COMPARISON OF EXPERIMENTAL AND ANALYTICAL RESULTS FROM TIME HISTORY ANALYSIS OF MULTIPLE RELAY PANELS

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SUMMARY

Numerical analyses, of the multi-segment relay panel arrangements, were conducted to demonstrate the adequacy of a numerical approach as compared to experimental results. The validation of the numerical model was conducted to extend the analyses of other large panel arrangement. The comparison of the natural frequencies and response spectrum diagrams obtained through experiments and numerical analyses showed good correlation between these two methods, allowing for seismic qualification by analysis.

INTRODUCTION

Single, double and four-section relay panels, designed for use at the Bruce NGS 'B' were tested at Ontario Hydro Research Division to determine their seismic response and the performance of the relays mounted on the panels. Numerical analyses were conducted using the same panels and the same time history inputs in an attempt to obtain identical seismic response spectra. The verification of the numerical procedure is conducted to ensure an adequate accuracy for future analysis of larger panel arrangements.

TEST PROGRAMS

The relay panels were tested on a biaxial shaker table in all three directions, one direction at a time, in accordance with the IEEE standards. Mounting of the panels onto the table closely resembled the specified site installation. In the single and double panels, the weight of the relays was simulated using lead blocks.

The four section panel had actual pre-wired relays mounted on it, as shown in Figure 1. Three types of tests were conducted on the panels:

- The impact technique was used for the transfer function measurements (Ref. 1) to establish natural frequencies and mode shapes of a panel. Only the four-section panel was tested using this method.

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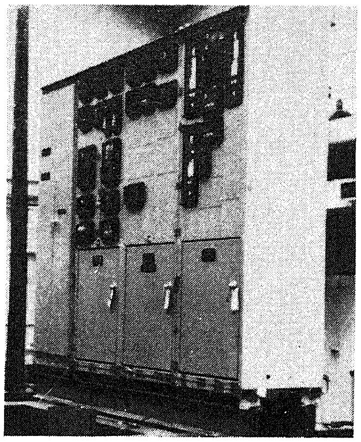
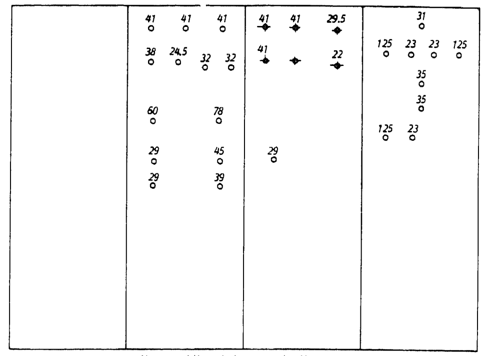


FIGURE 1
FOUR SECTION RELAY PANEL



Note: All weights are in Newtons

FIGURE 2
DISTRIBUTION OF CONCENTRATED WEIGHTS FOR FINITE ELEMENT ANALYSIS

- Sine sweep tests were used to determine the natural frequency and damping of all the panels (Ref. 2). Input acceleration was controlled manually. Response accelerations were monitored by accelerometers placed in a few selected locations. Locations of accelerometers on the four-section panel is shown in Figure 3, and is designated by the letter P.

- Pseudo-random input shaker table tests were conducted to simulate seismic excitations in each direction independently (Ref. 2). The response spectra generated at locations in Figure 3 show the anticipated responses of the relays. The input response spectrum (P999) enveloped the postulated floor response spectrum for the panel location at the Bruce Station 'B'. Actual panel damping of about 4% was used in tests. Response spectra at the relay locations were generated using 5% equipment (relay) damping. All time histories at the accelerometers' locations were recorded on a tape to be used as an input for analyses. A typical test record is shown in Figure 4.

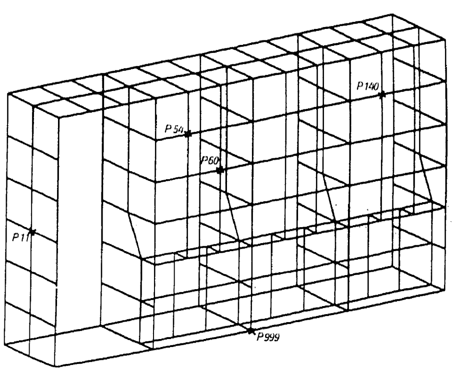


FIGURE 3
POINTS WHERE SEISMIC RESPONSE SPECTRA WERE GENERATED

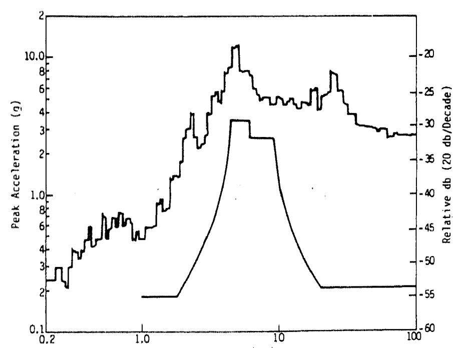


FIGURE 4
SAMPLE OF TEST RESPONSE SPECTRUM

COMPUTER CODE

The finite element analyses were conducted (Ref. 3) using a standard computer code MSC/NASTRAN, Level 60. This program is capable of performing the complete dynamic analysis including:

a) evaluation of natural frequencies and modeshapes,
b) evaluation of time histories at selected locations due to the specified input time history,
c) determination of response spectra of single degree of freedom oscillators at the locations where time histories are given or calculated.

MATHEMATICAL MODELS

A finite element model was generated to analyze the relay panel as shown in Figure 3. The panel was modelled with 176 nodes, 113 beam elements and 148 plate elements. Front and back doors were not modeled. However, their weight was added onto the weight of the panel along the perimeter of the doors. The doors were omitted because:

a) they do not contribute to the stiffness of the panel significantly.
b) we are not interested in the natural frequencies or response spectra of the doors.
c) simplification of the model yields easier interpretation of results and lower costs of analysis.

NATURAL FREQUENCIES AND MODE SHAPES

The natural frequencies were evaluated, for the four-section panel, using two techniques:

a) experimental - impact testing (Ref. 1)
b) numerical - finite element analysis (Ref. 4).

The first few natural frequencies are also extracted from the "sine sweep" tests done on the shaker table. The natural frequencies are shown in Table 1. Selected mode shapes are shown in Figure 5, 6 and 7. These results were obtained from finite element analysis. During the impact test, the grid in Figure 8 was used. Figure 9 shows the results of sign sweep test on the shaker table.

The finite element method indicated the largest number of natural frequencies because it can distinguish frequencies that are close together. The response spectrum analysis showed only two predominant frequencies. The numerical analysis and impact tests showed that the first natural frequency is about 13 Hz and that there is a large number of closely spaced frequencies between 13 and 37 Hz.

The comparison of mode shapes obtained through the numerical analysis and impact testing is difficult because of different mathematical models and the different way of presentation of results. Principal

TABLE 1

NATURAL FREQUENCIES

Natural Frequencies			
No	Numerical Results	Experimental Results	
		Impact Tests[1]	Shaker Table[2]
1	13.5	13.7	11.0
2	15.7		
3	16.4	17.7	
4	20.0	19.8	
5	21.5	22.1	
6	22.3	23.8	23.0
7	25.5		
8	27.5	27.0	
9	29.0		
10	33.4		
11	37.3	35.1	

Note :

Blank spaces indicate that these natural frequencies were not detected by the given method

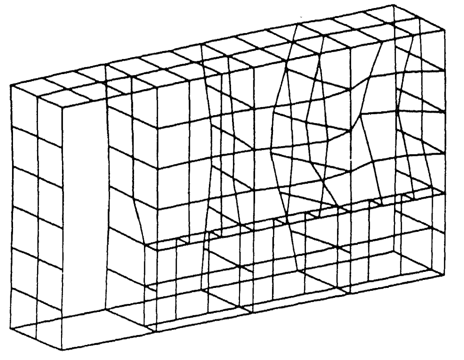


FIGURE 5

MODAL DEFORMATION 1ST NATURAL FREQUENCY OF 13.5 Hz FINITE ELEMENT ANALYSIS

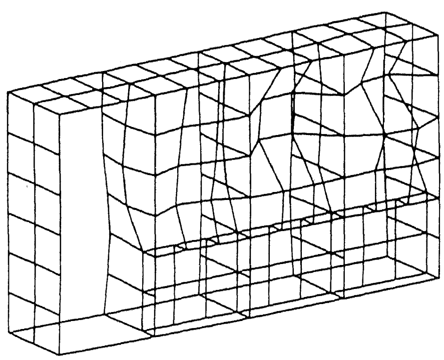


FIGURE 6

MODAL DEFORMATION 6TH NATURAL FREQUENCY OF 22.3 Hz FINITE ELEMENT ANALYSIS

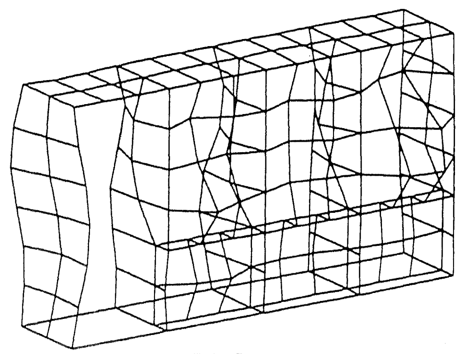


FIGURE 7

MODAL DEFORMATION 10TH NATURAL FREQUENCY OF 33.4 Hz FINITE ELEMENT ANALYSIS

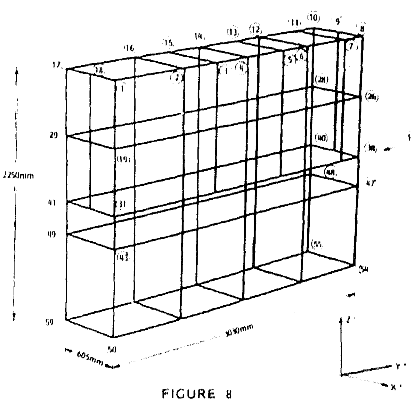


FIGURE 8

STRUCTURAL MODELLING TECHNIQUE FOR RELAY PANEL ASSEMBLY

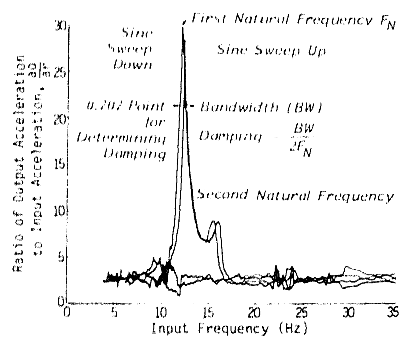


FIGURE 9

SINE SWEEP TESTS OF DOUBLE PANEL

directions of mode-shapes frequently could not be separated by examining the computer generated graphs.

RESPONSE SPECTRUM ANALYSIS

Response spectrum analyses were performed for the panels in the three principal directions. The single degree of freedom oscillators used in the evaluation of the response spectra had natural frequencies logarithmically distributed as follows:

$$f_i = f_1 \exp \{(i-1)[\ln(f_n/f_1)]/n\}$$

where: f_1 - lowest natural frequency: $f_1 = 0.1$

f_n - highest natural frequency: $f_n = 39.7$

n - number of oscillators: $n = 51$

i - oscillator number: $i \leq 51$

This selection of the single degree of freedom oscillators is designed to closely follow the suggested frequency intervals from Table 3.3 of CSA Standard N289.3 and to follow the frequencies used in the random vibration tests.

A damping factor of 5% was used in both experimental and numerical analysis.

The response spectra were evaluated at the selected points: P11, P54, P60, P140, and P999, shown in Figure 3. Three types of response spectra were obtained in the analysis; they show the maximum displacement, velocity and acceleration. We were only interested in the acceleration response spectra.

The response spectra, obtained for all panels in the horizontal (y) and in the vertical (z) directions, were identical for all analyzed points as illustrated in Figure 10. Thus, the frame of the panels is effectively rigid in the considered range of frequencies. This can also be seen in the mode shapes shown in Figures 5, 6, and 7.

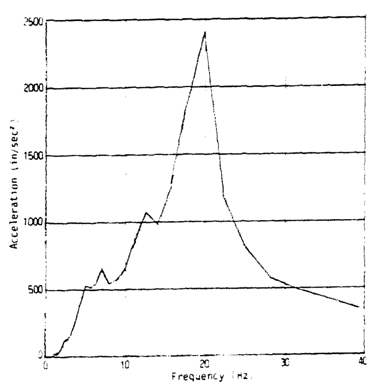


FIGURE 10

RESPONSE SPECTRUM AT ALL ANALYSED POINTS IN Z DIRECTION INPUT, ACCELERATIONS

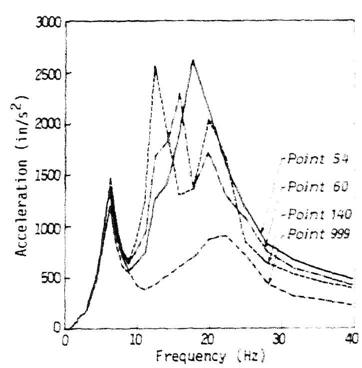


FIGURE 11

RESPONSE SPECTRUM AT SELECTED LOCATIONS FOR INPUT IN X DIRECTION

The spectral response of the four-section panel in the x direction is shown in Figure 11 for points P54, P60, P140 and P999 (input). The response spectrum of the frame of the panel was not analyzed because it was not expected to exhibit significant amplifications. From Figure 11 we can establish several items:

a) Natural frequencies are associated with single plates rather than with the panel as a single item - for example plate containing point 140 has natural frequencies of 13.5 Hz and 22 Hz while the plate containing point 54 has natural frequency at 16.5 Hz;

b) The input signal at 6 Hz is high, but the amplification factor is low, indicating a natural frequency of the shaker table or other part of the input system;

c) The strength of the input signal above 13 Hz is low, while output signals are high, indicating the existence of natural frequencies in the panel and high energy transfer from the table to the panel, at these frequencies;

d) The amplification of the response spectra drop rapidly above 23 Hz.

The largest ratio of the output acceleration signal to the input signal was equal to 5.97, found in numerical analysis. This amplification factor was obtained at 12.5 Hz, at point 140, for input in the x direction.

The largest amplification factor found in experimental analysis was equal to 7.10. It occurred at 11.0 Hz during input in x direction. The discrepancy between the amplifications can be explained as follows:

a) The largest amplification anticipated in the numerical analysis occurs at 13.5 Hz or at the first natural frequency while the response spectra were evaluated only at 12.5 Hz and at 14 Hz. If the interpolation was done assuming that the largest amplification occurred at 13.5 Hz, the amplification ratio would be 6.2.

b) The experimental results might be altered by the dynamic characteristics of the shaker table such as its natural frequencies, rocking modes and action of the actuating system.

TABLE 2

COMPARISON OF EXPERIMENTAL AND ANALYTICAL RESULTS

No	Frequency	Response Accelerations*, in Directions:					
		x		y		z	
	Hz	Analysis	Test	Analysis	Test	Analysis	Test
1	6	1.24	3.33	1.00	1.53	1.0	0.96
2	9	1.40	2.80	1.01	3.63	1.0	0.95
3	11	3.26	7.10	1.01	2.58	1.0	1.06
4	14	5.10	3.00	1.02	2.81	1.0	1.07
5	23	2.94	4.56	0.99	0.62	1.0	1.13
6	32	2.09	3.40	1.11	1.32	1.0	0.75

* *Values listed in this table show the largest ratio of output over input, with both signals acting in the same direction*

COMPARISON OF RESULTS

The random time history input was generated during experiments. The input was different for each panel and each direction. The obtained time history inputs were used as inputs for the numerical analyses. This allows us to compare the response spectra obtained from experiments with those from finite element analysis.

Comparison of Input Response Spectra

The time history was used in generation of the input response spectra were compared with the input spectra obtained from the numercial analyses. The corresponding results, obtained in the experimental and numerical methods were plotted on a log-log scale, are are included in Figures 12 and 13.

The good correlation between the experimental and numerical input response spectra can be seen. A drop in response at higher (above 20 Hz) frequencies is observed. This might be due to the fewer oscillators, used in this range, in the numerical model. However, the seismic signal attenuates at these frequencies. This region is of lower interest to us.

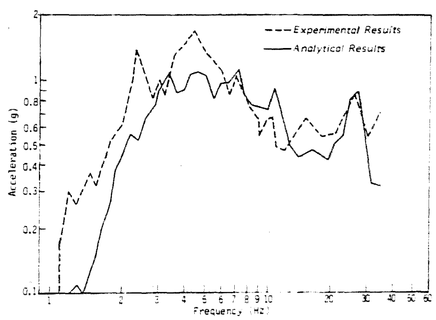


FIGURE 12

SINGLE PANEL, X DIRECTION, POINT 999 (INPUT)

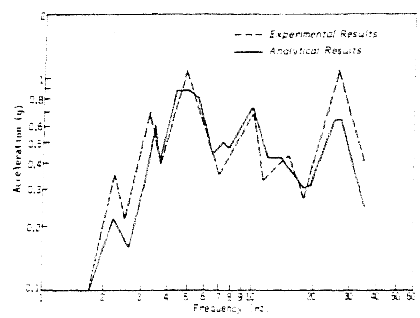


FIGURE 13

DUAL PANEL, X DIRECTION, POINT 999 (INPUT)

Comparison of Output Response Spectra

The output response spectra are shown in Figures 14, 15 16 and 17 and x direction of excitation, and for all panels.

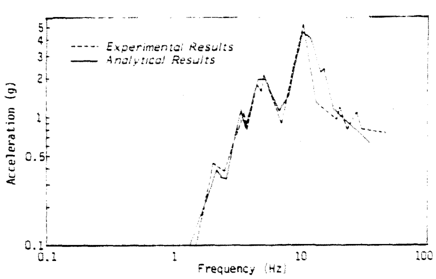


FIGURE 14

DUAL PANEL, X DIRECTION, POINT 83 (S757)

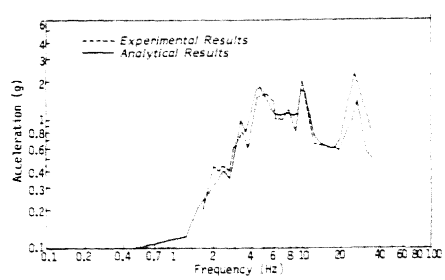


FIGURE 15

DOUBLE PANEL, Y DIRECTION, POINT 999 (INPUT)

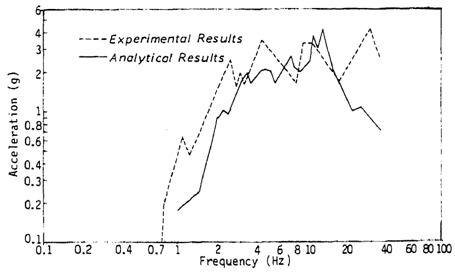


FIGURE 16

SINGLE PANEL, X DIRECTION, POINT 34 OR ACC. S901

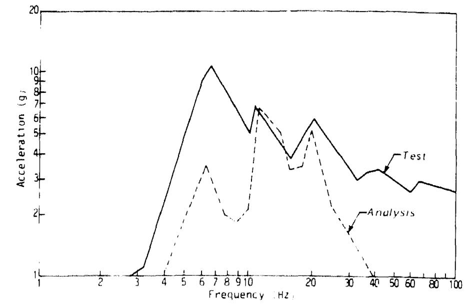


FIGURE 17

COMPARISON OF EXPERIMENTAL AND NUMERICAL RESULTS AT POINT 140, FOR X DIRECTION INPUT AND OUTPUT FOUR SECTION RELAY

The output response spectra in the x direction show good correlation between the experimental and analytical results.

CONCLUSIONS

The comparison of numerical and experimental results of seismic analyses was conducted to demonstrate the adequacy of the numerical procedure. It has been shown that the numerical method for seismic qualification of relay panels for use in the nuclear power generating station is adequate. A good correlation between the experimental and numerical analyses has been established. Furthermore, the numerical analyses can be conducted in a relatively short time.

Larger panels can be analyzed using the finite element approach described here. The cost of analysis increases with the complexity of the configuration and it may be practical to introduce some simplifying assumptions that reduce this complexity.

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