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Model Updating of a Full-Scale Building Structure Under Train Induced Vibration

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ABSTRACT. *Structure health monitoring (SHM) system is a method of monitoring and evaluation of structural health. Finite element method is extensively used to model the dynamics properties of a structure as it is believed to be an authentic tool for providing accurate results. To adopt a more precise dynamic properties of a structure, model updating technique involve updating a finite element model of a structure. However, due to many imaginary assumptions in the finite element (FE) model generation, the practical behavior of full-scale structures contradicts the model results. It may be due to uncertain boundary conditions, poorly defined material properties of the structure or because of the simplified modeling of complicated structural systems. In this paper, six storey frame structure building has been investigated for dynamic model updating. The building was subjected to train induced excitation. Four accelerometers were employed to measure the response. Manual updating of building FEM model is carried out as per design parameters of the finite element model (elastic modulus and boundary constraints) to diminish the inconsistencies between the field measurement and the results of finite element model. For the subject building the supposition of semi-rigid joints (rotational area springs) can most precisely depict the dynamic properties of the subject building. The modified parameters obtained from the updated model are logical having meaningful interpretation.*

Keywords: Dynamic response, Accelerometers, Frequency, Stifness, Vibration

1. INTRODUCTION

People have constructed buildings since prehistory but due to upgraded material and advanced structural engineering techniques, it has become trendy in modern world. Although the structures must be assembled with improved performance like safety and functionality to enable the reduction of long-term and short-term cost in terms of maintenance/repair. Simultaneously, adequate safety of aging building infrastructure must be warranted by regular monitoring and inspection. Dynamic properties of individual structures must be understood particularly to equip with the challenges of resilience. Understanding of these structures can be achieved through instrumentation and examination of the acquired results. Structural response and other dynamic characteristics during ambient and high energy excitation can be illustrated through this data. Modernization in structure health monitoring (SHM) and structure modeling can be achieved through extensive research of the dynamic behaviour of buildings which can be implemented in lifecycle maintenance of sustainable and state of the art construction.

Limited research has been conducted to analyze the dynamic characteristics of actual building on the basis of field measurements. Due to its capacity to handle complex assemblies and complicated structural geometry, it is appraised by Zienkiewics and Friswell [1-2], to be most effective and reliable mechanism for numerical modelling and studying dynamics of structure. Brownjohn et al. [3] has studied a 6-storey frame storey commercial building in Singapore. Finite element analysis (FEA) of the structure was developed to examine the dynamic properties of the structure. The building has framed tube system having RCC shear wall. Height of building was 80ft. External columns were connected to core wall by a longitudinal grid framing connected to the floor level. SAP2000 interface was used to develop the finite element model (FEM). Field measured data show good resemblance with the frequencies measured from the model constructed using detailed drawings.

Celebi et al [4] studied a 10-story frame structure building located at MIT campus. Experimental measurements were taken using 15 accelerometers and dynamic properties were studied. Yi et al. [5] worked on a 22m high building in Hongkong during the transit of typhoons using accelerometers installed in the building and studied the dynamic response using site measurements.

In this paper, a six-storey commercial building is being selected to analyze the dynamic behaviour of a full-scale structure by an array of four accelerometers. Mass and stiffness are the major factors affecting the dynamic behaviour of the building system. The experimental measurements are carried out under ambient vibrations and train induced excitation using accelerometers. A FEM was created in SAP 2000 to represent the physical response of the structure. The field data obtained from the accelerometers was examined to define the parameters of structure and dynamics of structure and also to authenticate the FE model of the building under consideration. Discrepancies between the numerical and experimental results were reduced by model updating.

2.METHODOLOGY

2.1 Description of case study building

A 6-story frame structure building is selected as a test-bed. The height of test building is 72ft. It is a reinforced concrete building having external layout of 84 ft by 64 ft. The clear story height of the basement floor is 10ft while the remaining floors have 11ft.Elevation and typical floor plan is shown. (Figure 1)

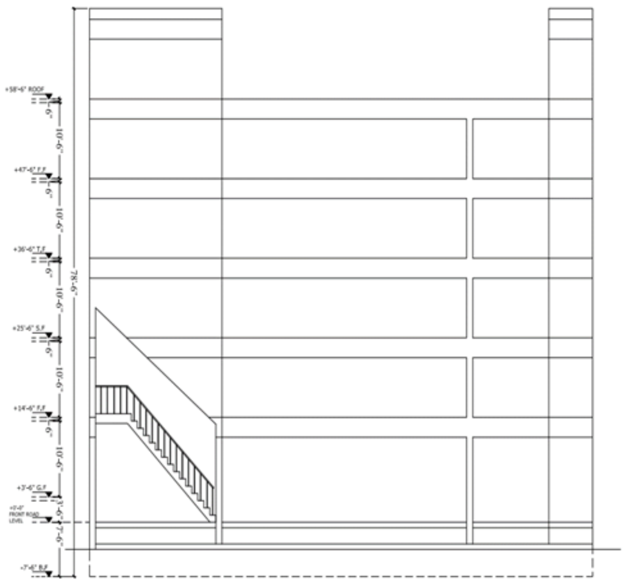

Fig-1: (a)Elevation of Test Building (b) Typical floor of building

2.2 Experimental setup

The subject building was instrumented with 4 Piezoelectric force balance accelerometers of 1000mV/g sensitivity, sample rate of 128 Hz with a recording range of ±2g. They were placed at retaining wall, first floor, 4th floor and roof level creating a measurement grid of 4 points. The accelerometers were connected to controlled data acquisition system via laptop. The position of the reference accelerometers was fixed in all test setups. The accelerometer’s arrangement is shown in Figure 2.

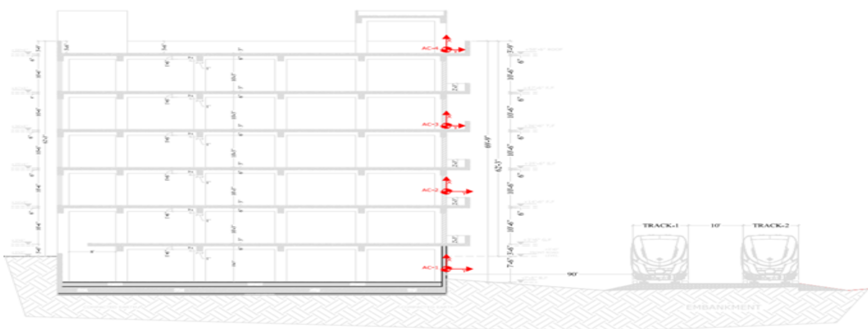

Fig-2: Orientation and placement of four accelerometers

Y-axis of each accelerometer was oriented perpendicular to the movement of train. The building's natural frequency was estimated from the train induced response measured by the accelerometers.

3. ANALYSES OF DYNAMIC CHARACTERISTICS USING FIELD MEASUREMENTS

Three sets of building acceleration data were collected using accelerometers. Ambient vibration and the vibration taken by the excitation of building by two different trains coming at different time were recorded.
In this paper only the frequencies of train 1 has been taken which were more evident as compared to ambient and the other counterpart. The experimental frequency (Mode 1) of accelerometers placed at 4th floor and roof has been detected in the direction perpendicular to the train. Butterworth filter was applied using Seismosignal to obtain the noise free data. (Figure 3)

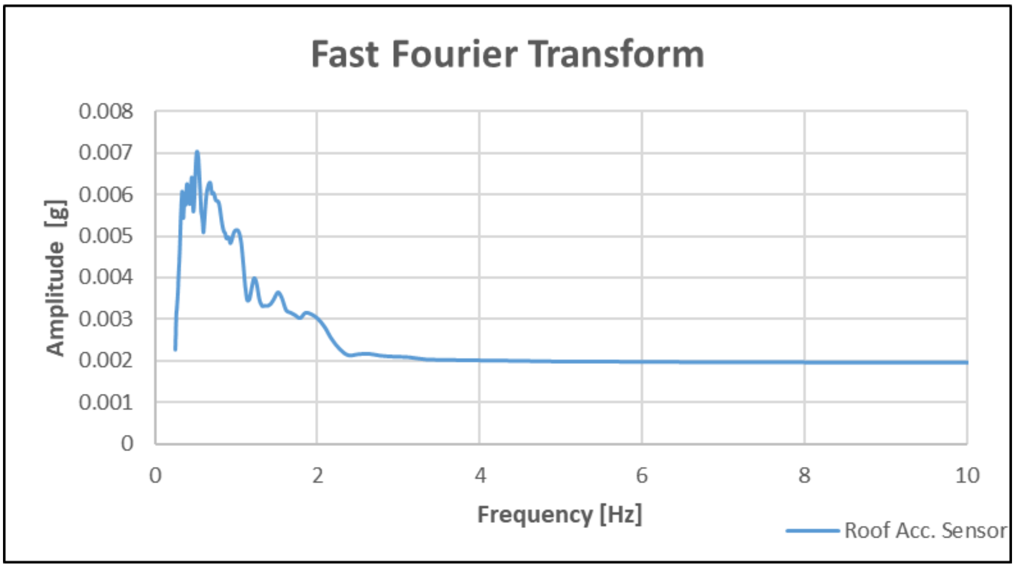

Fig-3: Train Induced Vibration of Building

Building's dynamic characteristics and structural behaviour was analyzed from the data collected through accelerometers to update FEM which can reflect the current behaviour of the building.

3.1 FEM Model

A modelling interface SAP2000 was utilized to develop the initial FEM of the test building. Initial FEM was created to represent the building as per detailed structural drawings. Columns are modeled as an axial elements and floor slabs as a plate bending elements. Initial FEM was analyzed by assuming the base as fixed i.e. more rigid condition (Figure 4).

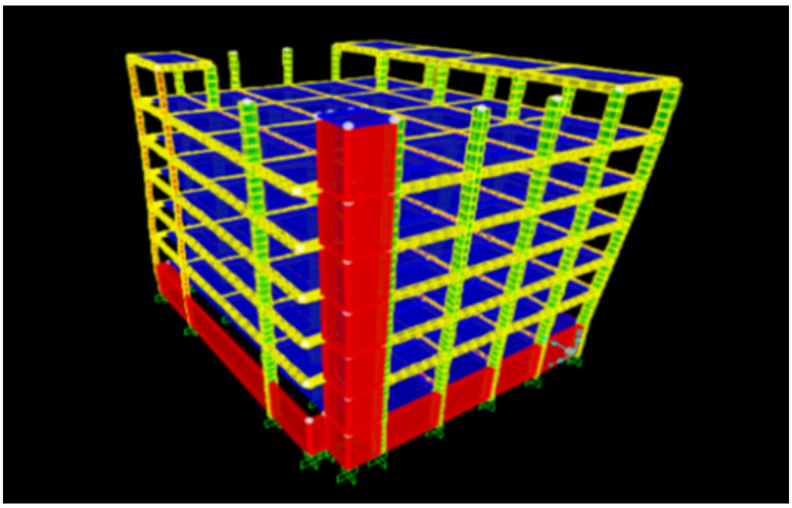

Fig-4: FEM Model of Building

The initial FE model was constructed to derive the natural frequencies of the subject building. By comparison of the results, it is apparent that for mode-I in Y-direction the initial finite element model differs the experimental value by 38% suggesting a huge difference between the initial FE model and real structure.

Table-1: Comparison of Experimental and Theoretical Frequencies

Modal Frequency (Hz)	
Experimental (Mode-1)	0.52
Initial Model (Mode-I)	0.84
Difference	38%

Frequency obtained by train induced vibration derived from accelerometer data was 0.52Hz as shown (Figure 3). However, the frequency value obtained by Initial FEM modelling was 0.84Hz. The initial finite element model was developed considering the detailed working drawings although it doesn't take into account the other unpredicted situations, thus some unavoidable differences exist. Typically, these errors are always there in initial model. As the initial finite element model cannot represent the response of the actual structure, therefore model updating is essential in order to ensure the accuracy of FE model predicted results. The manual tuning/updating was done to conform the variation between the initial FE model and its experimental counterpart as large error exists between the experimental and numerical data.

In finite element model updating there are several candidates that could be utilized to achieve the desired results. Choice of a particular updating parameter and the number of parameters is a crucial issue. In this engineering project; Initial FEM was updated based on two factors i-e flexural rigidity (EI) and boundary conditions to tune the measured natural frequencies from the accelerometer with the FE model.

The strength of frame members (columns and beams) was measured by Schmidt hammer (Figure5). The average strength of members came out to be 2200psi as compared to designed strength of 3000psi, which is almost 25% less than the designed value. The change in boundary conditions correlates with the wide range of causes including progressive degradation of structure.

Fig-5: Schmidt Hammer Testing

Normally such changes or damages are typically due to changes in rotational stiffness of the supports. Boundary condition of the model was transformed into area spring boundary condition i-e more flexible condition. (Figure 6). Value of raft area spring was taken as 40320 lb/ft2/ft as calculated by Bowles method.

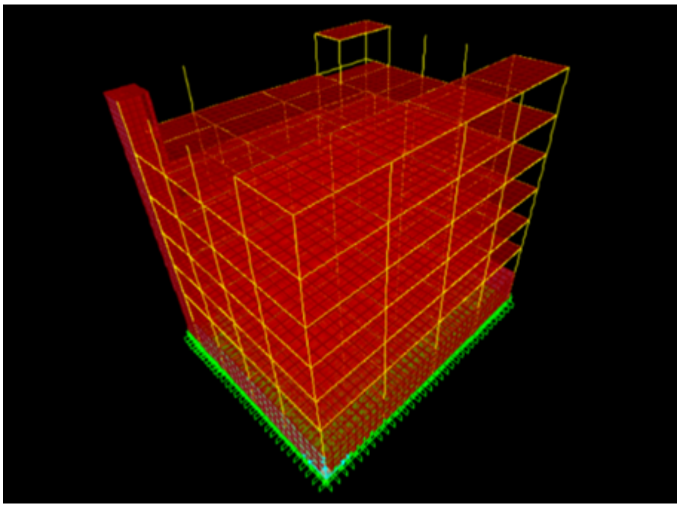

Fig-6: Updated FEM having area spring supports

In Initial FEM moment of inertia was fully taken into account. However, in actual, the structural elements tend to attract forces. These forces are susceptible to initiate cracks in tension zone thus reducing the area of cross-section and stiffness of the member subsequently reducing the moment of inertia of members. Stiffness modifier were adjusted (decreased by 20%) in updated model to reduce stiffness (defining structural member as a cracked section) and to adapt the actual strength of the frame member as calculated by Schmidt hammer.

Table-2: Stiffness Modifiers Comparison

Stiffness Modifiers		
	Column	Beam
Initial Model	1.0	1.0
Updated Model	0.8(20% reduced)	0.8(20% reduced)

Updated natural frequencies were obtained based on updated parameters. The specified results are shown in Table 3.

Table-3: Comparison of testing results and FE updated model results

Modal Frequency (Hz)	
Experimental (Mode-1)	0.52
Initial Model (Mode-I)	0.84
Updated Model	0.554
Difference	4%

The results of finite element model updating shows that the accuracy of modal frequencies have been significantly refined. Errors in the initial model have been reasonably reduced to 4% as compared to 38% in the initial model. Therefore, the updated finite element model can be utilized to predict the long-term structural health monitoring of the building structure.

4. CONCLUSIONS

The following are the conclusions drawn from this study:

1. Frequency obtained by train induced vibration derived from accelerometer data was 0.52Hz.
2. Frequency value obtained by Initial FEM modelling was 0.84Hz
3. Frequency value obtained by updating model parameter was 0.554Hz.
4. A reduction of 20% in the updating parameters is observed.

Updated model was legitimate by the comparison of train induced frequencies with the collected field data. Simulation of the train induced excitation indicated the model to have good similarity with the experimentally collected field data. The principal concept of model updating is to have an ultimate simulation of structure that can reflect the real structure behaviour. The final updated model results founded reasonable with frequency difference errors reduced from 38% to 4%.

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