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SEISMIC RESPONSE ANALYSES FOR REACTOR FACILITIES AT SAVANNAH RIVER

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DISCLAIMER

ABSTRACT

The reactor facilities at the Savannah River Plant (SRP) were designed during the 1950's. The original seismic criteria defining the input ground motion was 0.1 G with UBC provisions used to evaluate structural seismic loads. Later ground motion criteria have defined the free field seismic motion with a 0.2 G ZPA and various spectral shapes. The spectral shapes have included the Housner spectra (TID-7094), a site specific spectra, and the US NRC Reg. Guide 1.60 shape. The development of these free field seismic criteria are discussed in the paper. The more recent seismic analyses have been of the following type: fixed base response spectra, frequency independent lumped parameter soil/structure interaction (SSI), frequency dependent lumped parameter SSI, and current state of the art analyses using computer codes such as SASSI. The results from these computations consist of structural loads and floor response spectra (used for piping and equipment qualification). These results are compared in the paper and the methods used to validate the results are discussed.

INTRODUCTION

The Department of Energy (DOE) operates reactors at the Savannah River Site (located on the Savannah River about 100 miles upstream from Savannah, Georgia). These facilities were designed and constructed during the 1950's and have been, to varying degrees, operational since that time.

The seismic criteria that have been applied to the facilities have varied greatly over this operational time span, and fairly well represent the variation of the state of the art in seismic design since the 1950's. The reactors have been shut down over the past three years while extensive seismic reanalyses and upgrades have been performed. State of the art methodologies are being applied to evaluate the appropriate seismic hazard, determine seismic loadings and floor response spectra, and to design upgrades to equipment, piping systems, and structures. The objective of this paper is to review the changes that have occurred in the seismic free field input motion definition and the methodology used to compute floor response spectra. This historical perspective is useful in evaluating the extent and directions in which seismic criteria have changed for nuclear facilities over the past 40 years.

The facility is first described and this is followed with discussions of the evolution of the free field criteria and the calculation of floor response spectra. Finally, conclusions are drawn.

DESCRIPTION OF FACILITY

Much of the material in this section is taken directly from the Safety Analysis Report (Ref. 1). The SRP is located between Augusta, Georgia and Aiken, South Carolina. It is located about three miles north of the Savannah River and about twenty five miles southeast of Augusta. The site is approximately circular in shape and has an area of about three hundred square miles (see Fig. 1). The elevation of the site is between 90 and 400 feet above mean sea level with all areas on the site draining to the Savannah River. Several state highways and a line of the Seaboard Coastline Railroad pass through the site. The older facilities at the site have been operational for about thirty five years.

The function of the SRP facilities is to produce and process plutonium and heavy water. Five reactors (P, K, L, C, and R) were constructed to perform the basic function. In addition to the reactors the site contains facilities to: process and store the radioactive waste from irradiated fuel and target assemblies; fabricate reactor fuel and target assemblies; and reconcentrate the products. Research and development and administrative facilities are, of course, also located at the site. The discussions in this paper are limited to the reactor facilities.

The SRP site is located on the Atlantic Coastal Plain (Ref. 2 and 3). This consists of from 900 to 1000 feet of sedimentary deposits overlying crystalline rock formations. Fig. 2 is taken from Ref. 2 and provides a general description of the soil layers at the site. The soil data available at the site appears to be limited to that data which were collected during the design program, and required for foundation design. This data consists of boring data which contains blow count information, and a visual description of the material. The material is mostly sand with small clay pockets. The top twenty feet of the soil has blow counts of 25-30 blows per foot while the deeper material appears to average about 20 blows per foot. Most of the borings go to depths of between 100 and 200 the low strain shear wave velocities at the site to be about 1000 fps. Some downhole and crosshole seismic measurements were made at the F, S, and H areas of the site. The May 27, 1988 revision of the SAR reports shear wave velocities of about 1500 feet per second for the top 30 feet and then decreasing to about 1000 feet per second for depths down to 60 feet. There is a new soils exploration program underway which includes split spoon samples, cone penetrometer tests, and cross hole tests. While this work is still in progress, the early results support the wave velocities developed from the blow count data.

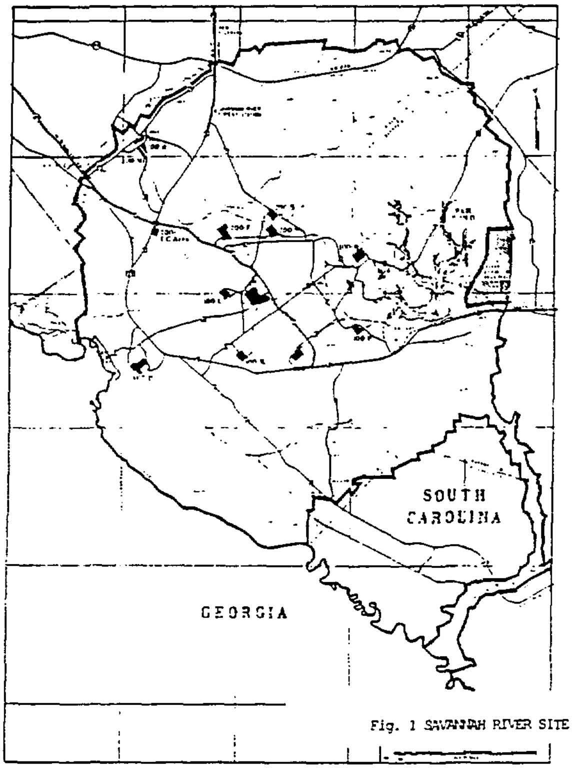

Fig. 1 SAVANNAH RIVER SITE

The SRP site is located in seismic zone 2A as defined in the Uniform Building Code (Ref. 4). Two earthquakes of VII MM or greater have occurred within 100 miles of the site. The largest was the MM intensity X Charleston earthquake in 1886. This earthquake was centered about 90 miles from the site. The other was an intensity VII-VIII event at Union County, SC in 1913. This was located about 100 miles from the site. Numerous smaller events have been felt at Augusta, Georgia but none as severe as the Charleston event.

There are three primary buildings that are essential to the safe shutdown of the reactors: the reactor building; the cooling water basin and pumphouse; and the cooling water recirculation pumps. The reactor building is a large reinforced concrete, shear wall structure. A sketch of this structure is shown on Fig. 3. The structure is about 300 feet by 300 feet in plan, is embedded about 50 feet in the soil and raises to about 150 feet above grade. The structure is rather stiff, especially below grade, having wall and slab thicknesses in the 2' to 6' range. The fundamental, fixed base frequency of the structure is about 10 cps. The two highest portions of the structure are the stack, and the actuator tower. The space into which the control rods are raised. Exhaust from the building is through the stack after passing through a filter system.

FORMATION	GEOAGE	EXPOSURE	DESCRIPTION	WATER CONTENT	THICKNESS
Alluvium	Recent		Fine to coarse sand, silt, and clay	Very little	0-30 ft
Terrace Deposits	Pleistocene	Flood plains and terraces of stream valleys	Tan to gray sand, clay, silt, and gravel with blanket deposits of coarse gravel on higher terraces	Moderate to none	0-30
Alluvium	Pliocene		Gravel and sandy clay	Little or none	0-20
Hawthorne	Miocene	Large part of ground surface	Tan, red, and purple sandy clay with numerous clastic dikes	Small to moderate	0-10
Barnwell	Eocene	Large part of ground surface near streams	Red, brown, yellow, and buff, fine to coarse sand and sandy clay	Limited quantities that are sufficient for domestic use	0-90
McBean Congaree	Eocene	In banks of larger streams	Yellow brown to green, fine to coarse quartz sand inter-calcated with sandy marl and lenses of siliceous limestone	Moderate to large amounts	100-250
Ellenton	Upper Cretaceous	Not exposed on plant	Dark gray to black sandy clay containing crystalline gypsum and coarse quartz sand	Moderate to large amounts	5-100
Tuscaloosa	Upper Cretaceous	Not exposed on plant	Tan, buff, red, and white sand and gravel interbedded with clay and kaolin	Large amounts	0-600
Newark Series	Triassic	Not exposed on plant	Gray, brown, and red sandstone, siltstone, claystone	Low yields	Unknown

Fig. 2 GEOLOGIC FORMATIONS AT THE SAVANNAH RIVER SITE

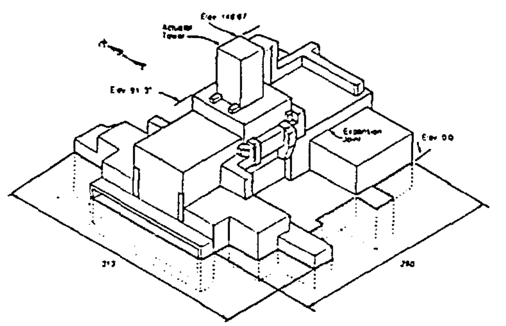

Fig. 3 REACTOR BUILDING

The other buildings are associated with the cooling water system. The cooling water is pumped from the Savannah River (or the onsite pond) to a basin that is located close to the process area. The basin has a capacity of about 25 million gallons and is 800 feet by 250 feet in plan and about 19 feet deep. The top of the basin is flush with the ground surface and open at the top. Water from the basin flows into the pump house and then through underground pipes into the reactor building. After passing through the heat exchangers in the reactor building, the cooling water flows through underground pipes into a small retention reservoir. The reservoir is divided with a weir. Water that flows over the weir is returned (by gravity) to the river. Water from the upstream side of the through underground pipes, to the basin. It is important to note that sufficient water is retained in the basin to support the shutdown requirements for at least 72 hours. The system supplying river (or pond) water to the basin is therefore not a safety related system. It is also important to note that the basin is at a higher elevation than the reactor area, and that gravity feed can be relied upon to provide sufficient cooling water to maintain the reactor in a shutdown state.

FREE FIELD SEISMIC MOTION

The free field seismic criteria used for the SRP is discussed in this section of the paper. The original design of the plant was based on the version of the Uniform Building Code (Ref. 4) that was current at the time of the design. This resulted in a specified peak free field acceleration (ZPA) of 0.1 G's, based on the seismicity map of the United States which was incorporated into the UBC. It should be noted that the current version of the UBC seismicity map places the SR site in a more active seismic zone (2A) giving a ZPA of 0.15 G's. The UBC requires that this free field motion be translated to equivalent static loadings for structural design. Since the plant was designed to resist rather severe blast loadings (assumed to act independently from other severe accident loadings like seismic), the UBC seismic loading was not critical and had no influence on the design. There was no requirement to determine floor response spectra or to qualify equipment or piping contained within the facility.

All of the significant seismic design studies performed on SRP have been based on criteria developed since the original UBC criteria. The first serious study of the seismicity of the SRP site was performed in the late 1960's. Housner (Ref. 5) developed a criteria that was based upon a detailed review of the local geology and seismic events which had occurred in the vicinity. These studies indicated that the most severe seismic motions at the site were induced by the Charleston, SC earthquake in 1886. This had a maximum intensity of X with an estimated intensity at the SRP site of VIII. Based on measurements taken during the Tehachapi earthquake of 1952 in southern California and the similarity of this earthquake with the Charleston earthquake, Housner estimated that the likely peak acceleration at the SRP site during the 1886 earthquake was about 0.05 G's. Allowing for the possibility of a similar earthquake occurring somewhat closer to SRP, he suggested a likely peak ground acceleration of 0.1 G's. Housner then specified a safe shutdown earthquake to have a peak free field acceleration of 0.2 G's (allowing for a factor of safety of 2). Current seismological studies (Refs. 10 and 11) would place a return period of about 5000 years for a 0.2 G earthquake at the site. The spectra of the free field motion, specified by Housner, are shown on Fig. 4. The shapes of these spectra were taken from TID 7024 (Ref. 6). As an alternative to the spectra, shown on Fig. 4, Housner suggested that the TAFT time history could be used provided that the time be scaled so that the spectra of the time history envelope the spectra given on Fig. 4.

The definition of the safe shutdown earthquake was revisited by URS/Blume (Ref. 7) in 1983. This study also concluded that the Charleston 1886 earthquake was the most prominent event determining the seismicity at the SRP site. The peak ground acceleration of 0.2 G's was also recommended. The recommended shape of the spectra defining the ground motion was significantly different than that proposed by Housner, however. The Blume study considered the possibility of smaller earthquakes occurring closer to the site. Nine earthquake accelerograms were taken from events which occurred in California, but were judged to be similar to that which could occur near to SRP. The specified spectra were then selected as the spectra which enveloped all of the nine spectra. The

and 5 indicate that the Blume spectra are about twice the Housner spectra over the 1 to 10 cps frequency range.

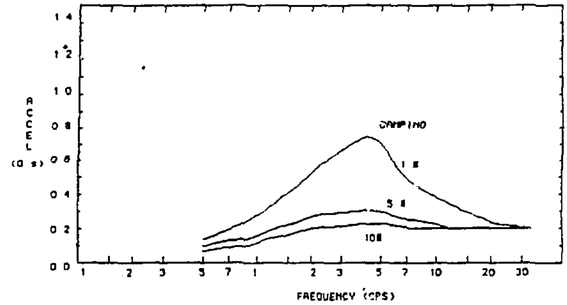

Fig. 4 HOUSNER FREE FIELD SPECTRA

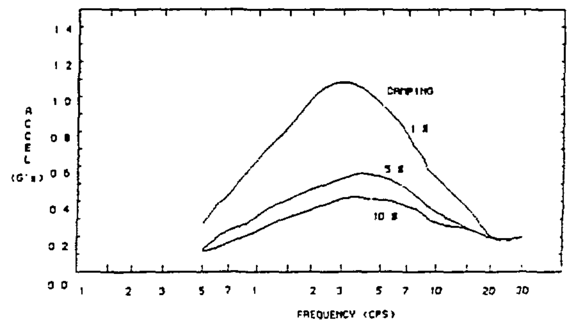

Fig. 5 URS/BLUME FREE FIELD SPECTRA

The seismic qualification work that has been underway since 1985 has been based on criteria specified by DOE in Ref. 8. This criteria establishes the free field seismic motion based on Reg. Guide 1.60 (Ref. 9) spectra anchored at 0.2 Gs. These spectra are shown on Fig. 6. A comparison of the Reg. Guide and Blume 5% damped spectra are shown Fig. 7. As may be seen, the Reg Guide spectra envelope the Blume spectra but the differences are rather small for frequencies less than 3 cps.

The change in the input motion criteria is not as severe as indicated at first glance. The Housner 1968 seismic criteria specify significantly lower spectra than the Reg. Guide spectra, but the Housner criteria also permit a much lower damping ratio than is permitted with the Reg. Guide. For example, Housner restricts pipe damping to 1% while Reg. Guide allows 3% damping for large bore piping. ASME Code case N-411 specifies damping at 5% for frequencies less than 10 cps, 2% damping for frequencies greater than 20 cps, and a linear variation between the 10 cps and 20 cps values. A comparison of spectra for these three cases (1% damped Housner spectra, 3% damped Reg Guide spectra, and N-411 damped Reg Guide spectra) is shown on Fig. 8. as may be seen the Housner "piping" spectra are unconservative relative to the Reg Guide spectra, but the differences are not as large as indicated by a direct comparison of the two free field criteria.

Work now in progress is focusing on the development of site specific spectra. This work includes consideration of the LLNL (Ref. 10) and EPRI (Ref. 11) seismic hazard studies, effect of local soil properties on the spectral shapes, and detail studies of small faults in the area (e.g., Pen Branch). Final results of these studies are not yet available, although there is some indication that the ZPA may be increased and the spectral shapes may indicate a shift in energy content of the seismic wave from lower to higher frequencies.

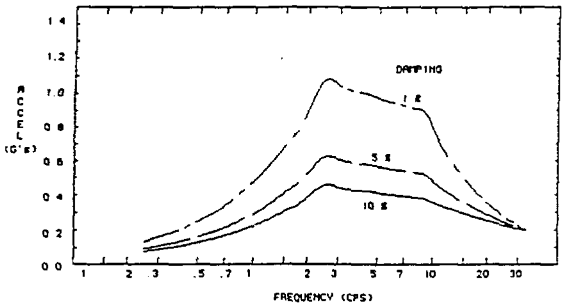

Fig. 6 REG GUIDE 1.60 FREE FIELD SPECTRA

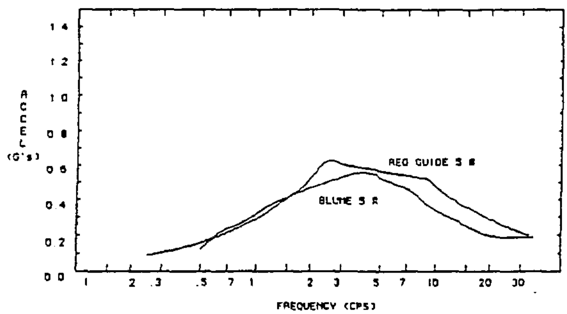

Fig. 7 COMPARISON OF REG GUIDE AND BLUME SPECTRA

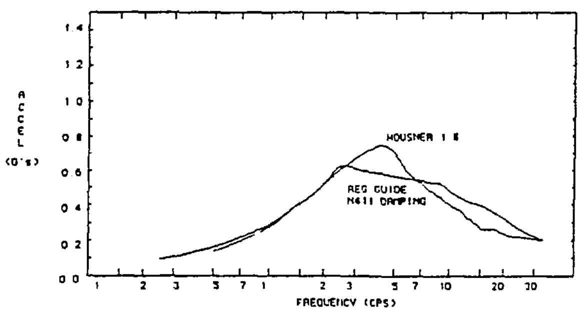

Fig. 8 COMPARISON OF HOUSNER 1% SPECTRA WITH REG GUIDE N-411 SPECTRA

FLOOR RESPONSE SPECTRA

The structural motion differs from the free field because of soil/structure interaction (SSI) effects and amplifications that occur because of structural flexibility and damping. Of course, neither of these were included in the original design criteria which were UBC based. Statements contained in the Housner criteria (Ref. 5) imply that the free field motion criteria were specified so as to include SSI effects. The Housner criteria were applied by amplifying the free field motion (or foundation motion since SSI effects were not included) by factors which varied from 1.1 for elevations up to grade to 1.77 at 150 feet above grade. These structural amplification factors were based on an assumed fundamental vibrational mode shape.

In late 1968, URS/Blume (Ref. 12) performed a study of the reactor building. The Housner free field motion was input to a fixed base (i.e., no SSI effects were included) stick model representing the reactor building. Peak seismic loadings determined from the stick model were then used to analyze potentially critical portions of the structure. As a result of this study it was determined that the actuator tower and the stack required modifications to safely withstand the seismic loading. Buttresses were added to the actuator tower so that the seismic shear and moment loadings could be transferred directly to the walls rather than pass through the roof slab of the building. The lower portion of the stack was thickened so that it could withstand the seismic load. In 1983 URS/Blume performed a comparative study using the Housner and Blume free field motion as input to the stick model, and it was found that the Blume criteria resulted in higher responses throughout the structure. SSI effects were then included with the Blume free field input, and it was found that the structural loads determined using the Blume input and including SSI effects were close to the structural loads found using the Housner input but neglecting SSI effects.

The first serious efforts to generate floor response spectra were made in 1988 with the work summarized in Ref 13. The free field input motion was developed to "envelope" the criteria free field response spectra. The seismic response analysis of the Reactor Building was based on the FREDA computer code. This solution utilizes a lumped mass stick model of the structure connected to the free field through SSI frequency dependent functions. The structure was modeled with two degrees of freedom (horizontal displacement and flexural rotation of the nodes in the stick model). The model did not include vertical and torsional responses.The response computation included the first five modes of vibration. The E-W frequencies ranged from 6.9 cps to 31.8 cps and these modes accounted for 95% of the mass. The N-S frequencies ranged from 9.5 cps to 36.8 cps and these modes accounted for 99% of the mass. Structural damping was taken to be 7%.

The soil was modeled as an elastic media having properties computed as a weighted average of those for the soil within one diameter of the foundation. The shear modulus and damping of the soil were varied with soil strain by using the Seed-Idriss strain dependency functions. Prior to performing the SSI calculations, the SHAKE code was used to obtain peak soil strains in the soil column. These strains were then used to determine the soil properties for the SSI analysis. The SSI coefficients were based on work performed by Kausel et al (Ref. 14) that included effects of embedment, depth to bedrock, and soil damping.

The SSI coefficients used in the FREDA solutions raise some questions because layering effects are not included and the frequency range (non dimensional frequencies greater than 2) of interest is beyond the limits set in Kausel's work. These comments were treated by developing horizontal response spectra using the SASSI computer program. The same stick model representation of the structure used for the FREDA analyses was attached to a rigid circular embedded foundation. The top 150 feet of soil was modeled with semi infinite horizontal elastic layers overlying an elastic half space. The layering effects were explicitly treated in this solution. The SSI solution in the SASSI code is based on the integration of point solutions coupling each location on the foundation to the adjacent soil, and as such represents a rigorous solution. The SASSI solutions, therefore, resolve any questions regarding the approximate solutions obtained with the FREDA code. Four solutions were obtained with the SASSI code: high strain soil properties with the free field criteria motion applied at the surface and attenuated to the foundation depth (HS); low strain soil properties with the free field criteria motion applied at the surface and attenuated to the foundation depth (LS); high strain soil properties with the free field criteria motion applied at the foundation depth (HN); and low strain soil properties with the free field criteria motion applied at the foundation depth (LN).

Spectra are generated from these results and compared with the FREDA spectra. The four SASSI spectra at the ground elevation in the building, 66 feet above the ground and at the top of the structure are shown on Figs. 9, 10, and 11. The FREDA spectra are shown on the same figures for comparison purposes. As may be seen from the SASSI results the effect of scattering is significant while the effects of strain degradation of soil properties is much less important. In the lower portions of the building (elevation 0 and lower) the FREDA spectra are more severe than the SASSI spectra except for the LN case where the high frequency end of the SASSI spectra are about 10% higher than the FREDA spectra. At elevations above 66 feet the SASSI LN and HN spectra are generally more severe than the FREDA spectra, and the LS and HS SASSI spectra are less severe. For example at elevation 66 feet, the SASSI LN spectra are about 40% higher than the FREDA spectra, and the HS spectra are about 60% of the FREDA spectra. At the higher elevations (above 66 feet), the HS SASSI spectra are more severe than the FREDA spectra for frequencies less than 3 cps. This exceedance ranges from about 10% at 66 feet to 50% at 148.67 feet. The HS SASSI results are the most realistic. This case includes soil property variations with strain level. It also places the criteria motion at the surface. Comparison of the HS and HN cases indicate that the ZPA of the basemat level input motion is attenuated by 20% when going from the HN to HS case.

The FREDA and SASSI spectra shown above do not include any consideration of torsional effects. URS/Blume (Ref. 12) contains a study of these effects by including torsional effects in a FREDA analysis. The structural stiffness and mass eccentricities were included in the model. Rigid links were added to the model spanning from the center of mass on each floor to the four extreme corners of each floor. Response spectra were generated at each of the four corners and the FRS selected as the envelope of the corner spectra. The ratio of FREDA spectra with and without torsion was found to be about 1.25 for elevations below 34 feet, 1.35 for elevations between 34 and 91 feet, and 1.02 for elevations above 91 feet.

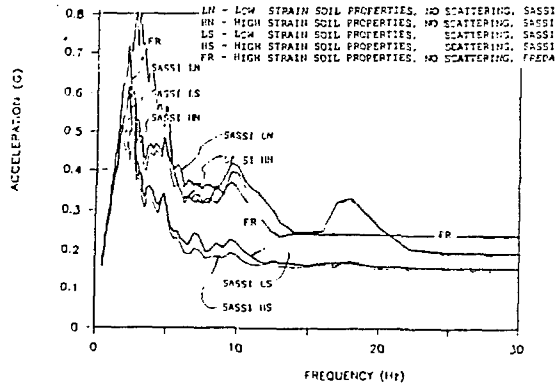

Fig. 9 COMPARISON OF SASSI AND FREDA 5% N-S SPECTRA - ELEV 0'

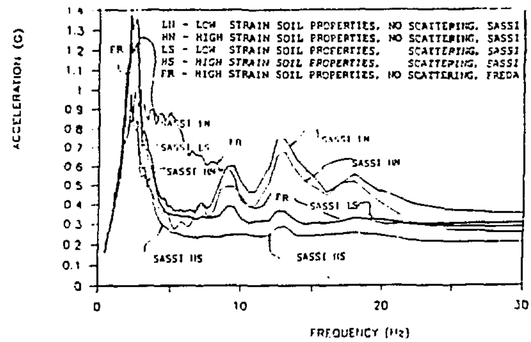

Fig. 10 COMPARISON OF SASSI AND FREDA 5% N-S SPECTRA - ELEV 66'

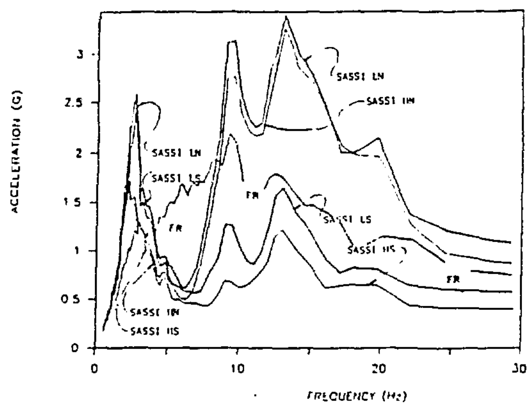

Fig. 11 COMPARISON OF SASSI AND FREDA 5% N-S SPECTRA - ELEV 148.67'

CONCLUSIONS

The following conclusions are drawn for the study. It should be cautioned that these conclusions are based on the structural and soil parameters found at Savannah River, and may be applicable to other sites or to structures having different mass and stiffness characteristics from those found at Savannah River.

1. The current definition of the free field seismic hazard is more severe (both in terms of ZPA and spectral shape) than was during the design period and for the early seismic reevaluations. The early criteria also allowed lower damping values than is currently allowed so that the effect of the increased severity of the newer free field criteria is somewhat mitigated.

2. The inclusion of SSI effects have reduced structural loads.

3. The SASSI computer solutions indicate that scattering effects are significant while strain degradation effects are relatively unimportant.

4. The lumped parameter SSI models used in the FREDA computer code generally give conservative results as compared with the SASSI solutions. Most of this conservatism is due to the fact that the free field motion is applied at the basemat level for the FREDA solutions.

5. Torsional effects have about a 25% effect of the floor response spectra.

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