COMPARISON OF SOIL DAMPING BY EXPERIMENTAL AND ANALYTICAL METHODS SONGS -1

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1.0 INTRODUCTION

This report presents a study to compare the differences between soil damping, as calculated by analytical and experimental methods. This study demonstrates that the damping used in the San Onofre Nuclear Generating Station Unit 1 (SONGS-1) Reactor Building analysis is correct and compares well with experimental results.

This study has been prepared to respond to questions posed by the Nuclear Regulatory Commission (NRC) to the Southern California Edison Company (SCE) for the topic of soil damping used for SONGS-1.

2.0 BACKGROUND

To respond to the NRC's systematic evaluation program, SCE has reevaluated all structures at SONGS-1 and calculated their seismic responses. This reevaluation has taken place over a number of years.

Between 1972 and 1982, SCE performed seismic analyses of the SONGS-1 Reactor Building. The results of these analyses have been used to evaluate the response of the Reactor Building, and the systems and subsystems inside the Reactor Building.

In 1985, SCE reperformed the seismic analysis of the Reactor Building, to develop floor response spectra. These spectra are then used for the qualification of the piping systems and equipment in the Reactor Building, for the long term service of the plant.

During this time period, there have been improved analytical methods to study the effect of soil-structure interaction. The 1985 analysis uses the SASSI and CLASSI computer codes to perform the soil-structure interaction analysis. The earlier analyses used the BSAP computer code to perform the soil-structure interaction analysis.

The following section describes the difference between the two soil structure interaction analyses, with an emphasis as to how they treat soil damping. The subsequent section describes the soil damping study currently performed, and concludes that the damping methodology used in the 1985 analysis is correct, and compares well with test results.

3.0 SOIL-STRUCTURE INTERACTION ANALYSIS METHODS

This section describes the soil-structure interaction (SSI) analysis methods used in the 1972-1982 and the 1985 evaluations.

3.1 BSAP REACTOR BUILDING ANALYSIS

In the 1972-1982 analyses, the Reactor Building SSI analyses were performed using the BSAP code.

The BSAP code is based on the SAP-IV computer program. It performs the SSI analysis using frequency independent soil springs, both for soil stiffness and for soil damping. Cross coupling between soil horizontal and rocking modes is not included. Reactor Building to Enclosure Building coupling is not included. The Reactor Building is modeled with finite elements, having several thousand degrees of freedom. The SSI dynamic analysis is performed in the time domain.

3.2 SASSI AND CLASSI REACTOR BUILDING ANALYSIS

In 1985, the Reactor Building SSI analysis was performed using the SASSI and CLASSI programs for soil structure interaction. The SASSI program was used to calculate the soil stiffness and damping properties. The CLASSI program was used to calculate the time history response of the coupled building and soil system.

SASSI and CLASSI perform SSI analyses using frequency dependent soil springs, both for soil stiffness and soil damping. Cross coupling between soil horizontal and rocking modes is included. Reactor Building to Enclosure Building coupling through the soil is included. The Reactor Building is modeled with the same BSAP detailed element mesh used in the previous analyses. The Enclosure Building is modeled with a simplified stick. The SSI dynamic analysis is performed in the frequency domain. A more detailed description of the 1985 analysis is included in [Ref. 1].

4.0 PROCEDURE TO COMPARE SASSI AND EXPERIMENTAL DAMPING PROPERTIES

The SASSI code calculates frequency dependent soil damping properties, using the finite element method. This study demonstrates that the damping properties calculated by SASSI correspond well with observed damping properties from test results. To demonstrate this, the following SASSI analysis case was performed:

- Horizontal analysis.
- Concrete disk (10 foot diameter, 5 foot high) on soil surface.
- Soil modeled as a uniform halfspace.
- Soil shear modulus equal to 2100 ksf.
- Soil material damping taken as 2%.
- A horizontal ramp load is applied at midheight of disk.

The step by step procedure to compare the SASSI and experimental damping studies was as follows.

1. Develop a SASSI model which corresponds to the experimental work performed by Woodward-McNeill [Ref. 2].

2. Apply a ramp loading to the SASSI model, to approximate the loading method used by Woodward-McNeill.

3. Print out the time history of velocity response from the SASSI analytical model.

4. Calculate damping from the SASSI response by using the logarithmic decay method for free vibration.

5. Compare the SASSI calculated damping value with that found in the experimental work.

6. Compare the SASSI calculated frequency of response with that found in the experimental work.

4.1 Detailed Assumptions

4.1.1 Model

The model is shown in Figure 1. One quarter of the model is included, taking advantage of one plane of symmetry and one plane of anti-symmetry. Two layers of concrete brick elements are used to allow the application of applied load at the midheight of the concrete disk.

Beneath the concrete disk, the soil is modeled as a uniform halfspace (not shown). The soil has an assumed shear modulus of 2100 ksf, and an assumed soil material damping value of 2%.

4.1.2 Soil Modulus

Since the experimental work did not explicitely measure soil strains, G could not be chosen for the SASSI analysis based upon the formula [Ref. 2, Figure 2]:

$$G = \{100\} \{K_m\} \{s_m^{2/3}\} \qquad [1]$$

where K_m = shear modulus versus soil strain factor

s_m = effective soil confining stress

The assumed value of G = 2100 ksf corresponds to a shear wave velocity (at low to medium strains) of 708 feet per second. This is based upon the formula:

$$V_s = \{\sqrt{G / m}\} \qquad [2]$$

where V_s = shear wave speed

G = soil shear modulus

m = mass density of soil

As very low strain shear wave tests at the SONGS site have shown that V_s is in the range of 900 to 1200 feet per second, near the surface, and some reduction in G is expected due to induced soil strains during the test, it was concluded that the assumed value of G = 2100 ksf was reasonable for an assumed uniform halfspace.

4.1.3 Applied Loading

An applied lateral ramp load with peak load of 10 kips was applied to duplicate the original test conditions. The ramp load is described as a slowly increasing load to 10 kips, then a period of constantly applied load of 10 kips, and then a sudden drop to zero load in 0.003 seconds, followed by zero load for the duration of the analysis. The ramp load function is considered to be a good fit to the actual testing conditions. In the original test, a crane was used to slowly increase applied load until a pin suddenly broke, thereby applying a shock loading to the concrete disk.

This peak value of 10 kips is approximate, as exact shock loading values for each test were not explicitly monitored. However, it is known that the peak shock load for any test was between 3 and 16 kips [Ref. 2, Section 2.2.2]. The loading was applied at midheight of the concrete disk, same as in the experimental test.

4.1.4 Calculation of Total Damping

The time history of velocity response of the disk was plotted from the SASSI output. Total damping is computed based on the logarithmic decay formula:

$$d_{total} = \left\{ \ln \frac{\Delta_n}{\Delta_{n+m}} \right\} / \{2 \pi m\} \qquad [3]$$

where d_{total} = total damping (percent of critical) (including radiation and material damping)

Δ_n = peak velocity, cycle n, during free vibration, from SASSI output

Δ_{n+m} = peak velocity, cycle n+m, during free vibration, from SASSI output

n,m = cycle numbers used in the calculation

From the SASSI output, several different values of d_{total} were calculated, depending on which values of n and m were used to perform the calculation. To obtain an average SASSI damping value, a logarithmic decay curve for an ideally damped single-degree-of-freedom oscillator was fitted to the SASSI time history of response. This curve was expressed with the following formula, taken from [Ref. 3]:

$$v = p\, e^{-d w t} \qquad [4]$$

where: v = velocity at time, taken from SASSI analysis

p = a constant, found by best fit

d = percentage of critical damping, found by best fit

w = frequency (in radians/second) of concrete disk response, taken from SASSI analysis

t = time

The best fit was approximated by visual inspection.

4.1.5 Calculation of Radiation Damping

Both the experimental and SASSI damping values are calculated by using the log decay approach (equation [3]) on the time history of velocity response of the slab. Using the log decay approach results in calculating the total amount of damping. The total amount of damping can be assumed to equal the sum of the material and radiation amounts of damping. For the results presented in Table 1, then ,

$$d_{total} = d_{material} + d_{radiation} \qquad [5]$$

This is the same assumption used by Woodward-McNeill in [Ref.2].

Depending upon which cycles of velocity motion are used in the log decay damping calculation, one obtains different values for damping. This was observed to be true for both the experimental and analytical velocity time histories.

The average total damping for the SASSI analytical results is calculated by enveloping the velocity time history by the exponential decay function (equation [4]) described above. The average d was then taken as the value which produced the best fit of exponential decay over several cycles of response.

The average total damping from the experimental results is calculated by arithmetically averaging the damping data points given in Figure D-2 of [Ref. 2]. The exponential decay best fitting procedure was not performed as many of the experimental test velocity time histories were not available.

The material damping for the SASSI analysis was input to the analysis as 2%.

The material damping for the experimental test can only be approximated, as no soil strain measurements were taken. It is assumed that the soil material damping was about 3% to 6%.

Radiation damping is calculated as total (average) damping, less material damping, based on equation [5]. This is done for both SASSI and experimental results.

4.2 Results

The frequency and damping results are give in Table 1.

4.2.1 Discussion - Frequency

The SASSI and the experimental test frequencies match closely (20.5 Hz versus 20 Hz, respectively).

4.2.2 Discussion - Damping

Total damping compares well between the SASSI and experimental results (27% versus 29%, respectively).

Material damping was input to the SASSI analysis as 2%, for all soil elements. Therefore, radiation damping from SASSI results is calculated as:

$$27\% - 2\% = 25\%.$$

Material damping for the experimental tests is assumed to be within 3% to 6%. Therefore, radiation damping from experimental results is calculated as:

29% - (3% to 6%) = 23% to 26%.

As the SASSI frequency is slightly above the experimental frequency (20.5 Hz versus 20 Hz), it is expected that fine tuning the SASSI model to 20 Hz will slightly reduce the SASSI radiation damping, to possibly 24%.

4.2.3 Discussion - Soil Iteration

Owing to the expected low to medium range value of strain in the soil, iteration on soil properties was felt to be not necessary. This is because soil properties directly beneath the concrete disk would not largely change between cycles. Damping results are also not expected to change significantly with iteration.

4.3 Conclusions

The main conclusions are as follows:

- A uniform shear modulus of G = 2100 ksf results in close matching of SASSI and experimental frequencies.
- SASSI radiation damping of 25% closely matches experimental radiation damping of between 23% and 26%.

5.0 Summary

This report has presented a comparison of SASSI and experimental test results for soil structure interaction. The comparison shows that SASSI correctly accounts for soil radiation damping.

6.0 References

[1] Generation of Floor Response Spectra for the Reactor Building and Turbine Building, San Onofre Nuclear Generating Station Unit 1, Report No. 01-0310-1430, Revision 0, Impell Corporation, July, 1985. (to be released)

[2] Development of Soil Structure Interaction Parameters. Proposed Units 2 and 3, San Onofre Nuclear Generating Station, Woodward-Mcneill associates, January 31, 1974.

[3] Dynamics of Structures, R. Clough and J. Penzien, McGraw-Hill, 1975.

SASSI/WOODWARD-McNEILL TEST DATA CORRELATION

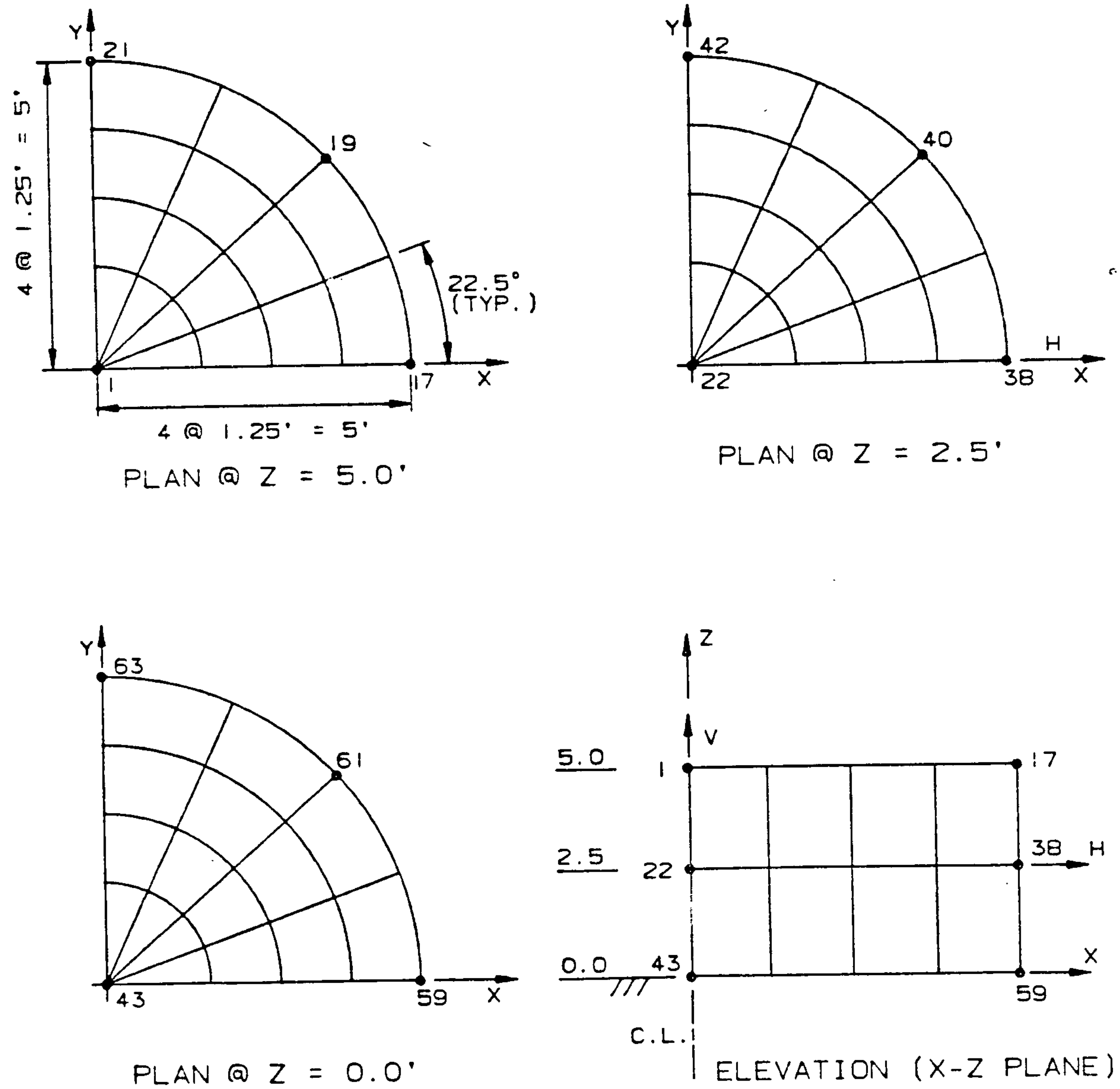

FIGURE 1. SURFACE-FOUNDED SLAB
ONE-QUARTER FINITE ELEMENT MODEL

TABLE 1. SASSI VERSUS EXPERIMENTAL RESULTS.

	WOODWARD-MCNEILL EXPERIMENTAL	SASSI ANALYTICAL
Frequency	20 Hz [Ref. 2, table A-1]	20.5 Hz
Damping		
total, average	29%	27%
material	3% to 6%, based on assumed soil strains	2%
radiation ($=total_{avg}$-material)	23% to 26%	25%

SASSI analysis parameters:
$G = 2100$ ksf
$d_{material} = 2\%$
Loading = 10 kips, ramp loading
Soil modeled as halfspace.