strong-Motion Records including Records from the Imperial Valley, California, Earthquake," BSSA, Vol. 71. No. 6, pp. 2011-2038, December 1981.

18. L. H. Wight, C4, WT, Exhibit LHW-1, entire.

19. Campbell, K. W.: "Near-Source Attenuation of Peak Horizontal Acceleration," BSSA, vol. 71, No. 6, pp. 2039-2070, Dec. 1981.

20. I. M. Idriss, WT, Exhibit IMI-1, IMI-2, IMI-3, IMI-4, IMI-6.

21. G. L. Frazier, C4, WT (entire).

22. USNRC: "Development of Criteria for Seismic Review of Selected Nuclear Power Plants," by N. M. Newmark and W. J. Hall, NUREG/CR-0098, May 1978, (entire document).

23. R. L. McNeill, C4, WT18, L01 to WT23 L19.

24. Data collected from files of California Division of Safety of Dams.

25. I. M. Idriss, C4, WT, Exhibit IMI-C.

TABLE 1

STUDY OF EXCEPTIONAL RECORDINGS

(1) Date	(2) Identification	(3) M	(4) R, km	(5) Faulting Style	(6) Measured IPGA Mi, Ri	(7) TERA msd IPGA Mi, Ri	(8) Scaled IPGA M7, R8
17 May 76	Gazli, USSR, EW	7.2	5	Thrust	0.74g	0.60g	0.60g
	NS	7.2	5	Thrust	0.64	0.60	0.52
16 Sep 78	Tabas, Iran, Trans	7.7	3	Thrust	0.78	0.71	0.54
	Long	7.7	3	Thrust	0.83	0.71	0.58
15 Oct 79	IV-79 942-230	6.9	1	Strike-S	0.45	0.74	0.30
	942/140	6.9	1	Strike-S	0.72	0.74	0.48
	5054/230	6.9	2	Strike-S	0.81	0.69	0.58
	5054/140	6.9	2	Strike-S	0.66	0.69	0.47
	958/230	6.9	4	Strike-S	0.50	0.60	0.41
	958/140	6.9	4	Strike-S	0.64	0.60	0.52
	955/230	6.9	4	Strike-S	0.38	0.60	0.31
	955/140	6.9	4	Strike-S	0.61	0.60	0.50
	5165/360	6.9	5	Strike-S	0.51	0.57	0.44
	5165/270	6.9	5	Strike-S	0.37	0.57	0.32
	5115/230	6.9	10	Strike-S	0.43	0.42	0.50
	5115/140	6.9	10	Strike-S	0.33	0.42	0.39
	5058/230	6.9	13	Strike-S	0.38	0.36	0.52
	5058/140	6.9	13	Strike-S	0.38	0.36	0.52
09 Jun 80	Victoria, BC, N15W	6.3	2	Strike-S	0.85	0.64	0.53
23 Nov 80	Italian; ST-NS	6.5	18*	Normal#	0.24	0.22	0.53
	ST-EW	6.5	18*	Normal#	0.35	0.22	0.78
27 May 81	Mammoth 99/180	6.3	10	Normal##	0.33	0.32	0.50
	99/90	6.3	10	Normal##	0.27	0.32	0.41
	3679, Long	6.3	10	Normal##	0.38	0.32	0.58
	Trans	6.3	10	Normal##	0.17	0.32	0.26
	3754, Long	6.3	8	Normal##	0.76	0.38	0.98
	Trans	6.3	8	Normal##	0.47	0.38	0.64
						Average =	0.51g

* Epicentral distance, used incorrectly but conservatively, for purposes of study.

\# Reported dip-slip, conservatively assumed to be normal for purposes of study.

\## Or strike-slip.

TABLE 1-U

STUDY OF USGS-365 SCALING OF EXCEPTIONAL RECORDINGS

(1) Date	(2) Identification	(3) M	(4) R, km	(5) Faulting Style	(6) Measured IPGA Mi, Ri	(7) USGS msd IPGA Mi, Ri	(8) Scaled IPGA M7, R8
17 May 76	Gazli, USSR, EW	7.2	5	Thrust	0.74g	1.16g	0.53g
	NS	7.2	5	Thrust	0.64	1.16	0.46
16 Sep 78	Tabas, Iran, Trans	7.7	3	Thrust	0.78	1.74	0.37
	Long	7.7	3	Thrust	0.83	1.74	0.40
15 Oct 79	IV-79 942-230	6.9	1	Strike-S	0.45	1.18	0.32
	942/140	6.9	1	Strike-S	0.72	1.18	0.51
	5054/230	6.9	2	Strike-S	0.81	1.15	0.59
	5054/140	6.9	2	Strike-S	0.66	1.15	0.48
	958/230	6.9	4	Strike-S	0.50	1.04	0.40
	958/140	6.9	4	Strike-S	0.64	1.04	0.51
	955/230	6.9	4	Strike-S	0.38	1.04	0.30
	955/140	6.9	4	Strike-S	0.61	1.04	0.49
	5165/360	6.9	5	Strike-S	0.51	0.97	0.44
	5165/270	6.9	5	Strike-S	0.37	0.97	0.32
	5115/230	6.9	10	Strike-S	0.43	0.68	0.53
	5115/140	6.9	10	Strike-S	0.33	0.68	0.40
	5058/230	6.9	13	Strike-S	0.38	0.56	0.57
	5058/140	6.9	13	Strike-S	0.38	0.56	0.57
09 Jun 80	Victoria, BC, N15W	6.3	2	Strike-S	0.85	0.81	0.87
23 Nov 80	Italian; ST-NS	6.5	18*	Normal#	0.24	0.33	0.61
	ST-EW	6.5	18*	Normal#	0.35	0.33	0.88
27 May 81	Mammoth 99/180	6.3	10	Normal##	0.33	0.48	0.57
	99/90	6.3	10	Normal##	0.27	0.48	0.47
	3679, Long	6.3	10	Normal##	0.38	0.48	0.66
	Trans	6.3	10	Normal##	0.17	0.48	0.30
	3754, Long	6.3	8	Normal##	0.76	0.56	1.13
	Trans	6.3	8	Normal##	0.47	0.56	0.70
						Average =	0.53g

* Epicentral distance, used incorrectly but conservatively, for purposes of study.
\# Reported dip-slip, conservatively assumed to be normal for purposes of study.
\## Or strike-slip.

TABLE 2

CONFIDENCE COMPARISON
SONGS 1 VERSUS SEP

- Ground Motion Model

  Greater confidence due to availability of

  1) extensive and relevant ground motion data

  2) thoroughly reviewed and accepted analysis techniques

- Source Models

  Greater confidence due to more accurate and better understood seismotectonics.

- Seismicity Models

  OZD occurrence model conservative compared to historical record.

- Hazard Model

  1) Data uncertainty (σ, b-value and M_u) used both at SONGS and in the SEP.

  2) Zonation uncertainty conservatively bounded compared to range of alternative opinions.

TABLE 3

COMPARISON OF RESULTS OF SONGS SEISMIC HAZARD ANALYSIS WITH TYPICAL SEP RECOMMENDATIONS

Type of Analysis	Return Period (Years)	
	SONGS (0.67 g)	Typical SEP Recommendation
Conventional Hazard Analysis	10,000 to 100,000	1,000 to 10,000
Historical Hazard Analysis	30,000 to >100,000	5,000

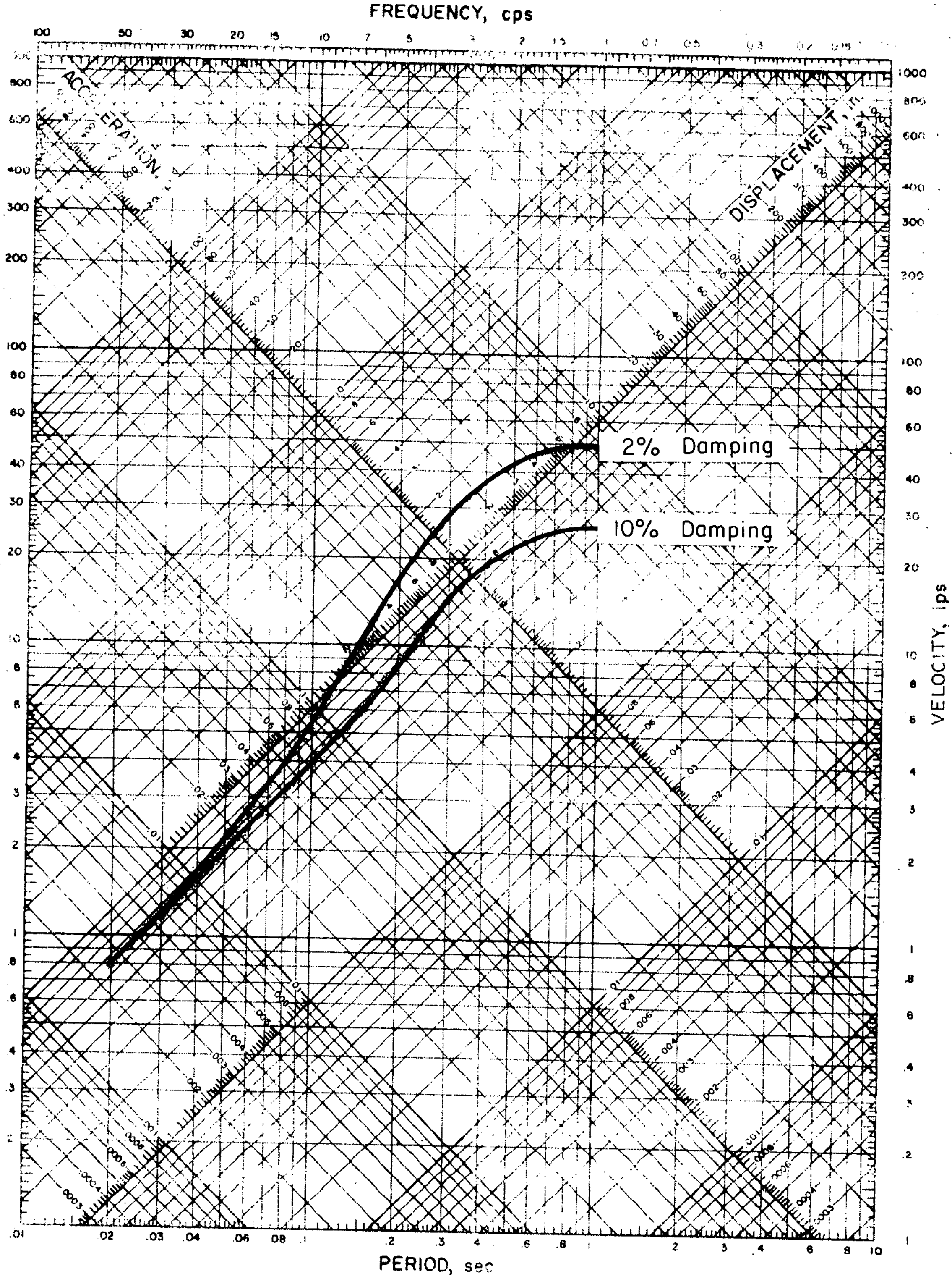
TABLE 4

COMPARISON OF RESULTS OF SONGS "APPENDIX A" APPROACH
WITH TYPICAL SEP RECOMMENDATIONS

SSE Design Parameters	SONGS	Typical SEP Recommendation	Comments
Earthquake Magnitude	7.0 M_s	5.3 M_L[a]	SEP value represents the center of the range M_L 4.8-5.8 used to select real time histories; 7.0 M_s is the maximum earthquake.
Source-to-Site Distance (km)	8	12[a]	SEP value represents average distance of 33 selected real time histories.
Exceedance Probability of Design PGA (%)	2	50[b]	SONGS 0.67 g seismic reanalysis acceleration provides a greater level of protection than the acceptable limits recommended for SEP plants.

a These parameters were defined by NUREG/CR-1582 to select an ensemble of real time histories to be used with the deterministic approach of Appendix A to 10 CFR Part 100.

b This probability was recommended by NRC for comparison of the design ground motion of the SEP plants with the ensemble of real time histories compiled by NUREG/CR-1582.



Project: SONGS Unit 1 Project No. A103	Reanalysis Spectra, Design Forms	Fig. 1

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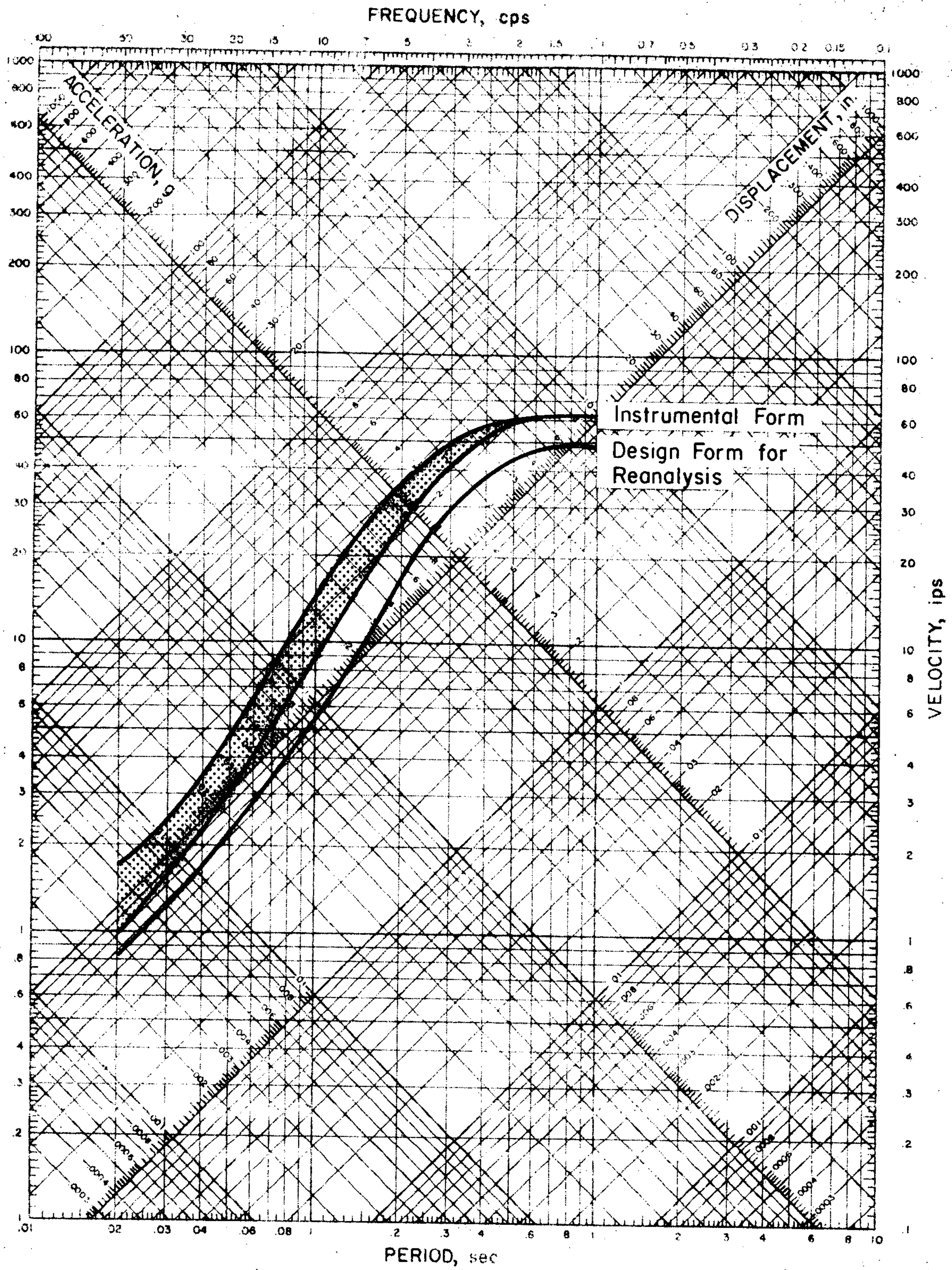

Project: SONGS Unit 1 Project No. A103	Instrumental and Design Forms of Unit I Reanalysis Spectrum, 2% Damping	Fig. 2

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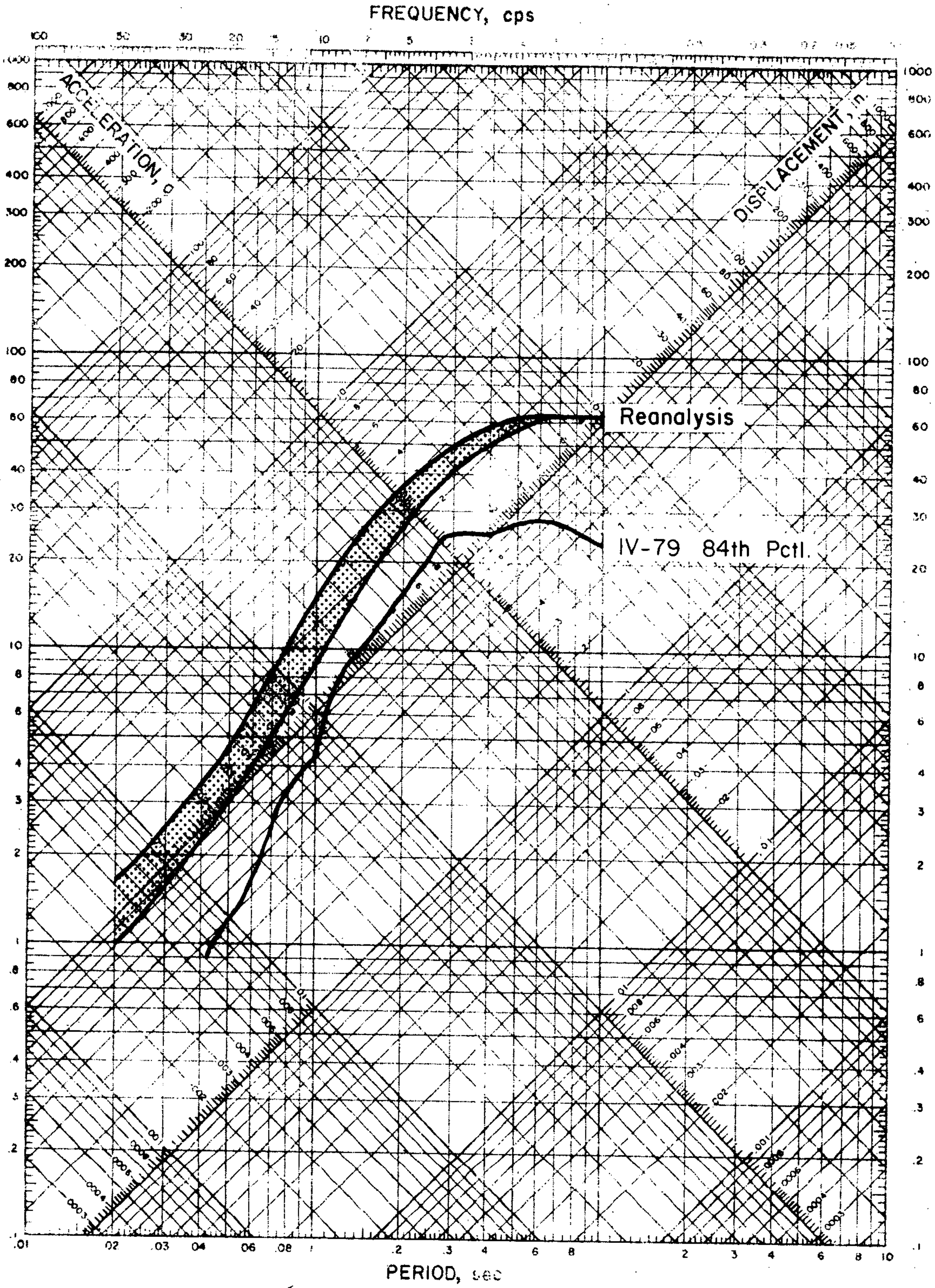

Project: SONGS Unit 1 Project No. A 103	Instrumental Reanalysis Spectrum Compared to Instrumental IV-79 Spectra, 6-13 km, 2% Damping	Fig. 3

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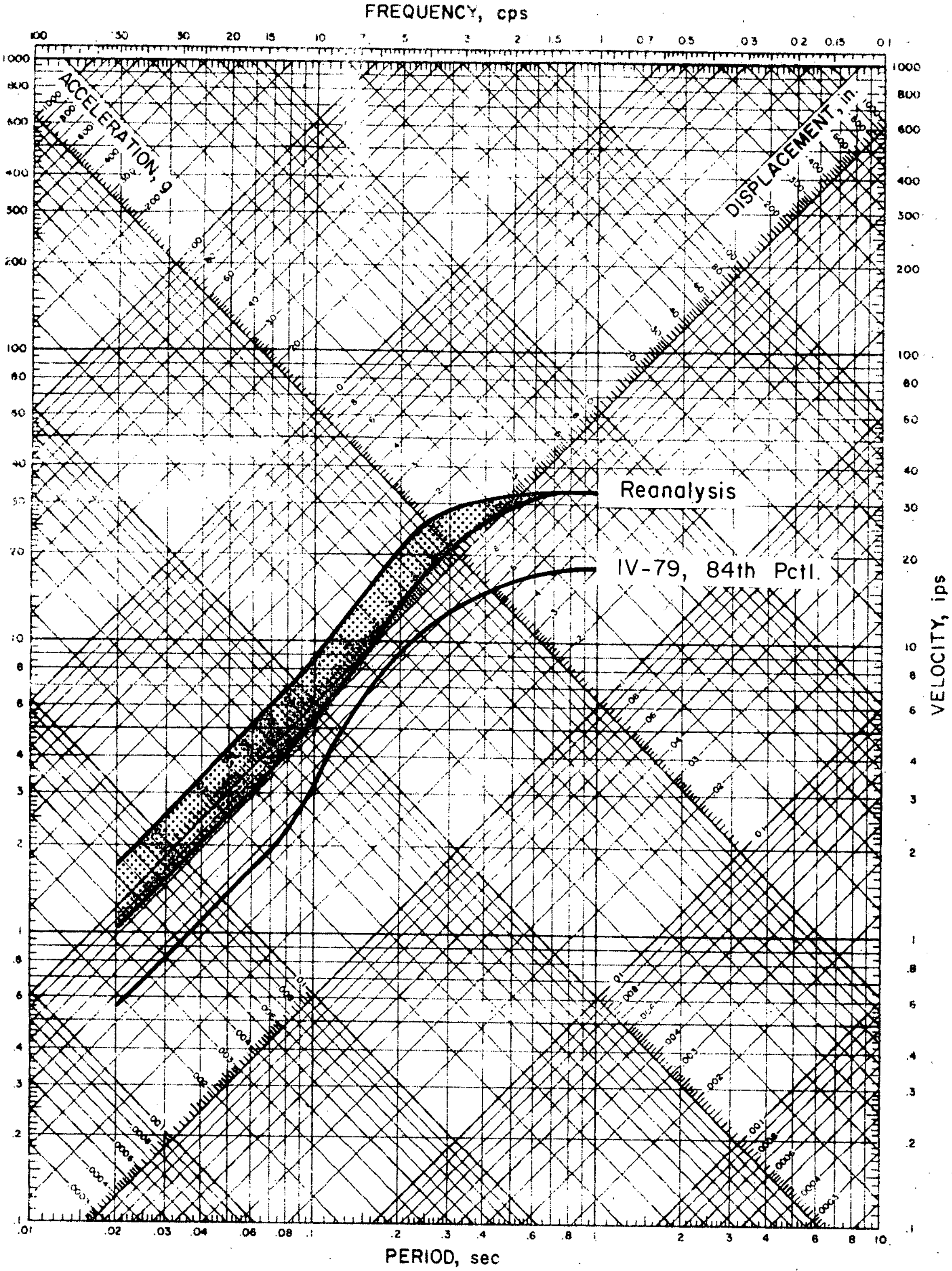

Project: SONGS Unit 1 Project No. A103	Instrumental Reanalysis Spectrum Compared to Instrumental IV-79 Spectra, 6-13 km, 10% Damping	Fig. 4

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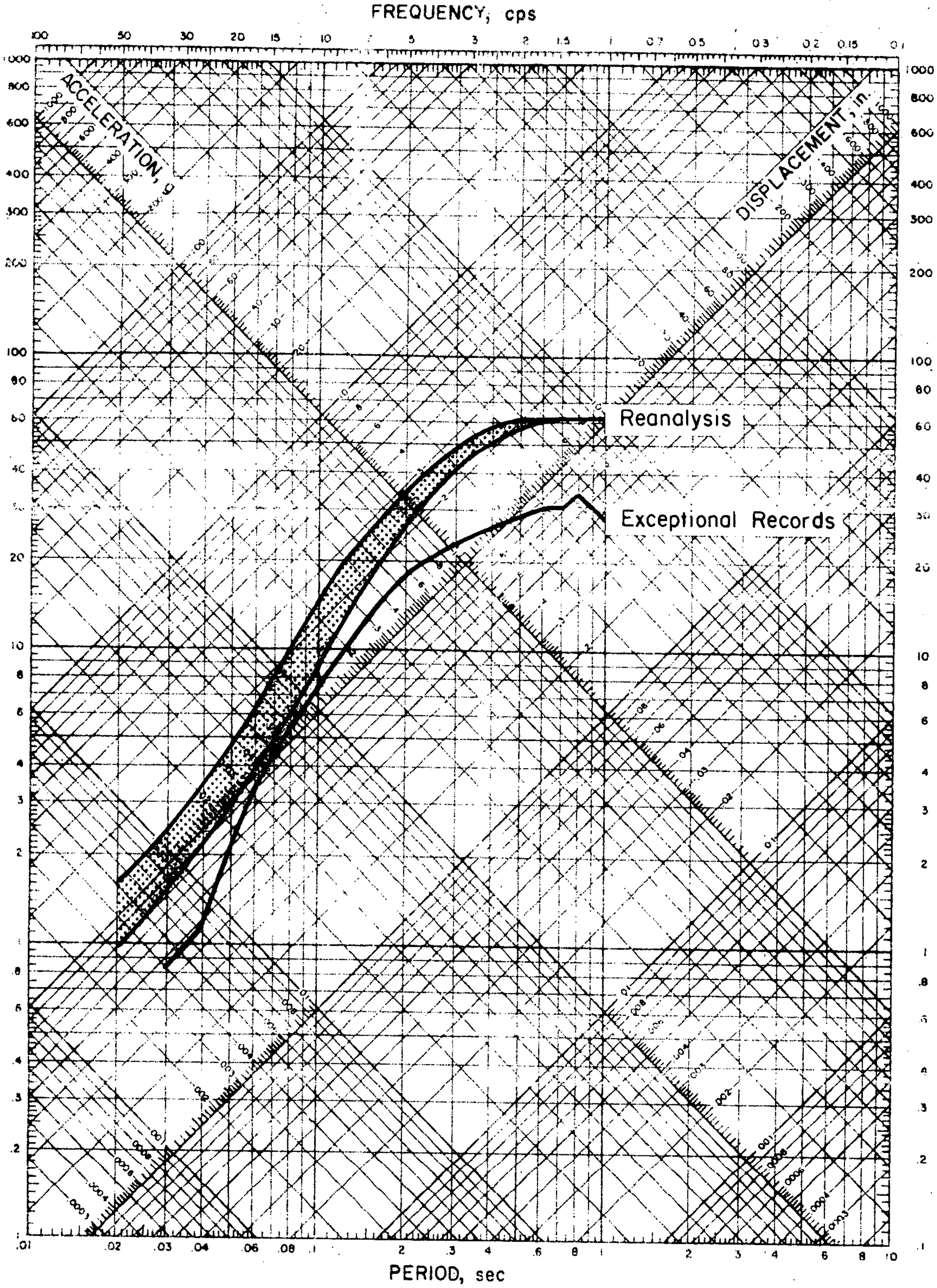

EXCEPTIONAL RECORDS: One or more components exceeded TERA 84th percentile prediction. Curve is average of 23 exceptional recordings from five earthquakes.

Project. SONGS Unit 1 Project No. A103	Instrumental Reanalysis Spectrum Compared to Exceptionally Strong Recorded Instrumental Motions, 2% Damping	Fig. 5

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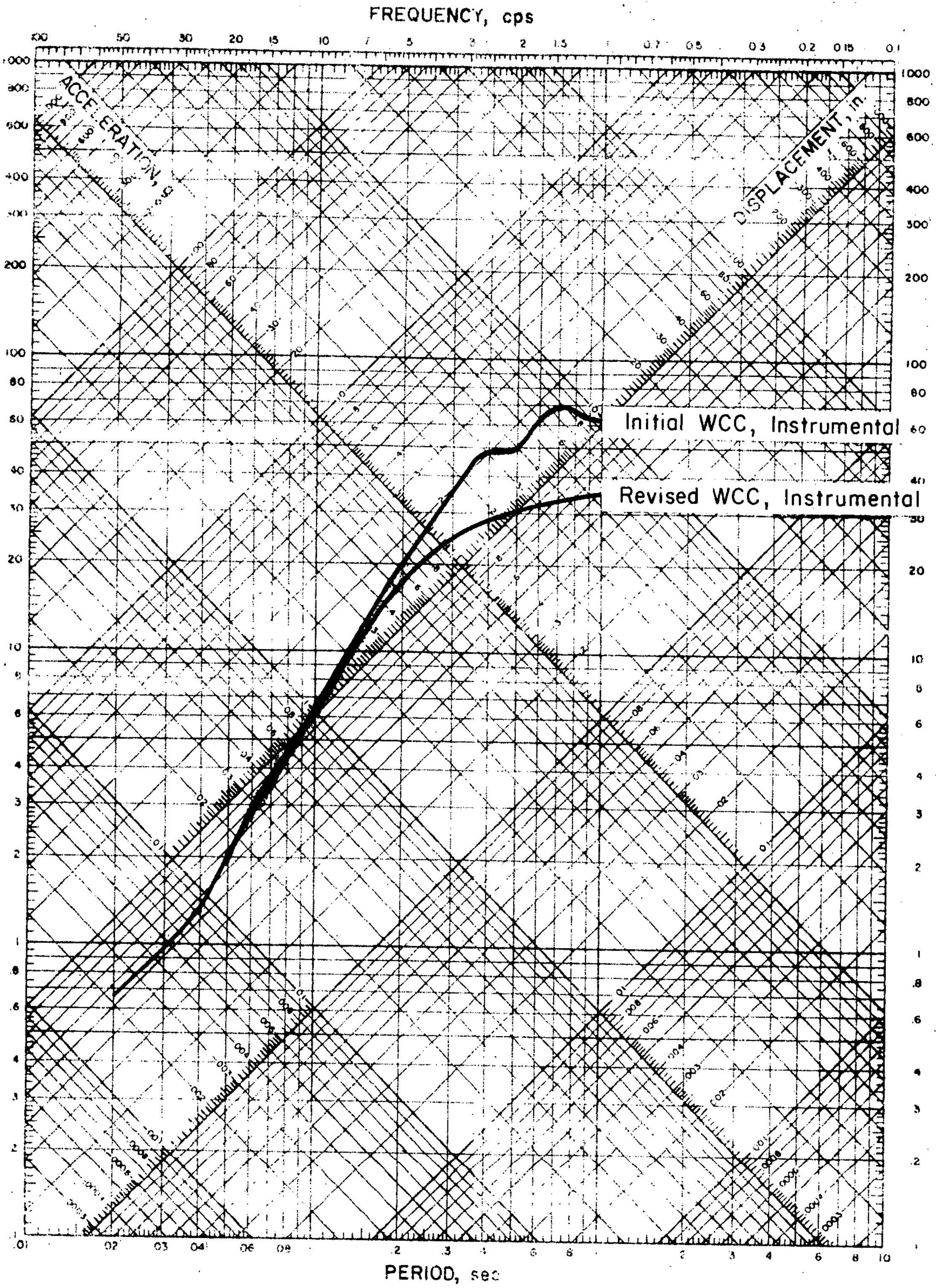

Both are 84th Percentile.

Project. SONGS Unit 1 Project No. A103	Updated WCC Spectrum, 2% Damping	Fig. 6

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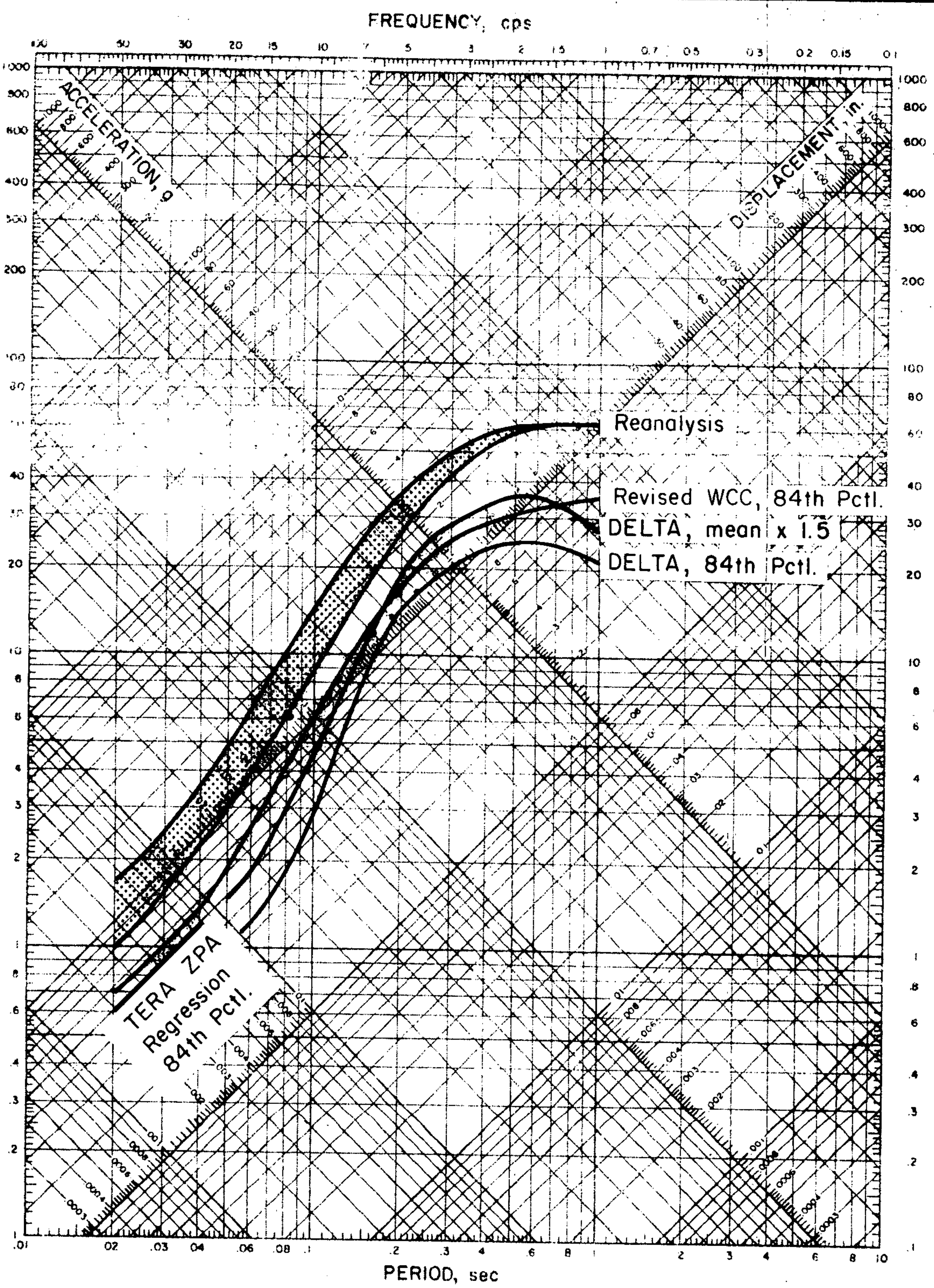

Project: SONGS Unit 1 Project No. A103	Instrumental Reanalysis Spectrum Compared to Instrumental Calculated Spectra, 2% Damping	Fig. 7

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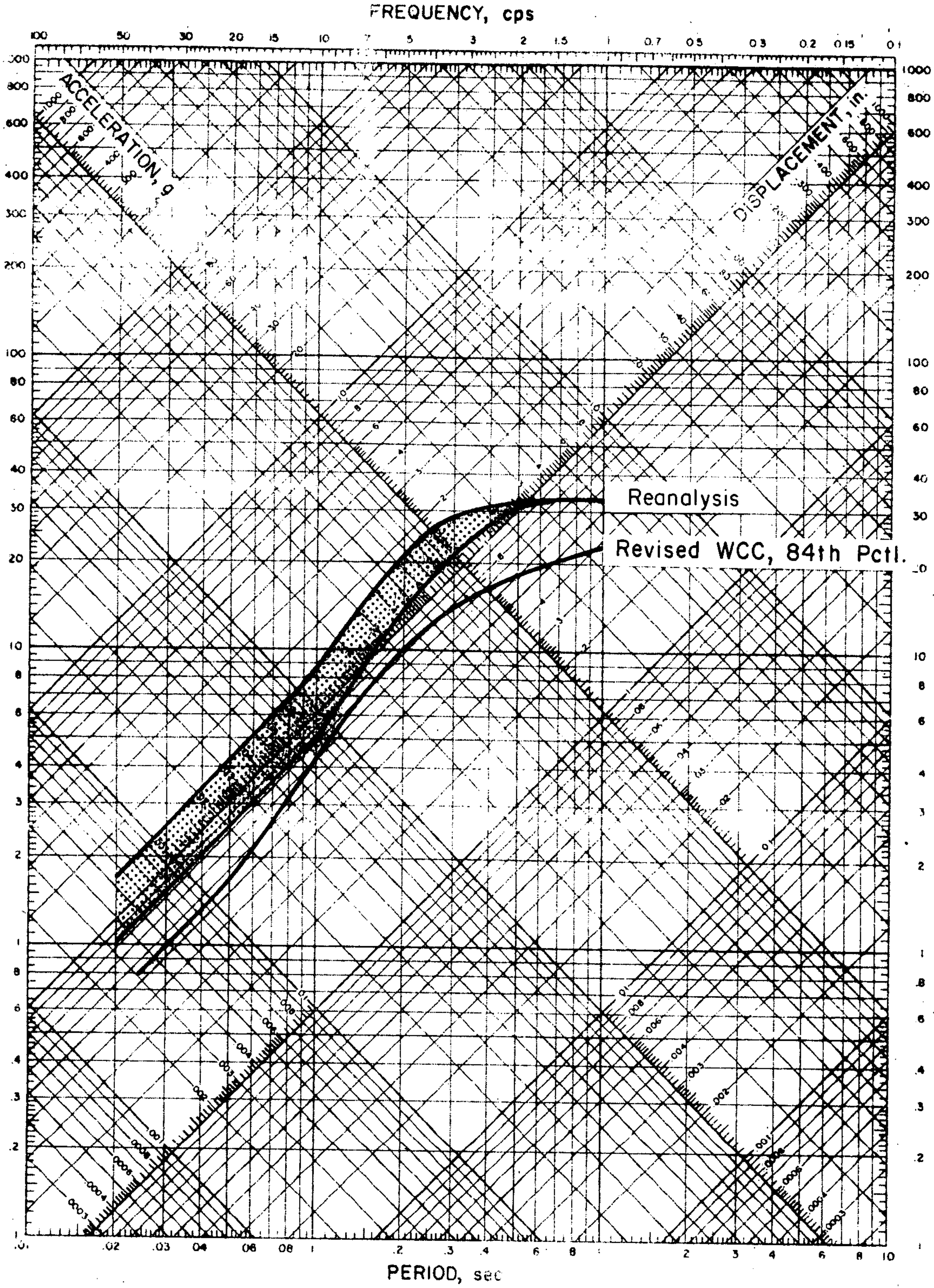

Project: SONGS Unit 1 Project No. A103	Instrumental Reanalysis Spectrum Compared to Instrumental Calculated Spectra, 10% Damping	Fig. 8

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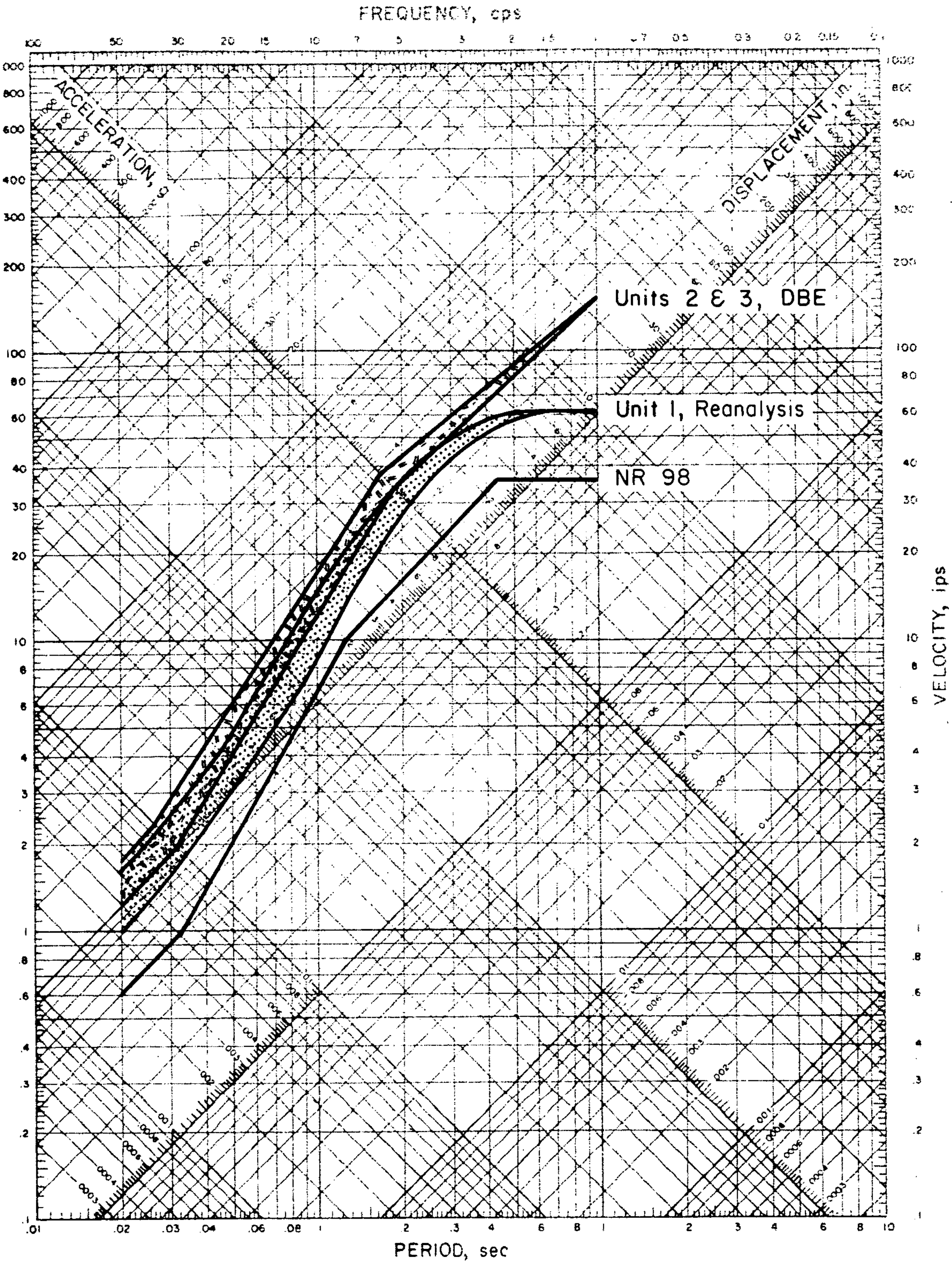

Project: SONGS Unit 1 Project No. A103	Instrumental Reanalysis Spectrum Compared to Instrumental Regulatory Spectra, 2% Damping	Fig. 9

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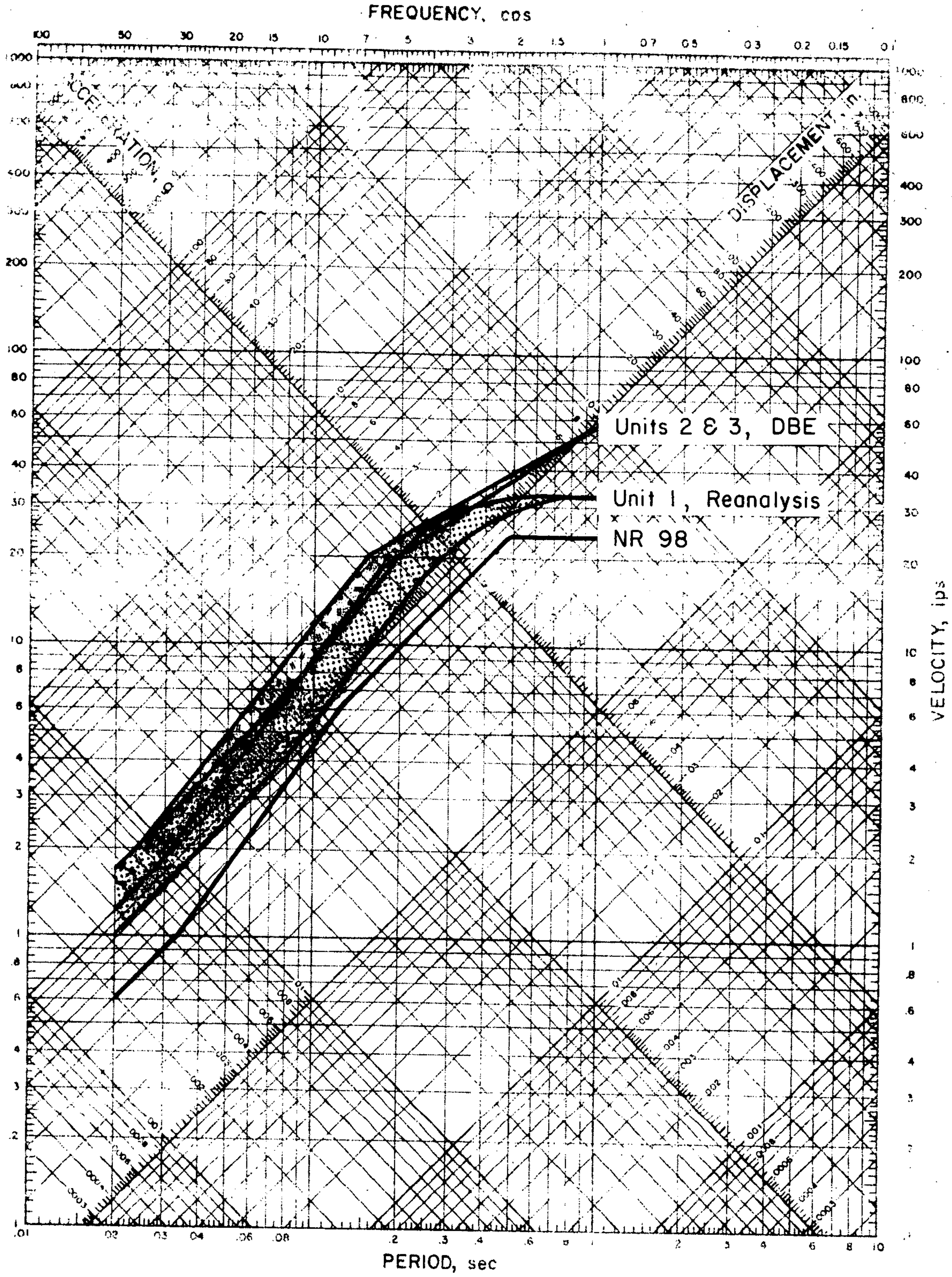

Project: SONGS Unit 1 Project No. A103	Instrumental Reanalysis Spectrum Compared to Instrumental Regulatory Spectra, 10% Damping	Fig. 10

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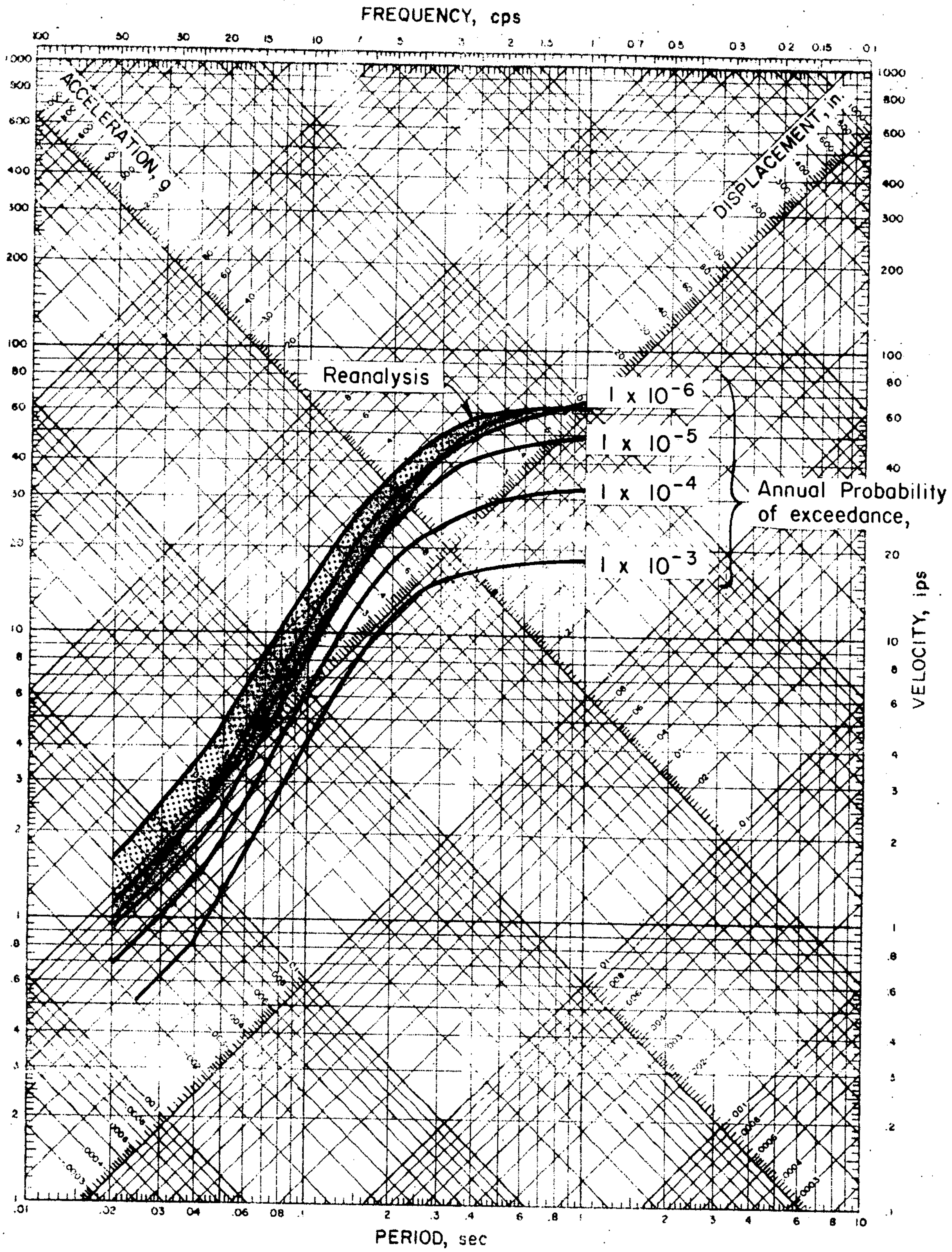

Project: SONGS Unit 1 Project No. A103	Instrumental Reanalysis Spectrum Compared to Instrumental Equal Probability Spectra, 2% Damping	Fig. 11

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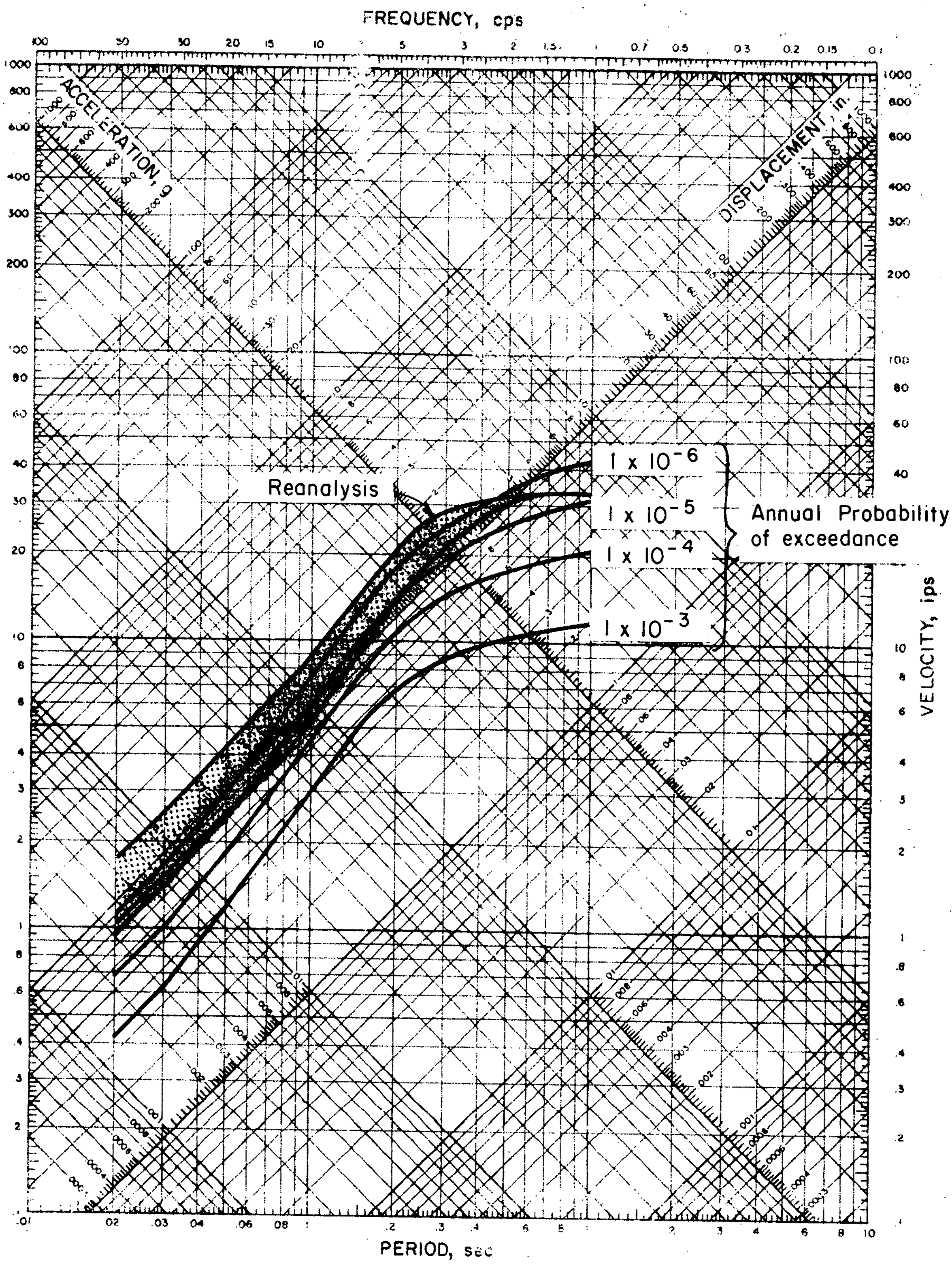

Project: SONGS Unit 1 Project No. A103	Instrumental Reanalysis Spectrum Compared to Instrumental Equal Probability Spectra, 10% Damping	Fig. 12

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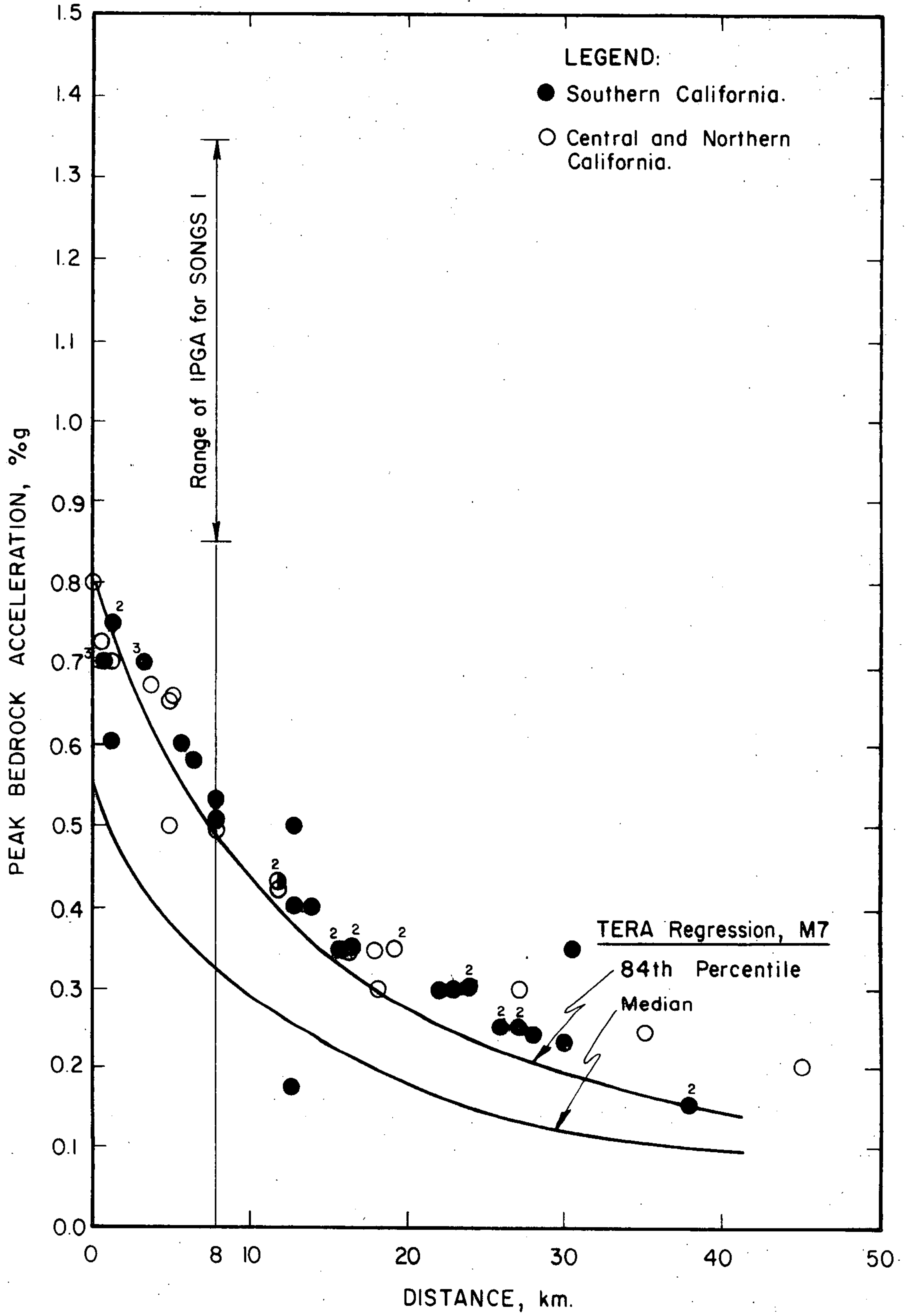

Project: SONGS Unit 1 Project No. A103	Peak Bedrock Acceleration used for Design or Reevaluation of Dams in California Magnitude 7 Earthquakes	Fig. 13

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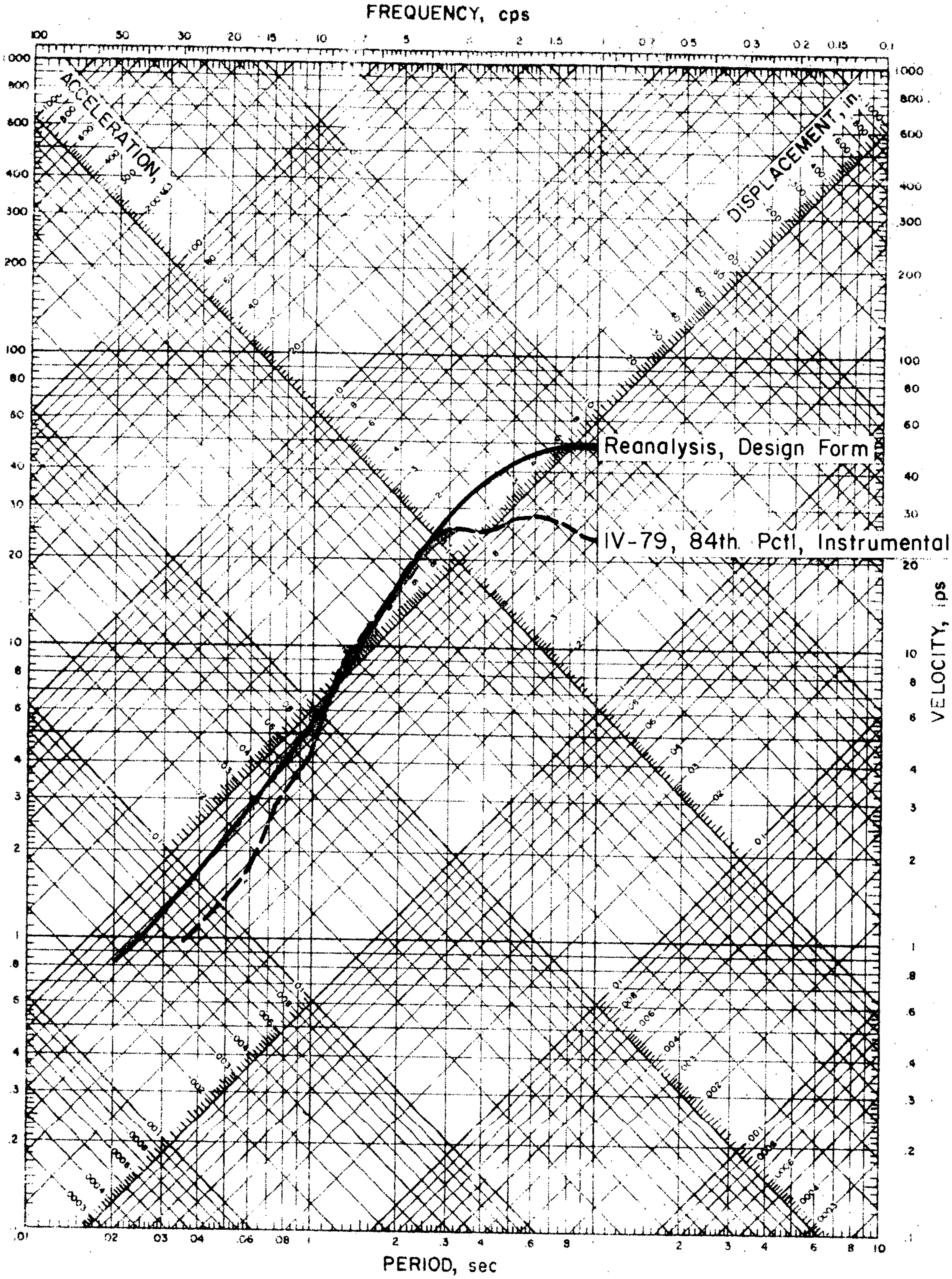
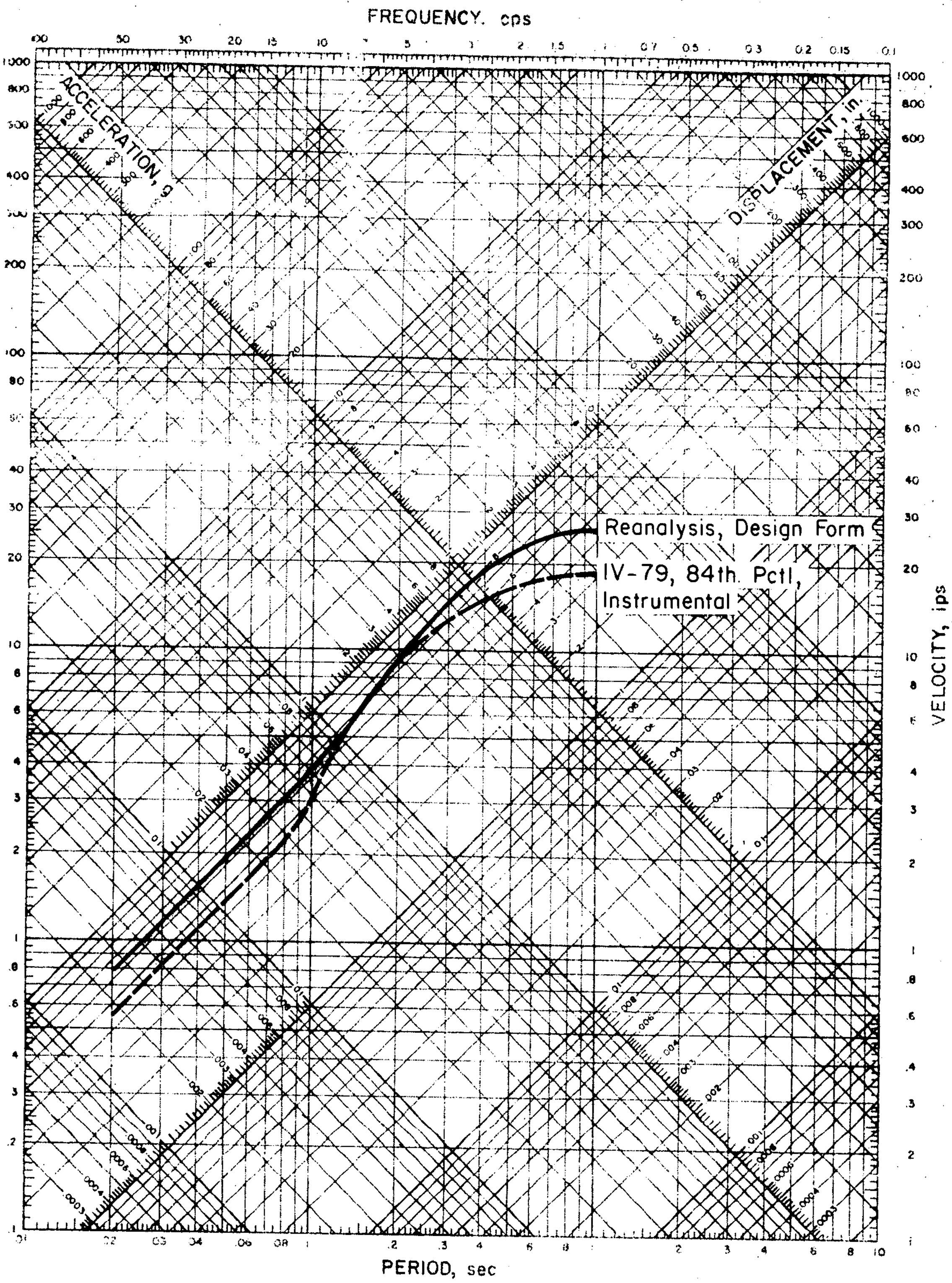


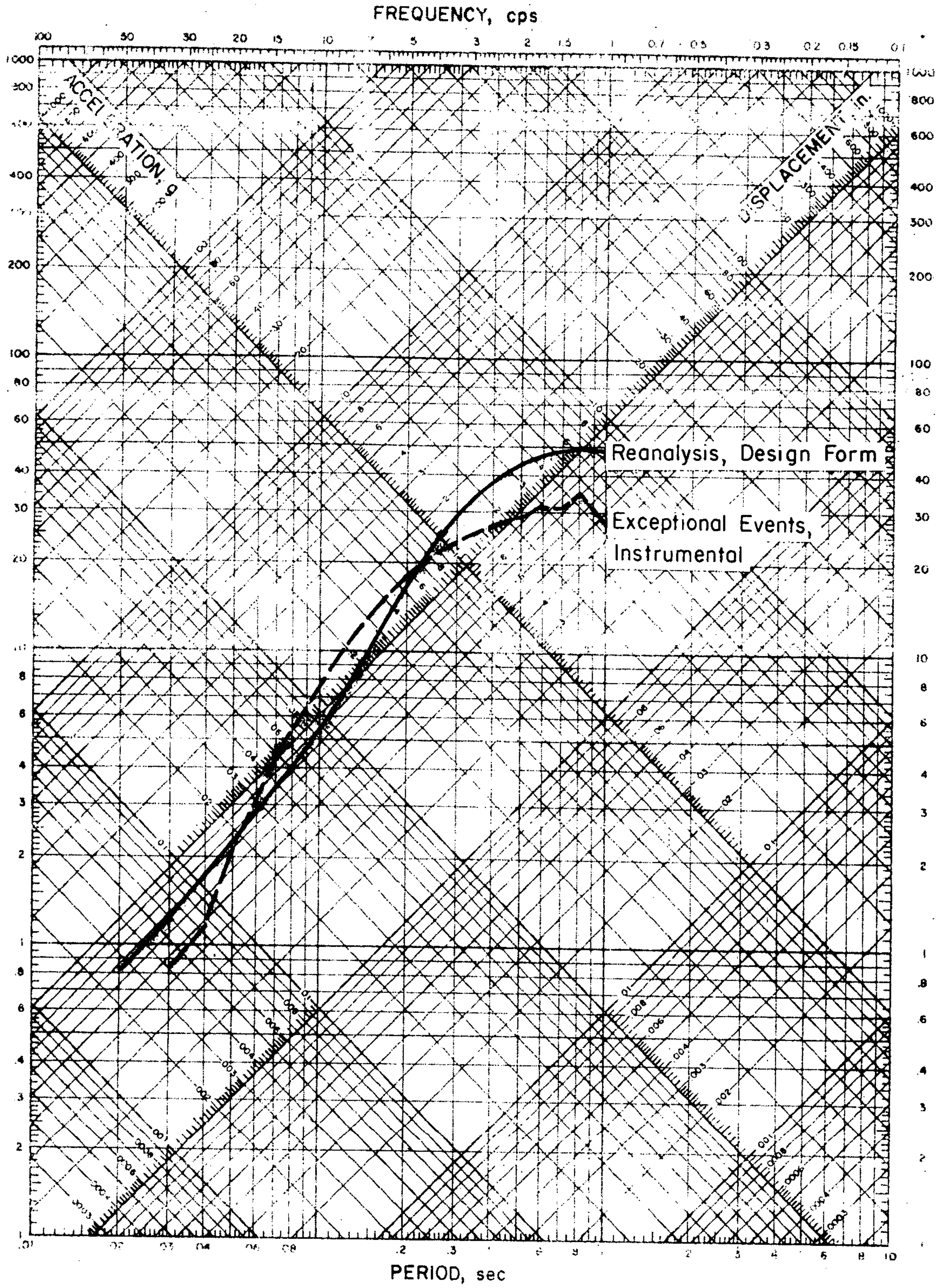
IV-79, all records from 6 to 13 km.

Project: SONGS Unit 1 Project No. A103	Design Reanalysis Spectrum Compared to Instrumental IV-79 Spectrum, 2% Damping	Fig. 14



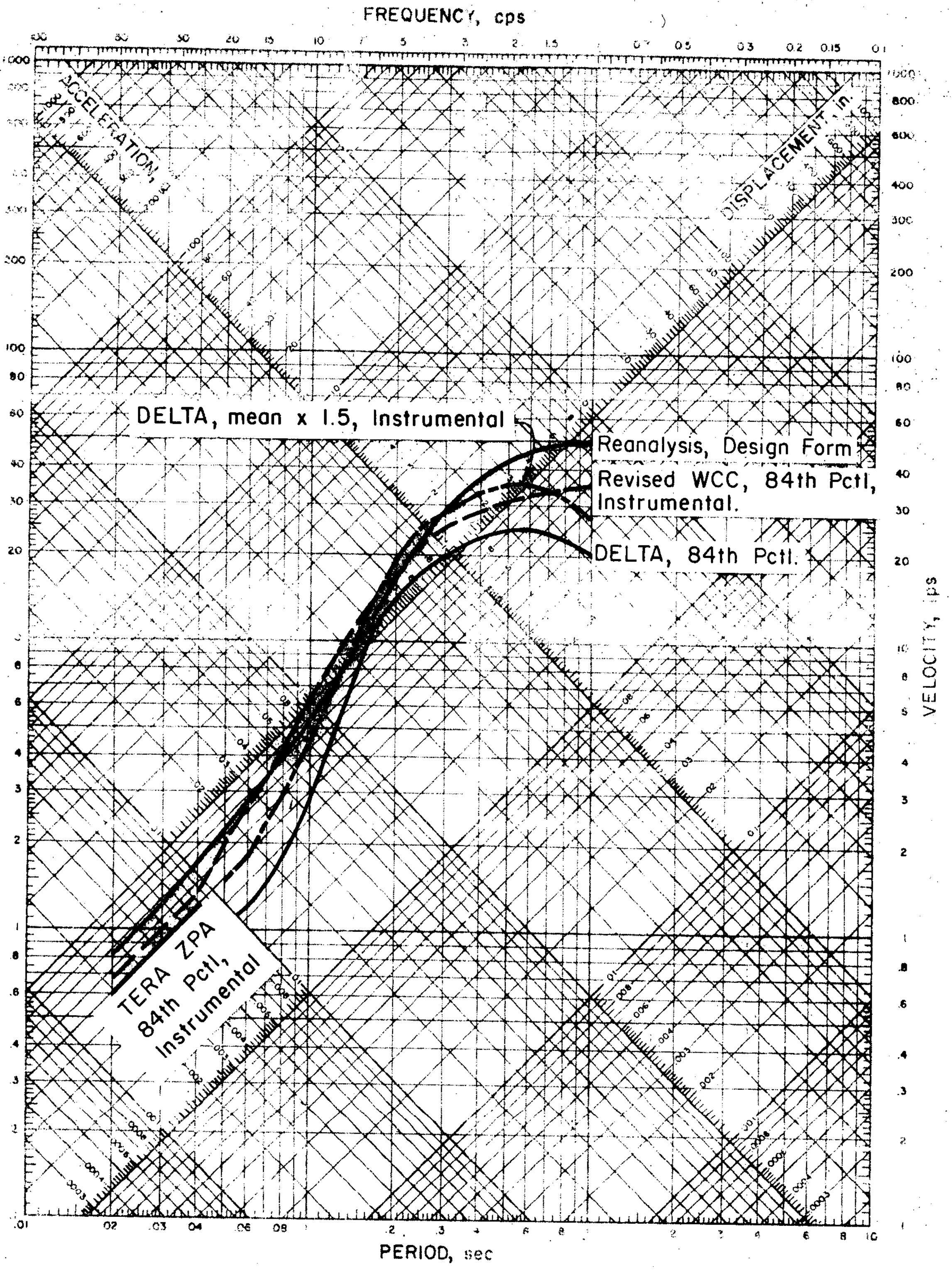
IV - 79, all records from 6 to 13 km.

Project: SONGS Unit 1 Project No. A103	Design Reanalysis Spectrum Compared to Instrumental IV-79 Spectrum, 10% Damping	Fig. 15

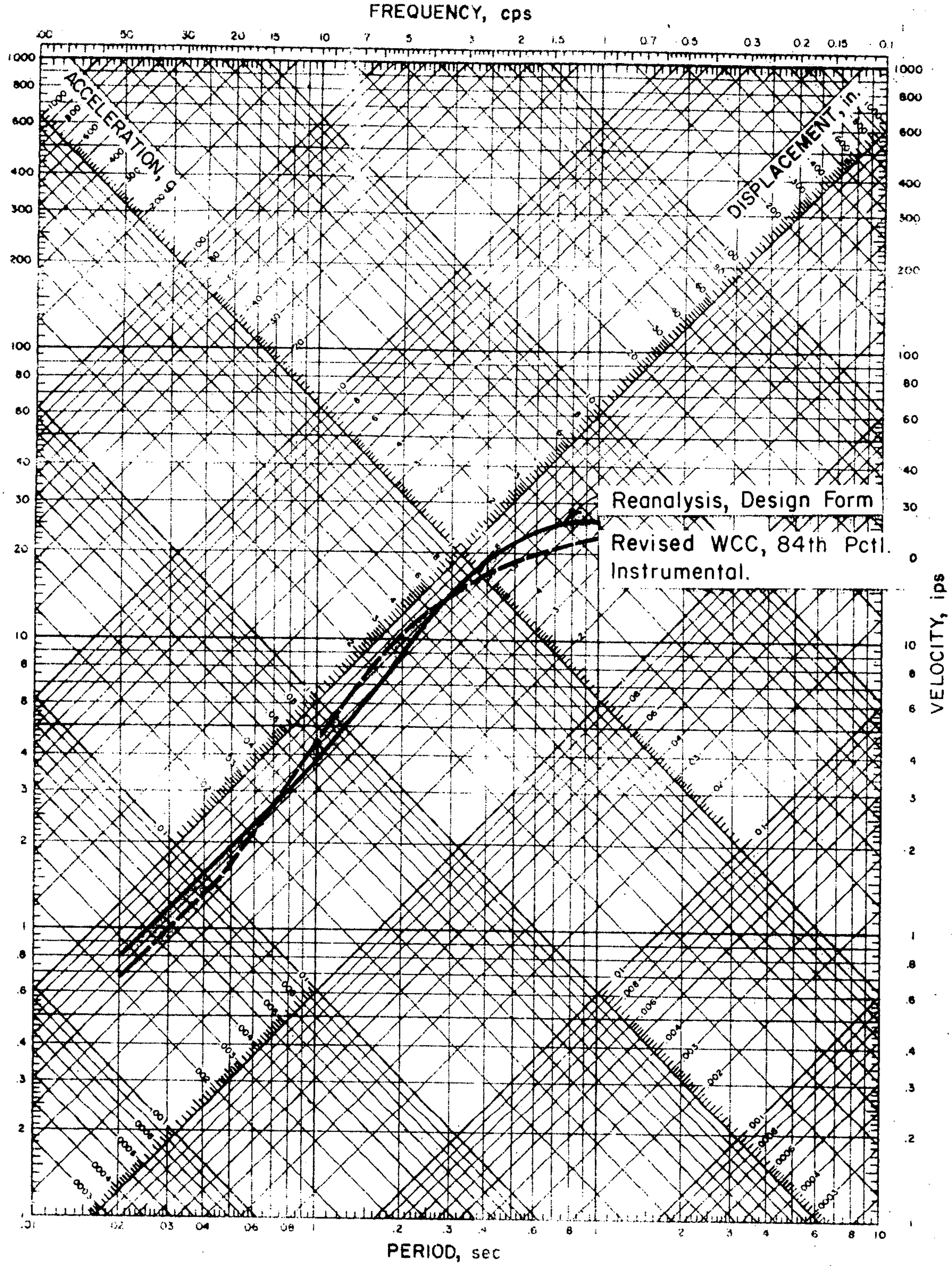


EXCEPTIONAL RECORDS: One or more components exceeded TERA 84th percentile prediction. Curve is average of 23 exceptional recordings from five earthquakes.

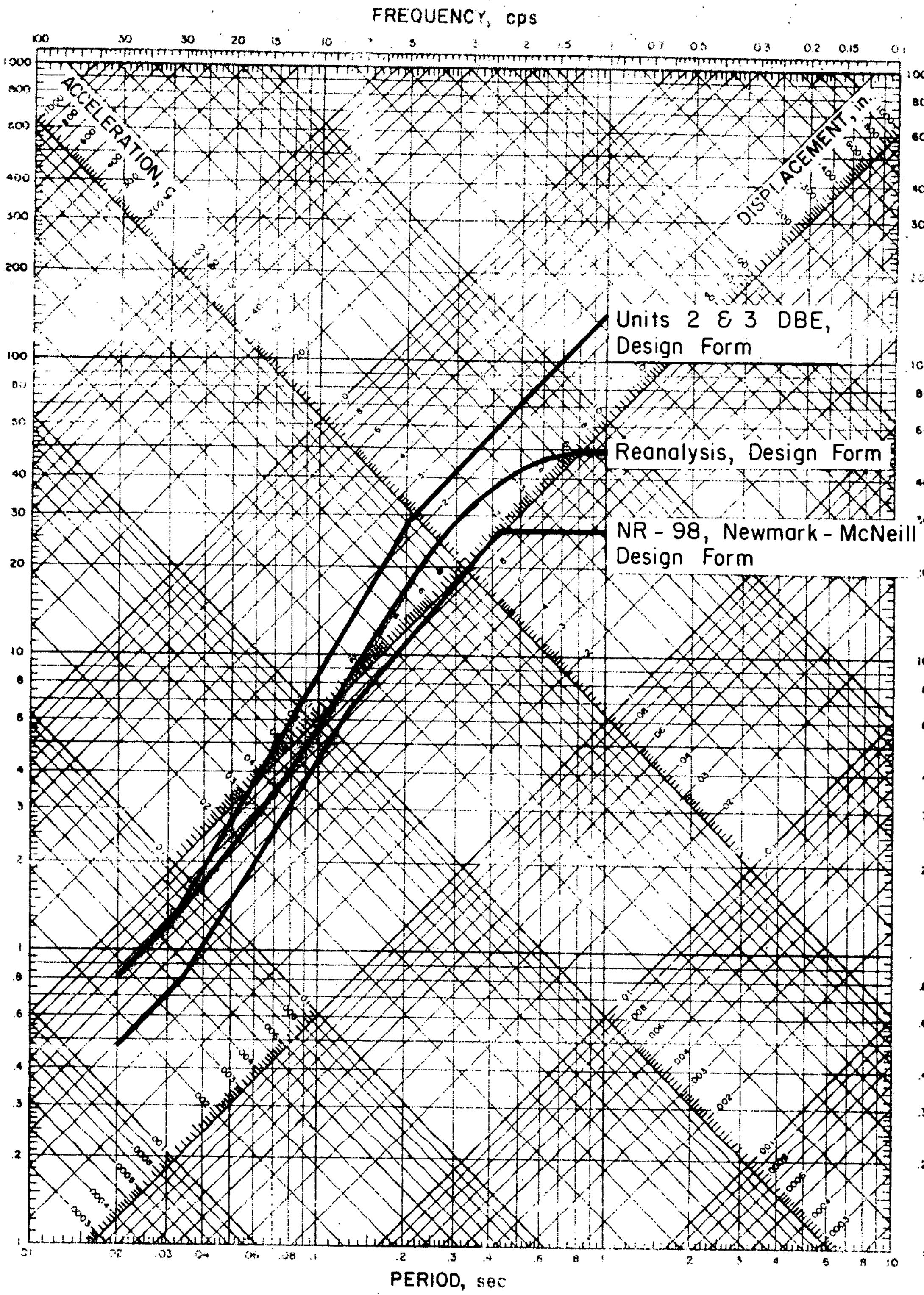
Project: SONGS Unit 1 Project No. A103	Design Reanalysis Spectrum Compared to Average of Instrumental Exceptional Records, 2% Damping	Fig. 16



Project: SONGS Unit 1 Project No. A103	Design Reanalysis Spectrum Compared to Calculated Instrumental Spectra, 2% Damping	Fig. 17



Project: SONGS Unit 1 Project No. A103	Design Reanalysis Spectrum Compared to Calculated Instrumental Spectra, 10% Damping	Fig. 18



Project: SONGS Unit 1 Project No. A103	Design Reanalysis Spectrum Compared to Various Regulatory Spectra, 2% Damping	Fig. 19

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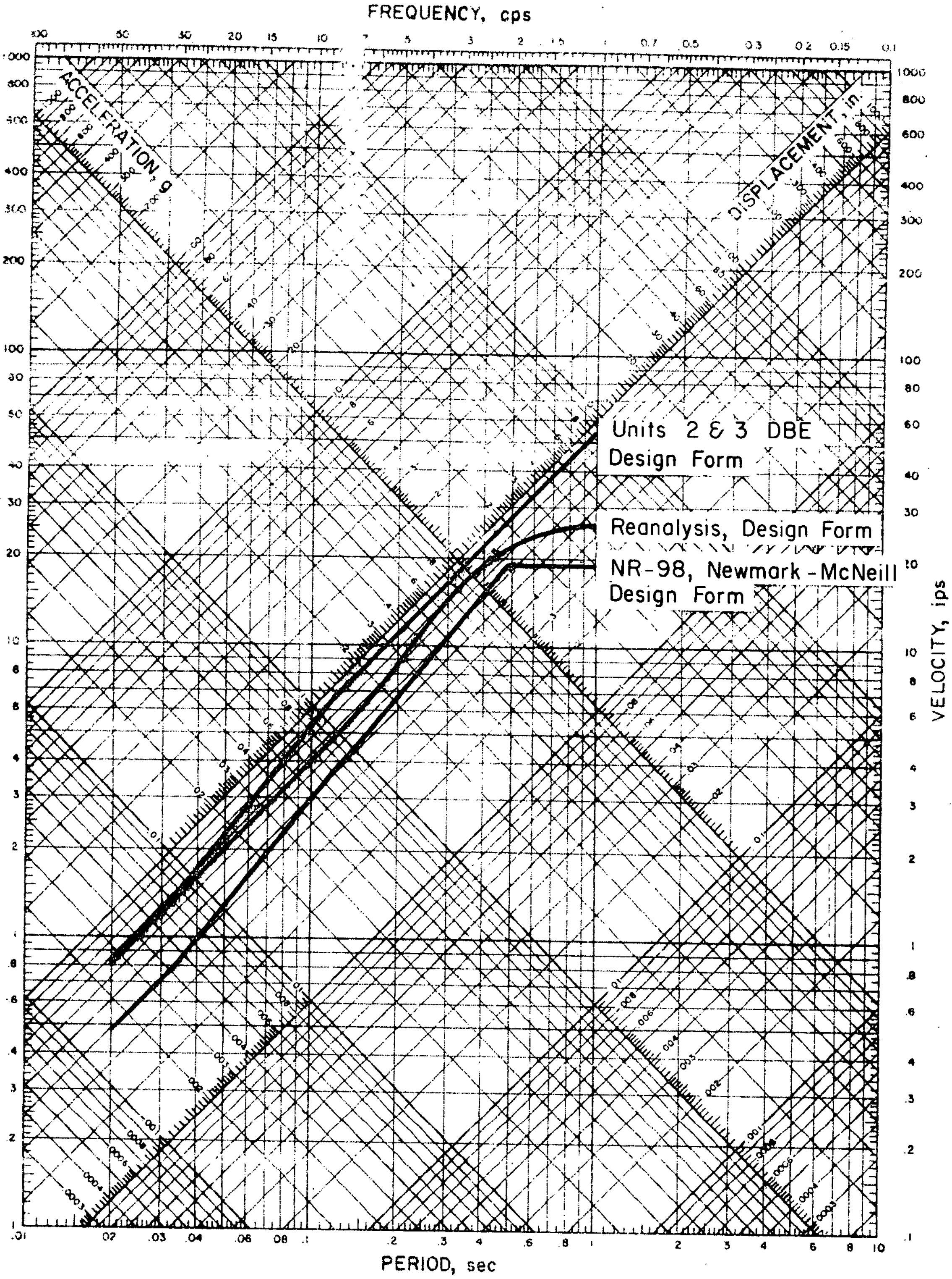

Project: SONGS Unit 1 Project No. A103	Design Reanalysis Spectrum Compared to Various Regulatory Spectra, 10% Damping	Fig. 20

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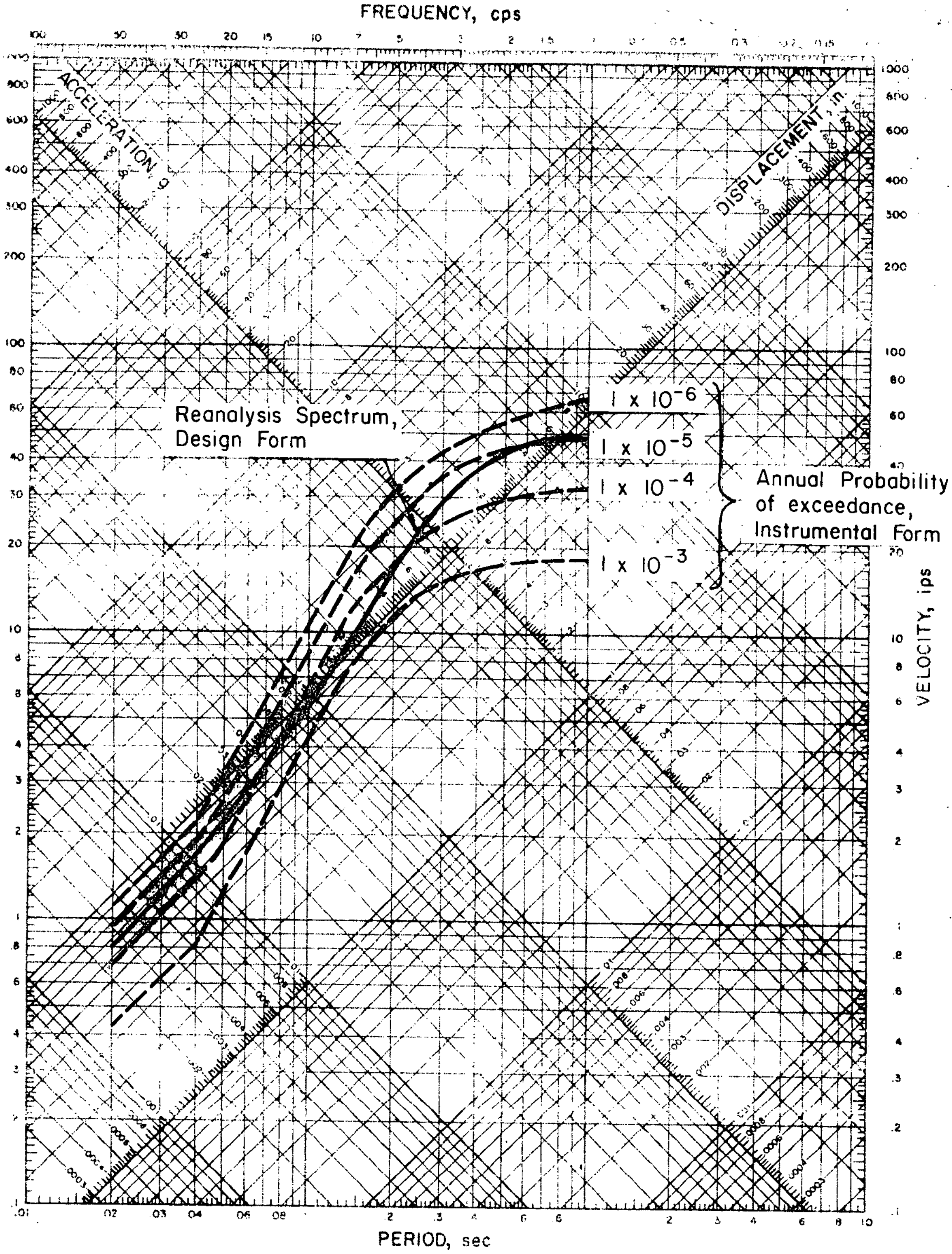
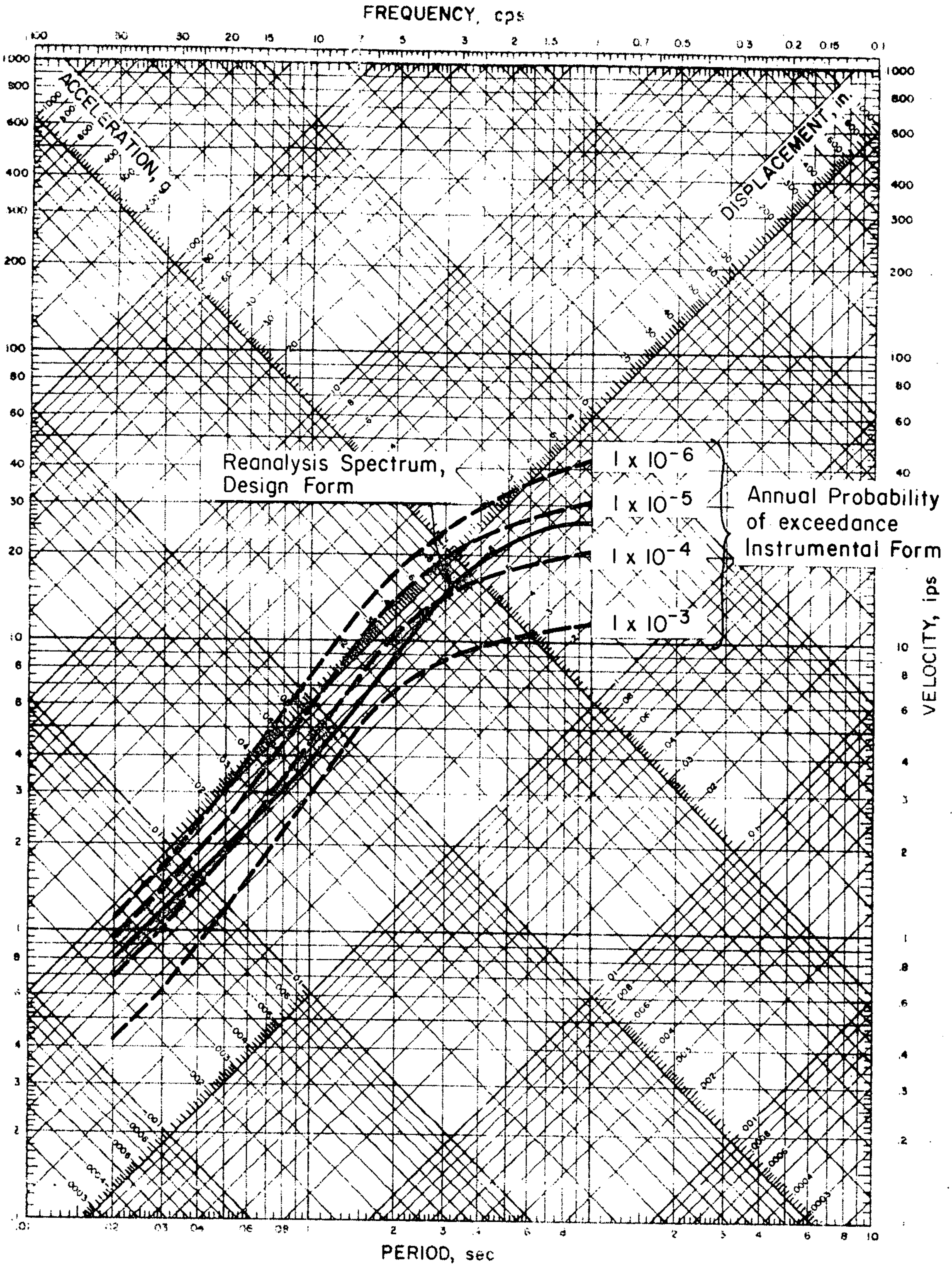


Project: SONGS Unit 1 Project No. A103	Design Reanalysis Spectrum Compared to Instrumental Equal-Probability Spectra, 2% Damping	Fig. 21



Project: SONGS Unit 1 Project No. A103	Design Reanalysis Spectrum Compared to Instrumental Equal-Probability Spectra, 10% Damping	Fig. 22