Modal Updating for a Simple Structure against Impact Loading

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Abstract: **Impact loadings (e.g. blast or missile attack) can cause severe damages to structures. There is a growing trend in studying the experimental and analytical behaviors of structures against impact loadings. Such experimental works are very expensive. Analytical approaches can be economical but these are complicated. Also, there is a need of model updating in understanding the relatively real behavior of structures under impact loadings. In current work, model updating for studying the precise response of a simple structure against impact loading will be presented. For this purpose, a prototype structure of single storey and single bay is prepared. Impact load is applied and recorded at the bottom of one of the four columns and the response will be recorded at the top of the two columns for relative study. Finite element modelling of prototype structure is done in commercially available software SAP2000. Numerical response is then compared with that of experimental one. A set of modifiers is updated based on available literature in order to reduce the difference between numerical and experimental responses. Detail discussions on set of modifiers and their effect before and after model updating is made. Accordingly, recommendations are given for future directions.**

Keywords: **Impact loading, modelling, modifiers, prototype structure, model updating.**

I. INTRODUCTION

Construction of safe and economical structures have always been a constant mission for Engineers. Modern structures faces severe damage by different loadings like earthquake, blast, missile attacks, wind etc. Impact loadings are one of crucial loadings that create catastrophic failure of structures. Impact loadings include blast loadings nearby or inside structures and missile loadings. In order to design the structures against impact loadings, the behaviour of structure against these loadings need to be explored. Different investigations have been reported in literature to determine the behaviour of structures against these type of loadings. Loss of human lives and damages to properties costed of millions of dollars [1] which was the consequence of a successfully bomb attack. While initial casualties are due to direct over pressure released by the explosion, falling of structural elements may extensively increase the total figure. Most Structures which are constructed, likely to be vulnerable or potential to mitigate the impact of terrorist bombing. Currently building and planning control authorities are identifying the risks which are associated with present environment of global terrorism. Therefore, it is important to carry out vulnerability and damage assessment of buildings subjected to blast loads to provide mitigation strategies.

Prototype structures have been used in literature for simulation of impact load on structure. The response of these structures are then inflated to real structures. Shabir and Omenzetter [2] prepared simple model for computing response of real structure. The simple laboratory structure mounted on shake table was used to measure the response of prototype structure using four accelerometers. Jun et al. [3] investigated the, ultra-high performance concrete (UHPC) material formulated based on reactive powder concrete (RPC) was developed. Columns which were made pf these materials was field blast tested. 70% more loading capacity was preserved on a columns with micro steel fibre reinforcement “UHPC” after detonation of 35 kg trinitrotoluene explosion at a distance of 1.5m standoff e, on the other hand only 40% of loading capacity was maintained after the detonation of 8 kg of trinitrotoluene explosion at a distance of 1.5m standoff. Shabbir and Omenzetter [2] prepared the full scale bridge model using SAP2000 to study the dynamic behaviour of structure. Xu and Lu [4] was proposed a 3D finite element model by using LS-DYNA and SAP2000 for modelling of reinforced concrete plates subjected to blast loading. Ali et al. [5] study the dynamic response of mortar-free interlocking structure by applying the impact loading at base of prototype structure.

Techniques of model updating is about updating a finite element model of a structure so that it can assume higher accuracy of structure dynamics. Quite a few methods of structural model updating have been introduced as shown in Table-1 and this topic is currently under study in various sectors. Mostly these studies centred on approaches such as the optimal matrix updating, parameter estimation based on sensitivity-based parameter estimation, Eigen-structure assignment algorithms and neural-networks updating methods. Zhang et al. [6] proposed an improved sensitivity-based parameter updating method. Response surface methods for finite element modelling was used by Marwala. Genetic algorithms calculation were used for updating parameters of the finite element modelling by optimizing the surface response equation. Yan et al. [7] presented a statistic structural damage detection algorithm using the sensitivity of MSE for the process of damage detection based on ambient vibration measurements, where operational mode shapes is the only available data. Updating parameters are the most important in finite element model. The consideration of these factors not normally taken into account in regular model construction [8].

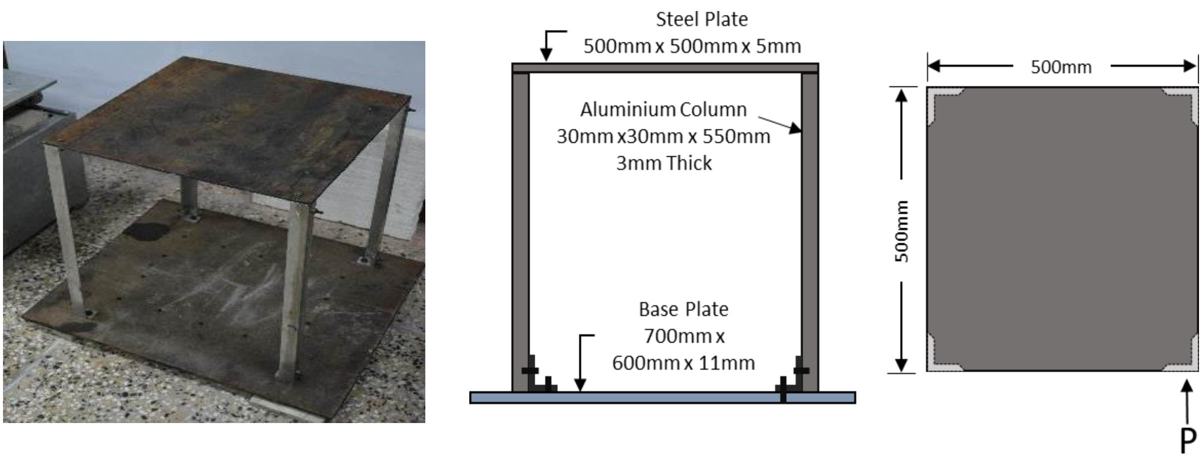
Table 1: Model updating parameters and percentage improvement by other researchers

Model Description	Emphasis	Updating Procedure			Percentage Improvement	References
		Description	Before	After		
Finite Element Model of Column	Model updating is implemented by the proposed algorithm to get the uncertain parameters.	• Modulus of Elasticity • Poison's Ratio • Connection Rigidity	2.04256E 11 N/m^2 0.33 95,000 Nm/rad	2.04702E 11 N/m^2 0.33 94,870.66 Nm/rad	90%	Basaga et al. (2011).
Simple Model For Computing Response of Real Structure	Model updating methods, especially the sensitivity approach is used. The presented methods allow the processing of time and frequency domain data.	• Modulus of Elasticity • Stiffness "K"	70,000 MPa 6	72,000 MPa 4	70%	Fritzen et al. (1998)

II. MATERIALS & METHODS

A. Prototype Structure, Instrumentation and Testing

The simple 3D prototype structure is shown in Figure 1a, whereas Figure 1b shows the schematic diagram of prototype structure considered in this study. The structure is made of a steel top plate supported on four columns made of aluminium angles. It has a height of 550 mm. The steel plate is 500 mm x 500 mm and has a thickness of 5 mm. The aluminium angles have dimensions of 30mm x 30 mm with a thickness of 3 mm. The columns are attached to the steel plate at the top and to a bottom steel plate with L-shaped aluminium brackets having a width of 30 mm, thickness of 4.5 mm and length of 75 mm. Bolts are used to connect each bracket with the top steel plate, bottom steel plate and an aluminium angle. A total of two accelerometer were used to measure the response of structure under impact loading. The impact force P is applied at the bottom of column with the help of hammer (Figure 1b). One accelerometers is mounted at the top of column to measure the response, whereas the second accelerometer was mounted on hammer to measure the acceleration of applied impact force. The result of accelerometer is recorded in MATLAB software in terms of acceleration-time history notated as $\ddot{u}_h$, $\ddot{u}_1$, and $\ddot{u}_2$.



a.

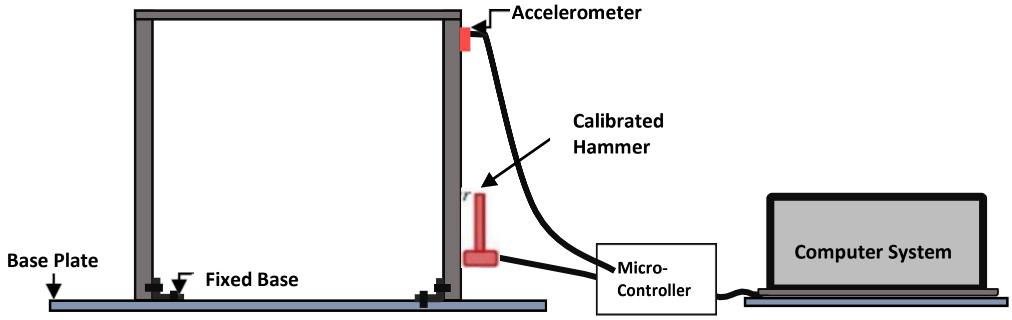


Figure 1: Experimental test setup,
a. prototype structure, b. Instrumentation

B. Finite Element Model and Updating Approach

In this study the numerical testing of structure is carried out in commercially available software SAP2000. A single bay, single storey 3D prototype structure is modelled as shown in Figure 2 having same dimensions and material properties as of prototype structure. The material properties of structure are shown in Table-2. The impact loading in terms of acceleration-time history, which is recorded through accelerometer is applied at the same location of column in numerical model as in experimental testing. After the application of loading and analysis, response of the structure was observed at the top of column.

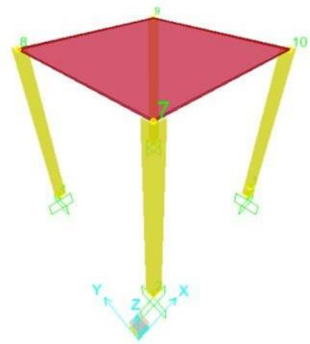


Figure 2: FE Model

Table 2: Material Properties

Material	Property	Before Updating	After Updating
Aluminium	Modulus of Elasticity	68.9 GPa 0.33	62.052 GPa 0.325
	Poisson's Ratio		
Steel	Modulus of Elasticity	200 GPa	200 GPa
	Poisson's Ratio	0.3	0.295

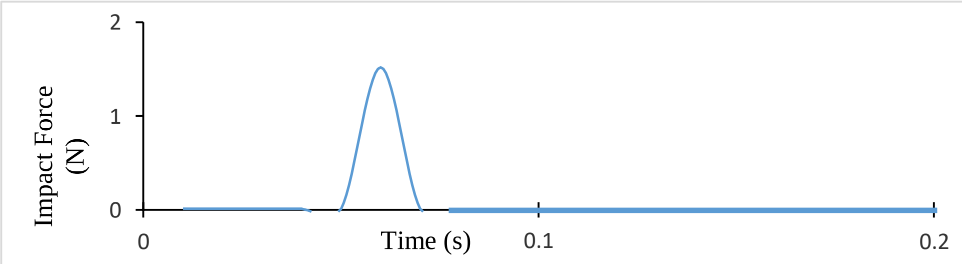
The obtained numerical results were than compared with that of experimental testing. Observing the difference in structural response during numerical and experimental analysis, modal updating approach is employed. Material properties such as moduli of elasticity (E) boundary conditions and load path were updated on the basis of literature review. After number of trials, moduli of elasticity was found to be more influential in modal updating process as compared to other considered parameters. Thus, an initially considered modulus of elasticity (E=10000 Ksi) for aluminium columns was then updated to 9000 Ksi after several trials to achieve the most accurate results.

III. RESULTS

A. Impact Load and Structure Response from Experiment

The structure was tested in laboratory by imposing the impact load at the bottom face of column 1 with the help of small calibrated hammer. Impact loading and structural response is recoded in term of acceleration-time history. The applied impact force P is shown in Fig. 3a. Since the impact force was applied manually, the obtained acceleration at the hammer was multiplied with its mass ($\ddot{u}_h \times m_h$) to get the applied force in Newtons. Whereas Figure 3b shows the experimental response of the structure at column 1 as $\ddot{u}_1$,.The dotted line represents the response of column 1 against applied loading.

a



b

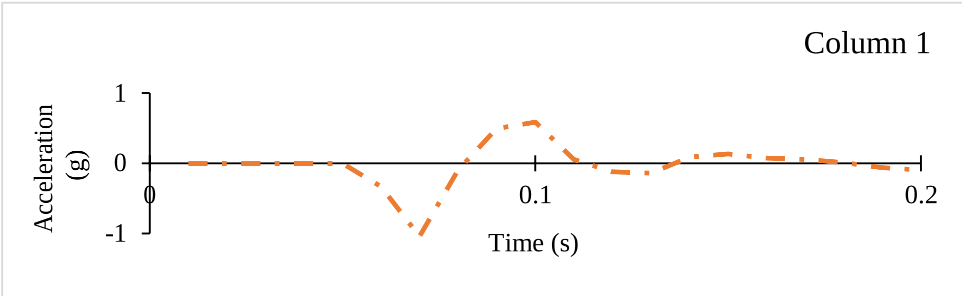
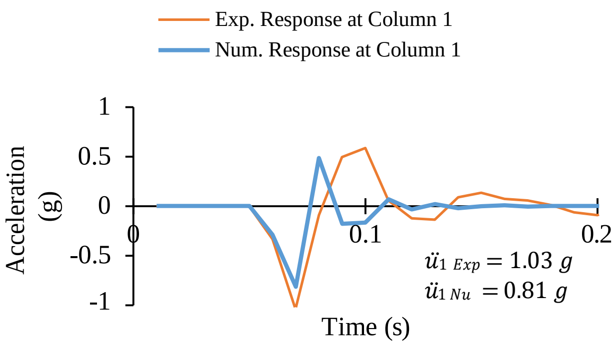


Figure 3: Impact load applied at bottom

B. Modal updating

The methodology of finite element (FE) modal updating was developed by combining the analytical results of FE analysis (FEA) with the experimental modal analysis (EMA). The specific goal of this research was to precise the geometrical, physical parameters or boundary conditions of the analytical model through a model updating procedure based on the experimental results such as measured displacement, frequencies and mode shapes, etc. Local methods are based on corrections applied to local physical parameters of the FE model, and therefore are physically meaningful. Global methods directly reconstruct the updated global mass and stiffness matrices from the reference data, so lack the advantages of local methods.

To make a tolerance between the FEA and EMA results, model updating of simple 3DOF laboratory structure is carried out to minimize the frequency differences between experimental and theoretical results equal to zero. it is very difficult process because of uncertainties in structural parameters like as modulus of elasticity, boundary conditions, mass density etc. In this study, modulus of elasticity effect the most as compared to boundary condition, model updating is carried out by reducing the `modulus of elasticity of aluminium and steel. Figure 3 show the displacement of structure under impact loading and after updating the uncertain parameter (material properties) of model respectively.



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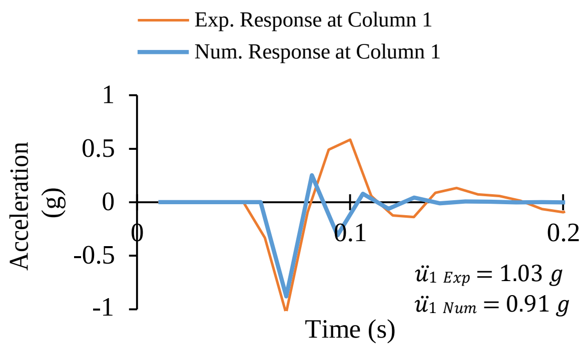

b.

Figure 4: Experimental and numerical response,
a. Response without updating, b. Response with updating

Model updating for studying the specific response of a simple 3d frame structure against impact loading is carried out. For this purpose, a prototype structure of single storey and single bay is prepared and numerical structure is modelled in commercially available software SAP2000. The response of structure is studied in terms of acceleration-time history. The peak acceleration recorded at top of column is shown in Table 3. Different parameters were considered for the purpose of model updating such as material properties and boundary conditions, to get the actual response of structure.

During this research it is found that the material properties of structure are more effected as compare to boundary condition for model updating to get the actual response of structure.

Table 3: Comparison of experimental and FE values of structure response at top

Column response	Experimental values (g)	Numerical values (g)	Percentage difference (%)
Before updating	1.03	0.81	21.3
After updating	1.03	0.91	11.6

A decrease of about 10.9% in peak accelerations is observed due to model updating in column 1. It is also evident from the results that the column 1 which was applied with impact force has 44.6 % more (experimental) accelerations because of impact load applied on the same column.

IV. CONCLUSIONS

In current work, a combination of numerical model has been analyzed to get the realistic results near to experimental and following conclusions are made:

- Modulus of elasticity of material is most effective in model updating as compare to other parameters.
- Maximum response values of analytical and experimental result are taken as comparison.
- It is noted that the difference in the analytical and experimental results is due to uncertain parameters of structure.
- A 10.9% average reduction was observed in peak accelerations by selecting the modulus of elasticity as updating parameter.

Further precise study considering more accurate material properties should be done for multi-story (steel and RCC) structure for more understanding.

V. RECOMMENDATIONS

This study has shown impressive results in terms of modal updating for a simple structure against impact loading. Further precise study considering more accurate results by getting the response of other structural members simultaneously, other than the member under the application of impact loading.

VI. ACKNOWLEDGEMENT

The author would like to offer thanks to every person/department who extended their support throughout the research work.

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