SEISMIC ANALYSIS PROCEDURES FOR THE PLUTONIUM PROCESSING BUILDING OF THE SPECIAL ISOTOPE SEPARATION PLANT

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ABSTRACT

This paper describes the methodology for the seismic soil-structure interaction (SSI) analysis of the Plutonium Processing Building (PPB) which is part of the Special Isotope Separation (SIS) Production Plant. The PPB consists of two structures, the enclosure building and the optics/separator area. These are founded on two independent foundations which are supported on the surface of a soil medium consisting of gravel overlying basalt. The PPB is classified as a safety related structure and is required to withstand the effects of a Design Basis Earthquake (DBE).

INTRODUCTION

The response of a structure during an earthquake depends on the characteristics of ground motion, the properties of surrounding soil, and the dynamic properties of the structure. In recent years, several techniques for soil structure interaction analysis have been developed. An adequate analytical procedure should account for the following:

- o Variation of soil properties with depth.
- o Non-linear and energy absorbing characteristics of soils.
- o Structure-soil-structure interaction effects.
- o The three dimensional nature of the problem.

To account for the above as applied to the PPB structure, the CLASSI (Continuum Linear Analysis for Soil Structure Interaction) computer program [1] was selected.

SEISMIC CRITERIA

Design Ground Spectra

The design ground spectra for the PPB analysis are the site-specific response spectra developed for the Idaho National Engineering Laboratory (INEL) site [2]. The design ground spectra normalized to an acceleration of 1.0 (g) for damping values of 0.5, 2.0, 5.0 and 10.0 percent are shown in Fig. 1.

The maximum zero period horizontal acceleration (ZPA) is 0.33 (g) and the vertical is taken as 2/3 of the horizontal or 0.22 (g). These ZPA values are based on the Preliminary Study of Earthquake Strong Ground Motions at the INEL site [3]. The design spectra are scaled using the above ZPAs.

Control Motions

The free-field seismic ground motion inputs used in the soil-structure interaction analyses consists of synthetic acceleration time histories which were generated for three orthogonal directions using the computer program BSIMOKE [4]. These time histories are statistically independent and their response spectra, in general envelop the design spectra for all applicable damping values and comply with the requirements outlined in U.S. NRC Standard Review Plan (SRP) sections 3.7.1. Each time history has a duration of 24 seconds with a time increment of 0.01 seconds and are scaled to 0.33(g) and 0.22(g) for horizontal and vertical input respectively. The acceleration, velocity and displacement time history plots for two horizontal and a vertical component are shown in Fig. 2 thru Fig. 4, respectively. The comparison of calculated response spectra versus design response spectra for 0.5, 2.0, 5.0 and 10.0 percent damping values are shown in Fig. 5 thru Fig. 7, respectively.

In the SSI analysis, the control motions are assumed to be the free-field surface motions prescribed at the grade level. The wave input is assumed to be composed of vertically propagating body waves.

Dynamic Properties of Soil

The sub-surface profile at the PPB site consists of 0 to 7 feet of predominantly silty or sandy gravel fill overlying a thin, generally cohesive, layer consisting of mostly lean clay with varying proportions of sand and silt. Beneath this surface layer is a sandy, silty, or clayey gravel extending to the top of the basalt bedrock at the depths ranging from 35 to 45 feet. The potentially compressible surface layer of natural cohesive soils will be replaced with sandy, silty or slightly clayey gravels. The sub-surface mean dynamic properties calculated using downhole seismic wave velocity measurements [5] are summarized in Table 1.

In order to account for the uncertainties in the measured soil properties, the analysis will be performed using mean, upper-bound (1.5 times mean) and lower-bound (0.67 times mean) soil properties and the results will be enveloped.

PLUTONIUM PROCESSING BUILDING

The PPB is a two-story reinforced concrete structure except for the portions on the roof over the optics/separator and laboratory areas which are non-safety related steel truss structures. The PPB is approximately 310 by 370 feet and 45 feet in height. The general view of PPB is shown in Fig. 8. The enclosure building houses the optics/separator area, special nuclear material processes and storage, chemical support processes and local control rooms, an analytical chemistry laboratory and plant operational support equipment.

Due to vibration isolation requirements, the optics/separator area is located on a foundation separated from the enclosure building foundation.

Dynamic Models

The optics/separator area is a symmetrical structure. It houses six separators and seven optics walls on a 3 foot thick basemat. these are represented using thirteen single mass stick models. Each mass has 3 dynamic degrees of freedom (DDOF) representing the E-W, N-S and vertical directions. The sticks are placed at the appropriate locations and linked rigidly at the base to form a multiple stick lumped-mass dynamic model.

The building consists of concrete walls, columns, and cast-in-place slabs supported on precast beams and precast panels. The superstructure is placed on a 2′-6′′ basemat. A detailed 3-D model was constructed using the Finite Element Method (FEM) and is shown in Fig. 9. All major structural elements; walls, slabs, beams and columns are included in the model with the exception of non-safety related steel trusses which are represented by masses lumped at the appropriate support locations. The cast-in-place slabs on precast beams, are modeled as quadrilateral and triangular plate elements with orthotropic plate properties. To reduce computer cost, the building masses will be distributed to a set of horizontal and vertical dynamic degrees of freedom. The number of DDOF is selected so that all significant modes of vibration of the structure can be reliability evaluated. The distributed masses are checked for center of gravity and rotational moment of inertia to ensure the structural eccentricities are properly included.

SOIL-STRUCTURE INTERACTION ANALYSIS

CLASSI is a linear analysis program; thus the strain-dependency of soil can not be directly considered. It requires separate analysis to obtain the strain-compatible equivalent linear soil properties for input. In general, the CLASSI analysis is performed in two stages as follows;

Site Response Analysis: to obtain strain-compatible soil properties to be used in the interaction analysis .

Interaction Analysis: to compute the impedances for the SSI system and the resulting SSI structural responses.

A flow chart describing the steps for performing the SSI analysis is shown in Fig. 10. The following summarizes the main steps in the analysis.

Site Response Analysis

The computer program SHAKE [6] is used to perform the site response analysis. This program models the site as a one-dimensional layered soil column and assumes that the input motion consists of vertically propagating horizontal shear waves. Soil nonlinearities are accounted for in SHAKE using the equivalent linear method through iterations of soil parameters, namely the shear modulus and damping ratio until strain-compatible equivalent soil properties are obtained.

These strain-compatible equivalent linear soil properties are then used to define the soil-foundation model in the CLASSI analysis.

For the PPB site response analysis, the site soil will be modeled as a 45 foot layer of gravel overlying an elastic halfspace with basalt properties. The mean soil properties from Table 1 will be used as the initial soil properties. The strain-dependent shear modulus and damping curves for gravelly soils [7] will be used. The input motions are the horizontal components of synthetic acceleration time histories. This analysis will be repeated for three soil condition; lower-bound, mean and upper-bound.

Interaction Analysis

The interaction analysis consists of the following steps. First, develop a three-dimensional model for the PPB foundations. The model will consist of two foundations representing the enclosure building and optics/separator areas. These foundations are discretized into a number of subregions with the finer ones concentrated around the perimeters of each foundation where the stress gradient is the highest. The strain-compatible equivalent linear soil properties obtained from the SHAKE analysis are used to define the properties of the layered soil system. Frequency dependent foundation impedances and seismic wave scattering matrices are calculated using CLASSI's GLAYER and CLAF program modules.

Second, calculate the fixed-base dynamic modal properties of the PPB and Optics/Separator area in terms of frequencies, mode shapes, modal participation factors and modal dampings up to the highest frequency of interest.

Finally, the results obtained from the first two steps along with the three control motions (two horizontal and vertical) are used as input to CLASSI's SSI program module to compute the foundation responses as well as the in-structure responses.

BRIEF DESCRIPTION OF "CLASSI" PROGRAM

CLASSI (Continuum Linear Analysis for Soil-Structure Interaction) is a linear three-dimensional seismic SSI analysis program developed by Luco and Wong [6] in 1976 at the University of California, San Diego. Since then, the CLASSI program has been continuously upgraded to expand its capabilities and efficiency from those of its initial development. Thus various versions of the CLASSI program exist in the industry, each covering somewhat different analysis capabilities and limitations. The CLASSI program used for this analysis is the Bechtel version originally developed in 1978, and recently modified by Wong and Luco in 1985. This version has been extensively tested against analytical solutions obtained from the technical publications or the comparable results obtained from validated public domain programs.

The program solves the SSI problems in frequency domain using the Fast Fourier Transformation (FFT) technique. CLASSI is comprised of program modules developed to solve the SSI problem in separate steps. The analysis method used in CLASSI is based on the substructuring technique which separates the analysis of kinematic interaction from that of inertial interaction in two successive steps. Considering a typical structure on a rigid foundation supported on a soil medium as shown in Fig. 11, the substructuring technique applied to this soil-structure system is schematically shown in Fig. 12.

The analysis of kinematic interaction as shown in block I of Fig. 12, is handled by first deriving the "so-called" seismic wave scattering matrix, which is then used to transform a given free-field seismic ground wave field into a set of effective free-field seismic motions associated with the structural base motion degrees-of-freedom. The analysis of inertial interaction is handled by first deriving the foundation impedance matrix using an integral equation method and Green's functions of a continuum halfspace [9]. The foundation impedances are then combined with the fixed-base structural impedances to form the SSI system, as shown in block II of Fig. 12. Finally, the interaction response is calculated as shown in block III of Fig. 12 by subjecting the SSI system to the foundation input motions at the structure base resulting from the kinematic interaction from block I as the input seismic excitation. For the case of multiple structures interacting through the foundation soil, the above procedure is extended in a generalized sense to involve the structural base motion degrees-of-freedom of all interacting structural foundations, as detailed in Ref. 8.

REFERENCES

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[6] Schnabel, P., et. al, "SHAKE - A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," EERC 72-12, University of California, Berkeley. 1972.

[7] Seed, H.B. et. al, "Moduli and Damping Factors for Dynamic Analysis of Cohesionless Soils", Journal of Geotechnical Engineering, Vol. 112, No. 11, Nov. 1986.

[8] Wong, H. L. and Luco, J.E. "Dynamic Response of Rigid Foundations of Arbitrary Shape", Earthquake Engineering and Structural Dynamics, Vol. 4, 1976.

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Table 1

Summary of Mean Site Dynamic Properties (Reference 4)

Material	Compress-ional(Vp) ft/sec	Shear (VS) ft/sec	Damping Ratio	Shear* Modulus kips/SF	Elastic Modulus kips/SF	Poisons Ratio	Unit Weight lbs/ft^3
Alluvial Gravel	3300	1400	1%	8200	22,000	0.39	135
Basalt	9200	3900	1%	71000	200,000	0.39	150

(*) For Low Strain Level of 10^{-4}

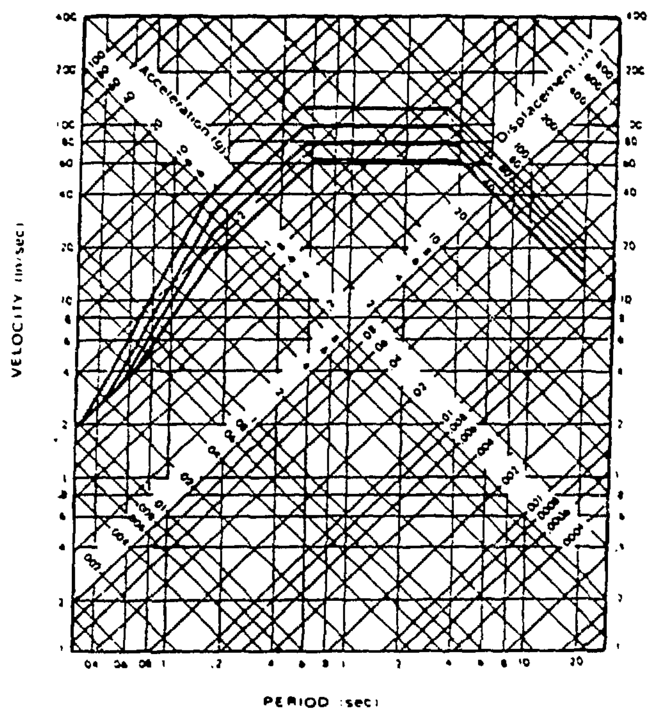

Figure 1
Design Response Spectra Scaled to 1.0g

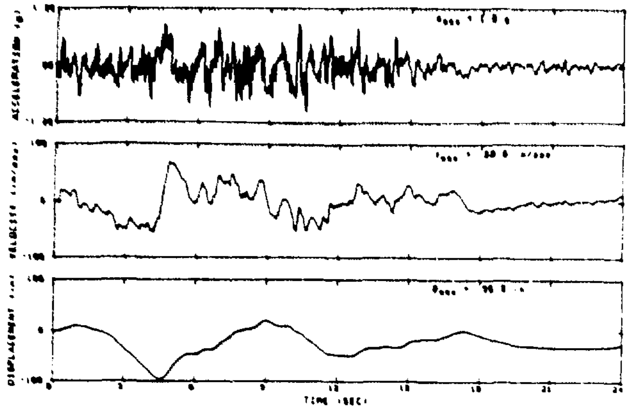

Figure 2
Horizontal (H1) Spectrum-Compatible Time History

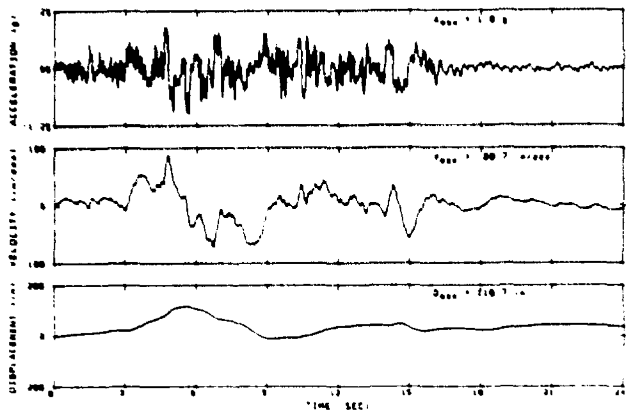

Figure 3
Horizontal (H2) Spectrum-Compatible Time History

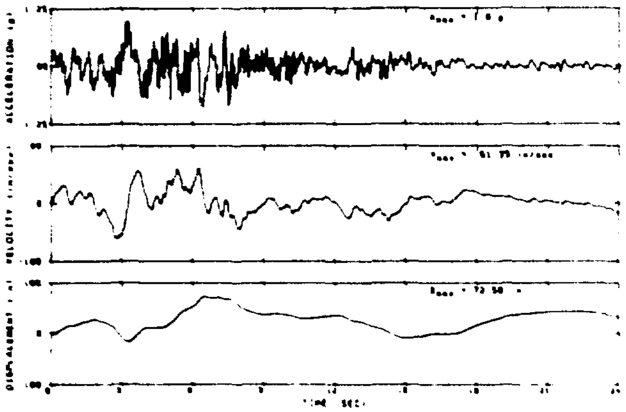

Figure 4
Vertical Spectrum-Compatible Time History

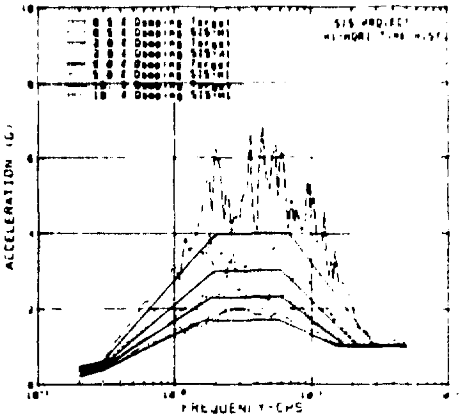

Figure 5
Comparision of Horizontal (H1) Response Spectra vs Design Response Spectra

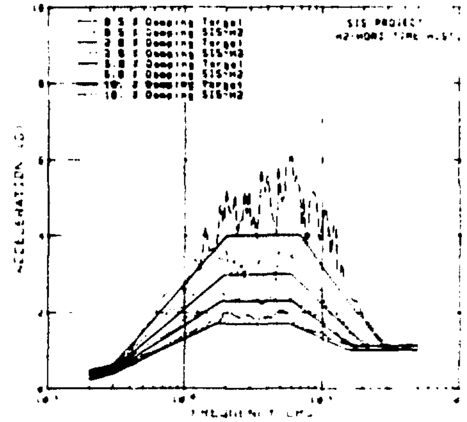

Figure 6
Comparision of Horizontal (H2) Response Spectra vs Design Response Spectra

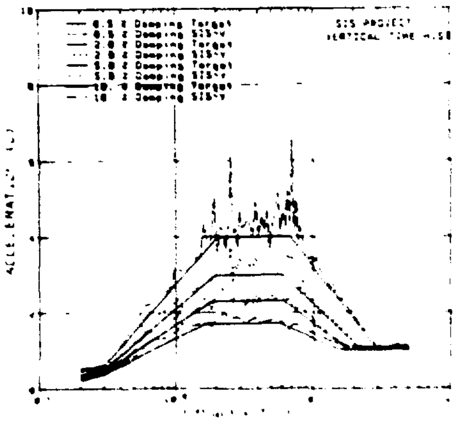

Figure 7
Comparision of Vertical Response Spectra vs Design Response Spectra

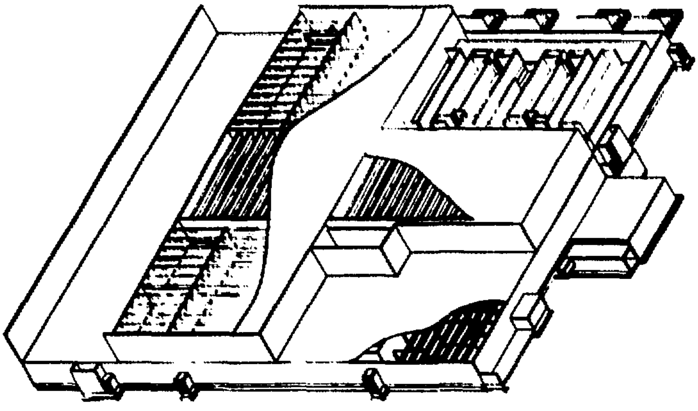

Figure 8
PPB Structure Isometric

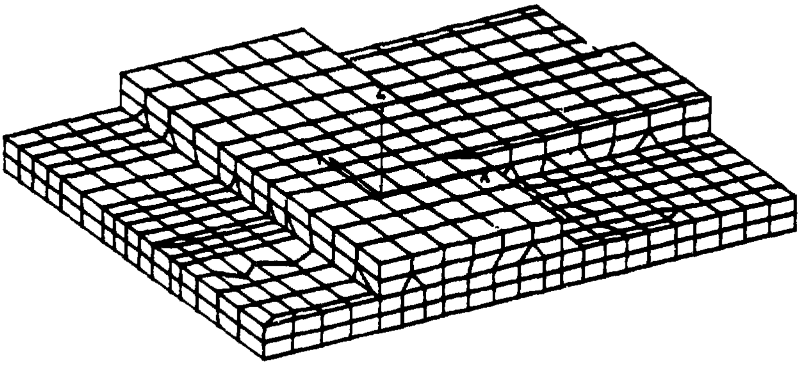

Figure 9
PPB Structure Finite Element Model

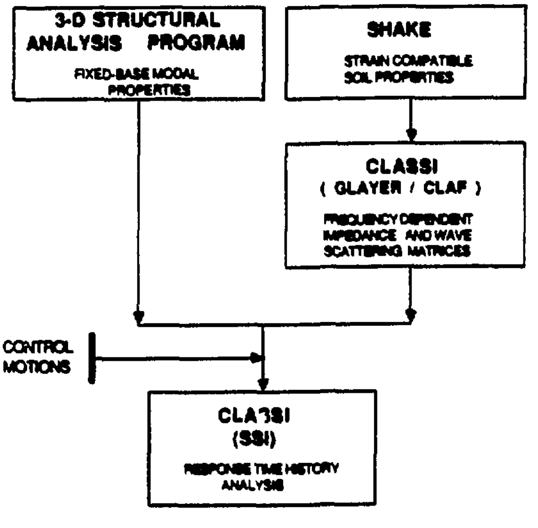

Figure 10
SSI Methodology Flow Chart

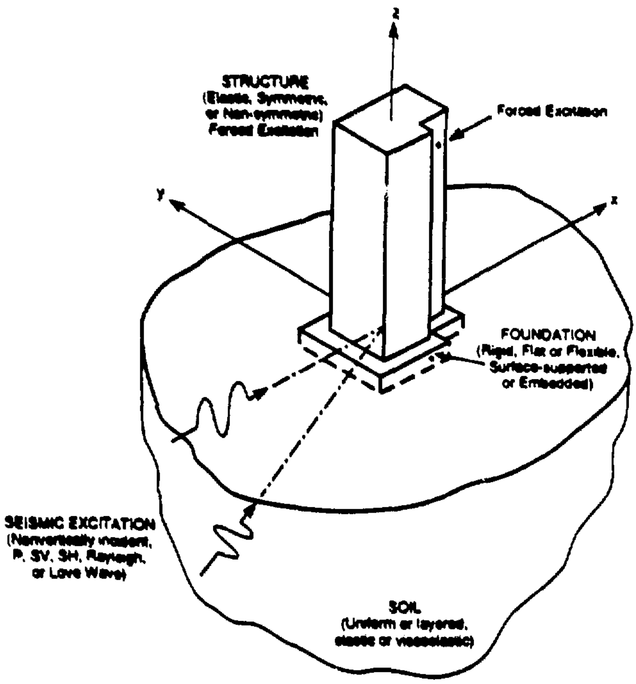

Figure 11
Description of Soil Structure System

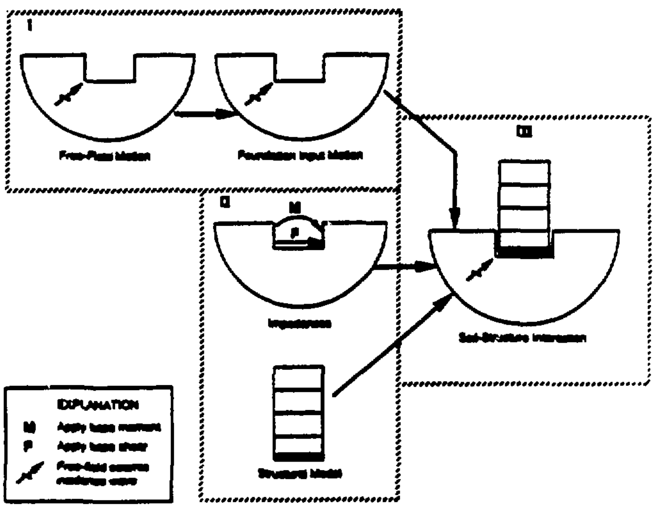

Figure 12
CLASSI Substructuring Technique