APPENDIX B
SEISMIC SAFETY EVALUATION PROCESS FOR EMBANKMENT DAMS AND FOUNDATIONS

B-1. Introduction.

a. Purpose. This Appendix provides detailed guidance for evaluating the seismic safety of existing USACE embankment dams and foundations. The process ensures: (a) that seismic evaluations/re-evaluations for embankment dams and foundations are accurately identified and conducted with minimum expenditure of project funds, manpower or delay and (b) that embankment dams and/or foundations not requiring modifications are accurately identified and removed from further study at the earliest possible point in the evaluation process.

b. Scope. This guidance is to be used in evaluating the seismic safety of existing USACE Civil Works embankment dams IAW provisions of the Dam Safety Assurance Program as defined in the main text of this ER.

c. Background. The seismic safety of many existing embankment dams must be evaluated or re-evaluated IAW requirements in ER 1110-2-1806. Seismic safety evaluation of major civil works projects, particularly embankment dams, is typically a complex, multi-stage process. It generally requires progressively more detailed definition of certain project characteristics and analysis of project response to the design earthquake ground motions at each subsequent stage. This process can be expensive and manpower intensive, and may take many months to several years to complete.

B-2. Seismic Safety Evaluation Process.

a. Evaluation Process. Stages of the seismic safety evaluation process are designated as (a) Seismic Safety Review, (b) Phase I Special Studies, and (c) Phase II Special Studies. The stages are described in the following paragraphs. A multi-page flow chart illustrating the process is located at the end of this Appendix (Figure B-1). The evaluation process is structured to validate technical conclusions and policy compliance as an integral part of each stage of the process. This is accomplished during appropriately timed Policy Compliance & Criteria Reviews (PCCR). The PCCRs eliminate the need for several report submission and approval cycles preceding the development of an official decision document. The evaluation process leads

either to negative findings (i.e., that critical project features are likely to perform in an acceptable manner during and following the design earthquake) resulting in removal of the dam from further evaluation, or to the conclusion that modifications are required to the embankment dam and/or its foundation to ensure acceptable performance when subjected to the design earthquake. Negative conclusions at any stage beyond the initial screening at the Seismic Safety Review stage require validation during a PCCR. Negative conclusions at any stage of evaluation require only minimal formal documentation. Conclusions which indicate additional studies are required or that the project requires some form of remediation or modification must be validated during a PCCR. Additionally, the evaluation process and resultant conclusions must be documented for record prior to proceeding into the next phase. An information copy of the memorandum for record must be provided to both the MSC and HQUSACE (CECW-EP & EG). If studies through the Phase II level lead to the conclusion that some form of remediation is required, the results of the evaluation process, recommended remediation or modifications and justification are presented in an official decision document designated the Dam Safety Assurance Program (DSAP) Evaluation Report.

b. DSAP Evaluation Report. The DSAP Evaluation Report documents the entire evaluation process and recommendation for remediation or modification. It is the only formal report required prior to proceeding into detailed design and subsequent development of plans and specifications for seismic modifications. It has a specific format for documenting and presenting the evaluation, analyses, conclusions, economic justification and recommendations for modifying the dam and/or other project features. A detailed description of the required content and format is contained in paragraph 11 in the main body and in Appendix C of this ER. The DSAP Evaluation Report is the formal decision document which must be approved by HQUSACE before proceeding into detailed design and subsequent development of plans and specifications.

c. Phase III/Detailed Design. Following official approval of the DSAP Evaluation Report, Phase III work should proceed in accordance with the approved schedule. This includes detailed design for the seismic modifications approved in the DSAP Evaluation Report as well as preparation of the plans and specifications for

those measures. In accordance with current guidance, Phase III work may be carried out using Operations and Maintenance, General appropriations or the maintenance portion of the FC, MR&T account, as described in paragraph 15 in the main body of this ER.

d. Funding. Consistent with current guidance, all work for the Seismic Safety Review, the Phase I Special Studies, the Phase II Special Studies and the DSAP Evaluation Report are to be carried out using project O&M funds or the maintenance portion of the Flood Control, Mississippi Rivers and Tributaries (FC,MR&T) account, IAW paragraph 15 in the main text of this ER. Budgeting for this work should normally be covered in the annual budget EC for Civil Works activities. The DSAP Evaluation Report is the formal decision document which must be approved by HQUSACE before budgeting for Construction General funds.

B-3. Seismic Safety Review

a. Basis for Review. A Seismic Safety Review (SSR) is required when certain conditions exist as described in ER 1110-2-1806, Para. 5.d.

b. Purpose and Scope. The purpose of the SSR is to review and document conclusions about the seismic safety of embankment dams and foundations for civil works projects IAW ER 1110-2-1806. This review will conclude whether or not a Phase I Special Study is required. The SSR is normally limited to office examination and screening of available data and the results of the most recent Periodic Inspection. In this review, available information, such as geologic maps, boring logs, seismic zone maps, acceleration contour maps, existing field investigation reports, as-built project records, and previous seismic evaluation reports, should be used. If the initial screening indicates that the embankment dam and/or its foundation may require remediation/modification for seismic adequacy, then limited, simple preliminary analyses using existing available data should be performed as part of the SSR. If these analyses indicate that there is potential for sudden, uncontrolled loss of reservoir pool or other form of unacceptable performance which causes loss of life as a result of the project being subjected to the design earthquake, then a Phase I Special Study should be recommended. Where specialized expertise is needed, subject matter experts, either USACE or external, should participate in the examination and analysis as early as practical in the evaluation process.

The level of effort to accomplish the SSR should be the minimum required to resolve whether or not seismic safety issues exist which require a Phase I Special Study. (The level of effort and associated cost are estimated to be on the order of a few man-weeks of office effort with costs in the range of $25-50K.)

c. Seismic Safety Issues. Issues that are relevant to the determination of seismic safety and the need for further investigations may include some or all of the following:

(1). Project Hazard Potential Classification, as described in Appendix E, which reflects the criticality of the project in terms of threat to public safety in the event of failure. It is USACE policy that seismic safety of USACE embankment dams, where failure would result in loss of life, must be assured. For embankment dams and other features for which the consequences of failure are economic and no loss of life is expected, the decisions about further investigations or other actions should be justified on an economic basis.

(2). Adequacy of past seismic evaluations, if any; including the adequacy of procedures used in selection of design ground motions and the appropriateness and adequacy of methods of analysis used, in light of the present state-of-the-practice.

(3). Proximity to seismic source zones.

(4). Changes in the state of knowledge of regional or local seismicity since the last review.

(5). Existence of soils that are potentially unstable due to buildup of excess residual pore pressures or degradation of strength from cyclic loading in either the embankment or foundation.

(6). Existence of slopes that may be seismically unstable, including embankment slopes, the abutments or the reservoir rims.

(7). Existence of project features that may become critical to safety after small deformations of the embankment dam (i.e., outlet works becoming non-operational or thin filter zones within the embankment being disrupted).

d. Policy Compliance and Criteria Review. A Policy Compliance & Criteria Review (PCCR) should be held after 95% completion of the technical examination and analysis for the SSR, but prior to forwarding a recommendation to the District Dam Safety Committee. The PCCR should include geotechnical representatives

from HQUSACE and the MSC as well as District representatives including representatives from Engineering and Operations. The Dam Safety Officer or a designated representative should also attend. A PCCR is not needed if the results of the SSR indicates that the dam is seismically adequate. The PCCR should summarize the examination and screening and should provide a recommendation with justification for the initiation of Phase I studies. Supporting documentation should be presented. If a Phase I study is recommended, then a scope of work, cost estimate and schedule for the Phase I study should be presented. If the SSR is done in conjunction with a periodic inspection, the results of the SSR should be incorporated into the Periodic Inspection Report. As a minimum, the District should document the SSR as well as the results and conclusions of the PCCR in a memorandum for record to project files. No formal report or documentation is required to be submitted to the MSC or HQUSACE for review and approval; the PCCR replaces the MSC and HQUSACE review and approval process for the SSR. An information copy of the memorandum for record must be provided to both the MSC and HQUSACE (CECW-EP & EG).

B-4. Phase I Special Study.

a. General. A Phase I Special Study is necessary when the PCCR for the SSR concludes that potential deficiencies exist in an embankment dam or foundation which could lead to sudden, uncontrolled loss of reservoir pool or other form of unacceptable performance likely to cause loss of life if the project were subjected to the Maximum Credible Earthquake (MCE), as defined in ER 1110-2-1806, or a lesser event.

b. Purpose. The purpose of Phase I study is as follows:

(1) develop site specific ground motions appropriate for seismic evaluation of all project features to be evaluated,

(2) perform limited field investigations and laboratory studies, and,

(3) perform preliminary analyses, based on the ground motions, field data and laboratory testing results, to determine the response of the dam to seismic loading and to identify potential problem areas which may need more detailed analyses.

c. Content. The type and level of study required in the Phase I study will be project dependent; however, the content of a Phase I study normally includes the following:

(1). Project Description. Provide a brief description of the project, including type of dam, major structures or other critical feature. Provide tabulated pertinent project data. Describe design and current project operations. Identify key operational pool levels such as conservation pool, power pool, seasonal pool levels, spillway crest, flood pool and maximum pool. Other relevant pool information should include reservoir pool history elevation versus time, average yearly maximum pool, and the reservoir pool elevation versus frequency relationship based on historical data supplemented with flood routing analyses for less frequent flood events as required.

(2). Purpose and Scope. Describe the purpose and scope of the study and the deficiency(s) identified in the SSR. (Estimating the level of effort and cost to perform a Phase I study is difficult to address on other than a project specific basis but are likely to range from many man-months to a few man-years of effort and involve expenditures in the range of $300-800K. Phase I duration should be limited to the shortest possible time period consistent with project complexity, manpower, funding and quality considerations.)

(3). Site Characterization. Perform limited field and laboratory investigations to define the soil and rock stratigraphy and to further clarify location and extent of potential problem areas. These investigations should be sufficient to develop preliminary soil and rock cross sections of the dam and foundation in areas which have potentially unstable soils. These investigations may include Standard Penetration Tests (SPT), Cone Penetration Tests (CPT), shear wave velocity, permeability, Becker Penetration Tests (BPT), conventional undisturbed sampling, and trenching in areas of much lateral heterogeneity or anisotropy.

(4). Seismotectonic Evaluation. Develop a detailed evaluation of the geology, tectonics and seismic history of the area, and the proximity of the dam to active seismic zones. Provide fault study and related field investigations and laboratory testing where necessary.

(5). Seismicity and Ground Motions. Select the final design earthquake ground motions and develop the ground motion parameters to which the project could be subjected. For all critical projects or features, these input ground motions will be obtained from a deterministic analysis of historic seismicity and active fault systems or seismic source zones and their activity. Develop several

accelerograms for site response computations. The accelerograms should contain energy, frequency and duration components appropriate for the source, the region and the feature being evaluated. Caution is advised to avoid undue conservatism in selection of ground motions for use in analyses. Selection of specific accelerograms or the manipulation of accelerograms to generate records with specific time histories not representative of the characteristic ground motion records within the region of the project should be strongly justified and well documented. Of particular concern is that accelerograms be developed with energy content and occurrence of the peak energy representative of the seismological setting of the feature(s) being evaluated. For effective stress analyses, where site permeability profiles and boundaries are accurately known and seismic generated residual excess pore water pressures will be simultaneously dissipated, input motion time histories should not be manipulated to shift the energy content to the end of shaking to minimize pore pressure dissipation and thereby maximize excess residual pore pressures during modeling of post earthquake response unless justified from seismological investigations and by expert seismologists. Selection of ground motions should be made with input from qualified seismologists, geologists and geotechnical engineers.

(6). Seismic Evaluations and Analyses.

(a) Liquefaction Potential. Evaluate the potential for liquefaction or development of excess pore pressure in soils of the embankment and foundation using standard methods. This should consist of using an appropriate empirical method linking documented field performance with site characteristics using field investigations. Use a 1-D analysis, such as SHAKE, to model propagation of earthquake induced rock motions through the foundation and the embankment.

(b) Post Earthquake Stability. Evaluate post-earthquake limit equilibrium slope stability for the reach(es) of the embankment where liquefaction of the embankment and/or foundation is indicated. Post-earthquake shear strengths for zones not indicated to liquefy should be estimated taking into account residual excess pore pressures. Post-earthquake shear strengths for zones which are indicated to liquefy should be selected based on residual strengths back calculated for well documented liquefaction induced failures. The further reduction in shear resistance below the residual level is not justified.

(7). Post Earthquake Deformed Shape. Assess the shape and amount of deformation in the embankment after sliding or slumping for the cross section where inadequate factors of safety are indicated by limit equilibrium slope stability analyses. Similar cautions noted for selection of strength and pore pressure values in evaluating limit equilibrium stability are to be observed in evaluating the post earthquake deformed shape of an embankment or other slope.

(8). Conclusions and Recommendations. Develop conclusions and recommendations on the need for a Phase II seismic evaluation or departure from requirements of ER 1110-2-1806.

(9). Cost Estimate and Schedule. If Phase II studies are recommended, develop a detailed scope, cost estimate and schedule for the proposed Phase II studies.

(10). Phase I PCCR. Conduct a PCCR for the Phase I study.

B-5. Phase II Special Study.

a. General. A Phase II Special Study is necessary when the PCCR for the Phase I concludes that potential deficiencies exist in an embankment dam or foundation which could lead to sudden, uncontrolled loss of reservoir pool or other form of unacceptable performance likely to cause loss of life if the project were subjected to the design earthquake. The Phase II study should be detailed and sufficiently comprehensive such that conclusions reached concerning the seismic adequacy of the dam in question are definitive and constitute the basis for selection, detailed design and construction of modifications or other form of remediation required to ensure seismic safety of the project.

b. Purpose and Scope. The purpose and scope of Phase II study are as follows:

(1) Perform comprehensive detailed analyses to evaluate performance of the critical project features when subjected to the ground motions identified in Phase I.

(2) Determine if the dam is seismically adequate or if remediation/modifications are required to ensure acceptable seismic performance.

(3) Establish remediation requirements.

(4) Evaluate various alternative remedial techniques and select the most appropriate alternative.

(5) Prepare cost estimates, scope, and schedule

for design documentation, plans and specifications, and construction.

c. Methods of Analysis. The recommended engineering approach to analysis of an embankment dam and foundation for seismic stability generally consists of assessing both post earthquake static limit equilibrium slope stability and deformation response of the dam using, as appropriate, detailed 2D and 3D numerical analyses. The steps involved in a Phase II seismic analyses for earth dams normally include:

(1) Use the recommended design earthquake ground motions and accelerograms developed in the Phase I study for site response computations. For all critical projects or features, these input ground motions will be obtained from a deterministic analysis. The selected accelerograms should be used in the application of an appropriate, validated dynamic finite element program used for modeling the deformation process in response to an imposed earthquake ground motion time history.

(2) Perform detailed field investigations which may include SPT, BPT, CPT, field vane shear tests, field permeability, ground water observation wells, conventional undisturbed sampling, geophysical evaluations, and laboratory testing, to develop a detailed understanding of site conditions, including stratigraphy, geometry, hydrology, material properties and their variability, and the areal extent of potential problem zones.

(3) Determine the pre-earthquake vertical effective shear stresses, and the initial static shear stresses on horizontal planes throughout the dam and its foundation.

(4) Determine the dynamic shear moduli of the soils in the dam and foundation.

(5) Using an appropriate dynamic finite element analysis procedure, determine the stresses induced in the embankment and foundation when subjected to the accelerograms selected for the design earthquake. Pore water pressure dissipation should be properly accounted for in determining pore pressure behavior during shaking and residual excess pore pressure level after shaking stops. Consider relevant soil properties and stratigraphy including permeabilities in soil layers adjacent to the liquefiable soil layer which restrict pore pressure dissipation.

(6) Determine the liquefaction resistance of the embankment and foundation

soils and the maximum potential residual excess pore water pressure that can be generated by the earthquake using corrected penetration data from in-situ tests such as SPT, CPT, BPT, and laboratory index tests.

(7) Map the areal extent of all suspect materials. Determine post earthquake shear strength of relevant soils. Prepare several generalized cross sections of the dam and foundation for final analysis to determine seismic response.

(8) Perform static limit equilibrium slope stability analyses of the generalized cross sections to assess post earthquake stability and to identify potential zones of the dam and foundation which may require remediation.

(9) Estimate the deformation response of the embankment dam and the post earthquake shape of the embankment by using an appropriate 2D and/or 3D finite element or other appropriate deformation analysis program.

(10) Remediation should be recommended when the embankment dam is (a) found to have inadequate limit equilibrium slope stability factors of safety and/or (b) projected to experience unacceptable deformations when subjected to the design earthquake and it is concluded that either situation would result in sudden, uncontrolled loss of the reservoir pool and loss of life. If remedial measures are recommended, establish the remediation requirements, evaluate various remediation alternatives, and select the most appropriate alternative.

(11) Perform additional post earthquake limit equilibrium slope stability and finite element analysis to determine preliminary remediation needs such as extent and location of remediation required, strength/resistance required and to determine the level of protection to be obtained by remediation.

(12) Evaluate various preliminary remediation alternatives and select the most appropriate alternatives for cost estimating purposes.

(13) Perform additional finite element deformation analyses to determine expected deformations in both remediated and non-remediated sections of the dam. Determine overall dam response and differential deformation.

(14) Develop detailed scope, cost, and schedule for PED phase (Preconstruction Engineering and Design) which includes preparation of design documentation and plans and specifications (P&S).

(15) Conduct a PCCR for the Phase II study.

(16) Prepare the Phase II study summary. This is the basis for a technical appendix to the DSAP Evaluation Report. The suggested format and content for the Phase II summary is described in Paragraph B-5.d below.

d. Phase II Study Documentation. There is no specific requirement for documenting the Phase II Special Study prior to development of the DSAP Evaluation Report, however, a detailed summary of the entire evaluation process including the Phase II study must be included as a Technical Appendix to the DSAP Evaluation Report. To facilitate the Phase II PCCR, a summary should be developed and presented at the PCCR in the general format and scope indicated as follows:

(1). Introduction.

(a) Authorization
(b) Purpose
(c) Project Description
(d) Method of Analysis

(2). Static Stress Analyses.

(a) General
(b) Development of Static Properties of the Dam
(c) Results of Static Stress Analyses

(3). Design Earthquake Motions.

(a) General
(b) Design Earthquake and Ground Motions
- Response Spectra
- Time Histories

(4). Dynamic Response Analyses.

(a) General
(b) Field and Laboratory Tests and Results
(c) Development of Dynamic Properties
(d) Dynamic Analyses
(e) Dynamic Response

(5). Seismic Stability Assessment.

(a) Evaluation of Dynamic Strengths
- Laboratory Data
- Field Data
(b) Dynamic Response and Stability
(c) Earthquake Induced Deformation Analyses

(6). Post Earthquake Stability Analyses.

(a) General
(b) Post Earthquake Strength Properties
(c) Slope Stability
(d) Post Earthquake Deformed Condition

(7). Deformation Response Analyses.

(a) General
(b) Deformation analyses of Remediated Sections
(c) Deformation Analyses

of Unremediated Sections

(8). Remediation Alternatives.

(a) General
(b) Potential Remediation Alternatives
(c) Cost Estimates for Potential Remediation Alternatives

(d) Estimated Construction Sequence, Schedule, Duration for Alternatives

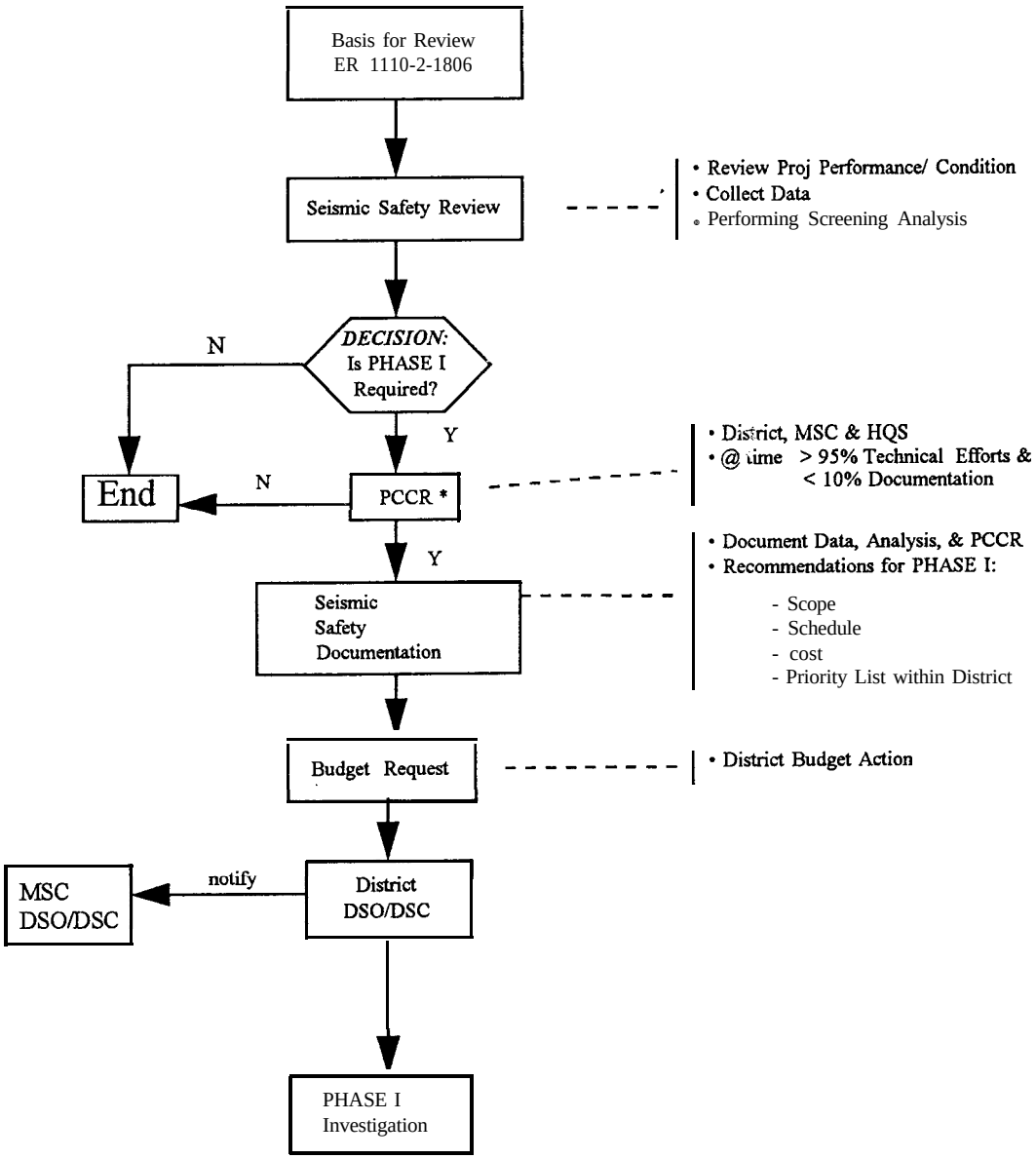
(9). Summary.

(10). Conclusions and Recommendations.

(11). References.

(12). Attachments.

Seismic Analysis Process
Liquefaction/Deformation Evaluation



* Policy and Criteria Compliance Review (PCCR)

Figure B-l

Seismic Analysis Process

Liquefaction/Deformation Evaluation -Continued

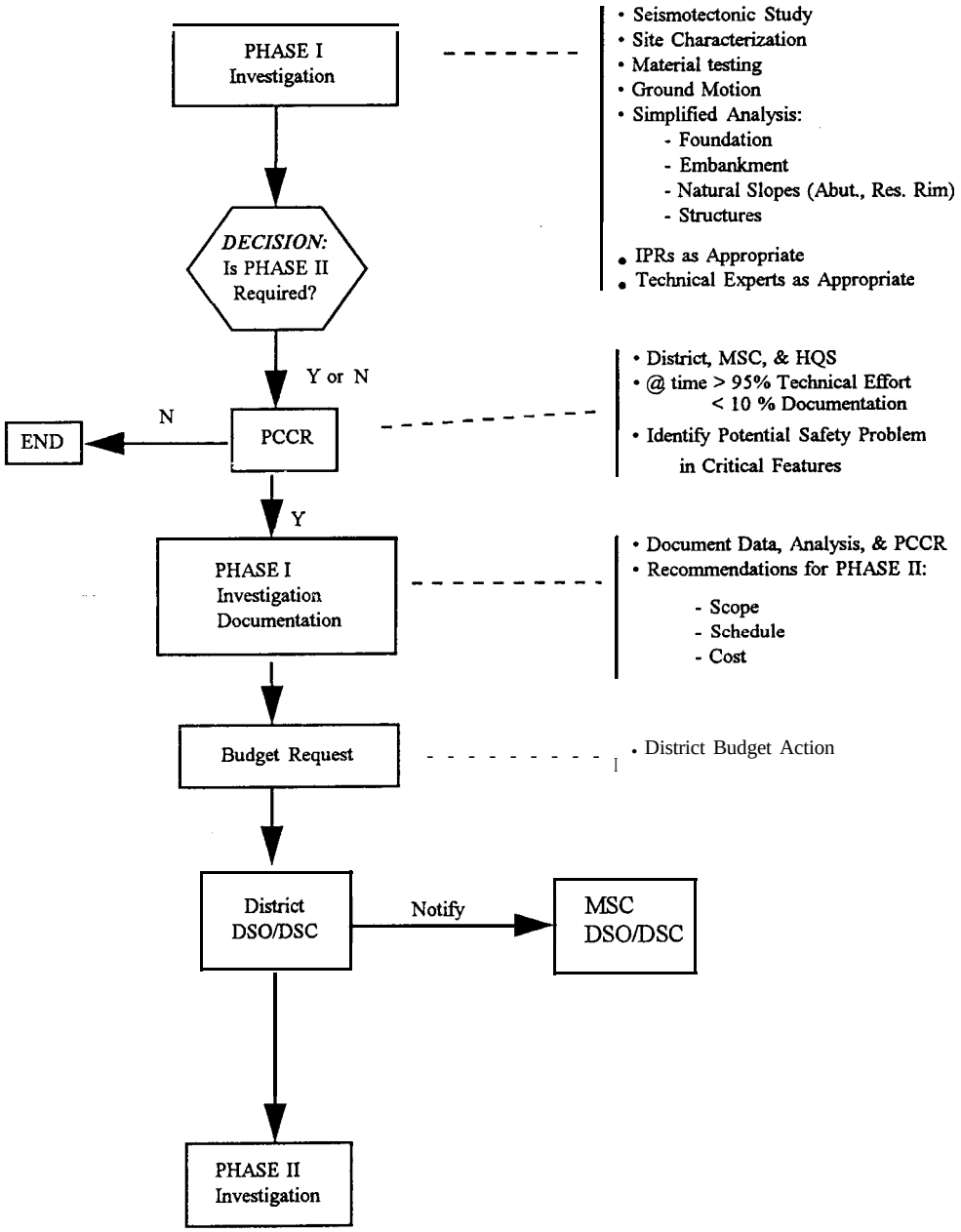
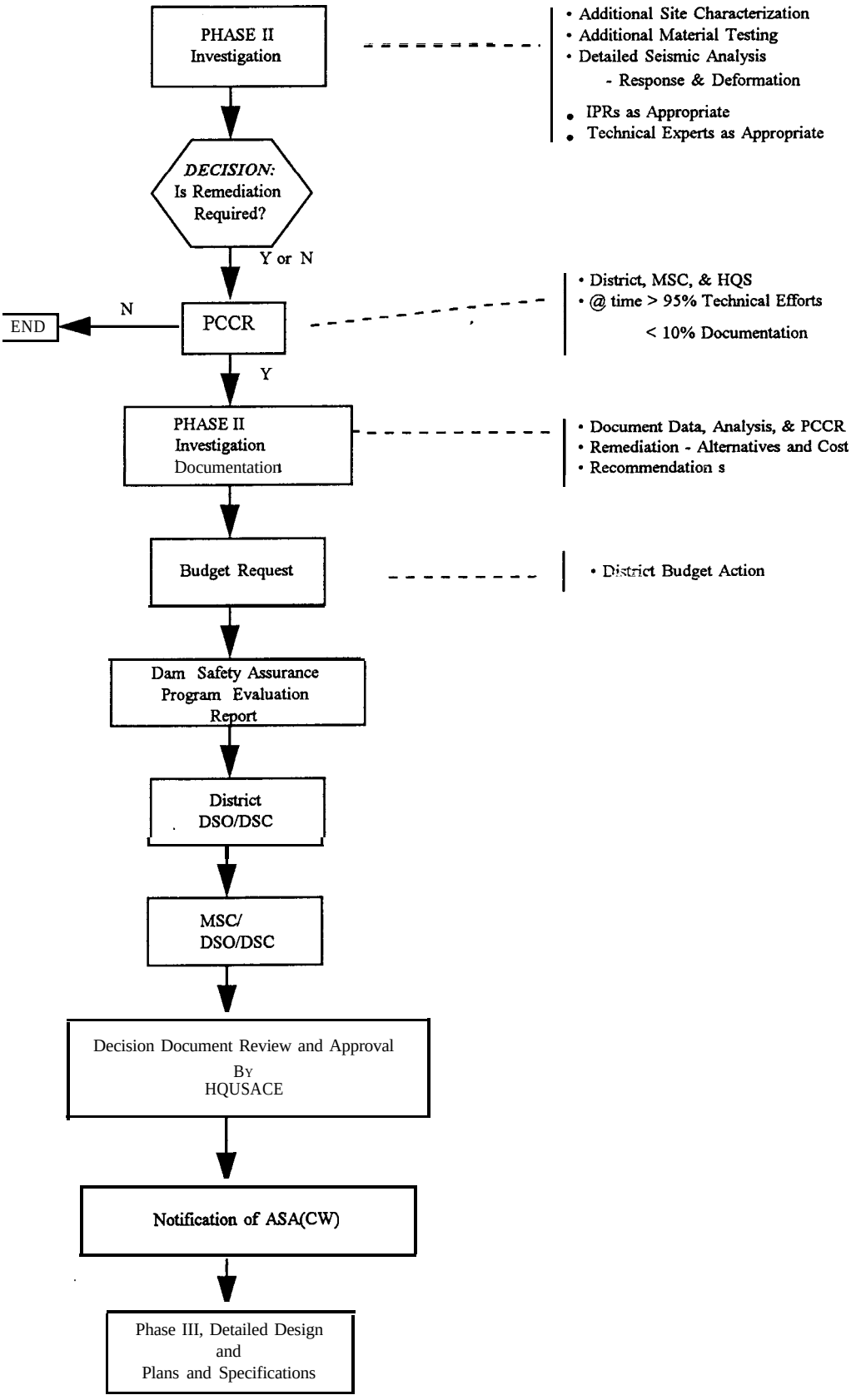


Figure B-l (Continued)

Seismic Analysis Process

Liquefaction/Deformation Evaluation -continued



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