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Dynamic Characteristics of Mechanical Components due to Earthquake

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1. Introduction

To obtain the dynamic response of structures and equipments in a nuclear power plant, utilities use their own methodologies and computer programs which are not made public. Therefore it is necessary to investigate the commercialized general-purpose computer programs for the regulatory purpose of the dynamic analysis due to earthquake.

Many commercial computer programs are available for the transient seismic analysis and one of them is ANSYS [1]. Up to Version 10 of ANSYS, there is no way to apply the acceleration time histories directly for the base excitation. Therefore the acceleration time histories are applied to the whole model using the ACEL command (designated as "ACEL" case hereafter). But ANSYS Version 11 made it possible to include the acceleration time histories in the D command which defines degree-of-freedom (DOF) constraints at nodes. Or, it is now possible to apply all kind of degree of freedom to specified nodes as a base excitation.

Therefore investigated in this study is the effect of the base excitation types on the responses by comparing response histories between various excitations. In addition to the base excitations, acceleration time histories are applied to the whole model using the command ACEL with a base fixed, which is a traditional case used in the transient analysis for the seismic excitation. Also, the response spectrum analysis is performed to generate stresses. All results of these analyses are compared with each other and the analysis characteristics are addressed for the responses such as displacement, velocity, acceleration, response spectrum and stress etc., with respect to the various excitation types for the seismic analysis. Finally the applicability of the analysis types is suggested for the regulatory audit calculation.

2. Analysis

2.1 Finite Element Model

Consider a simple cantilever beam with clamped-free boundary conditions at bottom and top ends. The beam has a height of 50 m and a width of 1 m. The physical properties of the material are as follows: Young's modulus = 69.0 GPa, Poisson's ratio = 0.3, and mass density = 2700 kg/m^3.

Two-dimensional model is constructed for the finite element analysis. The beam is modeled as 2-d structural solid elements (PLANE182) with four nodes having two degrees of freedom at each node: translations in the nodal x and y directions. This element can be used as either a plane element or an axisymmetric element.

2.2 Modal Analysis

Finite element analysis using a commercial computer code ANSYS 11.0 is performed to find the natural frequencies of the cantilever beam with a fixed – free boundary condition.

The Block Lanczos method is used for the eigenvalue and eigenvector extractions to calculate sufficient number of frequencies.

2.3 Time History Analysis

The corrected accelerogram of El Centro site Imperial valley irrigation district on May 18, 1940 is shown in Figure 1 for east-west direction. The corresponding velocity and displacement time histories are also generated. Theses three time histories are used as a forcing function as a base excitation for the transient time history analysis.

In addition to the base excitations, the acceleration time histories are applied to the whole model with a base fixed in all six degrees of freedom using the ACEL command.

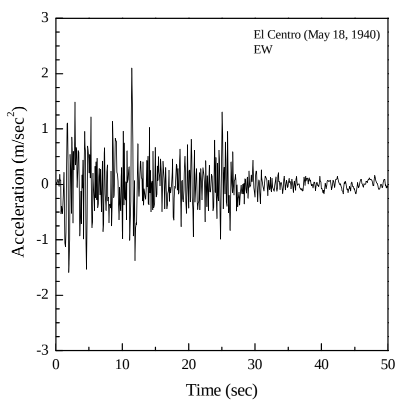

Fig. 1. Acceleration time history

2.4 Response Spectrum Analysis

The response spectrum is generated from the time history using the program developed in this study for 2% damping ratio as shown in Figure 3. It is applied to the bottom of the structure which is fixed in all six degrees of freedom. The responses of equivalent stresses at two typical elements are investigated.

3. Results and Discussion

Three time history analyses are performed using the base excitations of acceleration, velocity and displacement time histories. The resulting displacement, velocity and acceleration time histories at the top (103) and bottom (204) nodes of the beam are generated. When the bottom node is fixed and the acceleration is applied to the whole beam with the command "ACEL", the responses are shown in Figure 2.

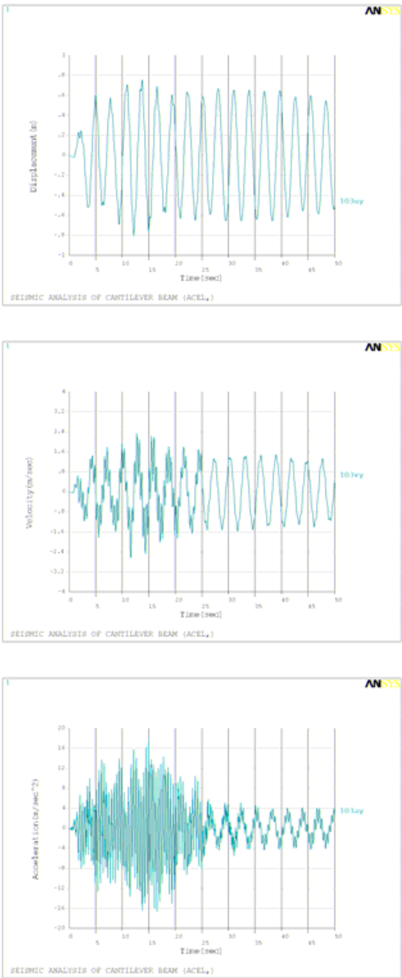

Fig. 2. Response histories of top node for ACEL excitation with bottom nodes fixed

When the excitation is applied as an acceleration time histories, the rigid body motion is appeared while the velocity responses are almost the same as the predetermined motions. If velocity time histories are used as a base excitation the finite element model follows the predetermined displacement motions, but the accelerations shows a very strange shape especially for the excitation points with almost zero values (1.0E-10). If displacement time histories are used as a base excitation, the velocity and acceleration responses are found not to be proper comparing with predetermined especially for the accelerations at excitation points with a very high value (1.0E+5). Figure 2 shows the responses when the acceleration is applied to the whole model with a base fixed instead of base excitation. In this case, the top node responses such as displacement, velocity and acceleration are very similar to those of the case for the base excitation of acceleration but the velocity and displacement behave not having a damping.

The maximum equivalent stresses are shown in Table 1 for all forcing terms. As indicated in the table, the displacement excitation gives the biggest responses among base excitations and the responses due to response spectrum and ACEL are almost the same. Therefore it is concluded that ACEL case generates the similar responses with the response spectrum analysis in the stress point of view.

Table 1. Equivalent stress summaries

Input forcing term	Equivalent stress (Pa)	
	Top element	Bottom element
Base excitation (Acceleration)	0.1666E+05	0.4484E+06
Base excitation (Velocity)	0.1844E+05	0.4080E+06
Base excitation (Displacement)	0.2518E+06	0.1766E+08
ACEL	0.2365E+05	0.2657E+08
Response spectrum	0.1217E+05	0.2720E+08

4. Conclusions

Three types of excitations are applied to the base of the structure for the seismic analysis and their responses are compared with each other. Also, accelerations are applied to the whole structure with a base fixed and response spectrum analysis is performed. The responses due to these excitation methods are compared, generating the following suggestions when using ANSYS for the time history analysis due to seismic excitations as follows:

- The only acceptable excitation type is ACEL, which applies acceleration time histories to the whole model with a base fixed.
- When acceleration time histories are applied as a base excitation, the rigid body motion may be appeared which should be carefully investigated.
- When velocity or displacement time histories are applied as a base excitation, the corresponding velocity, acceleration or response spectra generated during the analysis may not be correct.
- It is not recommended to use the D command which defines DOF constraints at nodes for the time history analysis due to seismic excitation.

REFERENCES

[1] ANSYS, Inc., 2009, Theory Reference for ANSYS and ANSYS Workbench Release 12.0, Canonsburg, PA.