Journal of Engineering and Applied Sciences 11 (11): 2383-2386, 2016
ISSN: 1816-949X

Reduced Order Model for Model Updating of a Jointed Structure

Wan Imaan Izhan Wan Iskandar Mirza, Muhamad Norhisham Abdul Rani,
Mohd Hakimi Othman, Salmiah Kasolang and Mohd Azmi Yunus
Center of Excellence of Dynamics and Control, Faculty of Mechanical Engineering,
Universiti Teknologi MARA (UITM), 40450 Shah Alam, Malaysia

Abstract: Modal tests and reduced order model have been used to investigate dynamic behaviour of a jointed structure made from thin metal sheets which has a large flat surface and has been assembled together by a number of scattered joints. An impact hammer and roving accelerometers were used in the modal tests to provide data to update the finite element model. NASTRAN Solution 103 was used to compute natural frequencies and modes of interest of the jointed structure. Meanwhile, NASTRAN Solution 200 coupled with the reduced order model was deployed to systematically improve the initial FE model of the jointed structure in the light of modal test results. The improvement of the initial FE Model was successfully and efficiently carried out via the reduced order model.

Key words: Dynamic behavior, finite element, welded structure, scattered joints, modal tests

INTRODUCTION

A modern, complex structure such as car body-in-white is an assembly of a number of substructures which are formed from many components. The components are made from thin metal sheets and are assembled together by thousands of joints. Resistance Spot Weld (RSW) is one of the joint types that is widely used in automotive engineering. Although, the highly sophisticated finite element method is used to predict dynamic behavior of assembled structures, the predicted results of the structures are often considerably different from the measured results (Friswell and Mottershead, 1995; David *et al*., 2010).

The inaccuracy of predicted results is believed to be largely due to the invalid assumptions about the initial finite element models and/or initial parameter values, particularly those about joints, boundary conditions and also loads (Craig *et al*., 2000). Therefore, model updating methods are usually used to improve the initial finite element models by using the measured results. However, most iterative model updating methods require a high number of iterations for computing the eigensolutions and associated sensitivity matrices of large, complex structures which usually possess a very large number of degrees of freedom. Therefore, the methods are perceived to be costly, time consuming and difficult to handle (Liu *et al*., 2008).

The chief objective of this study is to investigate and present an efficient method for investigating and updating of dynamic behaviour of the initial finite element model of a jointed structure using a reduced order model. The Craig-Bampton Component Mode Synthesis technique (Craig *et al*., 2000.) coupled with iterative model updating is used in the development of the reduced order model. The accuracy and efficiency of the ideas are discussed and then validated with the experimental results.

MATERIALS AND METHODS

Experiments: The structure under investigation is a jointed structure made from 1.5 mm-thick steel sheets. It consists of five components jointed together as shown in Fig. 1 and 2. There is the U-shaped floor (bent floor no 5), two side walls each with three flanges (side wall no 1 and 2) and two hut-like stiffeners (stoppers no 3 and 4). The test model was set-up in free-free constraint conditions. The frequency range of interest in this study was 0~155 Hz.

An impact hammer and roving accelerometers were used in the investigation of the dynamic behaviour of the test model. This is due to a large flat surface on the test model and also that it is made from thin steel sheets (Craig *et al*., 2000). The impact hammer was used to excite the structure in the Z direction as shown in Fig. 1. Meanwhile the dynamic data of the excited structure was acquired by the accelerometers. The load and response signals were processed by LMS SCADAS analyser.

Corresponding Author: Wan Imaan Izhan Wan Iskandar Mirza, Center of Excellence of Dynamics and Control,
Faculty of Mechanical Engineering, Universiti Teknologi MARA (UITM), 40450 Shah Alam, Malaysia

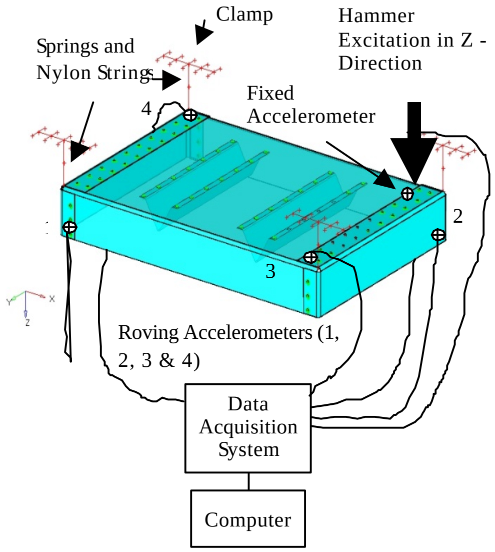

Fig. 1: Schematic diagram of the welded structure test set up

The FE analysis results were used to provide guidance on determining the frequency bandwidth of the testing, the locations of the excitation points, excitation directions and also response measurement points. As a result, the test was set up in the way as shown in Fig. 1 in which four springs and nylon strings were used to simulate free-free conditions of the structure.

Reduced order model and analysis: Reduced order model means a group of finite elements in which some of the degrees of freedom are condensed out for computational and modelling purposes (Craig *et al*., 2000). Using the reduced order model, a full FE model is divided into several substructures of condensed FE models.

The Craig-Bampton based reduced order modelling method has been used in FE modelling of complex and large-scale structures through which manageable size of FE models which are independently analysed, can be derived before a complete model is analysed. This method of combining motion of interface (constraint modes) with modes of the substructure, assuming the interface is held fixed, offers great advantages for model updating in which one or more components of the structure need to be modified and re-analysed while the others remain unchanged as reported by Craig *et al*. (2000).

In this study, the jointed structure was divided into five substructures, in which the degrees of freedom of four of them; side wall 1 (no. 1), side wall 2 (no. 2), stopper 1 (no. 3) and stopper 2 (no. 4) were condensed out using Craig-Bampton fixed interface method. They were then assembled to the bent floor (no. 5). The arrangement of the reduced order model of the jointed structure is shown in Fig. 2.

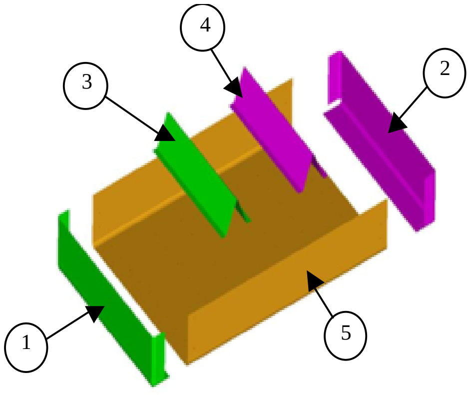

Fig. 2: Reduced order model of the jointed structure

The dynamic equation of motion for the Sth undamped reduced order model of substructure can be expressed as:

$$\left[K_{II}^{S} - \omega^{2} M_{II}^{S}\right] j_{I} = 0 \tag{1}$$

Where the superscript S relates to the substructure, the subscript I indicates interior degrees of freedom $M_{II}{}^{S}$,$K_{II}{}^{S}$ and ϕ_1 and Sth are the Sth substructure's mass matrix, stiffness matrix and eigenvector matrix respectively. The number of fixed boundary modes in Eq. 1 is calculated using NASTRAN.

The assembly of the reduced order model of the Sth substructure with the residual structure can be performed as usual, in practice by adding the submatrices at the boundary degrees of freedom, which generates the equation of motion of the coupled system:

$$\begin{bmatrix} M_{II}^{RS} & M_{BI}^{RS} & 0 \\ M_{IB}^{RS} & M_{BB}^{RS} + \hat{M}_{BB}^{S} & \hat{M}_{Bm}^{S} \\ 0 & \hat{M}_{mB}^{S} & \hat{I}_{mm}^{S} \end{bmatrix} \begin{Bmatrix} \ddot{X}_{II}^{RS} \\ \ddot{X}_{B}^{S} \\ \ddot{q}_{m}^{S} \end{Bmatrix} + \begin{bmatrix} K_{II}^{RS} & K_{BI}^{RS} & 0 \\ K_{IB}^{RS} & K_{BB}^{RS} + K_{BB}^{S} & 0 \\ 0 & 0 & \Lambda_{m}^{S} \end{bmatrix} \begin{Bmatrix} X_{II}^{RS} \\ X_{B}^{S} \\ q_{m}^{S} \end{Bmatrix} = \begin{Bmatrix} F_{II}^{RS} \\ F_{B}^{S} \\ F_{m}^{S} \end{Bmatrix} \tag{2}$$

Where RS, I and B indicate the residual structure, interior and boundary degrees of freedom respectively. In the absence of the external force, Eq. 2 can be rearranged and simplified to be eigenequations of motion as:

$$\left(\hat{K}-\omega^2\hat{M}\right)\varphi=0 \qquad (3)$$

Where and are the matrices of the complete assembly of stiffness and mass in Eq. 2. While corresponding to each natural frequency is an eigenvector representing the participation of the displacement coordinates.

RESULTS AND DISCUSSION

Table 1 shows a comparison of the results of natural frequencies between the test data and initial FE Model. The first comparison presented in the fourth column shows the difference between the test and initial FE results. They clearly indicate that there are big errors in the initial FE results, in particular in the first frequency (15.48%), the sixth frequency (5.39%) and the tenth frequency (4.97 %).

This suggests that there were considerable shortcomings in the initial FE Model. Therefore, FE Model updating is required in order to minimise the discrepancies. The updating procedure and selection of potential updating parameters which are used in this study to systematically improve the invalid assumptions about the initial FE Model in light of modal test data were clearly discussed in (Craig *et al*., 2000).

It was found that the initial stress arising as a result of welding the stoppers to the floor was responsible for the remaining big discrepancy in the natural frequencies of the structure and its effect was clearly explained and demonstrated by Liu *et al*. (2008) in a context other than model updating. When the initial stress and stiffness of the springs are both considered and represented by new updating parameters, the desired improvement is achieved as shown in the fourth column of Table 2 and 3.

The errors in the initial FE Model which are shown in Table 1 were drastically reduced, from 15.48 percent to 0.03% for the first frequency and from 45.13-10.85% for the total error of the full FE Model. The time taken (CPU time) to complete the updating process was 7240 sec.

Meanwhile, the notable achievement of the primary objective of this research which is establishing and using reduced order model in FE Model updating is gauged via the reduction in the discrepancies between the results of the test and reduced order model. The comparison is shown in the third and fourth columns of Table 3 with the total error of 11.06% and CPU time of 2302 sec.

This clearly shows that a significant reduction, particularly in time expenditure (CPU) and evidently indicates that the reduced order model of the jointed structure was successfully developed and efficiently used for model updating in comparison with the full FE model.

Table 1: Comparisons of natural frequencies between test and initial FE model

Mode (1)	Test data (Hz) (2)	Initial FE model (Hz) (3)	Before updating error (%) between 2 and 3 (4)
1	29.32	24.78	15.48
2	75.56	74.00	2.06
3	99.48	96.74	2.75
4	107.09	103.35	3.49
5	120.52	122.73	1.83
6	139.46	131.94	5.39
7	147.5	141.26	4.23
8	157.49	155.09	1.52
9	183.14	176.94	3.39
10	190.63	181.15	4.97

Total error (%) = 45.13

Table 2: Comparisons of natural frequencies between test and updated full FE model

Mode (1)	Test data (Hz) (2)	Initial FE model (Hz) (3)	Before updating error (%) between 2 and 3 (4)
1	29.32	29.31	0.03
2	75.56	76.69	1.49
3	99.48	100.33	0.85
4	107.09	106.04	0.98
5	120.52	120.97	0.37
6	139.46	138.56	0.65
7	147.5	146.43	0.73
8	157.49	159.55	1.31
9	183.14	179.99	1.72
10	190.63	185.45	2.72

Total error (%) = 10.85; CPU time (se) = 7240.00

Table 3: Comparisons of natural frequencies between test and updated reduced order model

Mode (1)	Test data (Hz) (2)	Initial FE model (Hz) (3)	Before updating error (%) between 2 and 3 (4)
1	29.32	29.32	0.02
2	75.56	76.88	1.75
3	99.48	100.56	1.09
4	107.09	105.79	1.21
5	120.52	120.88	0.30
6	139.46	138.19	0.91
7	147.5	146.41	0.74
8	157.49	159.77	1.45
9	183.14	180.81	1.27
10	190.63	186.20	2.32

Total error (%) = 11.060; CPU time (sec) = 2302.000

CONCLUSION

The dynamic behaviour of a jointed structure made from thin steel sheets was investigated experimentally and numerically. Two types of numerical models of the jointed structure namely the full FE Model and the reduced order model were constructed and used in minimizing the discrepancies between the experimental and numerical results. The cause for this discrepancy was discovered to be the initial stress and stiffness of the springs. The updating parameters identified were used successfully in the end to produce very good results for both the full updated FE Model and reduced order model. The latter has significant advantages over the former, with a similar degree of accuracy but considerable saving of CPU time. This achievement suggests that in terms of the accuracy of the updated results, the reduced order model has almost the same capability as the full finite element model has. However the comparative study of CPU expenditure for two different methods of model updating clearly suggests that the reduced order model will be more beneficial when it is used in an analysis involving large complex structures and also a huge number of computational iterations.

ACKNOWLEDGEMENTS

M.N Abdul Rani gratefully acknowledges the Malaysia Ministry of Higher Education (MOHE) and Research Management Institute (RMI) of University Teknologi MARA (UiTM) for providing financial supports for this study through the research acculturation grant scheme (RAGS)- 600-RMI/RAGS 5/3 (159/2014). He would also like to express his appreciation of helpful comments, suggestions and technical supports given by Mr. David Starbuck and Mr Fauzi Said.

REFERENCES

Craig, R.R., 2000. Coupling of substructures for dynamic analyses: An overview. Proceedings of the Conference on AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference and Exhibit, April 3-6, 2000, The University of Texas at Austin, Atlanta, GA, USA., pp: 1573-1584.

David, W.O.S., J. Wang and R. Cooper, 2010. Finite element model updating of a thin wall enclosure under impact excitation. Appl. Mech. Mater., 24: 337-342.

Friswell, M.I. and J.E. Mottershead, 1995. Finite Element Model Updating in Structural Dynamics. Kluwer Academic Publishers, Netherlands, pp: 286.

Liu, Y., Z. Duan and H. Li, 2008. An updating method suitable for finite element model updating of large-scakled structures. Mater. Forum, 33: 79-86.