Paper No. 608. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

SEISMIC DESIGN AND SEISMIC MARGIN ASSESSMENT OF THE ABB-CE SYSTEM 80+ STANDARD NUCLEAR POWER PLANT

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ABSTRACT

This paper provides a summary of the design parameters used in the seismic design of the Asea Brown Boveri/Combustion Engineering System 80+ Standard Plant. The System 80+ seismic design is developed with the objective of having a standard design which would envelop the majority of sites in the world with the possible exception of sites near major active faults in areas of known high seismicity. The seismic design basis was developed based on the current state-of-the-art as well as consideration for both current and anticipated future Nuclear Regulatory guidance. The paper discusses seismic design requirements, selection of generic soil sites, selection of design control motions, soil-structure interaction analyses, site acceptance criteria and seismic margin assessment of the plant.

KEYWORDS

Power plant; standard design; seismic design basis; soil-structure interaction; seismic margin

INTRODUCTION

The Asea Brown Boveri/Combustion Engineering (ABB-CE) System 80+ standard plant is one of the four designs which are currently being developed by the U.S. nuclear plant NSSS designers/manufacturers as the next generation of nuclear power plants. All four designs are based on the concept of standardization. The System 80+ design is an Advanced Light Water Reactor (ALWR) design which is an evolution of the existing System 80 design featuring enhanced safety features and improved performance. The System 80+ design includes a 200 foot (61 m) diameter, 1-3/4 inch (44.5 mm) thick, free standing spherical steel containment vessel enclosed in a cylindrically shaped concrete shield building with a hemispherical dome (figure 1). The Nuclear Island consists of two general areas, the reactor building and the nuclear annex. The reactor building consists of the shield building, steel containment vessel, interior structures of the containment vessel, and the area below the steel containment vessel, which is referred to as the subsphere. The nuclear annex consists of the Chemical and Volume Control System (CVCS) area, the fuel handling and storage area, the control complex, emergency diesel generator rooms, and main steam valve house areas. Figure 2 shows the plan of the Nuclear Island. All Nuclear Island structures are reinforced concrete structures, with the exception of the steel containment vessel, founded on a common 10 foot (3 m) thick basemat with a 52 foot (15.8 m) embedment. The plan dimensions of the basemat is 380 foot (116 m) long by 320 foot (98 m) wide.

SEISMIC DESIGN REQUIREMENTS

The seismic design requirements for the plant is a Design Basis Earthquake (DBE) of 0.3g. The spectral shape and the selection of control motion are further discussed below. There are no specific design requirements for the Operating Basis Earthquake (OBE). At the start of the program, design requirements for OBE were set at 0.1g level. However, through a collaboration effort between the industry and the U.S. Nuclear Regulatory Commission (USNRC), explicit design requirements for OBE has been eliminated. The System 80+ has established a Seismic Margin Earthquake (SME) level of 0.6g. This is the earthquake level at which High Confidence of Low Probability of Failure (HCLPF) levels for essential structures and components required to bring the plant into cold shutdown status are 0.6g or higher.

SELECTION OF CONTROL MOTIONS

The System 80+ design has 3 design control motions specified as the basis for its design. These are referred to as Control Motion Spectrum (CMS) 1, 2, and 3 respectively. All control motion design spectra are anchored to a 0.3g horizontal peak ground acceleration. They were developed with the objective of covering the majority of site conditions in the world as well as being in full compliance with various regulatory and industry requirements. The selection of the 3 control motions ensures compliance with USNRC's Regulatory Guide 1.60, NUREG-0800 guidance, as well as the EPRI ALWR Utility Requirements Document (URD). Each of the 3 control motions were chosen with the following thought process in support of design and standardization:

1. Control Motion Spectrum 1 (CMS1): This spectral shape is identical to the Regulatory Guide 1.60 spectrum. It is considered in design in order to cover sites with deep soil deposits. Design to this spectral shape satisfies the EPRI URD requirements for advanced nuclear plant designs.

2. Control Motion Spectrum 2 (CMS2): This is rock outcrop spectrum and is developed to cover sites typical of Eastern North America which could experience earthquakes with high frequency content.

3. Control Motion Spectrum 3 (CMS3): This is a rock outcrop spectrum and is developed based on the recommendations of the NUREG/CR-0098 (Newmark and Hall, 1978) primarily to cover lower frequency motions which may not be covered by CMS2. In addition to being in full compliance with the recommendations of NUREG/CR-0098 (Newmark and Hall, 1978), it is enhanced in the higher frequency range to cover earthquakes with high frequency content. The maximum spectral acceleration range is extended to 15 Hz, as opposed to 8 Hz which is used in NUREG/CR-0098 (Newmark and Hall, 1978) motions.

All of the above Control Motion Spectra are shown in Figure 3. CMS2 and CMS3 are applied at the rock outcrop, whereas CMS1 is applied at the free-field ground surface. All three motions are applied to each of the site categories as defined below in order to develop the design basis of the plant.

For the vertical direction, CMS2 and CMS3 are anchored to a vertical peak ground acceleration of 0.2g (two thirds of the horizontal PGA). CMS1, being defined as a control motion for application at the free-field ground surface, is defined to have a vertical peak ground acceleration of 0.3g, the same as the horizontal PGA.

SELECTION OF ENVELOPE OF SOIL SITES

In order to cover an envelope of site conditions suitable for construction of the System 80+, the design considered selection of 12 generic soil sites as well as rock site conditions. The site parameter variation within these 13 conditions were chosen such that when combined with the effects of the 3 design control motions, the resulting free-field ground surface spectra would contain earthquake energy in all frequency ranges which are important in design of structures and components. Site conditions were chosen to cover sites with shear wave velocities as low as 500 fps, to rock site conditions. Various impedance mismatch scenarios were also considered in order to cover the effects of such site conditions in design.

Initially, four site categories defined as A, B, C, and D were chosen. These correspond to depth of soil to bedrock values of 52 feet (15.8 m), 100 feet (30.5 m), 200 feet (61 m), and 300 feet (91.5 m) respectively (figure 4). Within each site category various soil property variations were chosen to cover the range of interest. At first, one case was chosen for site category A (A1), 4 cases for site category B (B1, B2, B3, & B4), 3 cases for site category C (C1, C2, & C3), and 1 case for site category D (D1). These 9 cases together with the rock case formed 10 site conditions initially chosen for the site envelope. Upon examination of the free-field response of these site conditions to the rock outcrop spectra, it was decided to introduce intermediate site conditions in order to obtain spectral peaks at certain intermediate frequency ranges where the initial 9 soil cases did not produce significant energy. Subsequently, three intermediate site conditions of B1.5, B3.5, and C1.5 were added to the design basis, making 13 generic site conditions which were used as the basis for design.

Figure 4 shows all 13 site conditions used in the design basis of System 80+. Figures 5 and 6 show the envelope of free-field surface spectra resulting from the excitation of each of the above site conditions to rock outcrop control motions CMS2 and CMS3, for the horizontal and the vertical directions respectively. Superimposed on these figures are the original design control motion spectra (CMS1, CMS2, and CMS3). As evident from these two figures, the seismic design basis of System 80+ is well in excess of the Regulatory Guide 1.60 requirements and the 0.3g free-field PGA, making the plant robust for construction even in areas of high seismicity.

SOIL-STRUCTURE INTERACTION ANALYSES

Soil-Structure Interaction analyses were performed in order to develop the seismic response of the System 80+ for the site envelope. Lumped parameter stick models were developed to model all the structures on the nuclear island with the exception of the SCV. Finite element modeling using shell elements was used to represent the SCV because of its spherical shape and expected membrane action to the applied seismic loads.The stick model section properties were developed from detailed finite element models. These stick models were "tuned" such that the mode shapes, frequencies, and mass participation factors matched those obtained from detailed three-dimensional finite element models. Figure 7 shows the SSI model used for the analyses of System 80+.

All SSI analyses were performed using the SASSI computer program (Lysmer et al. , 1981). Soil column studies indicated that the free-field surface response of two of the soil cases (D1 and B3) were completely enveloped by other soil cases at all frequencies of interest. As a result, SSI analyses were performed for 10 site conditions only. In addition, fixed-base analyses were performed to simulate the rock site conditions. Two fixed-base analyses were performed. The first analysis utilized the traditional assumption of fixity at the base of the structure only, representing construction with soft backfill material. The second analysis was performed using the assumption of fixity at the base and the sides of the structure within the embedded region, representing site conditions with concrete type backfill material.

As such, a total of 10 SSI cases and 2 fixed base conditions were analysed for each of the 3 control motions, making 36 analyses cases forming the seismic design basis of the System 80+. Figures 8 and 9 provide a schematic representation of how the 3 control motions were applied in the SSI analyses.

Site acceptance criteria were also established for suitability of a site from a seismic design point of view for the System 80+. For a prospective site, it is first determined whether the control motion is either applied at the free-field or at the rock outcrop. If the earthquake spectral shape is defined for the rock outcrop, the next step is to determine the free-field ground surface spectrum. If this spectrum falls within the envelope of the System 80+ seismic design envelope, then the site is seismically qualified for construction of System 80+.

SEISMIC MARGIN ASSESSMENT

Seismic margin evaluations were also performed to determine the ability to safely shut down the plant following a Seismic Margin Earthquake (SME) with PGA of 0.6g. At first, the systems and components that are involved in the shutdown path of the plant were selected. Then, the fragilities of the structures and components in the selected systems were assessed. Approximate seismic fragility curves were computed using deterministic HCLPF and lognormally distributed fragilities. HCLPF accelerations for the selected structures and components were evaluated using the Conservative Deterministic Failure Margin (CDFM) approach (Reed et al., 1991). The selected spectral shape used as the SME shape was the CMS3 motion. The CDFM HCLPF for all structures and components were calculated to be at least 0.6g.

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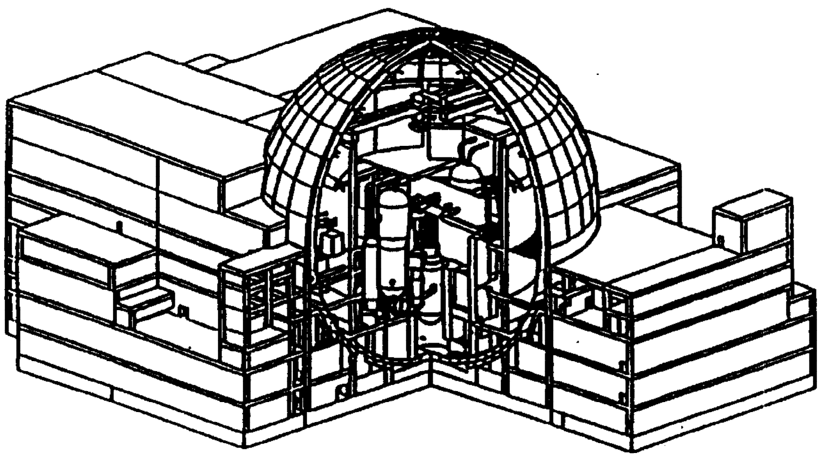


Figure 1: System 80+ Nuclear Island, Isometric View

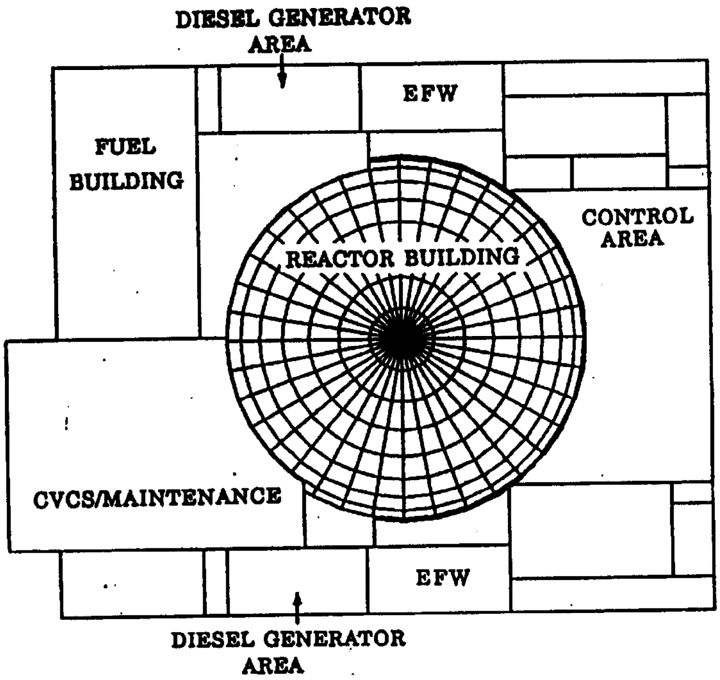


Figure 2: System 80+ Nuclear Island, Plan View

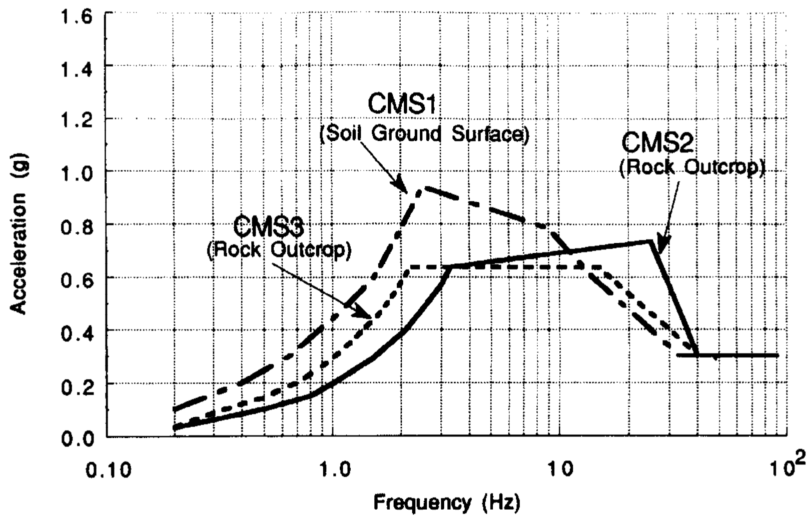
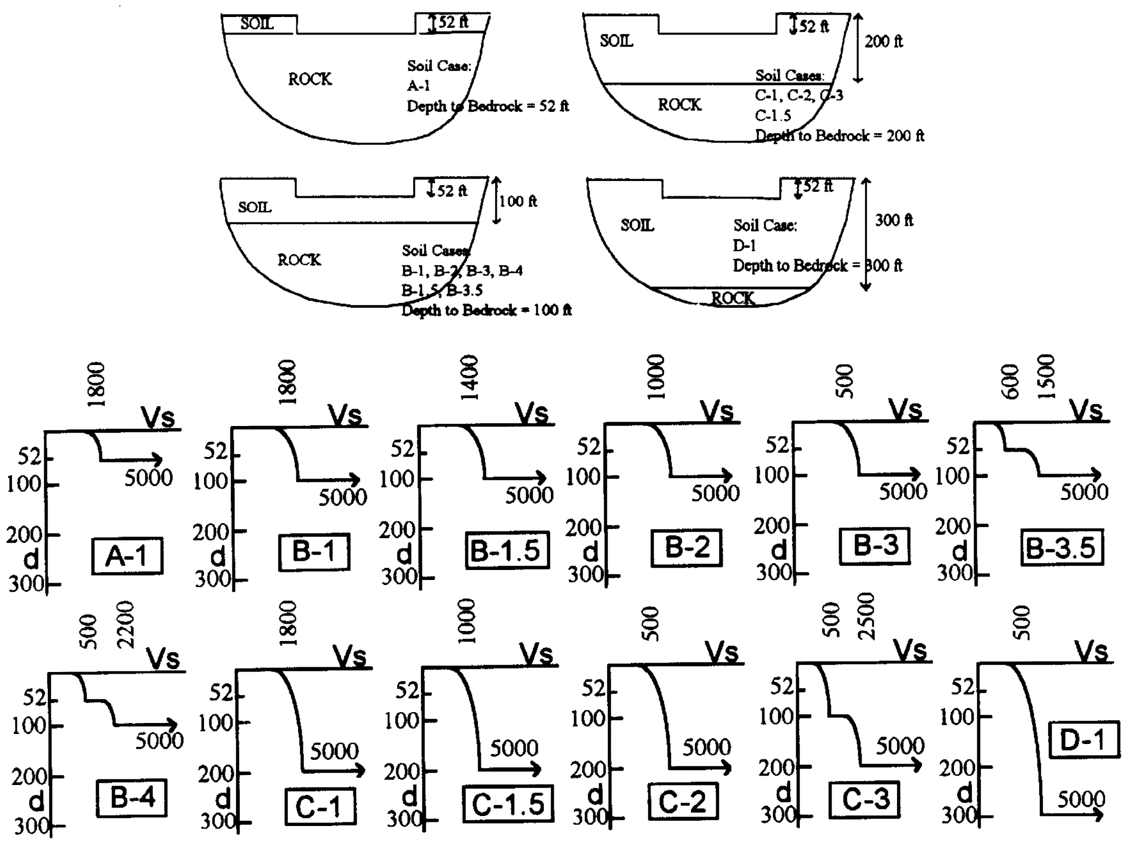


Figure 3: System 80+ Control Motion Spectra



Units of Depth in Feet
Units of Shear Wave Velocity (Vs) in ft/sec
Shear Wave Velocity of Bedrock = 5000 ft/sec

Figure 4: System 80+ Generic Site Conditions Used to Develop the Seismic Design Basis

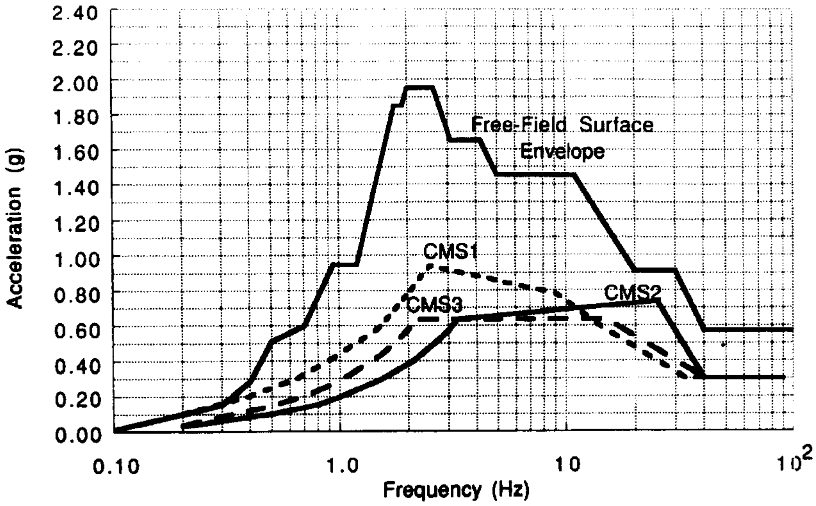


Figure 5: Envelope of Free-Field Ground Surface Spectra From CMS2 and CMS3
Horizontal Direction, 5% Damping

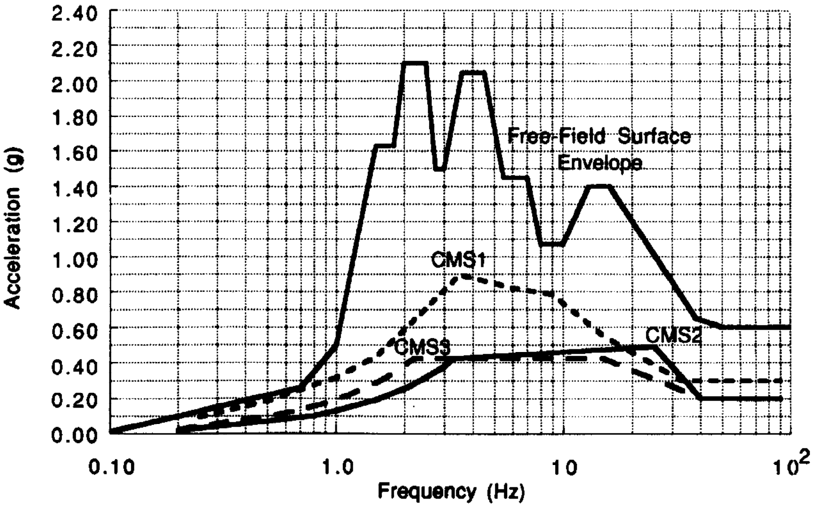


Figure 6: Envelope of Free-Field Ground Surface Spectra From CMS2 and CMS3
Vertical Direction, 5% Damping

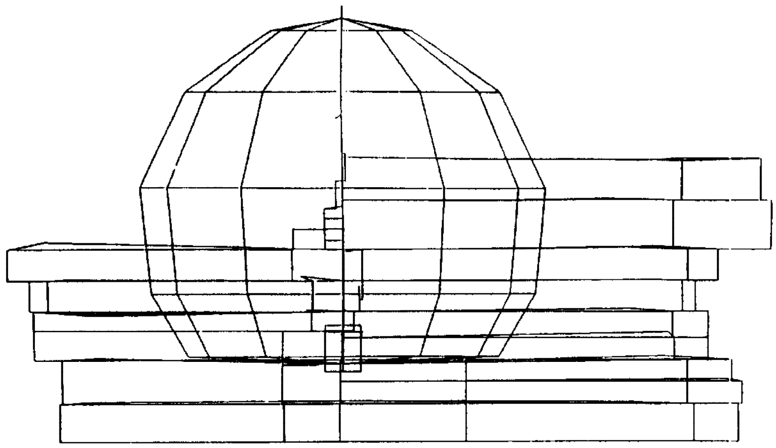


Figure 7: System 80+, Horizontal Soil-Structure Interaction Model

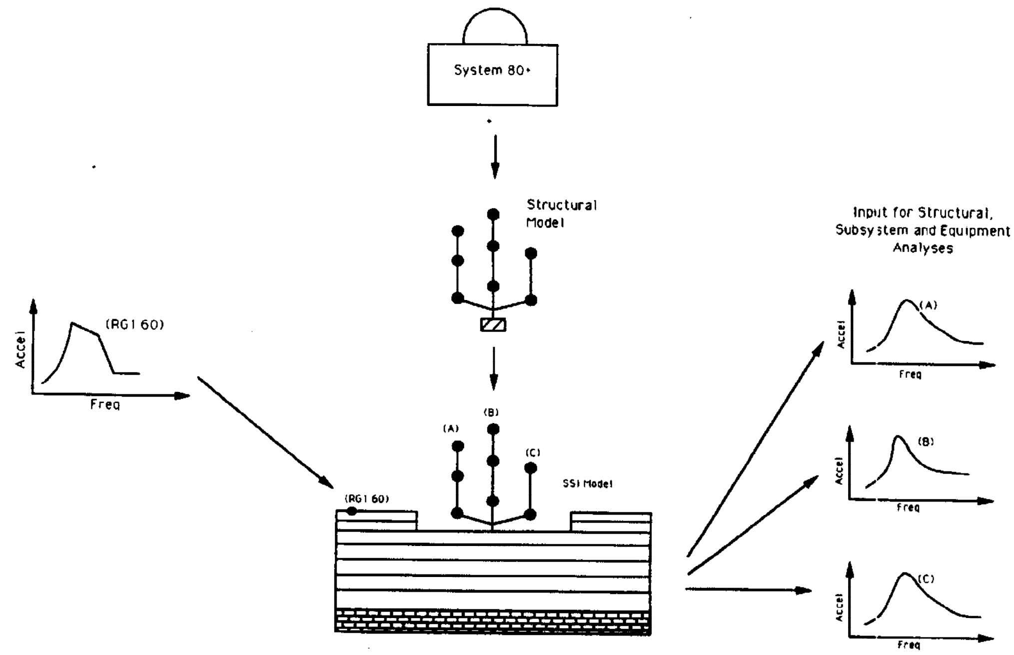


Figure 8: Application of Control Motion Spectra (CMS) 1 in the SSI Analyses

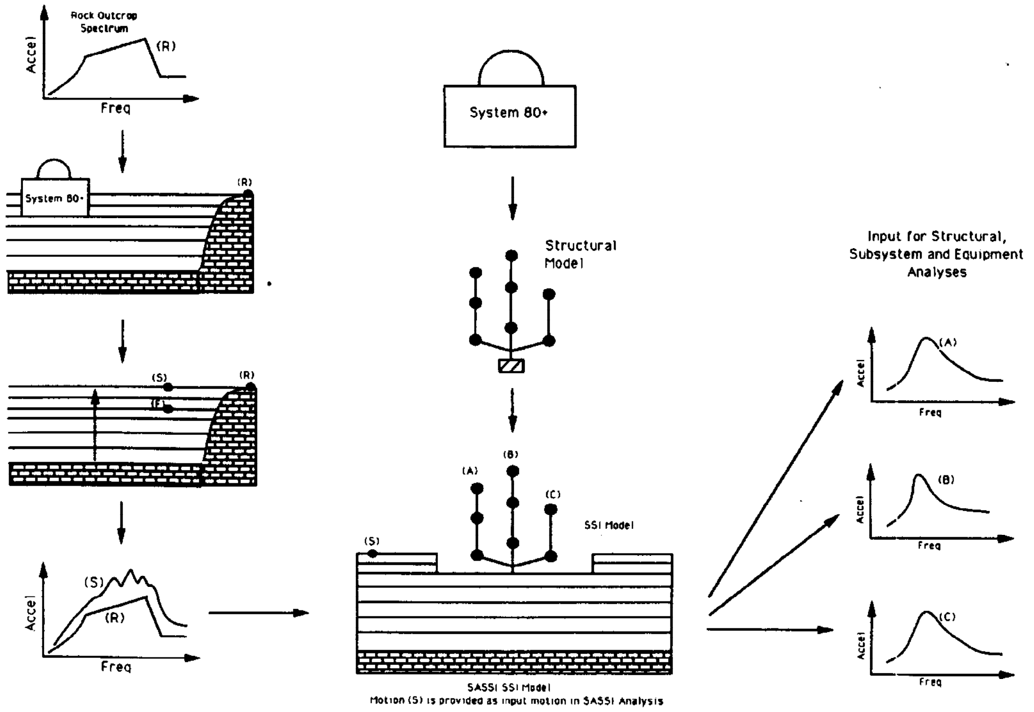


Figure 9: Application of Control Motion Spectra (CMS) 2 and 3 in the SSI Analyses