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An Investigation of Eigenvalues of Sheet Metal Undergoing Bending Stresses

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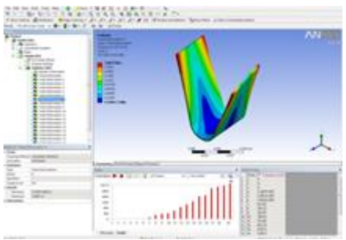
Graphical abstract



Abstract

Accurate prediction of dynamic properties of system is important to ensure the dynamic based design integrity of its member is not compromise. It will reduce or possibly eliminate the possibilities of further modifications in-situ of real system. On this account, this study investigates the modal parameters of the pre-stress sheet metals undergoing bending stresses which is commonly used in practice as structural members. In addressing this issue, three different shapes of sheet metals of similar thickness were studied i.e. straight plate, U-shaped and V-shaped plates. The natural frequencies of these configurations were determined experimentally using the Operational Modal Analysis (OMA). Numerical values were obtained using ANSYS software. Results of these shapes acquired experimentally and numerically were then compared and analyzed. Significant reduction in the eigenvalues of is observed on bent plates both experimentally and numerically as compared to flat plate.

Keywords: Operational Modal Analysis, natural frequencies, eigenvalues, mode shapes, model updating

1.0 INTRODUCTION

A proper design of any structure taking into account of its dynamics behavior has become more important than ever. These will enhance the system performance together with other common criteria in the design such as safety, stability, comfortability, economics and lifecycle. Since the past few decades, sustainability has been a major concern among engineers. All of these factors are paramount especially in vibration and noise of structures and machines. Poor design consideration may lead to excessive vibration and noise level, thereby creating unpleasant surroundings. Often some modifications on an already-to-use model need to be carried out which in turn incur additional cost and time consuming. A proper design at the early stage is very enviable in order to avoid such repercussions. To address this issue, model updating has been extensively researched in search of design uncertainties for accurate model responses. However, the effort has not been done comprehensively on all types of loading conditions and on design uncertainties, particularly, in bending stresses. Disregarding these stresses will have significant effects on the structures' behaviors.

Experimental methods in vibrations, such as Operational Modal Analysis (OMA) and Experimental Modal Analysis (EMA) have been well-established and become powerful approaches in identifying the dynamics properties of structure [1, 2], while on the other hand, Finite Element Method (FEM) has been used extensively in modeling and obtaining these properties under assumed ideal conditions. The reliability of these experimental methods and the limitations of FEM could be further enhanced in searching for better and consistent results obtained in the present of uncertainties and nonlinearities. The improvisation of parametric data into analytical model based on experimental method is known as model updating. The reliability of this analytical model matters most at the early stage in design processes.

Many attempts have been made by researchers in order to get accurate analytical models in structural dynamics. Some researches focused on the method [3,4] while others on parameterization process [5]. Generally, there are two methods in model updating namely direct method and iterative method. Both methods require modal data obtained from the experiment which will be updated by some correlation techniques. They yield comparable results but the direct method requires a very high quality of experimental data especially for complex structures [6-8]. Iterative method, on the contrary, needs a sensitivity-based method in improving the correlation between the predicted and measured eigenvalues and eigenvectors. These results, however, are applicable for parameterization in model updating.

The updating process has been studied on the inclusion of important parameters such as pre-stress. Structural joints have been put into consideration in parameter's modeling. Experience has shown that many of the joints commonly used on structures, serving as design requirements can result in substantial and often unpredictable reductions in the stiffness of the primary structure [9-10]. On top of that, in the absence of reliable analysis methods for estimating joint effects on structural stiffness and dynamics, a common practice is to rely on experimental data for the definition of joint properties. The shortcoming of this approach, however, is that the data obtained for a particular type of joints on a given structure often cannot be confidently extrapolated in different structural designs or even, in many cases, to a different location on the same structure.

Bolted joint is one of the joint types for joining structural components. Being easily dissembled, maintained and inspected has made bolted joint becomes one of the prevailing joint types in practical work of engineering industry. This type of joints, nonetheless, has many complexities such as pretension, nonlinear frictional behavior, and etc., which are very difficult to investigate and compute yet, are important for joints [11]. The results obtained were extremely reliable for the application in the finite element analysis.

The updating on welding parameters has been dealt with comprehensively by taking into account the current levels, electrode force, surface condition, material type and material thickness [12]. The results revealed that those parameters are of important inputs in finite element analysis for materials under zero pre-stress condition.

However, none of the aforementioned studies has been focusing on the parametric model updating on sheet metals under the bending stresses prior to execution of further manufacturing processes like in spot welding and riveting. This research dealt with the investigation of the modal parameters of sheet metal under the pre-stress of bending process. The dynamical properties of flat sheet metal will be first analyzed numerically and experimentally followed by the U-shaped and V-shaped sheet metal plates. The natural frequencies obtained from the three configurations are then compared analyzed.

2.0 EXPERIMENTAL AND NUMERICAL METHOD

To implement the dynamic study of the various shapes and sizes, three specimens of identical dimensions were prepared from the same piece of mild steel sheet metal. Figure 1 shows the A36 mild steel of the flat plate. The dimensions of the flat plate are 350 mm x 100 mm with the thickness of 40 mm. The weight of each sheet metal is weighed as 1.066 kg. One of the sheets is maintained as it, while the two remaining specimens were formed to U and V-shapes using the Universal Testing Machine (UTM).

Figure 1 The A36 mild steel flat plate

The U-shape sheet metal was bent before it reached the plastic deformation while the V-shape was bent beyond the plastic region. Both of the plates underwent the three point bending process as shown in Figure 2.

The study includes both numerical simulation and experimental work. In the simulation, the finite analysis software (i.e. ANSYS software version 15.0) was used to obtain the numerical values of the modal parameters, the natural frequencies in particular. The solver used was 103 Modal Analysis. The properties of the mild steel A36 was used as input value for material properties and geometry. As for the experimental results,

Operational Modal Analysis (OMA) was used to extract and animate the modal parameters as shown in Figure 3. In the experiment, the Bruel & Kjaer Pulse TM multi-analyzer instrument was used and was connected to a computer with MTC software and Operational Modal Analysis (OMA) Pro software. There were 12 accelerometers used in the experiment.

Figure 2 Three-point bending process

Figure 3 The testing of specimens

Once the experimental and numerical data are captured and obtained, these results are compared and analyzed to observe the effect of the shapes on the natural frequencies.

3.0 RESULT AND DISCUSSION

The results of the flat plate, U and V-shape plates from the numerical and experimental studies can be tabulated as in Table 1. There are six (6) modes that were be captured experimentally and hence compared with simulation results.

From Table 1, it is obvious that the first five modes of the flat and U-shaped plates show that the natural frequencies of the FEA are much greater than the natural frequencies obtained experimentally. However, for the V-shaped plate, all the natural frequencies obtained from the experiment are greater than that of FEA. The FEA shows no difference in the natural frequencies for the flat and U-shaped plates while the values of the natural frequencies obtained experimentally dropped slightly. The discrepancy of the natural frequencies of the flat, U-shaped and V-shaped plates varies from 7.7-16.8 %, 9.5-17.3 % and 9.5-16.4 % respectively. Most importantly, the experimental eigenvalues decreased from flat plate to U-shaped and V-shaped plates.

4.0 CONCLUSION AND RECOMMENDATION

The study carried out has successfully determined and identified the eigenvalues of the three different specimens. In conclusion, the changes on the configuration of a system due to bending processes have changed the properties of the system. Therefore the parametric updating is utterly needed to be performed to get an accurate prediction of systems subjected to initial pre-stress loading. It is suggested to provide better insight on the modal behaviour, the investigation be extended to similar loading environment with various material thicknesses. Besides that, actual material properties need to be obtained through tensile test and density test to furnish the updated FEM analytical model hence enhancing the accuracy of the results, thus reducing the percentage error between the simulation and experimental results.

Table 1 Natural frequencies of the plates

Mode	Flat Plate			U-shaped Plate			V-shaped Plate		
	Frequency (Hz)		Discrepancy (%)	Frequency (Hz)		Discrepancy (%)	Frequency (Hz)		Discrepancy (%)
	OMA	FEA		OMA	FEA		OMA	FEA	
1	157.8	169.9	7.7	154.9	169.9	9.7	109.5	91.5	16.4
2	316.8	358.8	13.3	306.6	358.8	17.0	307.1	267.2	13.0
3	437.1	471.2	7.8	430.1	471.2	9.5	389.9	352.9	9.5
4	655.5	749.6	14.4	639.0	749.6	17.3	454.8	384.9	15.4
5	844.8	927.3	9.8	829.5	927.3	11.8	669.0	572.9	14.4
6	1445	1201.8	16.8	1422.0	1201.8	15.5	937.1	821.3	12.4

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