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DYNAMIC ANALYSIS METHODS FOR NUCLEAR FACILITIES

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DYNAMIC ANALYSIS METHODS FOR NUCLEAR FACILITIES

by

Bryan K. Horsager(1) M.ASCE

ABSTRACT

A comparison is made between three different dynamic analysis methods commonly used in the analysis of nuclear facilities. The methods are applied to a typical non-reactor type nuclear facility; namely, an early configuration of the High Performance Fuel Laboratory which was to have been designed and constructed to house an automated fuel process line on the Hanford Reservation near Richland, Washington. The fuel to be handled was mixed plutonium and uranium in powder and pellet form which, therefore, required design for severe earthquake and tornado conditions. The structure is a two-story reinforced concrete shear wall building with a high bay on one end. The comparison is made for earthquake motion in the lateral horizontal direction only. The response spectrum method is used throughout. Spectra used are the 7% damped Regulatory Guide 1.60 spectra scaled to .25 g. Comparisons are made in the resulting shears in the main shear walls and in the maximum displacements at various locations on the process floor level. Comparisons are also made in the amount of computer and calculation time involved.

The first method employs a three degree of freedom spring mass system with the masses lumped at the three floor and roof slab levels. After shears are obtained they are distributed to the shear walls in proportion to their stiffnesses. Floor and roof slabs are assumed rigid but eccentricities are accounted for in the shear distribution. The problem is done by hand calculations with the aid of a programmable TI-58 calculator.

The second method utilizes a pseudo three-dimensional stick model. The shear walls and horizontal floor and roof diaphram are modeled as three dimensional beam elements using the SAP IV computer Code. All nodal points are in the X, Y plane (Z - 0) but motions in this plane are restricted with unrestricted translation in the Z direction. This enables shears to be obtained in all the walls and diaphrams without resorting to "lumping" walls together and in addition, automatically accounts for eccentricities in the direction being considered.

The third and last model is a three dimensional finite element model. All walls and diaphrams are modeled using plane stress quadrilateral membrane elements again using the SAP IV Computer Code.

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INTRODUCTION

The comparison of analyses contained herein is intended to show the advantages and disadvantages of each method and to point out where each may be applicable in the design of nuclear facilities. The analyses compared are those typically used in the design and analysis of nuclear facilities and range from hand calculations to those which can only be accomplished by sophisticated computer methods. All the models used are fixed base type and assume that the effects of soil structure interaction have been accounted for in the response spectrum used.

DESCRIPTION OF BUILDING ANALYZED

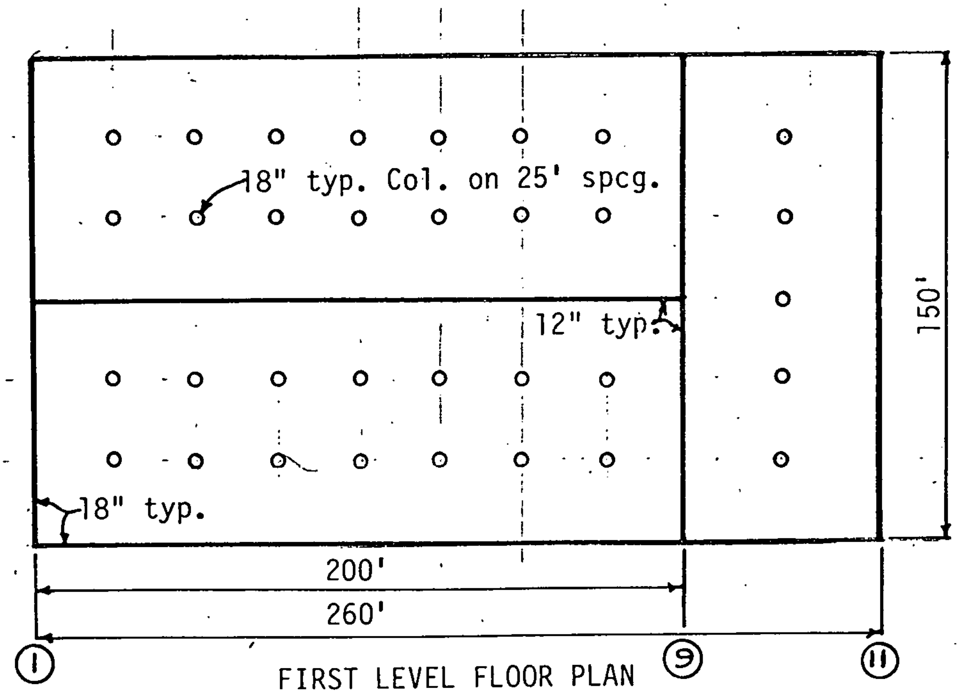
The building used for the comparison is a slight simplification of an early configuration of the High Performance Fuel Laboratory (HPFL) intended for construction near Richland, Washington. The facility was to have been designed and constructed for the Department of Energy and was to house a nuclear reactor fuel fabrication line. The fuel was to have been a plutonium uranium oxide in powder and pellet form in the early stages of the process. Because the building contained plutonium in dispersable form, severe tornado and seismic design conditions were imposed. Conceptual design was accomplished by Fluor Corporation of Anaheim, California and Preliminary design was by Ralph M. Parsons Company of Los Angeles, California. The design resulted in a two story reinforced concrete structure with a high bay on one end. A slightly simplified version of the building is shown in figures 1 and 2.

DESCRIPTION OF HPFL ANALYSIS

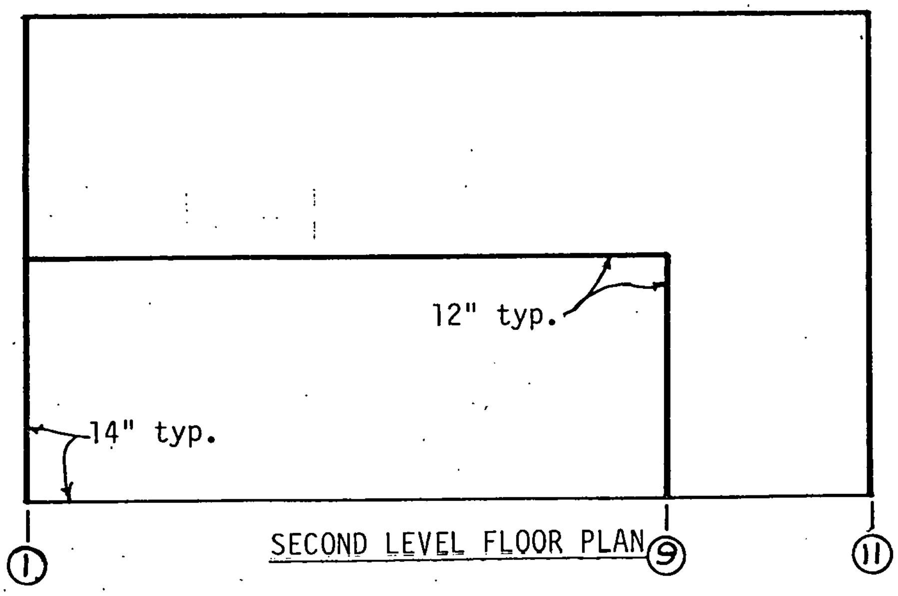
The seismic analysis of the High Performance Laboratory was accomplished in several stages; the first stage was the soil structure interaction analysis which utilized the program FLUSH (reference 1). The results of the FLUSH analyses were used as input (both time history and response spectra) to the building model but since FLUSH contains beam elements and two dimensional plane stress elements, the results were also used in the early stages of structure design.

In later stages of preliminary design the FLUSH results were used as input to two different two dimensional models. First the building was modeled in each direction using a combination of beam elements and membrane elements to determine out of plane stresses in walls, floors, and roofs. The inplane stresses in this model can only be found in a very over-all way since all the walls through the depth of the building in the direction considered must be lumped together. Secondly, the building was modeled in each direction using beam elements to represent floors, walls, roofs, etc. with motion in the out of plane direction. This model was used to determine in-plane shears. Both of these models were analyzed using the computer program SAP (reference 2). The results of these analyses were used in combination with other applicable loads to size all of the structural elements.

Although the final analysis was not completed because of programmatic changes, it was to have been accomplished using a three dimensional finite element model again using the program SAP. The FLUSH results

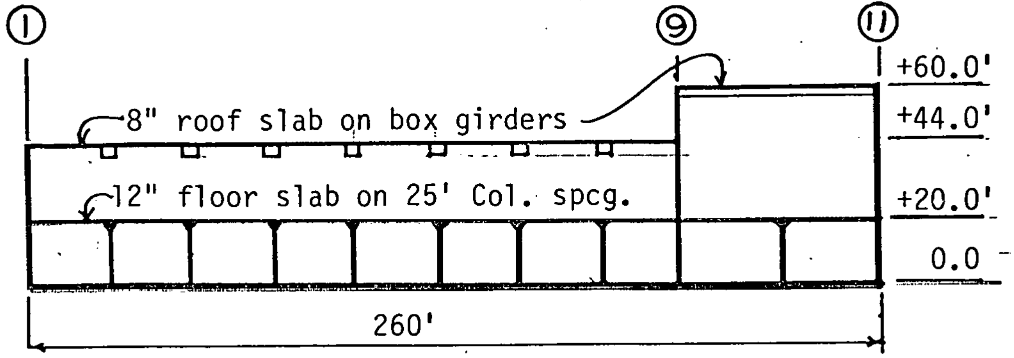


FIRST LEVEL FLOOR PLAN



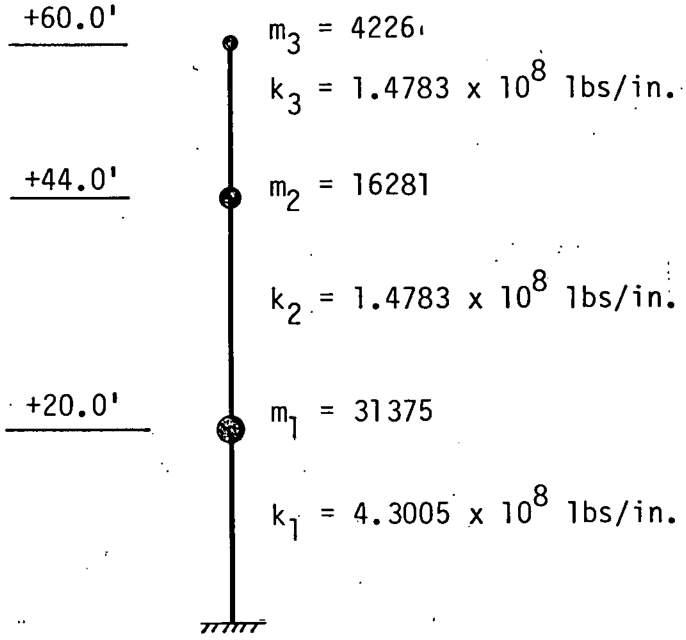
SECOND LEVEL FLOOR PLAN

Figure 1.



LONGITUDINAL SECTION

Figure 2.



MODEL NO. 1

Figure 3.

were to be used as input to this model also. Input to this model would have been both the response spectra and the time histories derived from the soil structure interaction analysis. Results from the response spectra analysis would have been used in combination with other appropriately factored loads to refine structural element sizes if necessary, and to determine reinforcing steel requirements. The time history analysis would have been used to determine response spectra at equipment mounting points throughout the building.

INTRODUCTION TO ANALYSIS

The building used in the analysis comparison is shown in figures 1 and 2. The same analysis is used for all comparisons; that is a dynamic, modal response spectrum analysis. In each case the mass and stiffness matrices are formed, the Eignevalue problem is solved, participation factors are computed and accelerations are derived from the input response spectrum. The response spectrum used is the 7% damped NRC Regulatory Guide 1.60 horizontal spectrum scaled to .25 g. The only difference in the analyses is the choice of model and the assumptions inherent in each choice. Assumptions common to each case are:

(1) Fixed base model
(2) Response spectrum applied in Z direction only
(3) Normal weight concrete
(4) Modulus of elasticity and shear modulus equal for all cases
(5) Twenty-five percent of the floor and roof live loads is added to the mass matrix.

DYNAMIC ANALYSIS NUMBER ONE

The model used for dynamic analysis number one (1) is shown in figure 3. Motion is constrained to the Z direction only, so the stiffnesses for the various levels are computed from the walls on column lines 1, 9, and 11. Stiffness contributions from the out of plane walls are ignored. Stiffness and mass calculations are computed with the aid of a Texas Instruments TI-58 programmable calculator. A modal analysis was performed and the frequencies for the three translation modes were computed.

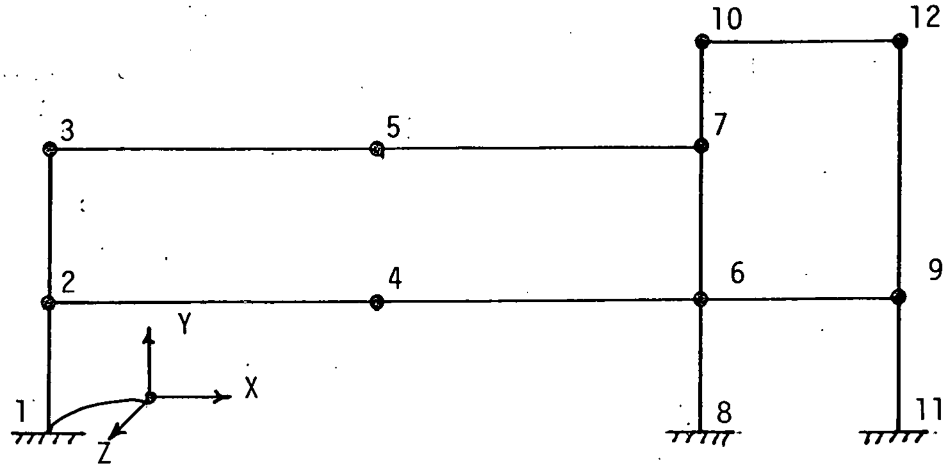
Story shears were determined by applying the NRC regulatory guide response spectrum and combining the results by SRSS.

Individual wall shears were determined by assuming rigid floor slabs and distributing the story shears to the walls in direct proportion to the stiffnesses.

Eccentricity was accounted for at each level by finding the center of mass and center of rigidity to compute a moment which would add or subtract from each wall shear (reference 3).

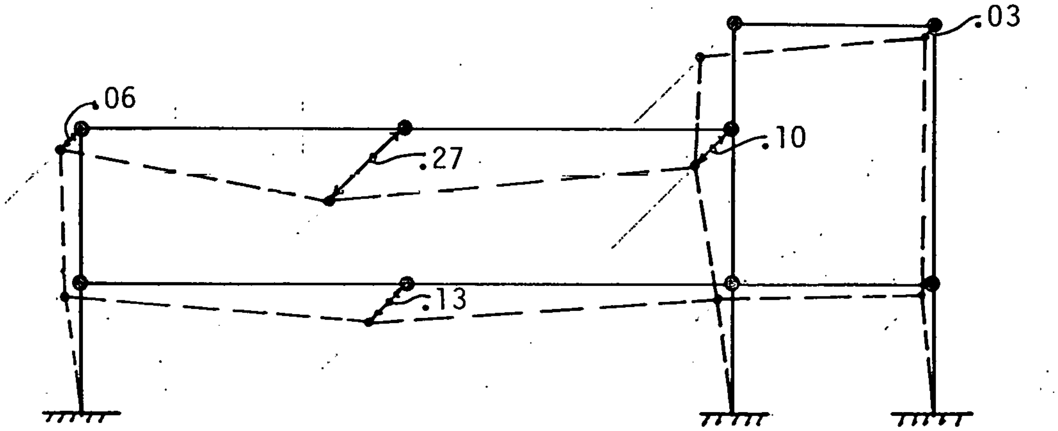
DYNAMIC ANALYSIS NUMBER TWO

The model for dynamic analysis number two is shown in figure 4. The model is a longitudinal section through the building shown in figures



MODEL NO. 2

Figure 4.



MODE SHAPE NO. 1

Figure 5.

1 and 2. Although the model is in the X, Y, plane, motion is constrained to the Z (lateral direction). The computer program SAP IV was used for this analysis. All the walls and slabs were modeled using three dimensional beam elements. Stiffness of the walls in the X, Y plane was ignored but their mass along with 25% of the live load was added as lumped masses to the various nodal points. Stiffness contributions of the lower level columns was also ignored.

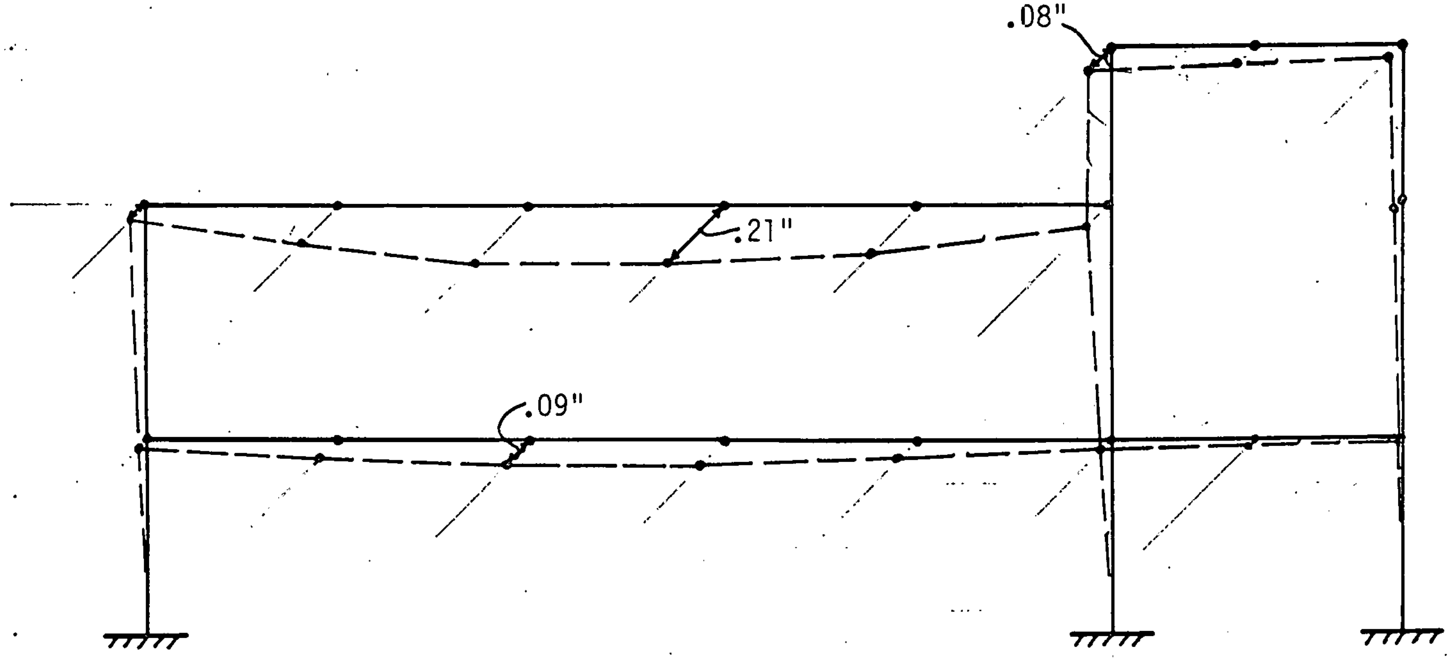
Mode 1 is the predominant contributor to wall shears and is depicted in figure 5. It should be noted that maximum displacements occur at the midpoint of the floor and lower roof slabs that were considered "rigid" in analysis number 1.

DYNAMIC ANALYSIS NUMBER THREE

The model for analysis number 3 is a three dimensional finite element model constructed of 128 quadrilateral membrane elements. The model contains 121 node points each with two or three degrees of freedom. Twenty five percent of the floor and roof live loads is lumped and added to the floor and roof node points. The computer program SAP IV is used for the analysis. Mode 1 is depicted in figure 6. As with the other models the response spectrum is applied only in the Z direction.

RESULTS AND DISCUSSION

A comparison of the results of the analyses on the three different models is shown in Table 1. These results show that, in general, model 1 is conservative compared to the other two. Since this is generally the case this model is often used in early stages of project design to determine initial configurations, element sizes and cost estimates. The use of this over simplistic model for anything more than that is questionable for several reasons. First, it leads to over-conservative results. The lower wall on column line 11 is an example which shows a shear 250% larger than the shear obtained from model 3. This kind of conservatism is not tolerable especially in light of the fact that in this example it does not increase the overall safety factor at all. Secondly, while this model usually produces conservative results it can yield underconservative results at building discontinuities or at locations where light walls are located near the midpoint of a large floor slab. The shear in the lower wall on column line 9 is lower in model 1 than in model 3. While the gross shear is only 4% low the maximum shear stress is approximately 28% low (260 psi vs. 334 psi). Third, the information obtained from this analysis is not adequate for a complete design. For example lateral stresses due to longitudinal motion cannot be determined from this model but are required to meet NRC regulatory guidelines. Perhaps the worst assumption inherent in this model is that the floor and roof slabs remain rigid. As can be seen from Table 1 and figures 6 and 7, the maximum displacements take place at the midpoints of the floor and roof slabs. There is more relative lateral displacement within these slabs than there is from base level to roof level on the wall lines. If floor response spectra were determined from this model the zero period amplitude would be off by a factor of 2 at the floor slab midpoint in the building



MODEL 3, MODE 1

Figure 6.

Table 1

		Model 1	Model 2	Model 3
Shear in wall on Col. Line 1	upper	4696K	3473K	3528K
	lower	7390K	6107K	5670K
Shear in wall on Col. Line 9	upper	909K	359K	805K
	middle	4785K	3201K	2719K
	lower	4486K	5545K	4636K
Shear in wall on Col.Line 11	upper	1594K	1361K	1808K
	lower	6533K	2211K	2577K
Displacement Col. Line 11	roof	0.120"	0.035"	0.029"
	floor	0.043"	0.011"	0.012"
Displacement Col.Line 9	upper roof	0.120"	0.110"	0.129"
	lower roof	0.107"	0.105"	0.139"
	floor	0.043"	0.041"	0.024"
Displacement @ between 9 & 11	roof midway	0.107"	0.275"	0.207"
Displacement @ between 9 & 11	floor midway	0.043"	0.141"	0.089"
Displacement Col. Line 1	roof	0.107"	0.061"	0.052"
	floor	0.043"	0.031"	0.027"
Mode 1 Frequency		10.84 CPS	8.30 CPS	9.36 CPS
Mode 2 Frequency		22.75 CPS	9.90 CPS	11.96 CPS
Analyst time		2 man-days	0.5 man-days	1.0 man-days
Central Processor time		- 0 -	3.19 sec.	44.78 sec.
Total Computer time (CDC 6600)		- 0 -	3 min. 18 sec.	7 min., 04 sec.

analyzed. Spectra peaks would also occur in different locations and the amplitudes would vary by large factors. Lastly from a comparison of the computer and analyst times in Table 1, there appears to be no economic advantage to using this model.

Model 2 gives results in shears and displacements which closely match model 3. In addition it gives a close approximation of mode shape number 1 (figures 5 and 6; Mode 1 contributes approximately 95% of the shears and displacements). Its chief disadvantage is the amount of information not obtained such as lateral contributions from longitudinal motions and maximum shear stresses in interior elements. In addition, no appreciable advantage is gained in analyst or computer time. Furthermore at least two such models would be required to obtain stresses and displacements in the three principal directions whereas model 3 will yield stresses and displacements in all directions. This model may have definite advantages in early design stages because it can be used with small desk top computers.

Model 3 is easily constructed, does not require an undue amount of computer time and yields the most accurate results and the largest amount of information. Although the finite element mesh in this example is quite coarse it is considered adequate for the building under consideration. In actual practice the interior shear walls would be analyzed again using the shears obtained from the dynamic analysis applied as static loads to a two dimensional wall model with a finer finite element mesh.

CONCLUSIONS AND RECOMMENDATIONS

Model 1 is appropriate for early stages of design but is not recommended for later stages or for producing equipment response spectra. If model one is used the limiting assumptions and possible errors noted above should be fully recognized.

Model 2 yields good results with some analysis economy and is adaptible for use by small desk top computers. It is appropriate for preliminary design but not recommended for the final analysis of critical nuclear facilities.

Model 3 is recommended for final analysis of critical nuclear facilities and for the production of equipment floor response spectra. The analysis costs are not a great deal higher than the simpler models and therefore this model could also well be considered for preliminary stages of design.

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