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내진검증(안전)을 위한 실험적 고찰을 이용한 해석 모델 개발연구

A Test Verified Model Development Study for Seismic Qualification(Safety)

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ABSTRACT

This paper includes discussion on developing the test verified finite element model for one of the seismic qualification(safety) approaches. It presents a test verified finite element model of a UPS(Uninterruptible Power Supply System) to be used at KMRR, KAERI. The test verified model predicts natural frequencies within 5 percent error for all major modes below 50Hz. This model accurately represents the dynamic characteristics of the actual hardware and is qualified for its use in the final stress analysis for seismic verification.

국 문 요 약

이 논문은 기기검증 중 내진검증(안전)을 위한 접근방법의 일환으로 실험을 통한 유한요소 해석 모델을 개발하였다. 이 모델은 한국원자력연구소 내의 하나로원자로 전기설비 중의 일부분인 UPS를 내진검증하기 위한 것이다. 이 시험증명용 모델은 50Hz 미만의 모든 주요 모드에서 고유진동수가 약 5%이내의 오차를 갖는 값을 예측하였다. 이 모델은 내진검증을 위한 최종 응력해석에 적합하였으며 실제 기기의 동적특성의 예측에 고 정밀도를 보여주었다.

1. Introduction

One of the compulsory requirements for the nuclear safety related systems and components is to be qualified for seismic events. This paper presents the test verified finite element

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model of a UPS for future use of the seismic qualification. This verified model will be made by Ehwa Electric Industrial Company, UPS Division. The UPS will be used at KMRR, KAERI.

The seismic qualification of these systems and components can be achieved using finite element analysis (FEA) techniques, seismic simulation testing or a combination of testing and analysis techniques[1,2]. For a electrical system or equipment, an analytical approach using FEA techniques is a very useful tool in most cases for seismic qualification as an economical point of view. This technique is obtained for a fraction of the cost of simulated seismic tests and provides detailed stress and deflection distributions for the entire structure. The finite element model and the analysis of the modified structure model is re-conducted easily. In addition, the finite element analysis approach can handle a large size structure and multi-load cases very effectively. Therefore, it is important to develop a FEA model of the UPS assembly.

Mathematical models used in the stress analysis of structural/mechanical components for use in nuclear power plants are usually verified by modal testing. For this purpose, the test results are assumed to be correct and the mathematical model is tuned to closely correlate with the test results.

2. Theoretical Formulation

Seismic qualification using the finite element analysis techniques is presented in this section. The analytical computer model development, modal frequency analysis method, and stress criteria will be discussed.

2.1 Finite Element Model

The accuracy of seismic qualification by FEA codes depends on the computer model. The finite element analysis model formulated by nodes and elements, is required to adequately represent the dynamic characteristics and mass distribution of the structure. The element material properties and geometry details should match with the actual structure. All components used in the real equipment should be considered in the analysis model. To simplify the structure analysis, the electric instruments, driving motors, control valves, and other components are simulated as lump mass elements. These installed components are qualified by either FE analysis, similarity analysis, or seismic simulated tests. The connections between the assemblies are simulated as gap elements for an accurate and conservative analysis. All installed components, simplified as lump mass elements in the structure analysis, are analyzed using the seismic loads from the structure seismic qualification analysis. The mounting conditions of the equipment should be accurately simulated in the computer boundary conditions. The finite element analysis model should be checked by the element and node plots and other display functions in the finite element analysis code.

2.2 Mode Frequency Analysis

Mode frequency analysis is conducted to determine the fundamental natural frequencies of a structure. Assuming that the model has a constant stiffness and mass effect, no damping, and free vibration, the motion equation, for the modal natural frequency analysis, is given by :

$$[M]\left\{\frac{\partial^2 u}{\partial^2 t}\right\}+[K]\{u\}=0 \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where [K] is the structure stiffness matrix, [M] is the mass matrix, and {u} is the vibration of the model. For a linear system, free vibration will be harmonic of the form :

$$u_i = \phi_i \cos \omega_i t \cdots\cdots (2)$$

where ϕ_i is eigenvector representing the mode shape of the ith natural frequency, ω_i is the ith natural frequency and t is the time.

Substituting equation (2) to equation (1), it yields :

$$\{ -\omega^2_i [M] + [K] \} \phi_i = \{0\} \cdots\cdots (3)$$

The natural frequencies are printed as

$$f_i = \frac{\omega_i}{2\pi} \cdots\cdots (4)$$

where the f_i is ith natural frequency.

2.3 Evaluation Criteria

The evaluation criteria to be used in this effort is to compare the natural frequencies obtained from the finite element analysis with those of the modal survey test. The results of the modal test will be assumed accurate, and the finite element analysis results will be tuned to within 5%.

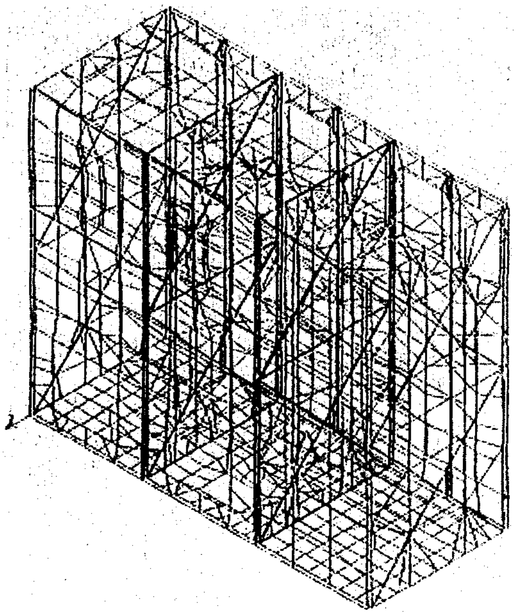


Fig. 1 An isometric view of UPS

2.4 Pre-test Analysis

A finite element of the UPS was originally developed for the purpose of preliminary seismic analysis. The model and the results of the seismic analysis were documented in the KONEL/Wyle Report # RN 001-93[3].

This model was used for the pre-test frequency analysis with a minor modification. The boundary conditions of the seismic model, fixed in the three global transitional directions and three rotational directions about the X, Y and Z, were kept intact. Eigenvalue analysis was performed and modes up to 50Hz were extracted using the Lanczos technique[4]. Results of the pre-test frequency analysis are tabulated in Table 1. An isometric view of the model is shown in Fig. 1, and includes a set of finite element plots.

3. Experimental Approaches

3.1 Specimen Description

A 120 VAC Uninterruptible Power Supply System, consisting of three cabinets(containing UPS Module, Static Transfer Switch, Mechanical Bypass Switch, Synchronizing Equipment and Protective Devices), is as shown in Fig. 2.

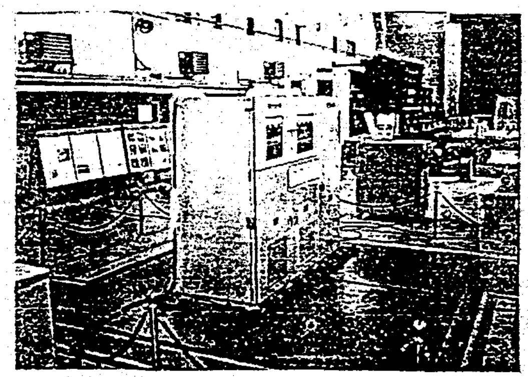


Fig. 2 Test setup details

3.2 Seismic Qualification Test

Seismic tests are performed by subjecting equipment to vibratory motion that conservatively simulates that postulated at the equipment mounting during an earthquake.

3.2 Modal Survey Test

The modal survey test of the UPS took place at Ehwa Dynamics Facility. The unit was rigidly mounted on a 30-foot square, 250,000 lbs concrete reaction mass. The four feet of the UPS were mounted to 2-inch thick carbon steel plates with 1.5-inch bolts. The 2-inch plates were then rigidly welded to embedded steel beams in the concrete reaction mass.

The UPS was instrumented with 40 accelerometers as shown in Fig. 3. The location of the accelerometers were selected based on the results of pre-test analysis and the size and mass of the selected components. Engineering judgment was used to optimize the number and location of accelerometers and yet extract all important modes. Small components with little mass were ignored since their contribution to the overall system behavior were judged to be insignificant.

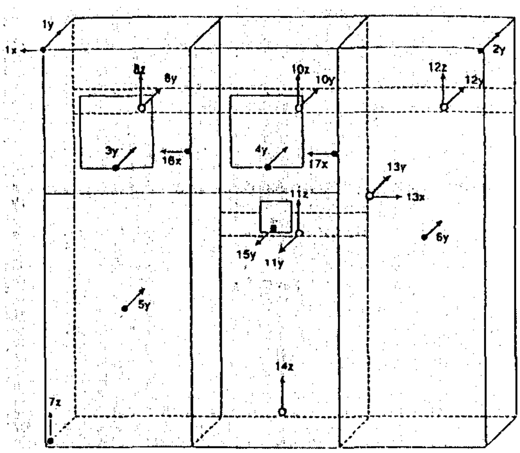


Fig. 3 Accelerometer mounting locations

The modal testing of the UPS was performed using a Hewlett-Packard(Model 5423A) Structural Dynamic Analyzer[3]. Data acquisition was accomplished by exciting the structure with the electrodynamic shaker applying random signals, and measuring both input force and output structural response at each accelerometer location. All modes with frequencies between 0 to 100Hz were extracted during the test. The natural frequencies and mode shapes of interest, between 0 to 50Hz, are documented in Table 1.

Table 1 Comparison of test and pre-test analysis frequencies.

Accel. No.	Axis	Nat.Freq. results		Ref.	
		Pre-test Analysis	Modal Test	Percent Error	Status
1X	S-S		19.2		
1Y	F-B		20.3		
2Y	F-B		20.5		
3Y	F-B		29.4		
4Y	F-B		28.3		
5Y	F-B	25.0	25.1		
6Y	F-B	15.1	15		
7Z	V		-		
8Y 8Z	F-B	34.2	29.7 -	15.0	Unacceptable
-		7	-		
-		10.0	-		
10Y 10Z	F-B V	34.4	28.7 -	20.0	Unacceptable
11Y 11Z	F-B V	29.0	20.8 -	40.0	Unacceptable
12Y 12Z	F-B V	35.2 12.0	28.8 -	22.3	Unacceptable
13X 13Y	S-S F-B	 20.0	20.8 19.0		
14Z	V		-		
15Y	F-B		28.8		
16X	S-S		38.3		
17X	S-S	20	19.5		

LEGEND : F-B = Front-to-Back
S-S = Side-to-Side
V = Vertical

4. Comparison of Measured and Predicted Frequencies and Results

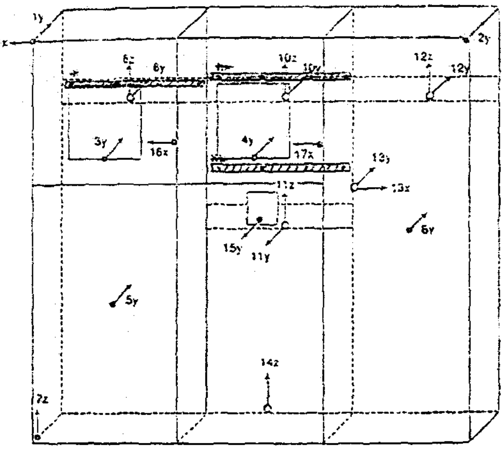
4.1 Post-test Analysis

The comparison of test and pre-test analysis results, as shown in Table 1, indicates significant differences. The pre-test analysis results produced a number of additional modes while missing a few major system modes. To begin with, the Rear of Charger Cabinet Panel Y mode was predicted at 34.2Hz with a percent error of 15.0. The Rear of Inverter Cabinet Y mode at 34.4Hz was predicted with unacceptable percent error. The No. 11 and 12 mode were missed completely, and other higher system modes were either missed or predicted with high percent errors.

The predicted analytical and measured test frequencies with the same mode shape characteristics were compared between 0 to 50Hz. Percent error in the predicted natural frequencies was calculated and compared to the evaluation criteria. The analytical model was revised accordingly to correct unacceptable differences and to extract the missing modes present in the test results.

4.2 Tuning of the Analysis Model

Correlation of the pre-test analysis and test frequencies was accomplished in several steps. To begin with, all rotary inertias which had been incorrectly calculated with respect to the global coordinate system were revised with respect to their local coordinate system. The boundary conditions at the base of the UPS were changed to fixed ones in the three translational directions only. All rotational fixations at the base of the UPS were released. The coupling of these changes resulted in lowering of the first system Y mode to within the acceptable 5% as shown in Table 2.



Note : Supplement bar dimension
* 30×2.6t flat bar
** 50×50×6 mm angle bar

Fig. 4 Outline of attached each supplement bar on Device Panels in the upper part of the Charger and Inverter Cabinets

The revisions to the upper device panels in the charger and inverter cabinets were made as shown in Fig. 4. Since a support system was not rigid enough to support mass of the devices in the cabinets, an attempt was made to rigidify the support system as attached each supplement bar on the device panels in the upper part of the charger and invert cabinets. These changes coupled with the revision in rotary inertias resulted in the first mode to jump above 15.1Hz.

5. Conclusions

The results of the UPS modal test indicate some distinct and major modes of vibration between 0 to 50Hz. Among these are the first fundamental frequencies of the unit in each of the three orthogonal directions, the second Y mode of the unit, and three higher system modes above 40Hz.

Table 2 Comparison of test and post-test analysis frequencies

Accel. No.	Axis	Nat.Freq. results		Ref.	
		Pre-test Analysis	Modal Test	Percent Error	Status
1X	S-S	24.7	19.2		
1Y	F-B	20.5	20.3		
2Y	F-B	20.9	20.5		
3Y	F-B	29.8	29.4		
4Y	F-B	28.6	28.3		
5Y	F-B	25.0	25.1		
6Y	F-B	15.1	15		
7Z	V				
8Y	F-B	30.6	29.7	3.0	acceptable
8Z			-		
-					
-			-		
10Y	F-B	29.3	28.7	2.0	acceptable
10Z	V		-		
11Y	F-B	20.2	20.8	2.5	acceptable
11Z	V		-		
12Y	F-B	29.9	28.8	4.0	acceptable
12Z	V		-		
13X	S-S	21.2	20.8		
13Y	F-B	19.6	19.0		
14Z	V		-		
15Y	F-B	29.2	28.8		
16X	S-S	38.9	38.3		
17X	S-S	20.1	19.5		

LEGEND : F-B=Front-to-Back
S-S=Side-to-Side
V=Vertical

Assuming test results to be correct, the analysis model is shown to include the same some modes in the 0 to 50Hz frequency range. These modes are further shown to correlate to within the expected 5% as shown in Table 2. This mode, having a frequency above 33Hz, will have no impact on the results of the seismic qualification analysis for which the tuned model is prepared.

The nuclear safety related systems and components can be qualified for an imposed seismic events by FEA techniques.

The results of the seismic qualification analysis by the verified model and the qualification by testing were that there was no statically significant difference in the seismic performance.

The evaluation criteria to be used in this effort which was to compare the natural frequencies obtained from the finite element analysis with those of the modal survey test was met to within 5%.

The test verified finite element model of the UPS presented in this paper satisfies the objectives of the tasks[1,2], and is ready to be incorporated in the final seismic qualification analysis. Therefore, it is important anyone to develop a FEA model of the UPS assembly.

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