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Modal Testing of Reinforced Concrete Floor

Aman Sharma* and Sumit Bansal**
**M. Tech. Scholar, Department of Civil Engineering, GIET, Sonipat, (HR), INDIA*
***Assistant Professor, Department of Civil Engineering, GIET, Sonipat, (HR), INDIA*

(Corresponding author: Aman Sharma)
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ABSTRACT: Over the years, building floors have been designed from an equivalent static loading condition, assuming that the inherent load factor or the factor of safety will take care of the variation into the dynamic loading conditions. The situation is mostly acceptable for simple structural configuration- both in terms of geometry and material usage point of view. Over a decade or so, the building floors are being designed to be more slender in nature owing to the technological advancement like post tensioning etc. This is done in order to save material and space. In addition to the design trend towards increased floor slenderness, the following factors have also contributed to the emergence of the vibration problem in concrete floors:

- **Trend towards reduced floor damping;**
- **Awareness of the potential of vibration serviceability problems occurring in the development of slender floors in relatively quiet occupancies, such as offices, and the lack of reliable information as to how to tackle it in the design stage; There are two basic approaches to understand the vibrational behaviour of a floor slab (a) By appropriate modelling or (b) By analysing on actually built structure. The present study has a natural extension to damage detection study and condition assessment of existing structures.**

I. INTRODUCTION

The Objective of this study is to carry out a combined analytical and experimental investigation to determine the realistic representation of modal properties of three existing Reinforced Concrete Floors. Through the investigation the following objectives were planned to be fulfilled

a) Use of a fully automatically controlled Long stroke reaction mass shaker system newly inducted in the Structural and Material Testing floor alongwith a measurement system using accelerometers to measure as accurately aspossible the fundamental and higher modes of floor vibration.

(b) Measured accurately force by design of force plate.

(c) To carry out combined experimental and analytical investigation into the modalproperties.

(d) To determine a realistic representation of modal properties of few existing reinforced Concrete slabs

To setup the newly arrived long stroke shaker and analyzer, study the shaker working principle and properties, study the analyzer and the software to implement the same for dynamic analysis of flooring systems. To carry out experimental modal analysis of two rectangular RC slabs by using the Long Stroke Shaker system to excite the floor to some of its natural frequencies and thereafter capture the Frequency Response Functions of various points on the floors. To learn the functioning of Modal Analysis software, such as ME Scope to extract the modal properties of floors such as its Natural frequencies, Mode shapes and Modal Damping factors.

To find suitable 3D Finite Element Modeling of Rectangular RC floors.(ii) Carry out Modal Analysis with the initial model as realistically as possible to obtain the natural frequencies and mode shapes. (iii) Compare the Finite Element results with the experimental results.

II. EXPERIMENTAL MODAL ANALYSIS

The modal model in the Finite Element Analysis is developed using the spatial properties of the structure following the theoretical route to the vibration analysis. But neither the modal model nor the spatial model are amenable to direct measurement. Therefore a Response model is necessary to for implementing the direct measurements (EWINS DJ, 2000).

Derivation of the Response Model. The matrix equation of motion for the forced vibration of a viscously damped system isgiven by:

$$[M]\{\ddot{X}(t)\}+[C]\{\dot{X}(t)\}+[K]\{X(t)\}=\{f(t)\}$$

Use of the Experimental Model. It is more usual in EMA to define the response model in terms of its modal properties,rather than its spatial properties, in order to simplify the mathematics. Unfortunately, themodal solution of Equation 1 using the techniques described in Section 2 isdifficult since a non-proportional viscous damping matrix [C] serves to make theeigenvalues and eigenvectors complex.

$$[M]\{\ddot{x}(t)\}+([K+iD])\{x(t)\}=\{f(t)\}$$

Dynamic Signal Processing. Most EMA is based on the calculation of FRFs from force and response signals,followed by curve fitting techniques which aim to determine modal properties, such asthose featuring in Equation 7. However, the exact method of calculation of the FRFfrom the force and response time domain signals depends on the types of signals inquestion.

Modal parameter estimation. The FRF matrix for a structure may beexpressed in terms of its modal properties. Modal parameter estimation is a set oftechniques by which the modal properties of the structure may be determined from partor all of the FRF matrix.

In the experimental work carried out, the software 'MEScope' was used for performing required modal parameter estimation.

Basic measurement system. The measurement system used in this work can be broadly divided into three major items based on its availability in the laboratory.

(a) Excitation Mechanism
(b) A transduction system(for measurement of force and response)
(c) An analyzer to process the signals and give desired output.

Excitation and Data acquisition system used for Experimental Modal Analysis

Two method to measure the force:

A. Indirect method

B. Direct method

Response transducers and Analyzer. Accelerometers (Model 393B04) with sensitivity of 1000 mV/g which were procured by the dept from PCB piezoelectronics were used for acquiring the data. The accelerometer was mounted on a circular base plate with leveling capability (Fig. 1). Since the acceleration of the floor was very less (less than 1g), no attempt was made to fix the accelerometers firmly to the ground.

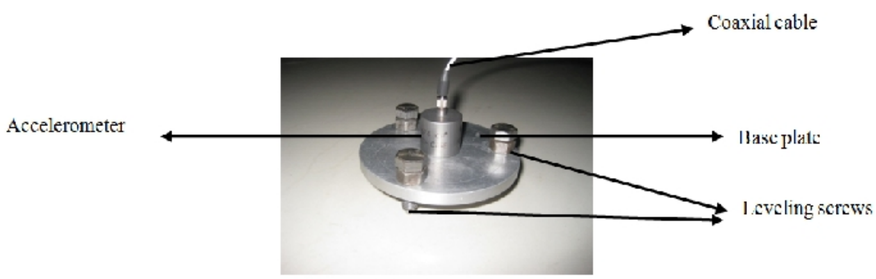


Fig. 1. Piezoelectric sensor with base plate.

Type of Excitation signal. The following signals were available with OROS analyzer to be used for exciting the shaker, (a) Sine, (b) Random, (c) Chirp, (d) Multisine

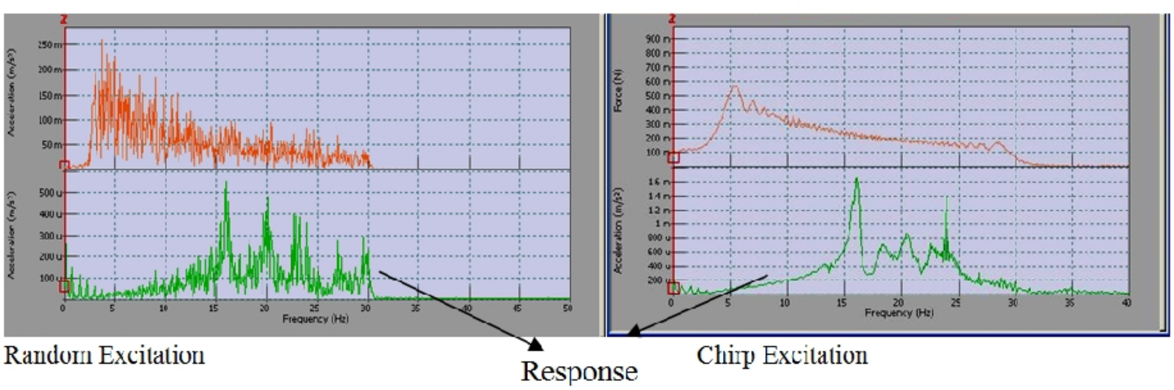


Fig. 2. Comparison of Random and Chirp excitation force spectrums.

Experimental Modal Analysis procedure. The Experimental Modal Analysis (EMA) which was followed in this work was structured to follow certain procedures so that high quality data is recorded. This was necessary to save on time from taking the recording again. For the same, the procedures were broadly broken into four major parts

(a) Preparatory phase.
(b) Logistics phase
(c) Exploratory phase
(d) Measurement phase

CASE STUDIES

Total modal testing procedure was thought to be practiced on different types of Reinforced Concrete floor systems. The usage of this type of system is actually independent of the size, type and properties of any flooring system. Slabs taken for case studies.

This floor was a lively indoor floor with floor finishes. Although the floor had little complex boundary conditions, the fact that it was indoors and posed less logistic problems, it was found to be a better slab to start with.

This was a slab with different geometry. The same procedure was tried on a floor.

Case Study 1. The test structure is the model room floor slab of UPRNN Hospital structure. Although the floor was little complicated in its geometry, it was chosen as the first test floor because the instruments need not be carried elsewhere and adequate time could be given to get acquainted to the system.

The dimensions of the floor are 20.4m × 9m with 150 mm total depth. E of floor slab – 2.0 x 10^{10} Pa

Poisson's ratio – 0.2

Density of concrete – 2400 Kg/m^3.

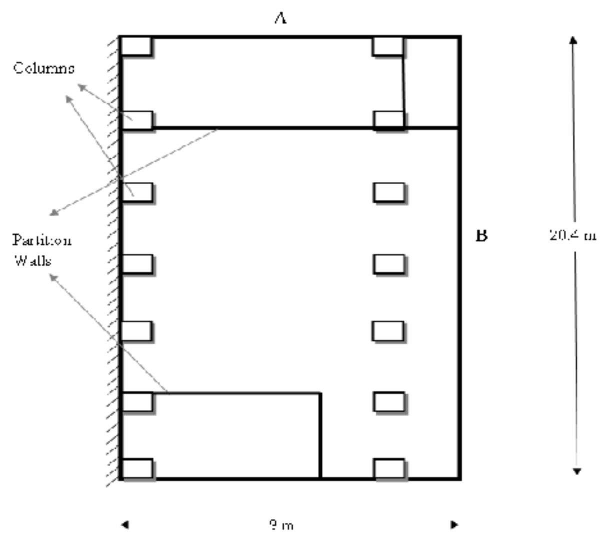


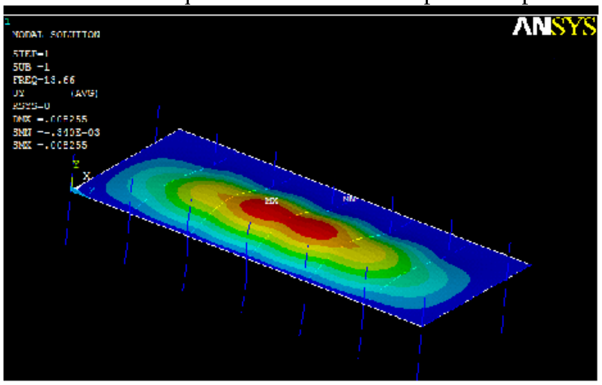
Fig. 3. Plan of test floor slab: Case Study 1.

Preparatory phase (Pre test analysis of the test floor). The purpose of a pre-test analysis is to give an indication of likely natural frequenciesand mode shapes of the structure prior to testing. A pre test analysis gives an indication of a frequency range to be used for the experiment so that the floor is safely excited. Since the entire structure was not taken for analysis, the supporting columns length were assumed up to 3m for top and bottom and all columns were pinned at the ends. The slabs were allowed rotation about their edges. The first 10 natural frequencies were recorded and are as tabulated below

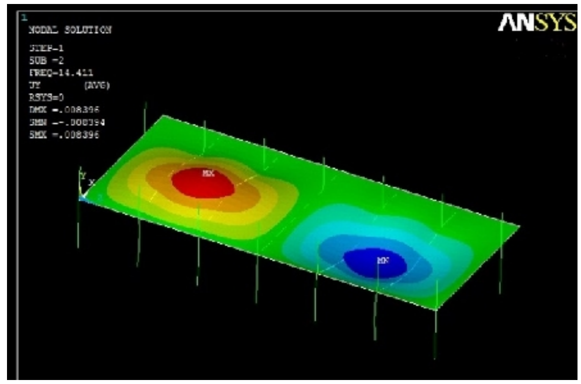
Table 1: First ten frequencies of Pre test model.

Mode	Natural Frequency(Hz)
1	13.660
2	14.411
3	15.774
4	17.847
5	20.640
6	25.523
7	29.101
8	33.146
9	34.101
10	34.517

The first two frequencies and mode shapes after pre test analysis are



First Mode



Second Mode

Fig. 4. Pre test analysis of model room floor slab: Mode shapes.

The grid consisted of 24 points which was created seeing the most likely points of excitation and nodes. It was suspected that there would be no movement near the partition walls. However some points were taken to test the response of slab at those points. The response at the walls was almost zero. So the points at the walls were neglected.

Measurement and Post analysis phase. After these, FRFs were recorded. The shaker was kept with the accelerometer mounted on it kept as the reference accelerometer. Three accelerometers were roved along the selected points. The FRFs near the partition walls were not of sufficient quality due to the local stiffness provided by them at the points. The available FRFs were exported to MEScope for modal parameter estimation. At present only first 3-4 modes were used for extraction of mode shapes. The values obtained from MEScope are given in Table. The comparison of frequencies of the pre test model and the experiment shows some variation. The comparisons in a tabulated form are given in Table. The comparison of frequencies shows that the stiffness of the slab in pre-test modeling was low.

Table 2: Data acquisition parameters.

Parameter	Setting value
Acquisition Bandwidth	Zoom 5 - 25 Hz
Acquisition Duration	20 s
No. of Frequency Domain Averages	7
Force Window Duration (% of Acquisition)	45%
Exponential Window Time Constant	0.35
Excitation Type	Chirp
Excitation Duration	8 s
Excitation Frequency Limits	5 - 30 Hz

Table 3: Modal parameters extracted using MEScope.

Mode	Frequency(Hz)	Damping ratio(ζ)(%)
1	15.9	1.99
2	19.4	2.39
3	22.7	1.98

Table 4: Comparison of Frequencies (Hz): Case Study 1.

Mode	ANSYS	Experimental
1	13.660	15.9
2	14.411	19.4
3	15.774	22.7

Case Study 2. The second example taken was a RC roof slab of UPRNN Hospital building was near to the laboratory. It is simply supported on the walls simply supported from three sides and fixed from one side. It's second par.

The dimension of the roof slab is 20.25 m × 10.4 m. The beams are of dimension 0.55 × 0.345 m (primary beam) and 0.35 × 0.20 m (secondary beam) and columns are of dimension 0.345 × 0.51 m. the primary beam is in the direction of shorter side and secondary beam is in the direction of longer side.

E of floor slab – 2.0 × 10^{10} Pa, E of Column and beam – 2.5 × 10^{10} Pa
Poisson's ratio – 0.2
Density of concrete – 2400 Kg/m^3.

Preparatory phase (Pre test analysis). The columns were considered fixed at the floor below which was at the height of 5.85 m. The modal analysis was carried out similar to that of previous case studies.

The first four natural frequencies of the pre test analysis are as given.

Measurement and Post analysis phase. The shaker position and 60 point grid was made for data acquisition. The slab was accessible. The data acquisition parameters were kept same as that of previous case study since the frequency range was found to be same. The FRFs were recorded for the points on the slab. The recorded signals were found to be good. There was no response seen at the edges of slab and at the line of columns. The FRFs were then exported to MEScope to extract the Frequencies and mode shapes.

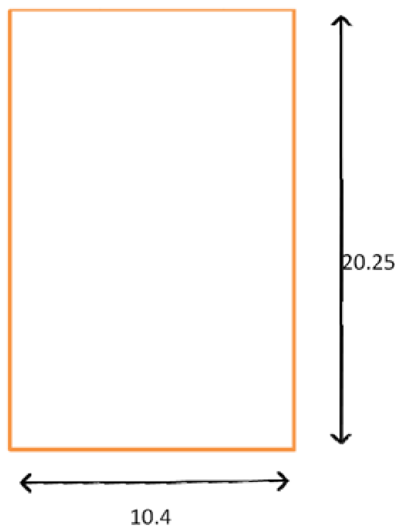
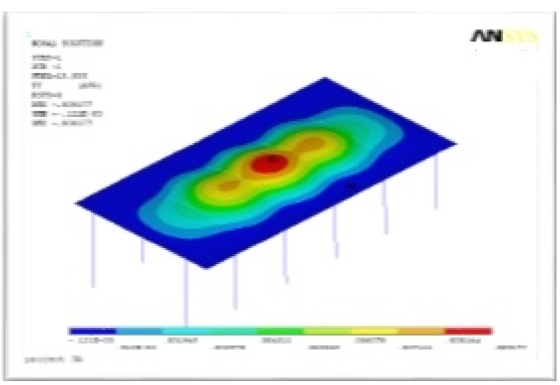


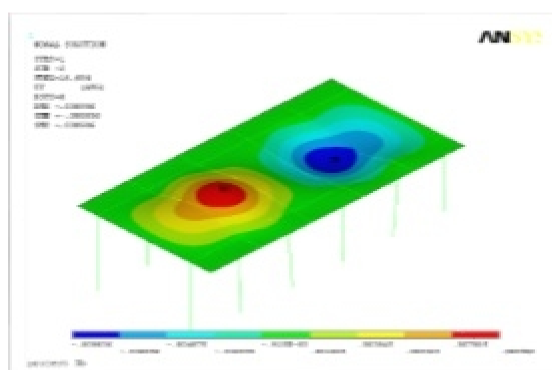
Fig. 5. Plan of roof slab: Case study 2.

Table 5: First four frequencies of Pre test model.

Mode	Natural Frequency(Hz)
1	15.835
2	16.684
3	18.278
4	20.814



First mode



Second mode

Fig. 6. First two mode shapes of pre test model (Case Study 2).

Table 6: Experimental natural frequencies of second slab.

Mode	Frequency(Hz)	Damping Ratio(ζ) (%)
1	-	-
2	13.65	1.62
3	14.98	1.09

Table 7: Comparison of frequencies.

Mode	Frequency (Hz)	
	Experimental	ANSYS
1	-	15.835
2	13.65	16.684
3	14.98	18.278
4	-	20.814

The comparison of frequencies shows that the stiffness of the slab in pre test modeling was high.

IV. RESULTS AND DISCUSSIONS

The system was utilized successfully for the estimation of natural frequencies, modal dampingratios and mode shapes of the slabs.

The comparison between the pretest analysis and the experimental values showed that modal properties obtained from the pre-test analysis did not match exactly with the experimental counterparts. The slab initially considered for modeling was less stiff. There were certain parameters like the material properties and boundary conditions which were assumed on engineering judgment were varied later owing to the difference in values. The consideration of fixed ends where the slab ends have walls on both sides gave more realistic modeling supported by experimental results.

From the cases 1 it is found that in one case the stiffness is low which is to be short out by damping or by increasing column or beam size that would also cost us more where in case 2 it is found that the stiffness is high where the slab pass even of such high frequencies equivalent to earthquake it resembles that we can build such structure which would not be effect by earthquake.

FUTURE SCOPE

A methodology has been presented here for the verification of analytical models of concrete slab type of structures through experimental modal testing. However, due to the limited time and resources available to this project and also due to the need of administrative approval of testing such live structures, only a small number of structures and simple ones were actually tested.

(1) It is recommended that a series of studies be initiated in which a large number of structures of various configurations are tested, so that their vibration behavior may be understood better leading to *improved design guidelines* and *improvedmodeling approaches*

(2) In this work, only rectangular RC slabs were considered. The study can be extended to structures with more complex geometry, composite flooring system, post tensioned floors, bridge deck slabs with addition of horizontal mass shakers, etc, to excite horizontal modes directly.

(3) The effect of non structural elements on the global responses can also be taken up as a different study.

(4) For any such experiment, proper data acquisition is always a challenge. A controlled excitation source was not used in this study, a controller is already used but not so effectively for this present study, this should be used in future.

(5) The present study has a natural extension to damage detection study and condition assessment of existing structures.

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