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CRITIQUE OF BROOKHAVEN NATIONAL LABORATORY REVIEW OF METHODS AND CRITERIA FOR DYNAMIC COMBINATIONS IN PIPING SYSTEMS

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Abstract

This document is a critique of the Brookhaven National Laboratory (BNL) study entitled, "Brookhaven National Laboratory Review of Methods and Criteria for Dynamic Combinations in Piping Systems, Final Report Fiscal Year 1979". The critique is based on the BNL draft submitted by the NRC to the Mark II Owners Group Licensing on December 26, 1979. Any significant technical changes or additions to the base BNL study beyond the December 26, 1979 submittal may require modifications to the critique contained herein.

EXECUTIVE SUMMARY

This report presents a critique of recent work performed by the Brookhaven National Laboratory on the Newmark-Kennedy Criteria for Square-Root-Sum-of-the-Squares (SRSS) combination of peak dynamic responses (Reference 4). In our judgement, the Brookhaven study has concentrated upon lightly damped free vibration responses and random responses which are not typical of actual Mark II response time histories for which SRSS combination has been proposed. In addition, Brookhaven continues to misinterpret the basis for judging the adequacy of SRSS response combination using the characteristics of the input loading. For these reasons, much of the Brookhaven study does not appear to be applicable for judging the adequacy of the Newmark-Kennedy Criteria for Mark II applications.

Based upon our review of the Brookhaven study, we continue to conclude:

1. Both Criterion 1 and 2 are adequate for Mark II application and Criterion 2 is also recommended for generic application.

2. The Brookhaven study has identified some ambiguities with Criterion 1. Although these ambiguities do not detract from the intent of the Criterion, if proper judgement is used in application, Criterion 1 should be modified if it is to be applied beyond the Mark II Program. Minor modification to Criterion 1 enables an alternate Criterion 1 to correct the concerns in the Brookhaven study. This alternate Criterion 1 is discussed in Sections 3.5, 3.6 and Appendix A. It is recommended that Alternate Criterion 1 be considered for generic applications.

1. INTRODUCTION

In August 1978, the authors were requested by the Mark II Owners Group to develop criteria for judging the acceptability of combining multiple peak dynamic responses by the Square-Root-Sum-of-the-Squares (SRSS) method. The resultant criteria (Newmark-Kennedy Criteria) and its basis are presented in Reference 1. Subsequently, a minor modification and detailed demonstration of the adequacy of the criteria for Mark II usage was presented in Reference 2. Further demonstrations of the adequacy of Criterion 2 is presented in Reference 3. During this same period of time Brookhaven National Laboratory was engaged by the Nuclear Regulatory Commission to review the acceptability of combining multiple peak dynamic responses by the SRSS method (Reference 4). A major part of their effort dealt with a review of the Newmark-Kennedy Criteria. The authors were engaged by the Mark II Owners Group to write this critique of the Brookhaven effort. This critique presumes the reader is familiar with references 1 through 4.

The Brookhaven Report (Reference 4) is organized along the lines of general theoretical studies (Chapters 2, 3, 4, and 5), a review of Newmark-Kennedy Criterion 1 (Chapter 6), and a review of Criterion 2 (Chapter 7). This critique will be organized in the same manner, as follows:

Chapter 2 - Critique of General Studies
Chapter 3 - Critique of Criterion 1 Review
Chapter 4 - Critique of Criterion 2 Review

2. CRITIQUE OF GENERAL STUDIES

2.1 INFLUENCE OF RELATIVE FREQUENCY CONTENT OF TIME-HISTORIES BEING COMBINED

In Chapters 2 and 3 (Reference 4), Brookhaven National Laboratory reports the results of a series of studies of combined response conducted using lightly damped and undamped sine waves. These studies show that for two lightly damped sine waves with random start time in which the frequency of the two waves is significantly different, the non-exceedance probability (NEP) for the SRSS combination is likely to be substantially less than 50%. A number of cases were demonstrated in which the NEP was about 30 to 40% or less. These findings are not new. Previous studies have also shown the same results and this has been the basis for concern with SRSS combination of peak responses when the peak responses occur in the free vibration domain after termination of the strong transient input motion. We concur with these findings but they are not relevant to the Mark II SRSS effort.

Lightly damped sine waves are only representative of response during the free vibration domain after termination of the strong portion of the transient input motion. For relatively stiff structures (such as those found in nuclear power plants), subjected to transient dynamic loadings such as earthquake motion, or safety relief valve (SRV) discharge, the peak responses occur during the time of the transient loading with the free vibration responses being relatively small compared to the peak transient response. For example, Figure 1 presents a representative earthquake acceleration time history and a representative SRV discharge structure acceleration time history. These input motions result in responses of attached systems such as piping. Figures 2 through 5 show the response time histories for 2 percent damped systems with 5 and 16 Hz natural frequencies to these earthquake and SRV input time histories, respectively. These figures are representative and

illustrate that peak response occurs during the time of the transient input motion. Furthermore, these peak transient responses are highly irregular in time of occurrence and the transient response time history cannot be approximated by lightly damped sine waves. These transient responses are characterized by a limited number of near peak response excursions which occur at irregular intervals.

The use of lightly damped sine waves greatly overestimates the influence of wide frequency differences on the NEP for the SRSS combined response. In fact, for highly irregular amplitude transient responses with a limited number of near peak excursions, wide differences in relative frequencies do not result in significant differences in the NEP for the SRSS combined response so long as the number of near peak excursions is held constant. This point is illustrated by cases reported in Reference 3 in which frequency content of one of the two response time histories being combined were shifted relative to the other response time history by a factor of up to 40 holding the number of near peak excursions constant. This was done by applying a time scale factor to one of the two response time histories. Shifting relative frequency content by factors up to 40 while holding the number of near peak response excursions constant resulted in no greater than a 0.03 percent change in the NEP for the SRSS combined response (for instance, in one case a factor of 40 shift in frequency changed the NEP from 0.83 to 0.80). The relative frequency content of earthquake-like transient responses is relatively insignificant. The important characteristics are the number and width of near-peak excursions.

2.2 INFLUENCE OF WIDTH OF NEAR PEAK RESPONSE PULSES

In Section 3.7 of Reference 4, Brookhaven National Laboratory reports a series of studies in which the number of near peak excursions were held constant but the width of these near peak excursions was varied (i.e., the percentage of the total time at which the response was near peak response was varied). This variation of the percentage of time at which response was near the maximum peak response was accomplished by

specifying response time histories by deterministic combinations of undamped sine waves. It was shown that the percentage of time that response is near the maximum reponse is more important than the number of near peak excursions on the NEP for the SRSS combined response. For instance, in a case of narrow response pulses in which the response exceeded 50 percent of the maximum response 37 percent of the time, the NEP for the SRSS combined response was 0.72. With wide pulses in which the response exceeded 50 percent of the maximum response 76 percent of the time, the NEP for the SRSS combined response was 0.28.

Criterion 1 of the Newmark-Kennedy Criteria limits the number of times that the responses can approach the maximum peak responses and still allow SRSS combination of responses. Based upon the Brookhaven results, for generic application Criterion 1 could be modified to limit the percentage of time that responses can approach the near peak response rather than the number of times. This subject will be addressed further in a subsequent section.

3. CRITIQUE OF CRITERION 1 REVIEW

The applicability of the Newmark-Kennedy Criterion 1 was reviewed by the Brookhaven National Laboratory in Chapter 6 of Reference 4. This section presents a critique of some of the points made in that chapter.

3.1 USE OF LOAD VERSUS RESPONSE TIME HISTORIES

Criterion 1 enables the check of the adequacy of SRSS combination of responses to be made using either the characteristics of the individual load time histories or those of the response time histories being combined. In many cases, the load time histories are available but the response time histories are not available. For instance, with a piping system the input load time histories are generally available as a result of a time history analysis of the structure supporting the piping system. However, the piping system is generally analyzed using the response spectra method so that only peak responses are obtained. In this case, the adequacy of SRSS combination of peak dynamic responses from multiple dynamic loadings must be judged based upon characteristics of the load time histories since these are the only time histories available. Therefore, we believe that a practical simple criteria for judging the adequacy of SRSS response combination must allow the use of the characteristics of the load time histories being combined.

As explained in Reference 1, the basis of Criterion 1 is as follows. SRSS combination of earthquake responses has been extensively used and is acceptable to the NRC. So long as the loadings for which peak responses are being combined have characteristics at least as favorable as those for earthquake loadings, we thus judge that SRSS combination of responses is adequate. In particular, so long as the dynamic loadings have less near peak excursions than do earthquake loadings, the dynamic responses will also have less near peak excursions from this loading than the dynamic response of the same structure due to

earthquake loading. Similar statements can be made with regard to the duration of near peak excursions. With less near peak excursions or shorter duration of near peak excursions, the SRSS combination of responses from other dynamic loads is at least as conservative as SRSS combination of earthquake responses.

Criterion 1 is based on the characteristics of earthquake loadings. A study of real earthquake time histories show that real earthquake loadings have 5 or less load excursions exceeding 75 percent of the maximum and 10 or less exceeding 60 percent of the maximum. Thus, Criterion 1 limits the number of load excursions exceeding 75 percent of the maximum to 5 or less and the number of load excursions exceeding 60 percent of the maximum to 10 or less. These limits are based on the characteristics of earthquake loadings and are most applicable when applied at the input-time history level. Response time-histories typically show more near peak excursions than do the input time-histories for low damped structures. Therefore, the use of the same limits (based on input characteristics) at the response level is conservative.

The important points are:

1. Criterion 1 is based on characteristics of earthquake loadings. There are generally a greater number of near peak response excursions than near peak load excursions. Therefore, use of Criterion 1 at the response level is conservative.

2. If the loading has less near peak excursions than earthquake loading, then the response will also have less near peak excursions than earthquake response. Thus, holding the loading to less near peak excursions than for earthquake loadings enables the SRSS combination of responses to be at least as conservative as it is for earthquake responses.

These points are illustrated using the earthquake and SRV load and response time histories shown in Figures 1 through 5. Table 1 presents the number of excursions exceeding 60 and 75 percent of the maximum value for both the loading and response time histories presented in these figures. It can be observed that:

1. Since the SRV loading has less near peak excursions than the earthquake loading, the SRV responses also have less near peak response excursions than the earthquake responses.

2. The number of near peak response excursions exceed the number of near peak load excursions in all cases.

This basis for Criterion 1 being applied at the input level appears to have been misinterpreted by Brookhaven National Laboratory. In Section 6.4, they state that our recommendation that Criterion 1 can be applied at the input level appears to be based on the reasoning that the response functions have less near peak excursions than the load functions. They then go on to illustrate that the response functions generally have more near peak excursions than the input functions and conclude that the input functions should not be used to judge the adequacy of SRSS response combination. On three occasions, we have attempted to point out that this reasoning was <u>not</u> the basis for our recommendation that Criterion 1 be used at the input level and that showing that responses have more near peak excursions than input was not an adequate basis for rejecting Criterion 1 since Criterion 1 was based on the characteristics of earthquake loading and not on the characteristics of earthquake response.

We continue to recommend that a simple criterion can be based on the characteristics of input functions to judge that SRSS combined responses are at least as conservative as SRSS combined earthquake responses. We believe the Brookhaven Study (Reference 4) does not present a valid basis for rejecting this recommendation.

3.2 EFFECT OF NON-ZERO MEAN

In Section 6.6 of Reference 4 guidance is provided on how to combine peak responses when the individual responses have non-zero means. It is suggested that the effective SRSS response be computed by:

$$SRSS = \sum|\mu_i| + \sqrt{\sum\left(R_{imax} - \mu_i\right)^2} \quad (1)$$

where μ_i and R_{imax} are the mean and maximum values of the individual response components being combined. We believe this equation would be more appropriately written as:

$$SRSS = \left|\sum \mu_i\right| + \sqrt{\sum\left(R_{imax} - \mu_i\right)^2} \quad (2)$$

If the individual responses are known to have a non-zero mean, then the sign of the mean is certainly known and the individual component means can be added algebraically rather than absolutely.

3.3 SIGNIFICANCE OF CORRELATION COEFFICIENTS OF RESPONSES

In Section 6.8 of Reference 4, it is pointed out that it is unnecessary for the cross correlation coefficient between individual responses to be low when there is a random start time (lag time) between the responses. We concur. Criterion 1 only requires that individual components be relatively uncorrelated. This lack of correlation is achieved if <u>either</u> the components have random start times, <u>or</u> a coefficient of correlation less than 0.4. It is unnecessary to have both.

3.4 EFFECT OF NUMBER OF NEAR PEAK EXCURSIONS

Criterion 1 limits the number of near peak excursions. This limit on near peak excursions (5 or less exceeding 75 percent of the maximum or 10 or less exceeding 60 percent of the maximum) is a simple way of limiting the upcrossing rate. Reference 3 shows that the NEP for the SRSS combined response can be determined directly from the upcrossing rates and the marginals (percentage of time that the function exceeds a given fraction of the maximum value). These upcrossing rate limits were chosen based upon the characteristics of earthquake input.

Reference 4 shows that the marginals probably have a greater influence on the NEP for the SRSS combined response than do the upcrossing rates (number of near peak excursions). Reference 4 presents several cases which pass Criterion 1 in which the time-phase only CDF curve show a NEP for the SRSS combined response less than 50 percent and for which SRSS response combination may not be desirable. These cases appear to be rare and barely meet Criterion 1 in that the number of excursions exceeding 60 percent of the maximum meets Criterion 1 but the number of excursions exceeding 55 percent of the maximum is far greater. Time histories with so large a number of excursions between 55 and 60 percent of the maximum do not appear to be representative of real responses and are an extreme test of the criterion which limits the number of excursions exceeding 60 percent but does not limit the number slightly below 60 percent.

It should be noted that out of 235 Mark II response combination cases which pass Criterion 1, all 235 cases are reported to also pass Criterion 2 (Reference 5) and are cases for which the SRSS combination of responses appear justified. Thus, for real Mark II cases Criterion 1 is adequate and could be adopted without change. However, for generic application Criterion 1 could be improved as a result of the Brookhaven studies.

3.5 POTENTIAL MODIFICATION TO CRITERION 1 AT RESPONSE LEVEL

The Brookhaven study (Reference 4) recommends that the acceptability of the SRSS combination of responses be judged based upon the characteristics of the marginals of the individual responses (percentage of time that the functions exceed a given fraction of their maximum value) as opposed to the number of near peak excursions. We concur that this appears to be a better description against which to judge the adequacy of the SRSS method of response combination.

Brookhaven recommends that the characteristic of the marginals can be adequately defined by the ratio of the standard deviation of response to the maximum response. For multiple responses this ratio can be defined by:

$$\left(\sigma/R_{max}\right)_{eff} = \frac{1}{\sqrt{n}} \left[\sum_{i=1}^{n} \left(\sigma_i/R_{i,max}\right)^2\right]^{1/2} \tag{3}$$

where σ_i and $R_{i,max}$ are the standard deviations and maximum responses for each response in the combination. The acceptable ratio for $(\sigma/R_{max})_{eff}$ would depend upon the acceptable NEP for the SRSS combined response. If based upon a time-phase only CDF curve (i.e., considering random time-phasing and ignoring conservatism in the amplitude definition) a NEP of 50 percent for the SRSS combination is acceptable then a value of

$$\left(\sigma/R_{max}\right)_{eff} \leq 0.37 \tag{4}$$

would be acceptable for SRSS response combination.

We believe that the most important characteristics of the marginals which influence the NEP for the SRSS combined response are the fraction of time that the responses are close to their maximum value. The ratio $(\sigma/R_{max})_{eff}$ is a rather imprecise measure of this fraction of time. It appears to us to be more appropriate to place limits on the fraction of time that the response exceeds high ratios of the maximum responses, such as:

$$\frac{T_{50}}{\Delta T} \leq f_{50} \quad \underline{\text{AND}} \quad \frac{T_{75}}{\Delta T} \leq f_{75} \tag{5}$$

where T_{50} and T_{75} are the total time that the response exceeds 50 and 75 percent of the maximum response, respectively, ΔT is the time interval over which the lag time between responses is considered random, and f_{50} and f_{75} are fractions which are given below. Having to meet both of two fractions provides versatility and protects against widely different marginal distributions. Use of a single characteristic, such as $(\sigma/R_{max})_{eff} \leq 0.37$, enables widely different fractions of time over which the response can exceed a given ratio of the maximum response. The appropriate value of $(\sigma/R_{max})_{eff}$ to achieve a given NEP should be sensitive to the marginal distribution (Gaussian, etc.).

The approach used to generate the response time histories used in the Brookhaven study (Reference 4) appears to lead to Gaussian marginal distributions for these response time histories. Thus, the conclusion that $(\sigma/R_{max})_{eff} \leq 0.37$ leads to a time-phase only NEP for the SRSS combined response greater than 0.50 appears to be relevant for Gaussian marginal distributions. With a Gaussian marginal distribution, $(\sigma/R_{max})_{eff} = 0.37$ leads to:

$$\frac{T_{50}}{\Delta T} = 0.088 \qquad \text{and} \qquad \frac{T_{75}}{\Delta T} = 0.021$$

Thus, for a Gaussian marginal distribution specifying that

$$\frac{T_{50}}{\Delta T} \leq 0.08 \qquad \underline{\text{AND}} \qquad \frac{T_{75}}{\Delta T} \leq 0.02 \tag{6}$$

is equivalent to $(\sigma/R_{max})_{eff} \leq 0.37$. However actual distributions may not be Gaussian and for these cases the requirement of having to meet both ratios in Equation 6 provides greater protection against excessively high ratios of time for the response to be at a near maximum value than does the single characteristic $(\sigma/R_{max})_{eff} \leq 0.37$.

3.6 POTENTIAL REVISION TO CRITERION 1 AT INPUT LEVEL

When Criterion 1 is used at the response level, the ratios ($T_{50}/\Delta T$) and ($T_{75}/\Delta T$) presented in Equation 6 could be used in lieu of the number of near peak excursions currently specified in Criterion 1. These ratios are directly based on the results presented in the Brookhaven study (Reference 4). However, the Brookhaven study provides no guidance as to ratios which should be specified at the input level.

A review of real strong earthquake input time histories shows that for an input time history to have a lower fraction of time at near maximum input it must meet:

Input

$$\frac{T_{50}}{\Delta T} \leq 0.04 \quad \underline{\text{AND}} \quad \frac{T_{75}}{\Delta T} \leq 0.01 \tag{7}$$

Equation 7 should be used at the input level and is based on the characteristics of real earthquake input. Based on a review of response time histories versus input time histories, it has been determined that Equation 6 (Response Level) and Equation 7 (Input Level) are consistent with each other. When the input satisfies Equation 7, there is high confidence that the response will satisfy Equation 6.

3.7 SUMMARY OF CRITIQUE OF CRITERION 1 REVIEW

The Brookhaven study has not demonstrated that Criterion 1 cannot be applied at the input level. However, the Brookhaven study has demonstrated that:

1. The fraction of time that the response is near its maximum value is more significant than the number of near maximum response peaks in influencing the NEP for the SRSS combined response.

2. On several points, the current Criterion 1 is ambiguous and can be misinterpreted.

Clarification of the ambiguities and the importance of the fraction of time that response is at a near maximum value can both be accommodated by a minor revision to the current Criterion 1. Appendix A which is based upon Sections 3.5 and 3.6 suggests an alternate Criterion 1 for generic application. It is believed that this alternate Criterion 1 addresses each of the legitimate concerns as related to generic applications expressed in the Brookhaven study.

For Mark II applications the current Criterion 1 is adequate. However, for generic applications the revised Criterion 1 would be preferable.

4. CRITIQUE OF CRITERION 2 REVIEW

The intent of the Newmark-Kennedy Criteria are to provide high confidence that the SRSS combined response will be approximately at the 84 percentile NEP or greater when the individual responses are defined at least this conservatively. This goal is shown by Equation 1 in Table 2. To achieve this goal Criterion 2 places two requirements (Equation 2 and 3 in Table 2) which must both be met by the time-phase only CDF curve. Figure 6 illustrates the difference between the time-phase only CDF curve and a more general CDF curve which account for both random time-phasing and amplitude dispersion. This figure illustrates how satisfying both parts of Criterion 2 with the time-phase only CDF curve forces the SRSS combined response on the more general CDF curve up to approximately the 84 percentile NEP when the individual amplitudes are defined this conservatively.

An extensive demonstration study on the adequacy of Criterion 2 was presented in Reference 2. This study concluded that:

1. In most cases Criterion 2 leads to a NEP for SRSS combined response of approximately 84 percent.

2. In some cases Criterion 2 is more conservative than necessary and forces the NEP for SRSS combined response substantially above the 84 percentile.

3. In no case can the 84 percentile NEP peak combined response exceed the SRSS combined response by more than 9 percent.

The overall conclusion was that Criterion 2 is an adequate, slightly conservatively biased criterion. These demonstration studies were further expanded in Reference 3 and these further studies support all of the conclusions of Reference 2.

A brief review of Criterion 2 has been conducted by Brookhaven (Reference 4). All of the data presented in Reference 4 appear to support the conclusions of Reference 2 as stated above. Even so, the Brookhaven study is critical of Criterion 2. Their criticism is twofold. First, they are critical of the method of constructing the CDF curves. Secondly, they express concern about whether the NEP chosen for Criterion 2 is sufficiently conservative.

4.1 METHOD OF CONSTRUCTING CDF CURVES

In the basic General Electric Mark II study (Reference 6) and all subsequent Mark II Owners Group sponsored studies (References 2 and 3), two CDF curves are generated for each response combination. Both a positive CDF curve and a complimentary (negative) CDF curve are generated. Both of these curves are compared against Criterion 2 and both must pass in order to justify SRSS response combination for that response case. This is the method recommended in Appendix N (Dynamic Analysis Methods) of the ASME Code (Reference 7) for generating and using these CDF curves.

However, Brookhaven has chosen to generate a single absolute CDF curve for each response combination. This curve shows the absolute maximum response as opposed to the two curves of individual signed responses.

The differences in results for these two methods were studied using the 6 Mark II response combination cases studied in Reference 2. Positive, Negative, and Absolute CDF curves and SRSS values are shown for each of these 6 cases in Figures 7 through 12. Table 3 present the NEP for SRSS combined response and 1.2 SRSS combined response from the two signed CDF curves versus from the single absolute CDF curves.

The Brookhaven report (Reference 4) states that the BNL approach is simpler and less ambiguous and always results in a more conservative NEP for the SRSS combined response. This is not true. As seen in Table 3, the GE and ASME code approach leads to lower NEP for the SRSS combined response in 5 of the 6 cases studied (Cases 1, 3, 4, 5, 6). Only for Case 2 is the BNL method more conservative.

All that can be said is that the BNL method leads to more conservative (lower) NEP for SRSS combined response than that from the higher of the two signed CDF values using the ASME and GE approach. Generally, the NEP for SRSS combined response obtained from the absolute CDF curve lies between the values obtained from the two signed CDF curves and thus is generally less conservative than that from the lower of the two signed CDF curve values.

We tend to agree that the BNL approach is simpler and less ambiguous but it is not more conservative. We see no major reason to prefer one approach over the other and believe that the results presented in Reference 5 which showed that all of the Mark II cases studied pass Criterion 2 remain valid.

4.2 ACCEPTABLE NEP

Brookhaven (Reference 4) expresses concern that the NEP values required by Criterion 2 for the time-phase only CDF curve may be too low because of questions concerning whether the loadings can be conservatively defined. We do not agree with this concern. The response combination method is not the place to try to make up for potential lack of sufficient conservatism in the load definitions. This point has been extensively discussed in Section 4 of Reference 1.

Criterion 2 provides high confidence that the SRSS combined response will be at approximately the 84 percent NEP if the individual responses are defined at approximately the 84 percentile NEP or 1.15 times the median, whichever is higher. If the individual responses are

lower than the 84 percent NEP, then Criterion 2 still ensures that the combined response will be at least as conservative as the individual responses being combined. This is all the response combination method should be expected to accomplish.

4.3 SUMMARY OF CRITIQUE OF CRITERION 2 REVIEW

We continue to recommend strongly that Criterion 2 be adapted. This criterion has been sufficiently studied in References 2 and 3 and has been demonstrated to achieve its goal. No evidence is presented in the Brookhaven study to cause us to change this recommendation.

TABLE 1

Number of Loading and Response Excursions
Exceeding 60 and 75 Percent of Their Maximum Values

TIME HISTORY	INPUT OR RESPONSE / NO. OF PEAKS	LOADING	RESPONSE: SDOF, 5 HZ 0.02 DAMPING	RESPONSE: SDOF, 16 HZ 0.02 DAMPING
OBE	N_{60}	5	23	9
	N_{75}	1	9	2
SRV	N_{60}	1	2	3
	N_{75}	1	2	2

TABLE 2

Criterion 2 Requirements

$R_{SRSS_{84}}$ = SRSS COMBINED RESPONSE WHERE EACH INDIVIDUAL RESPONSE HAS BEEN DEFINED CONSERVATIVELY AT 84TH PERCENTILE OR 1.15 · MEDIAN.

$R_{T_{84}}$ = RANDOM TIME PHASE COMBINED RESPONSE WHERE ALL AMPLITUDES DEFINED AT 84TH PERCENTILE.

R = COMBINED RESPONSE CONSIDERING BOTH RANDOM AMPLITUDE AND TIME PHASING.

GOAL OF SRSS COMBINATION

$$P\left[R \leq R_{SRSS_{84}}\right] \geq 84\% \qquad (1)$$

CRITERION 2 REQUIREMENT

$$P\left[R_{T_{84}} \leq R_{SRSS_{84}}\right] \geq 50\% \qquad (2)$$

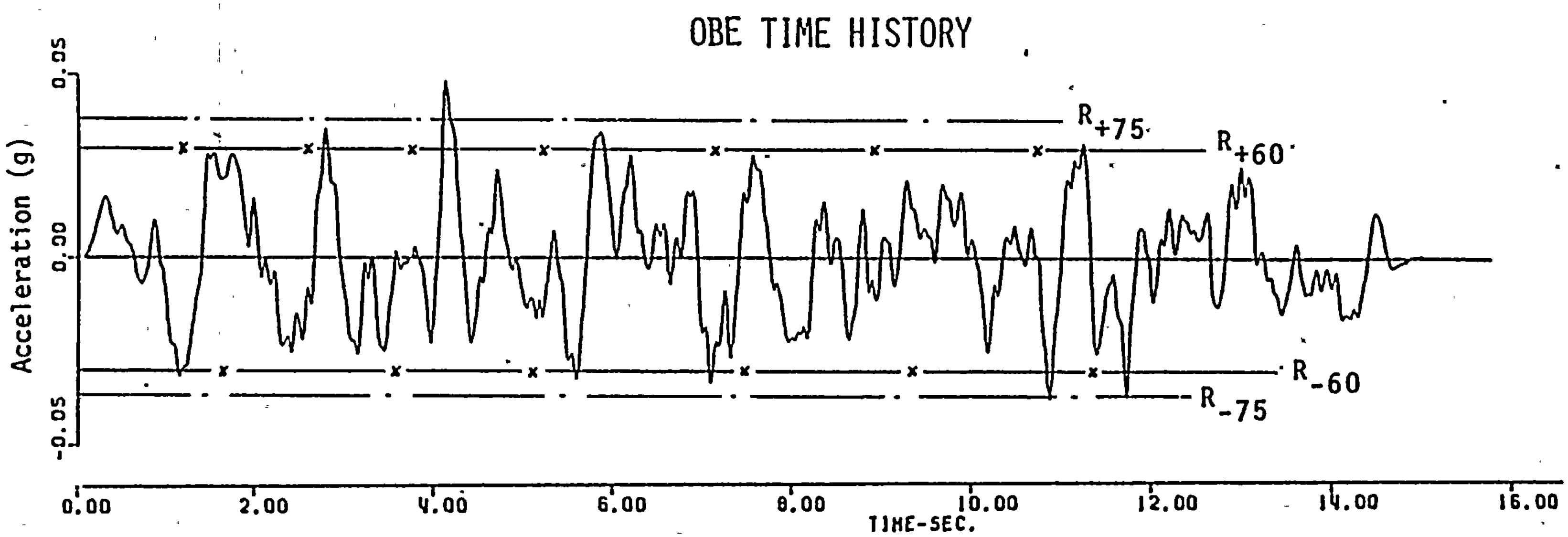
&

$$P\left[R_{T_{84}} \leq 1.2\ R_{SRSS_{84}}\right] \geq 85\% \qquad (3)$$

TABLE 3

NEP of Six Combination Cases Obtained from Signed and Absolute CDF Curves

CASE	SIGN	TIME PHASE ONLY, NEP		TIME PHASE ONLY NEP	
		SRSS	1.2 SRSS	SRSS OF ABSOLUTE MAXIMA	1.2xSRSS OF ABSOLUTE MAXIMA
1	+	0.40	0.98	0.45	0.98
	-	0.47	1.00		
2	+	0.66	1.00	0.55	1.00
	-	0.61	1.00		
3	+	0.54	0.95	0.62	1.00
	-	0.74	0.99		
4	+	0.70	0.91	0.80	0.99
	-	0.90	0.99		
5	+	0.74	0.91	0.84	0.98
	-	0.94	0.98		
6	+	0.73	0.96	0.96	1.00
	-	0.97	1.00		



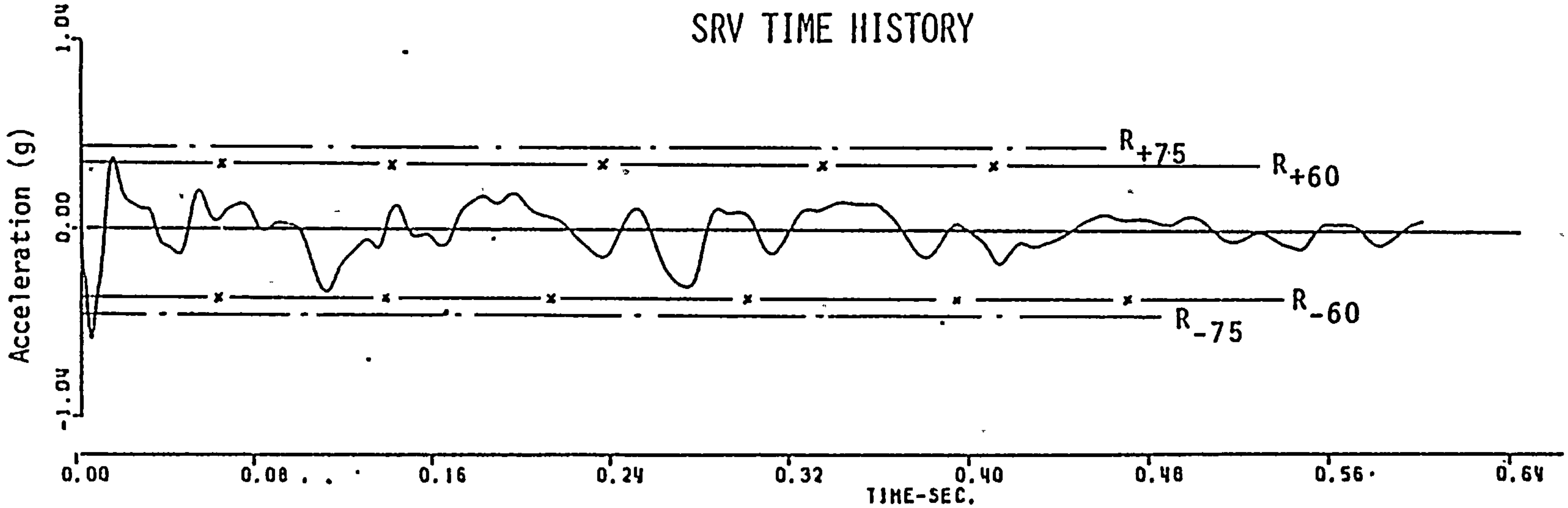


FIGURE 1. DYNAMIC EVENT LOADING FUNCTIONS

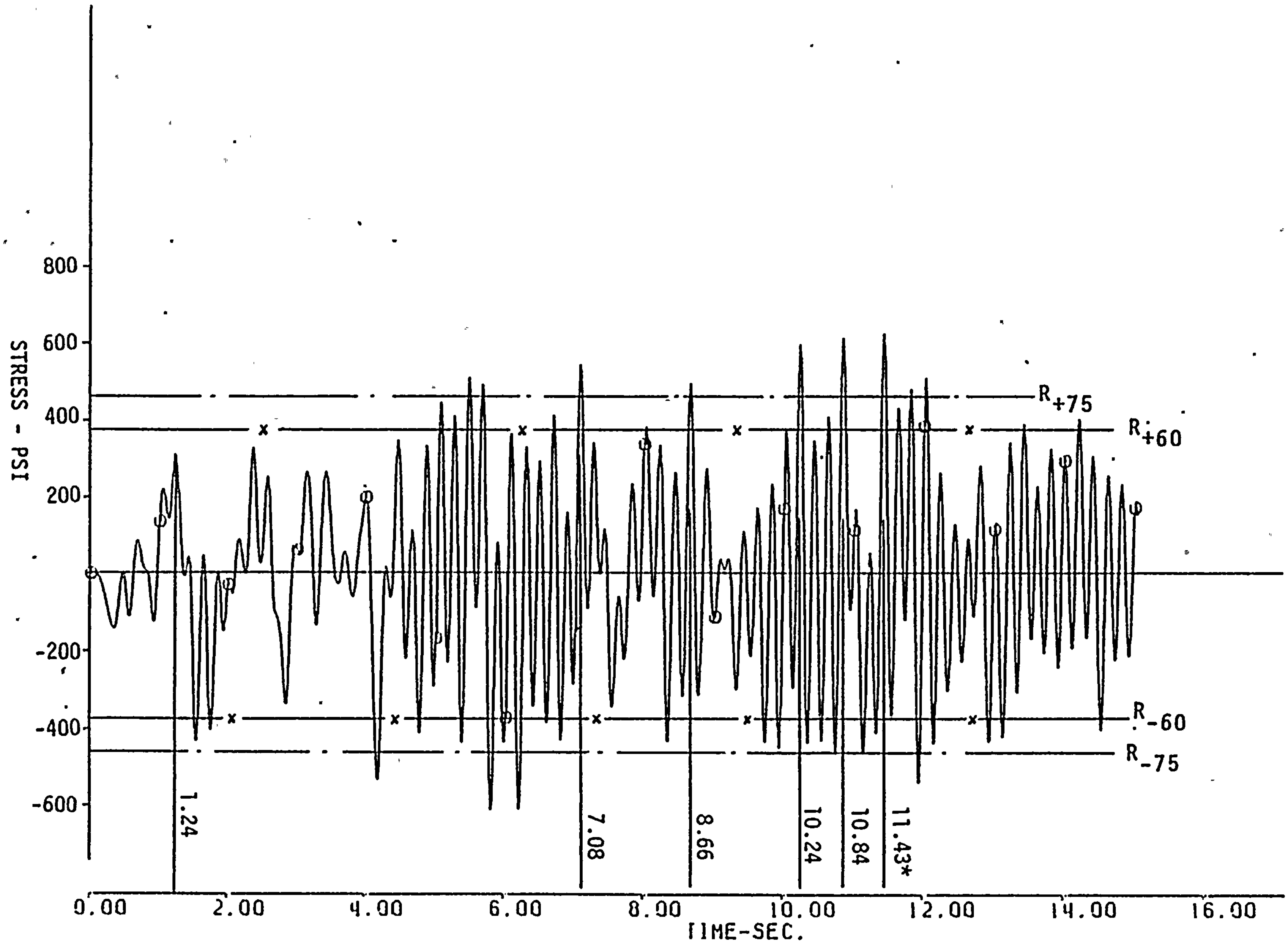


FIGURE 2 . ELASTIC RESPONSE TO UNSCALED OBE, 5 Hz MODEL, 2 PERCENT DAMPING

* Time for peak elastic response.

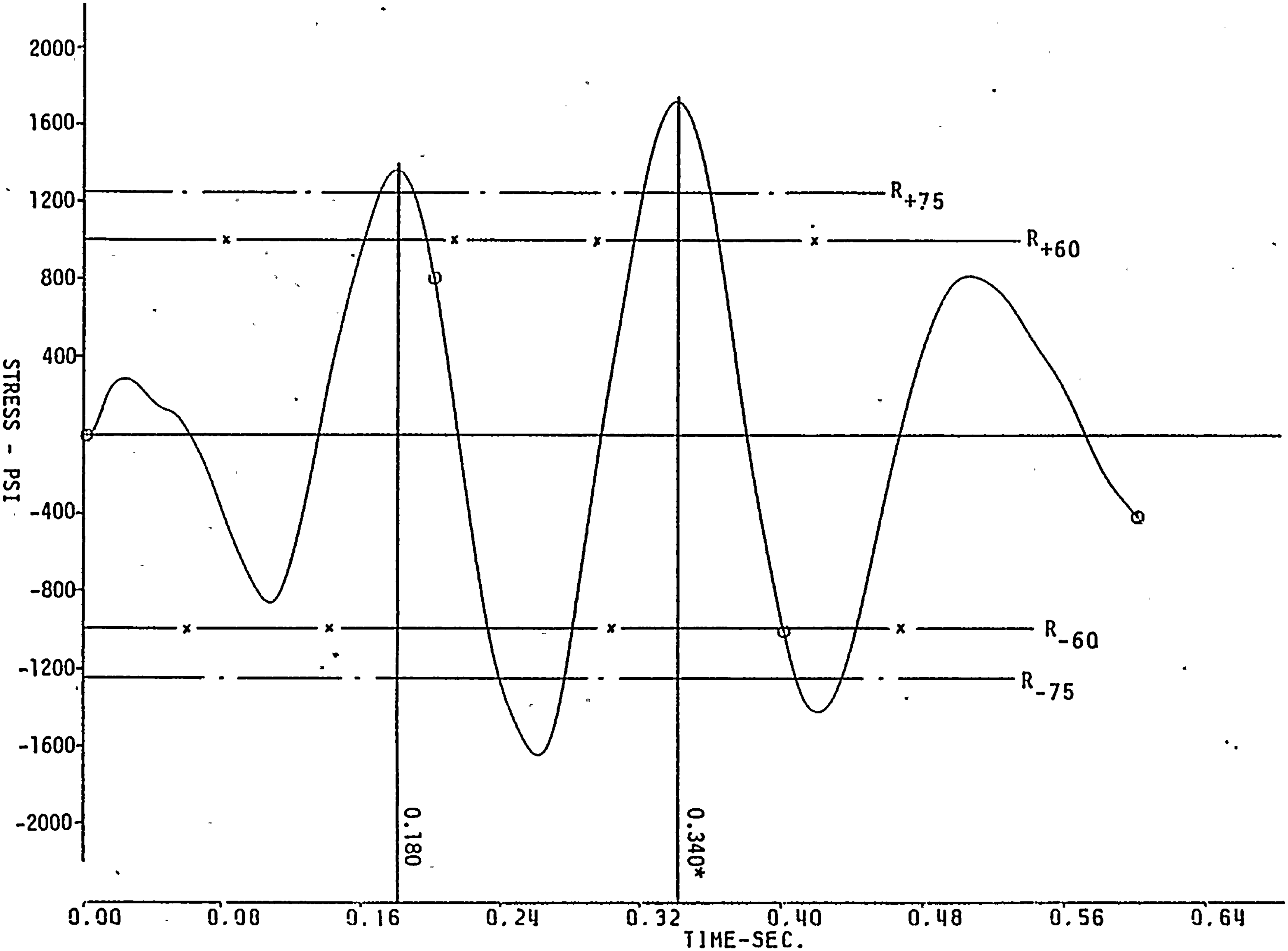


FIGURE 3 . ELASTIC RESPONSE TO UNSCALED SRV, 5 Hz MODEL, 2 PERCENT DAMPING

* Time for peak elastic response.

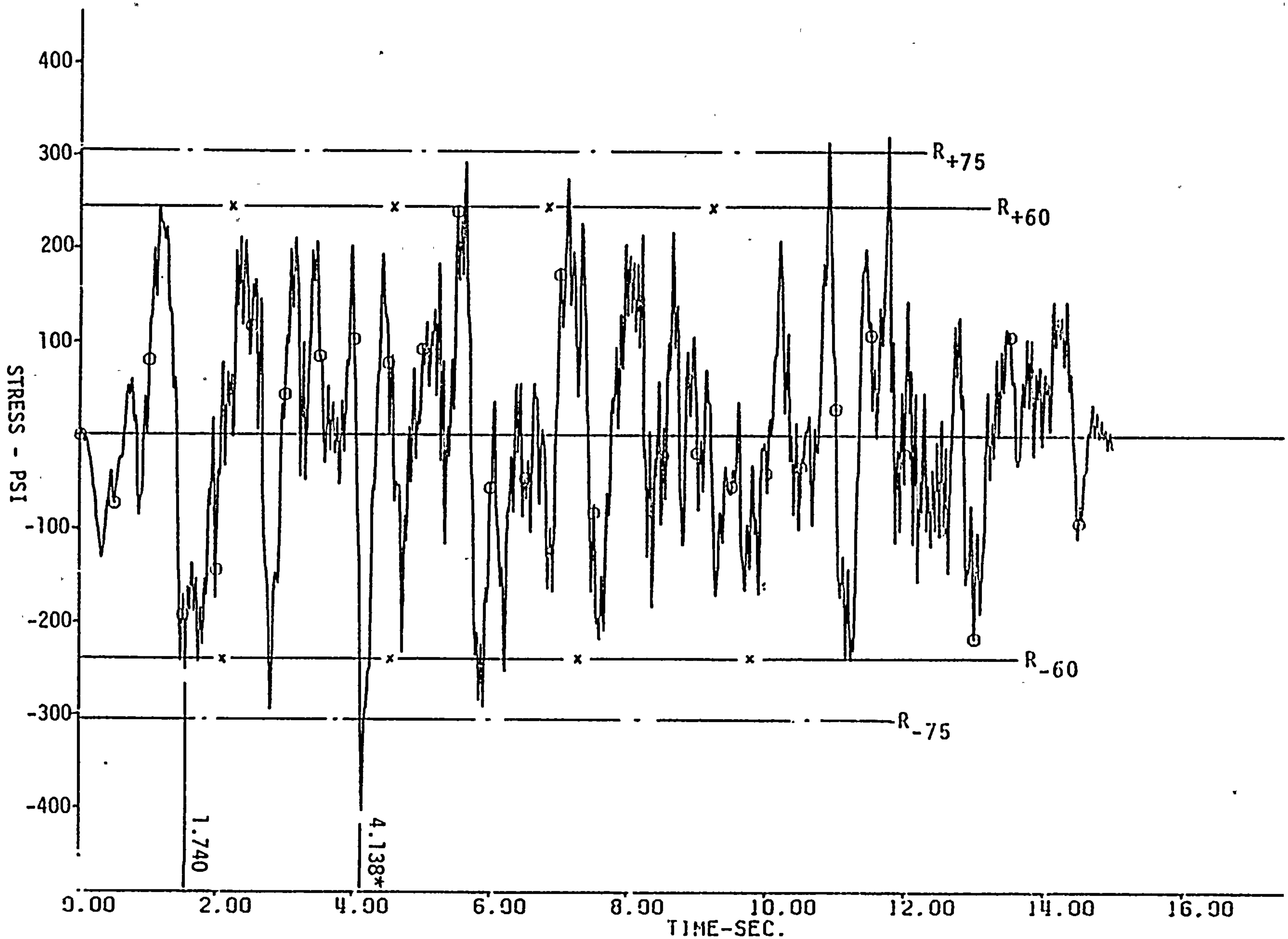


FIGURE 4 . ELASTIC RESPONSE TO UNSCALED OBE, 16 Hz MODEL, 2 PERCENT DAMPING

* Time for peak elastic response.

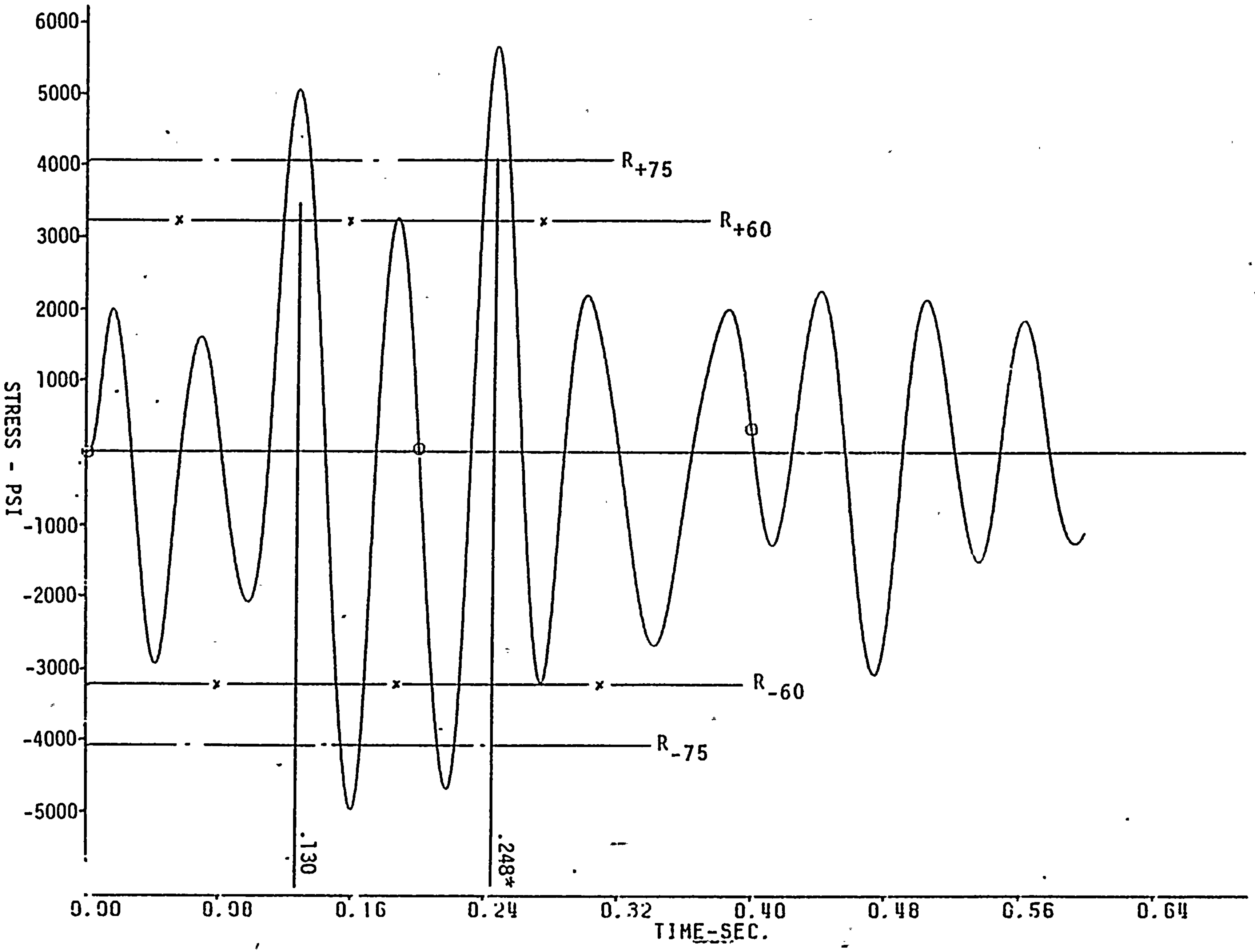


FIGURE 5 . ELASTIC RESPONSE TO UNSCALED SRV, 16 Hz MODEL, 2 PERCENT DAMPING

* Time for peak elastic response.

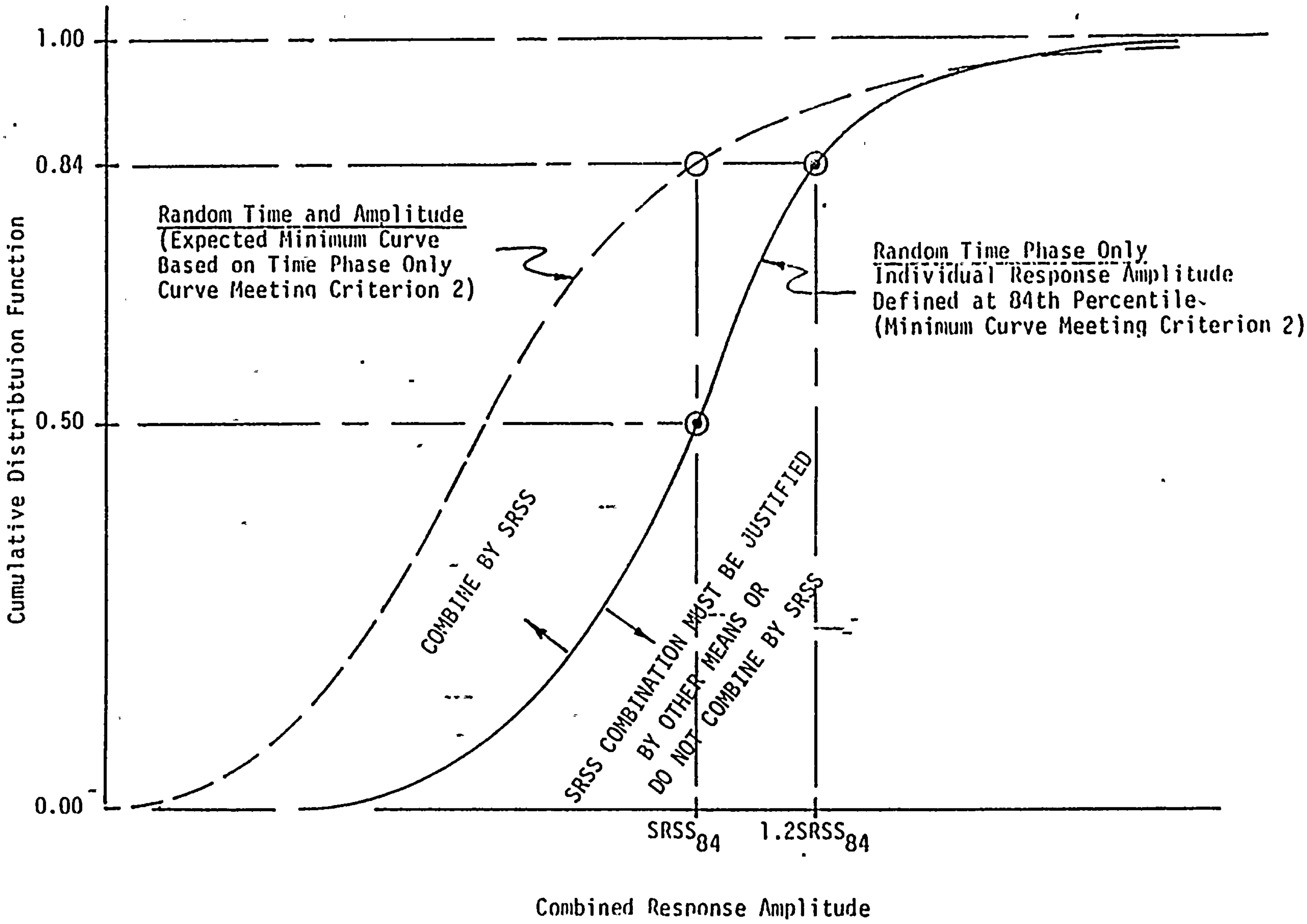


FIGURE 6 . COMPARISON OF RANDOM TIME PHASE ONLY CDF CURVES WITH RANDOM TIME PHASE AND AMPLITUDE CDF CURVES

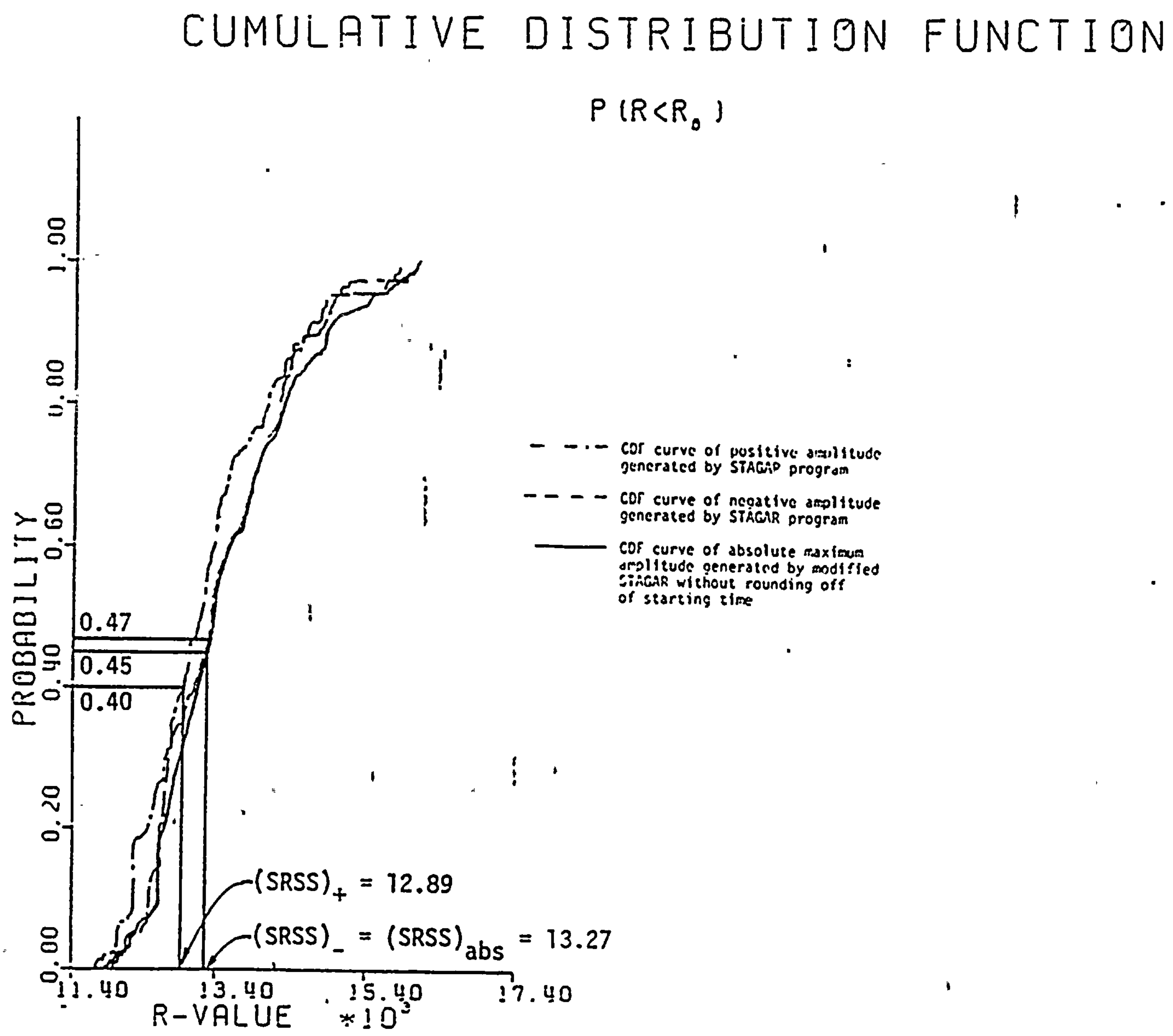


FIGURE 7. COMPARISON OF CASE 1 CDF CURVES AND NEP OF SRSS COMBINATION RESULTED FROM DIFFERENT APPROACHES

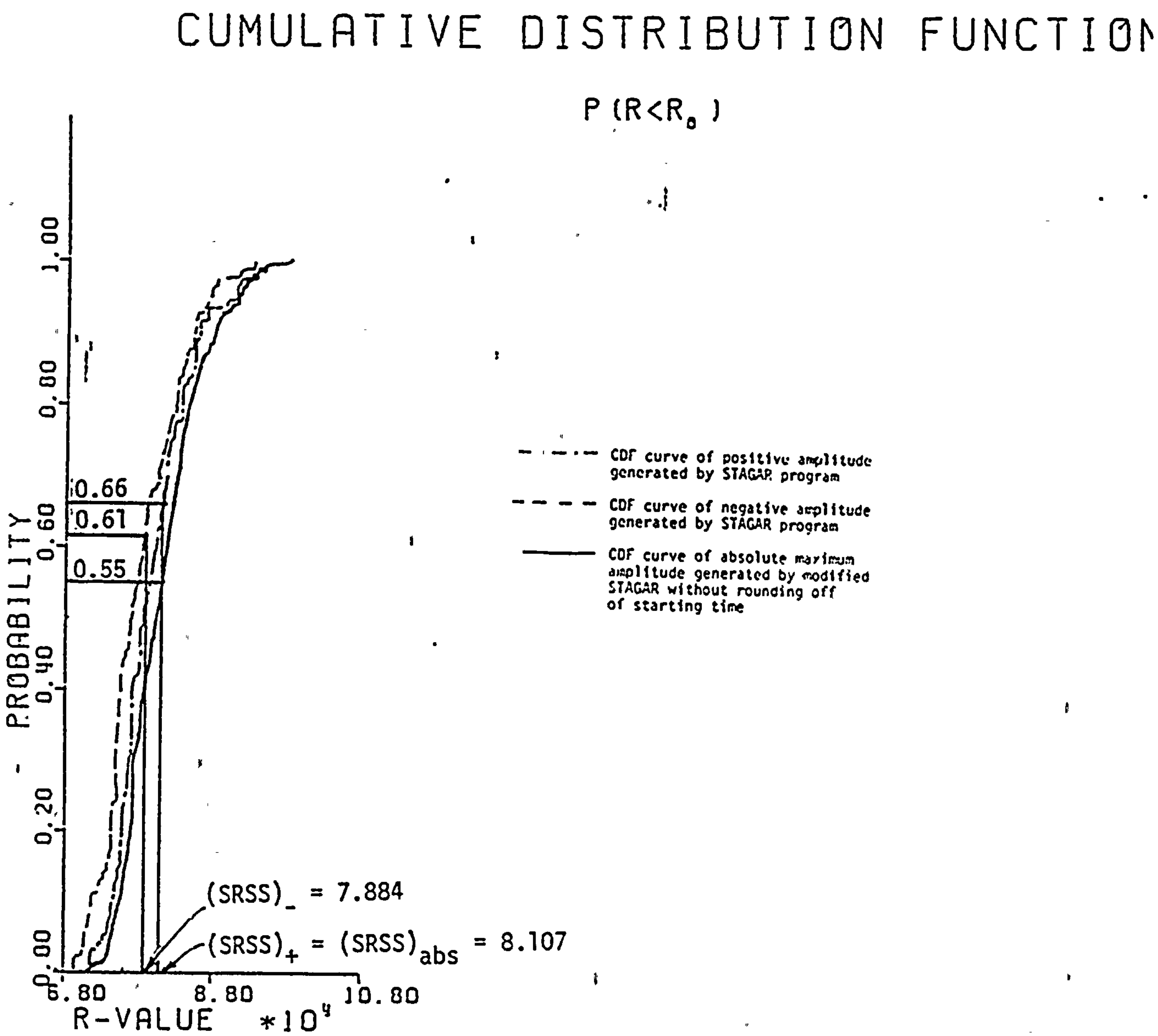


FIGURE 8 . COMPARISON OF CASE 2 CDF CURVES AND NEP OF SRSS COMBINATION RESULTED FROM DIFFERENT APPROACHES

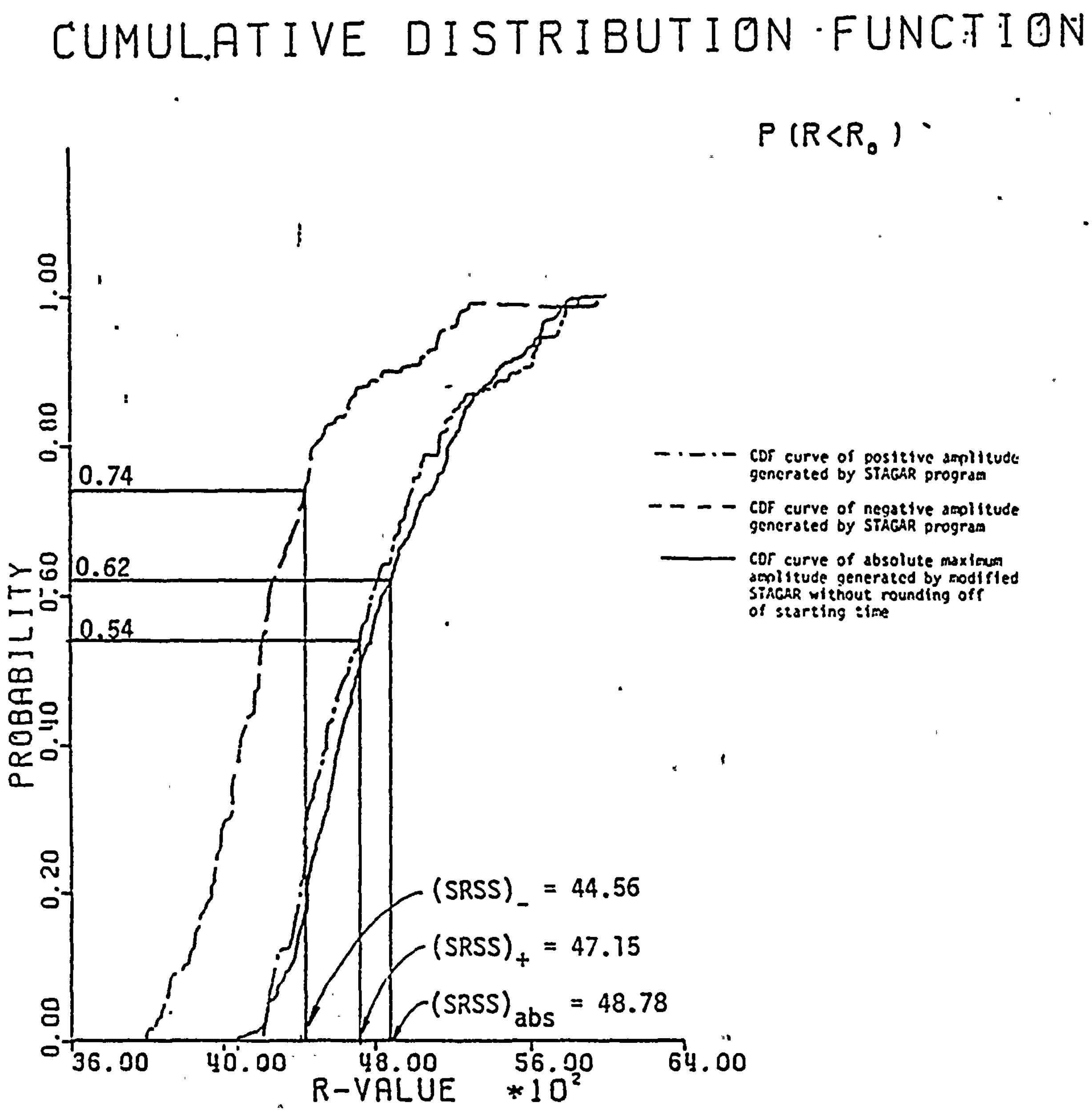


FIGURE 9. COMPARISON OF CASE 3 CDF CURVES AND NEP OF SRSS COMBINATION RESULTED FROM DIFFERENT APPROACHES

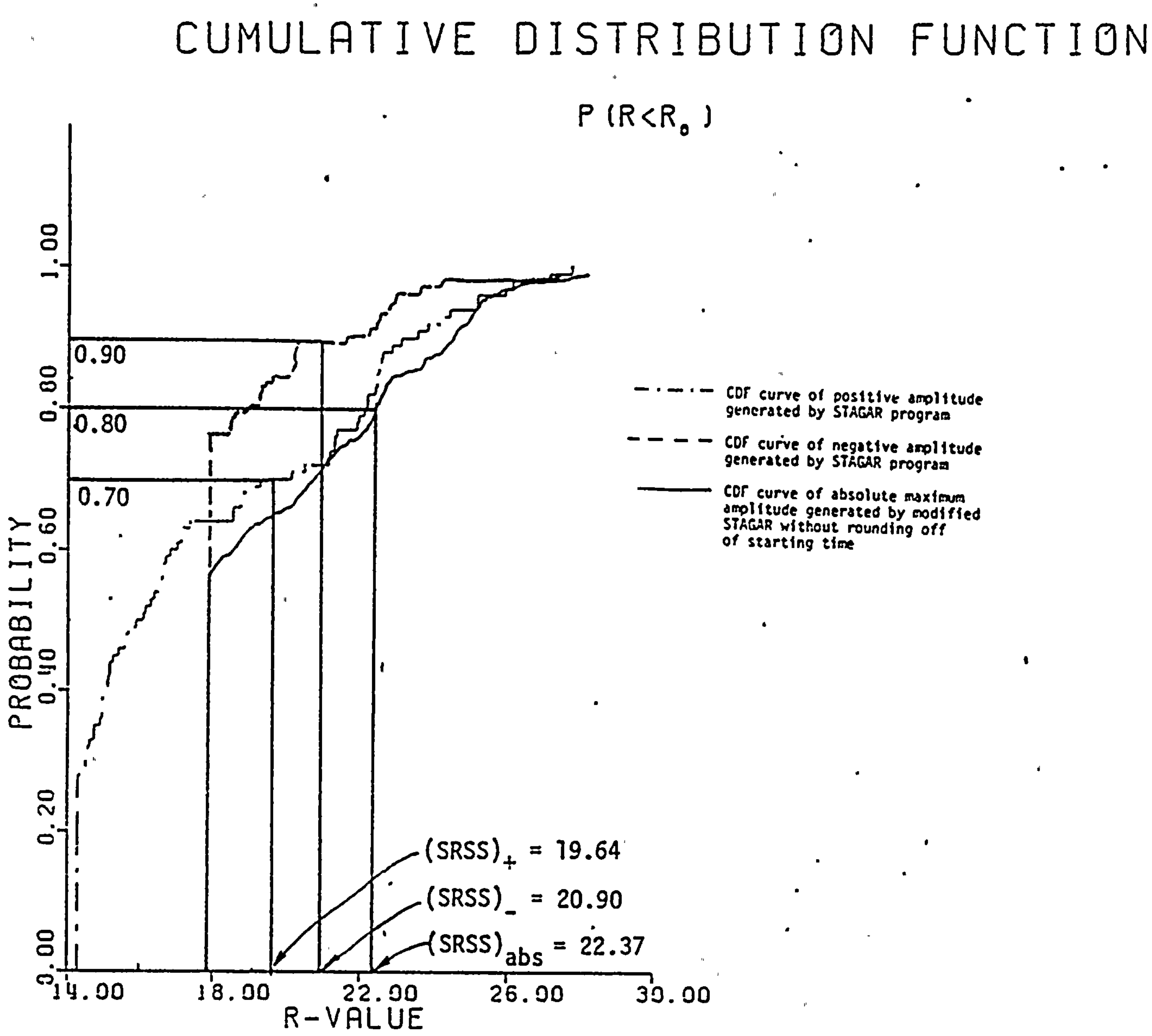


Figure 10. COMPARISON OF CASE 4 CDF CURVES AND NEP OF SRSS COMBINATION RESULTED FROM DIFFERENT APPROACHES

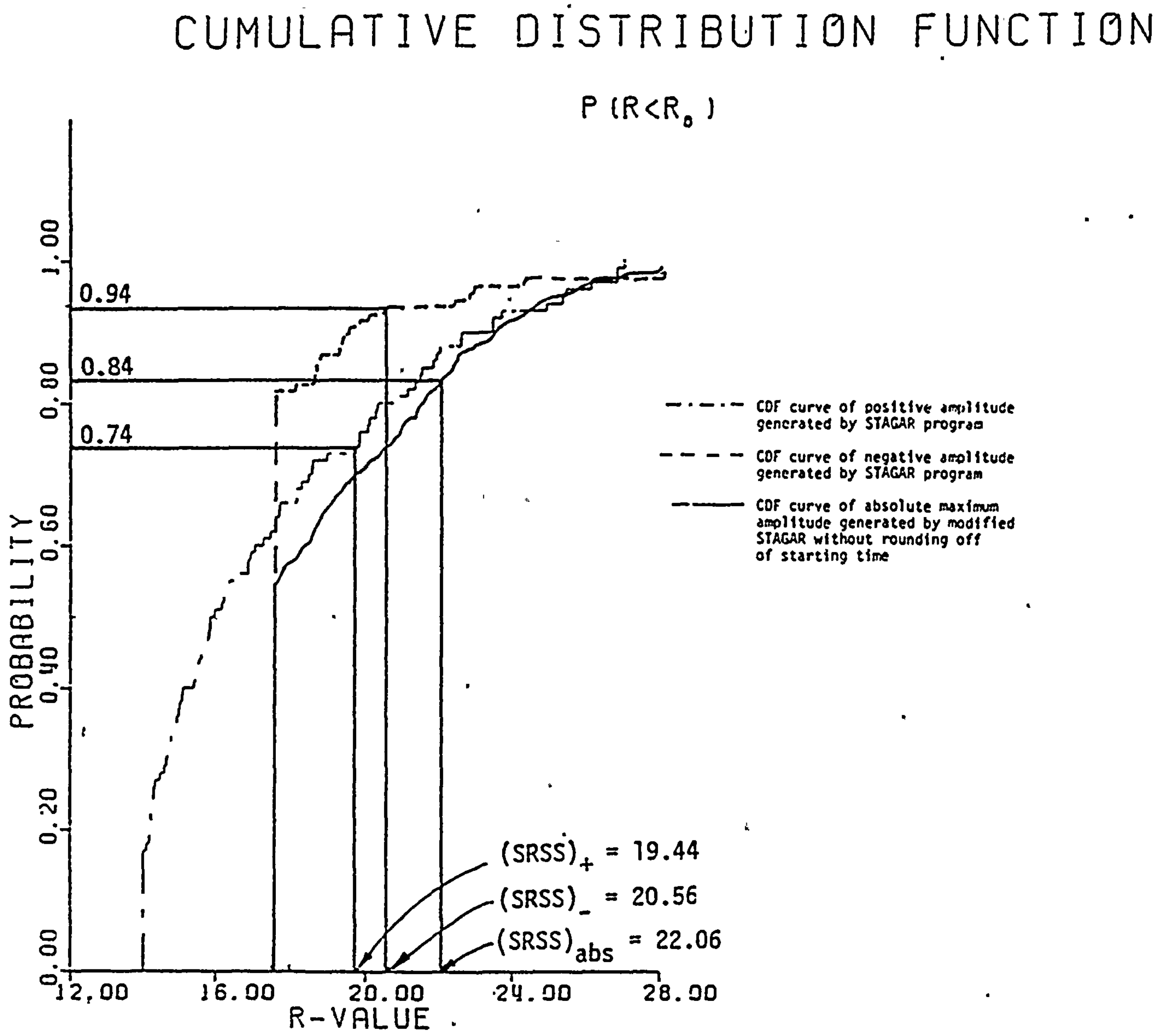


FIGURE 11. COMPARISON OF CASE 5 CDF CURVES AND NEP OF SRSS COMBINATION RESULTED FROM DIFFERENT APPROACHES

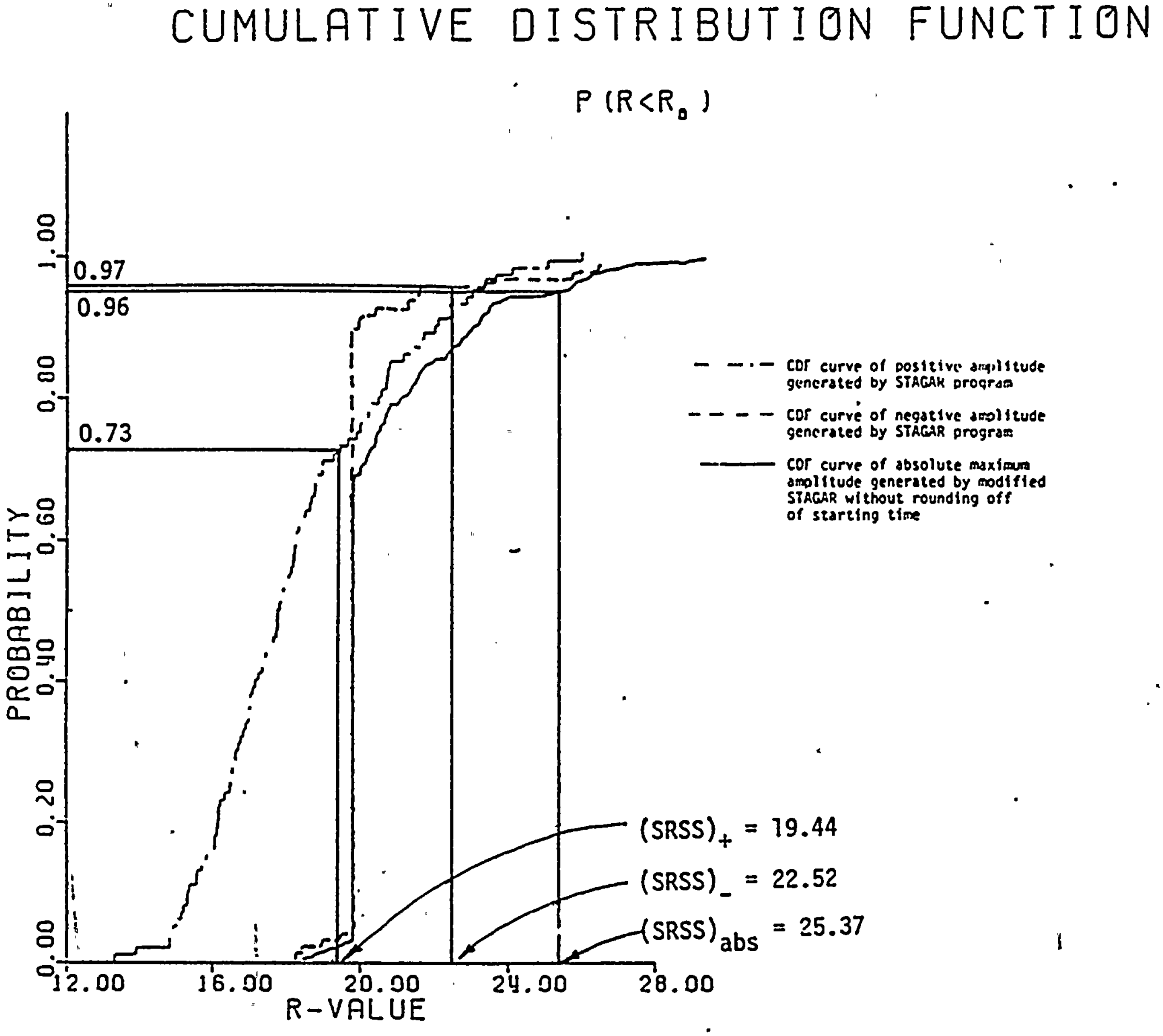


FIGURE 12: COMPARISON OF CASE 6 CDF CURVES AND NEP OF SRSS COMBINATION RESULTED FROM DIFFERENT APPROACHES

REFERENCES

1. R. P. Kennedy and N. M. Newmark, "Bases for Criteria for Combination of Earthquake and Other Transient Responses by the Square-Root-Sum-of-the-Squares Method", NEDO-24010-2, General Electric Company, San Jose, California, December, 1978.

2. R. P. Kennedy, W. H. Tong, and N. M. Newmark, "Study to Demonstrate the SRSS Combined Response Has Greater Than 84 Percent Non-exceedance Probability When the Newmark-Kennedy Acceptance Criteria Are Satisfied", NEDO-24010-3, General Electric Company, San Jose, California, August, 1979.

3. C. A. Cornell, D. Veneziano, and R. Kilcup, "An Analytical Method for Determining the Probability Distribution of the Maximum of Combined Responses - A Verification of the Newmark-Kennedy SRSS Criteria", C. Allin Cornell Consultants, Cambridge, Massachusetts, December, 1979 (Draft).

4. "Brookhaven National Laboratory Review of Methods and Criteria for Dynamic Combinations in Piping Systems, Final Report Fiscal Year 1979", Structural Analysis Group, Department of Nuclear Energy, Brookhaven National Laboratory, September, 1979.

5. A. K. Singh, and C. V. Subramanian, "SRSS Application Criteria as Applied to Mark II Load Combination Cases", NEDO-24010-1, General Electric Company, San Jose, California, October, 1978.

6. A. K. Singh, S. W. Tagart, and C. V. Subramanian, "Technical Bases for the Use of the Square-Root-of-the-Sum-of-Squares (SRSS) Method for Combining Dynamic Loads for Mark II Plants", NEDE-24010-P, General Electric Company, San Jose, California, July, 1977.

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APPENDIX A

SUGGESTED ALTERNATE TO NEWMARK/KENNEDY CRITERION 1 FOR GENERIC APPLICATION

Dynamic or transient reponses of structures, components, and equipment arising from combinations of dynamic loading or motions may be combined by SRSS provided that each of the dynamic inputs or responses has characteristics similar to those of earthquake ground motions, and that the individual component inputs can be considered to be relatively uncorrelated. This similarity involves a limited number of peaks of force or acceleration, with approximately zero mean.

The requirement of relatively uncorrelated inputs is met if either of the following is satisfied:

1. The individual dynamic inputs or responses are from independent events so that their relative start times are random.

2. If the relative start times are known, then the coefficient of correlation must be less than 0.4.

The requirement of approximately a zero mean is satisfied if, for the duration of strong input (or response), the ratio of the mean to maximum input (or response) is less than 0.20. If this requirement is not met, responses can be divided into two parts (non-zero mean part, and peak response relative to mean response). The non-zero mean part

of response can be combined algebraically (accounting for the sign of the mean response) and the peak responses relative to the mean responses can be combined SRSS if these relative responses meet the provisions of this criterion.

The requirement of a limited number of peaks is satisfied if any <u>one</u> of the following are met:

1. For each response time history in the combination:

$$\frac{T_{75}}{\Delta T} \leq 0.02$$

and

$$\frac{T_{50}}{\Delta T} \leq 0.08$$

where T_{75} represents the summation of time intervals for all peaks over which the response exceeds 75% of the absolute maximum response, T_{50} represents the time over which the response exceeds 50% of the absolute maximum response, and ΔT represents the relative time interval over which maximum response might be encountered. For the case of random relative start times, ΔT represents the time interval over which these relative start times may occur (generally taken as the duration of strong response of the longer time history). In determining the time T_{75} and T_{50} only the duration of peaks with the same sign (positive or negative) are additive. These definitions are illustrated in Figure A-1.

2. For each input-time history in the combination:

$$\frac{T_{75}}{\Delta T} \leq 0.01$$

and

$$\frac{T_{50}}{\Delta T} \leq 0.04$$

where the definitions are the same as above except with the substitution of input for response. These lesser time ratios for input than for response are chosen in recognition that the response will have more near-peak excursions than the input.

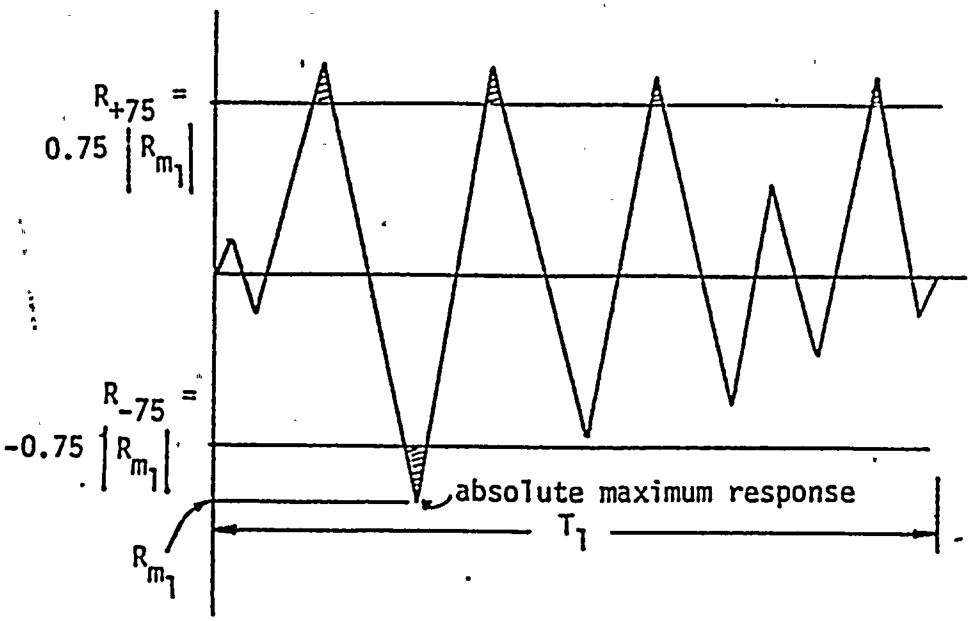
3. If the applicable item 1 or 2 above are not met by each of the inputs or responses in the combination, this requirement is still satisfied if the effective time ratios $(T_{75}/\Delta T)_e$ and $(T_{50}/\Delta T)_e$ for the response combination meet the requirements of item 1. The effective time ratios for the response combination are given by:

$$\left(\frac{T_{75}}{\Delta T}\right)_e = \sqrt{\frac{\sum_{i=1}^{N}\left(R_m T_{75}/\Delta T\right)_i^2}{\sum_{i=1}^{N}\left(R_m\right)_i^2}}$$

where i represents each individual response in the combination and $(R_m)_i$ represents the maximum response of that response component. The effective time ratio $(T_{50}/\Delta T)_e$ is obtained by substituting 50 for 75 in the above equation.

NOTE: Earthquake input and response time histories automatically satisfy the requirements of the characteristics similar to earthquake motion.

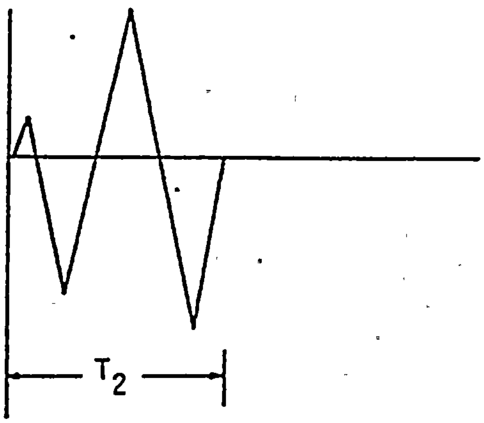
[illegible]



$T_{+75} = \sum$ time that response exceeds R_{+75}

$T_{-75} = \sum$ time that response less than R_{-75}

$T_{75} = \sum$ larger of T_{+75} or T_{-75}



$\underline{T_1 \geq T_2}$; $\Delta T = T_1$

FIGURE A-1. DEFINITION OF NOTATION