SAFETY EVALUATION REPORT
RETURN TO SERVICE PLAN - SEISMIC REEVALUATION PROGRAM
SAN ONOFRE NUCLEAR GENERATING STATION, UNIT NO. 1

INTRODUCTION

In a letter dated December 23, 1983, the Southern California Edison Company (SCE) submitted a program description to address the seismic capability of San Onofre Unit 1 as part of the justification for returning the plant to operation. The issues related to the seismic design of the plant were raised during the Systematic Evaluation Program (SEP) review of Topic III-6, "Seismic Design Considerations," and are described in the staff's evaluation dated November 16, 1981. In June 1982, SCE committed to structurally upgrade San Onofre Unit 1 to withstand the postulated Safe Shutdown Earthquake (SSE), which is the SEP site-specific ground motion characterized by the modified Housner spectrum scaled to 0.67g. 1/ The NRC issued an order on August 11, 1982 confirming SCE's commitment and requiring that NRC approval be obtained for restart.

The plant has remained shutdown since that time and a significant number of plant modifications have been completed. However, substantial additional analyses and resulting plant modifications would be necessary to complete the seismic upgrade program as it has been conducted thus far.

Consequently, SCE has proposed evaluation criteria to identify a limited number of plant modifications to demonstrate the ability of the plant to achieve and maintain a hot standby (mode 3) condition following the postulated SSE. These criteria would be used to screen previous analyses of the structures, systems and components within the SEP seismic reevaluation program scope. Implicit in this definition of capability to withstand the earthquake event and achieve and maintain a hot standby condition is adequate integrity of the reactor coolant pressure boundary and piping in the main steam and main feedwater systems such that there is reasonable assurance that an accident will not be induced by the seismic event.

The criteria proposed by the licensee are intended to provide necessary and sufficient justification that the plant can withstand the postulated SSE for the short-term, to permit plant restart until all of the issues related to the seismic capability of the plant can be resolved. The staff intends to address any outstanding issues related to the seismic design in the integrated plant safety assessment of the issues raised in the SEP topic reviews. The implementation schedules for the actions resulting from the SEP integrated assessment, as well as other pending licensing requirements, will be established as part of the licensee's "Integrated Living Schedule." For the purpose of this review, the staff has assumed that "short-term" is essentially between plant restart and the next subsequent refueling outage; however, in practice, each long-term requirement would be appropriately incorporated into the integrated living schedule based on the perceived safety significance of the specific implementation requirement involved.

EVALUATION

The licensee has proposed six evaluation criteria, each discussed individually below, which would be used to identify the minimum number of plant modifications necessary to ensure a capability to achieve and maintain a hot standby condition following the postulated SSE. To support this proposal, the licensee has described the general implementation procedures that would be used to apply the proposed evaluation criteria.

In previous evaluations, the staff has concluded that the modified Housner spectrum scaled to 0.67g is an appropriate safe shutdown earthquake (SSE) for San Onofre Unit 1. Based on the conservative nature of the seismic analyses conducted thus far, the staff agrees that capability to achieve and maintain a hot standby condition is sufficient for plant restart.

There were several issues raised during the course of the seismic reevaluation of San Onofre Unit 1 related to the adequacy of analysis methods, the lack of analyses to demonstrate seismic capability, and the effects of soil conditions. Based on the seismic risk perspective and the information related to these issues obtained thus far, the staff concludes that the potential for an SSE to occur coincident with unacceptable conditions related to these issues is sufficiently small that plant restart need not depend on their resolution nor would plant operation in the short-term pose an undue hazard to the public health and safety in the absence of their resolution, except as they relate to the hot standby capability.

In order to demonstrate hot standby capability, the licensee has proposed to apply six evaluation criteria to the structures (or structural elements) and piping systems which must be upgraded for the plant to withstand the postulated earthquake. These criteria would be used with and supplement previous seismic analyses of the plant design, with due consideration of the plant modifications completed thus far. The conclusions of the staff's review of each of these criteria and the manner by which they would be applied are as follows:

1. Containment Building Response Spectra

   In order to account for the effects of embedment, the licensee has proposed to apply a modified floor response spectra for the evaluation of components inside the containment. The licensee developed a revised floor response spectra, as shown in Figure 1, based on analyses and modelling performed by the Lawrence Livermore National Laboratory (LLNL) for the NRC.[2] LLNL analyzed the San Onofre Unit 1 auxiliary feedwater system as part of a generic research project.

The staff agrees that a reduction factor may be appropriate to account for embedment effects as shown by the previous earthquake recordings. However, the staff has found that modelling techniques and analysis methods used in the LLNL analyses significantly overestimate that effect. Those analyses were performed with the CLASSI computer code assuming vertically propagating seismic waves. This approach is equivalent to a "deconvolution" technique and results in an input ground motion for the analysis of the containment building which can be a factor of two to three lower than the free-field ground motion. Extensive peer reviews of deconvolution techniques have found that these techniques could be unrealistic. 3/

The staff has previously provided guidance on soil-structure interaction review which allows a reduction factor of up to 25% to the free field ground motion when applied for the structural analyses, depending on the nature of the earthquake records used to define the site-specific ground motion and local site conditions. 4/ The reduction factor can be derived from an analysis of the earthquake data used for the development of design basis earthquake ground motion at the site. The specific reduction factor allowed depends upon the extent to which surface measurements were used, the extent to which the site conditions match those where the strong motion data were recorded and the extent to which the site conditions justify such a reduction.

The resulting reduction factor would then be applied to calculated floor response spectra using the site-specific ground motion as an input at the foundation, provided that the floor response spectra are generated using linear-elastic, dynamic structural analyses.

The staff considers this approach appropriate for both restart and long-term resolution.

2. Damping Values for Piping Analyses

The licensee has proposed to use the damping values for piping systems recommended by the Task Group of the Pressure Vessel Research Committee (PVRC) of the Welding Research Council (WRC), instead of the Regulatory Guide 1.61 values.

The damping values recommended by PVRC reflect an extensive review of damping data and a reasonably conservative margin exists when using the spectral analysis method. On this basis, the staff concludes that the proposed damping values are acceptable for both restart and long-term.

If the time history analysis method is used, justification for the use of damping values as recommended by PVRC should be provided for the long-term operation.

3. Spectra Shifting

Regulatory Guide 1.122 recommends that the calculated dominant peaks of the floor response spectra be broadened to account for uncertainties in the structural frequencies owing to uncertainties in the material properties of the structure and soil and to approximations in the modeling techniques. The licensee has proposed to use a spectral peak shifting method, as depicted in Figure 2, where the licensee judges that overstressing is caused by the additional energy associated with the broadened peak.

The staff considers the proposed method more realistic and, therefore, acceptable for both restart and long-term, with two exceptions:

(a) This method is less efficient for independent multiple-support motion; i.e., different motion at different supports in a system. If such a situation arises in the evaluation of San Onofre Unit 1, the staff will require that the licensee justify the application of any spectral shifting and demonstrate the statistical significance on a case-by-case basis before restart.

(b) The specific method proposed by the licensee is based on a single spectral peak within a defined frequency range of interest. 5/ However, in some cases there is more than one "dominant" peak within this range. Therefore, the staff will require that the licensee justify the application of this technique on a case-by-case basis before restart for those cases in which there is more than one "dominant" peak. For the long-term, the staff will review the application of this technique to assure that there are no other instances of multiple dominant peaks.

4. Functionality Criteria for Piping and Pipe Supports

As part of the seismic reevaluation program for San Onofre Unit 1, the licensee proposed allowable stress limits for piping, pipe supports, and equipment (e.g., pumps and valves) based on the ASME Code and the NRC guidelines. These criteria have been referred to as the Balance of Plant Mechanical Equipment and Piping (BOPMEP) criteria. For plant restart, the licensee has modified the BOPMEP criteria and their application to address the functional capability of the systems required for hot standby. The staff normally distinguishes between criteria for functional capability and criteria for integrity; in our review of the restart proposal we have considered the adequacy of the revised stress limits with regard to functional capability for the purpose of assuring proper system operation. The evaluation of the proposed criteria are as follows:

(a) Piping

The licensee proposed that piping stresses should not exceed 2.0 Sy for carbon steel and 2.2 Sy for stainless steel, based on ongoing studies of the capacity of piping systems to withstand higher stresses. Further, the licensee proposed to evaluate all of the stress contributions with the appropriate intensification factors in accordance with the ASME Code, except seismic anchor movement (SAM).

The staff believes that there is sufficient evidence that piping systems will retain both integrity and function so long as the stresses are below 2.0 Sy for both carbon and stainless steel. Therefore, the staff will accept a single limit of 2.0 Sy for restart and allow SAM to be excluded because its contribution to the total stress is, in general, likely to be small except for those piping systems extending through different buildings. For those extreme cases, the licensee stated that all piping systems required for restart have already been checked for SAM stresses and have been shown acceptable in the final configuration. However, for the long-term the staff will require a lower stress limit to account for uncertainties and the analyses will have to include SAM to confirm that it is a small contributor. The staff will develop the specific criteria for the long-term evaluation in conjunction with the review of the licensee's implementation of the restart program; those criteria will also consider both functional capability and integrity.

With respect to the piping evaluation procedure proposed by the licensee (Section 5.3.1 of Reference 5), the criteria for decoupling of branch lines using a diameter ratio of 1/3 is acceptable for restart. However, for the long-term, small and large bore piping should not be decoupled if either of the following are factors:

(1) If an anchor or rigid constraint on the branch pipe is located near the run pipe and significantly restrains the movement of the run pipe, the branch pipe should be included with the model of the run pipe, up to the anchor (or up to and including the series of rigid constraints that effectively permits termination of the problem at some point remote from the pipe run).

(2) The branch pipe should be included in the mathematical model of the run pipe if more precise magnitude of reactions are required at terminal points (i.e., equipment, penetrations, etc.) to determine their (the reactions) acceptability.

(b) Pipe Supports

Based on the review of the Restart Plan, the staff concluded that the licensee has proposed an "energy balance" approach to determine whether pipe supports would fail under the postulated loading conditions and, if they do, whether the intact supports could survive the load redistribution. However, the staff was subsequently advised by the licensee that the proposed approach would only be applied to determine the effects of support removal or failure on the piping functionality and integrity to avoid the expense of a complete reanalysis.

The staff agrees in principle that the energy balance approach is reasonable to estimate the effects of support removal or failure on the piping runs, provided that the licensee demonstrates that the kinetic energy has been conservatively estimated for the specific piping configurations involved, and evaluates the failure modes and consequences for pipe supports that are postulated to fail and are not removed prior to restart.

The licensee would evaluate overstressed pipe supports using simplified analysis techniques to determine their ductile capability and potential for failure. Because of the complex nature of the piping analysis, simplified analysis techniques will have to be selected on a case-by-case basis. Therefore, the staff will require that the licensee identify all of the supports calculated to exceed yield stress and will audit the analysis techniques applied.

The staff will accept a definition of failure of the pipe supports at the yield stress, as defined by (1) the ASME Code or (2) actual materials certifications; separate criteria exist for buckling and anchor bolts. On a case by case basis, the staff would consider a support functionally capable if the peak stress does not exceed about 30% above the yield stress specified by the Code because of the inherent ductility strength of the support system.

For the long-term, the staff believes that the SEP guidelines should be used to evaluate pipe supports. 6/

(c) Equipment

The licensee has proposed to apply the BOPMEP criteria to equipment for restart.

The staff has previously concluded that equipment capability has been adequately resolved because (1) the functional capability of equipment is being actively pursued for all operating plants under the Unresolved Safety Issue A-46, "Seismic Qualification of Equipment," and (2) the licensee had previously committed to upgrade the integrity of equipment (i.e., to meet the acceptable stress limits) for the postulated SSE, including equipment supports. The staff will require that the licensee confirm that the equipment in the systems required for hot standby have been upgraded, as committed.

5. Inelastic Criteria for Structural Members

The licensee has proposed to evaluate structural steel members (excluding pipe supports covered under 4.b above) using a ductility ratio as a measure of the plastic deformation capacity. The staff agrees with this type of approach and accepted the allowable ductility factors presented in the licensee's February 23, 1981 submittal. [7] The proposed criteria for restart specify higher ductility factors; however, the basis for these factors has not yet been provided.

The staff has found that the approach proposed by the licensee appears to overestimate the yield displacement of structural elements in the basic definition of the ductility ratio. Moreover, the licensee did not adequately define the method of application for the proposed criteria.

The ductility factor is the ratio of the calculated displacement of a member to the "effective" elastic limit displacement, as shown in Figure 3. [8] The highly non-linear load (i.e. resistance) displacement relationship is approximated with an "effective" load-displacement curve of equal area, which projects the effective elastic limit. An analogous relationship exists for bending moments if the yield moments and displacements are used, as depicted in Figure 4; however, the licensee has proposed to use the plastic moment capacity instead of yield displacement to define the ductility ratio. In addition, the staff noted the following issues during the review of these proposed criteria:

(a) Because the relationship between the ratio of moments (M/M_p) and the ratio of displacements ($\delta/\delta y$) is not defined, it is not clear why M/M_p is used to calculate the ductility ratio, instead of the displacement ratio.

(b) The licensee did not justify the relationship

$$(2\mu-1)^{\frac{1}{2}} = P/_{py} + {}^{Mx}/_{Mpx} + {}^{My}/_{Mpy}$$

(c) The general relationship $(2\mu-1)^{\frac{1}{2}} = \delta/\delta y$ or $\theta/\theta y$ is valid roughly in the range of 2-8Hz. It is not clear what relationships would be used outside this range.

(d) When a structural member is loaded to its plastic moment capacity, there are material fabrication and construction considerations for possible failure modes which must be addressed. These include punched holes in tension zones, sheared edges, the ratios of b/t and h/w, the strength of connections and connectors, etc.

(e) The licensee should justify the adequacy of using bending moment "M" (or rotational displacement "θ") to calculate ductility factors for short and medium spanned beams.

(f) The licensee committed to develop criteria for connected members. 9/ Neither the criteria nor their bases have been provided.

The concept of the use of ductility ratio, as a measure of the degree to which a structural member can go into the inelastic range and still retain its function, is acceptable to the staff for both restart and long-term operation. However, the staff does not agree that the calculational method proposed by the licensee is acceptable. The staff concludes that a ductility ratio calculated based on the yield displacement instead of the plastic moment capacity of the beam is acceptable; other calculational techniques may be acceptable if the licensee can justify the method of application prior to restart.

6. Qualification of Small Piping

For piping with a nominal diameter of 2½ in. and less, the licensee has proposed a field walkdown together with the documented earthquake experience and test data, particularly recent tests performed in Germany by ANCO for KWU, to demonstrate the structural integrity and function of these small-diameter piping systems. The walkdown to be completed before restart would apply only to those systems required for hot standby.

The staff agrees that there is sufficient historical and experimental evidence that small-diameter piping systems have sufficient inherent resistance to large earthquakes to support plant restart. The staff also agrees that it is appropriate to conduct a walkdown of the hot standby systems, prior to plant restart, to identify any possible anomolous design and field conditions. Specifically, the piping supports should be evaluated where there are large eccentric masses mounted on the piping. For the long-term, however, the staff believes that some sampling analyses should be conducted to confirm the applicability of the historical and experimental evidence and to investigate the capability of any unusual or unique design features so that adequate safety margins are preserved in the small-bore piping systems. For efficiency, the nature and criteria for selection of sample analyses should be defined before any plant walkdowns are conducted so that candidate design and field conditions can be identified at the same time. Therefore, the staff will work with the licensee to develop appropriate criteria for sampling analyses prior to the conduct of a plant walkdown.

CONCLUSION

Based on the review of the licensee's proposed restart program, the staff concludes that the evaluation criteria, as modified by the staff's evaluation, are adequate to assure hot standby capability in the event of a postulated SSE earthquake for the short-term until the seismic design issue can be completely resolved. Moreover, the staff concludes that hot standby capability is sufficient to assure safe plant shutdown for the purpose of plant restart.

In specific cases, the application or combination of the evaluation criteria may not be appropriate. The staff considers such cases to be unlikely and, therefore, will address this issue in the review of the licensee's implementation of this program.

The staff has identified those areas where additional review are necessary to extend the restart program to completely resolve the seismic design basis for San Onofre Unit 1. The plant's capability to reach a cold shutdown condition and to mitigate possible transients and accidents resulting from a design-basis earthquake will be resolved in the SEP integrated assessment.

REFERENCES

1. Letter from W. Paulson, NRC, to R. Dietch, SCE, dated September 16, 1982.

2. LLNL Draft Report, "The Final Progress Report for the San Onofre Nuclear Generating Station Unit 1, Auxiliary Feedwater System Project - Seismic Safety Margins Research Program," June 18, 1982.

3. Transcript of the Proceedings of the U. S. Nuclear Regulatory Commission's Advisory Committee on Reactor Safeguards (ACRS) Seismic Activity Subcommittee meeting, February 8, 1977.

4. Letter from D. M. Crutchfield, NRC, to all SEP Licensees, "Guidelines for SEP Soil - Structure Interaction Reviews," dated December 15, 1980.

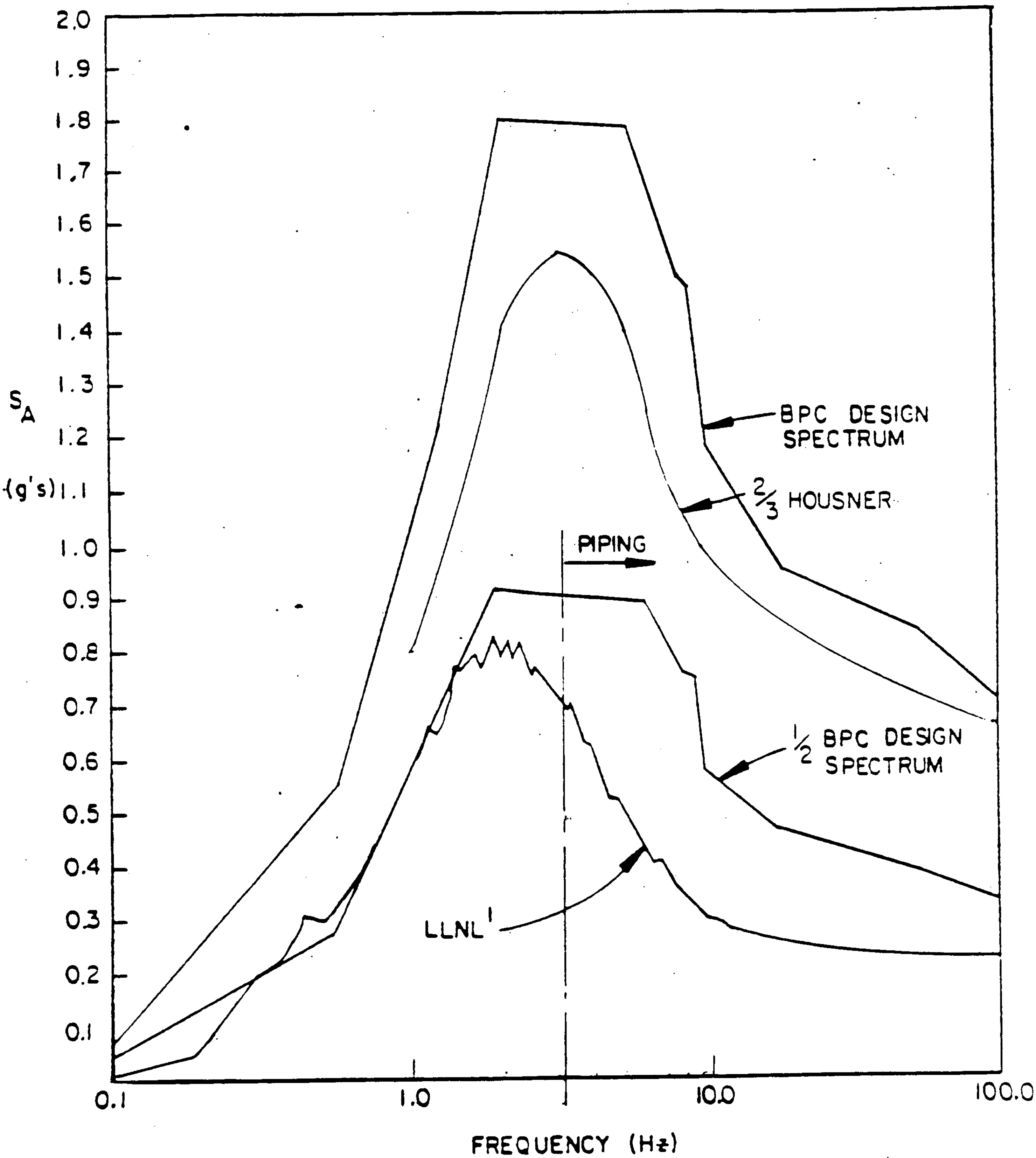
5. Letter from M. D. Medford, SCE, to D. M. Crutchfield, NRC, dated December 23, 1983.

6. Letter from W. A. Paulson, NRC, to R. Dietch, SCE, dated July 26, 1982.

7. Letter from K. P. Baskin, SCE, to D. M. Crutchfield, NRC, dated February 23, 1981.

8. N. M. Newmark and W. J. Hall, "Development of Criteria for Seismic Review of Selected Nuclear Power Plants," NRC NUREG/CR-0098, May 1978.

9. Letter from M. O. Medford, SCE, to D. M. Crutchfield, NRC, dated January 6, 1984.



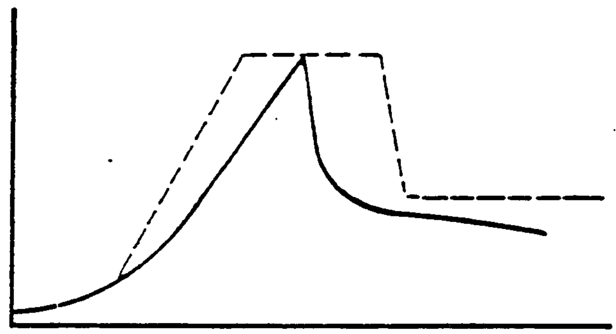
CONTAINMENT FOUNDATION RESPONSE SPECTRA[1]

1. TAKEN FROM LLNL DRAFT REPORT DATED JUNE 18, 1982

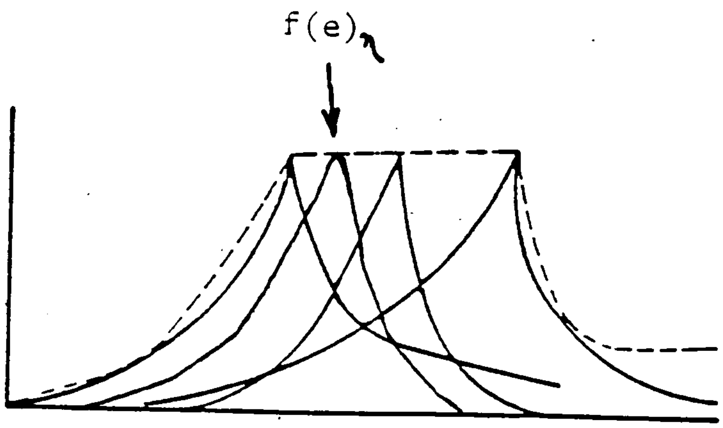
Fig. 1

APPLICATION OF SPECTRA SHIFTING

O BROADENING ACCOUNTS FOR UNCERTAINTY IN LOCATING PEAK

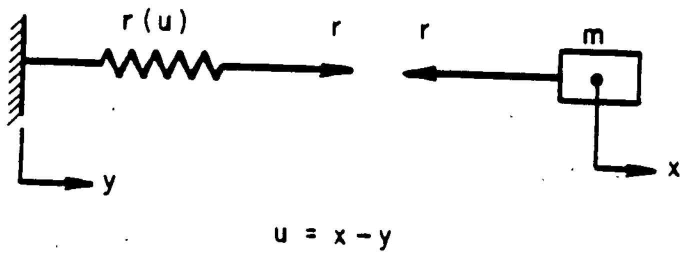


O ALTERNATE:



O BASIS IN SRP 3.9.2

Fig. 2



SIMPLE UNDAMPED MASS-SPRING SYSTEM

By Definition of Ductility Factor:
Area OABH Should Be Equal to Area OEH
Area OABCDG Should Be Equal to Area OEFG

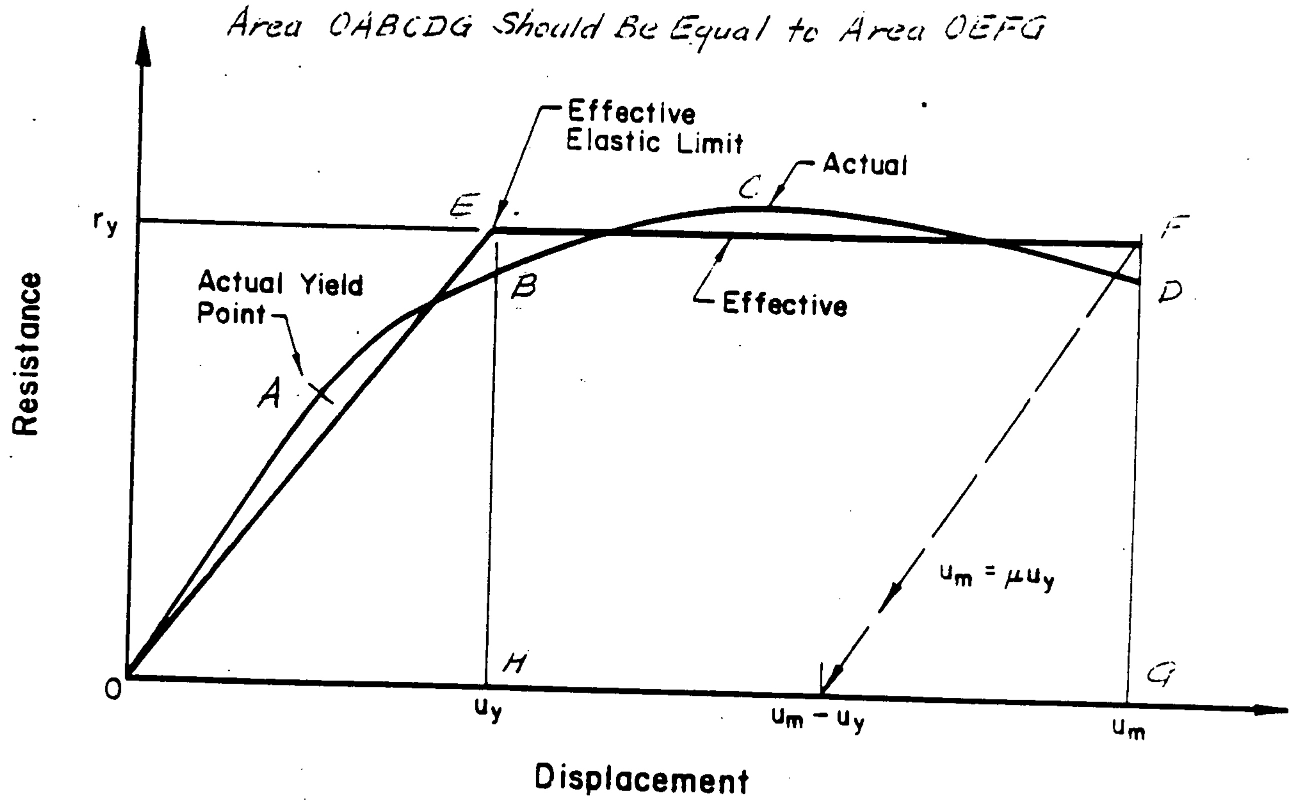


FIG. 3 RESISTANCE – DISPLACEMENT RELATIONSHIP
(From NUREG/CR-0098)

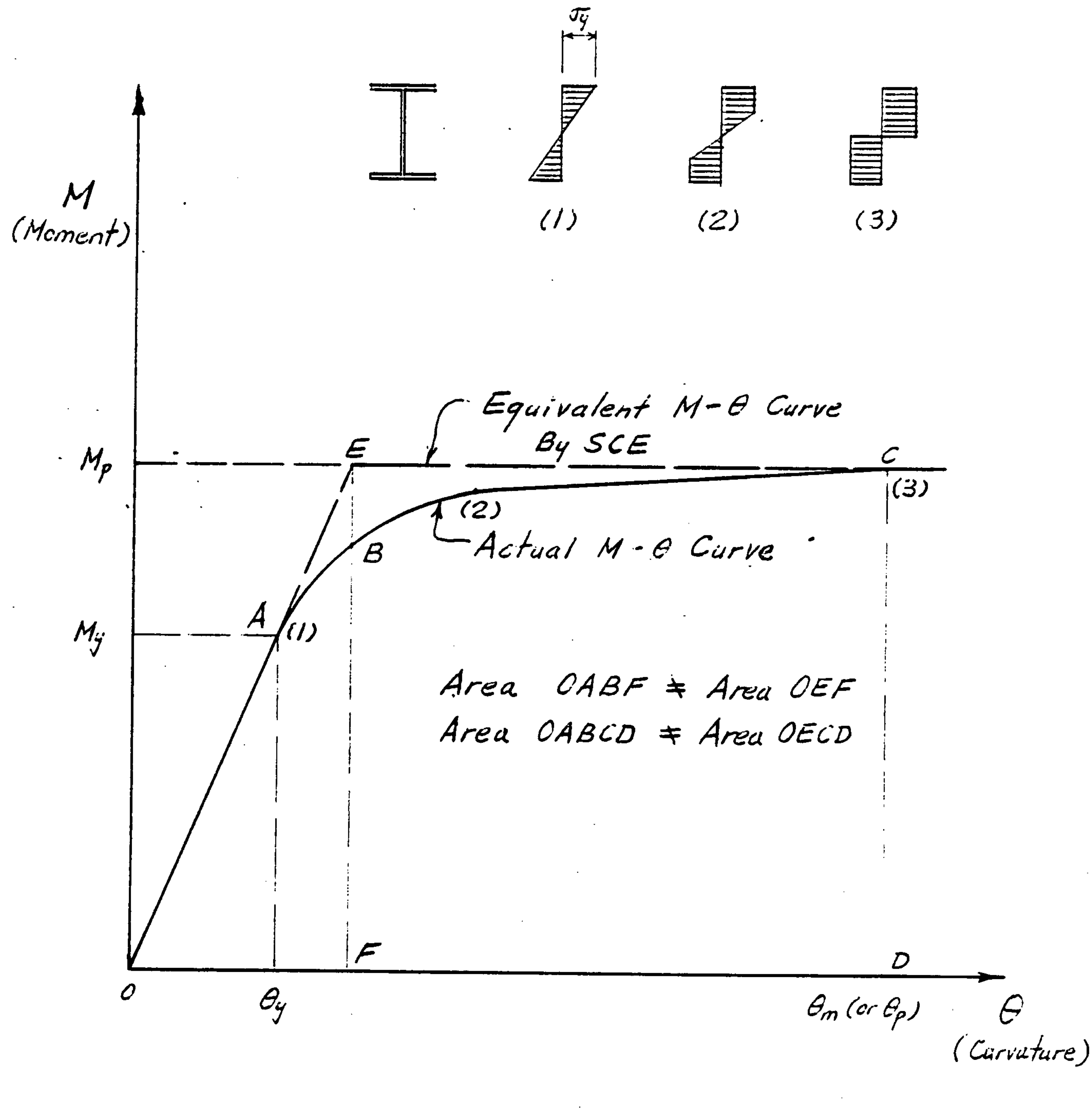


Fig. 4 Typical Theoretical Moment-Curvature Relationship For WF Steel Beam