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GUIDED WAVE PROPAGATION ON LOADED PLATE

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ABSTRACT

During in-situ monitoring, structures are exposed to load changes which may mask the damage-induced signal or produced false alarm unless compensation is performed. Studies on guided wave propagation due to symmetrical load have been done by previous researchers, so this research is concentrated on asymmetrical load applied to an infinite, thin aluminium plate with thickness of 1mm using ABAQUS in two-dimensional mesh. There is no analytical solution for the loaded plate, so dispersion curve provided by semi-analytical finite element (SAFE) method is used for verification purpose. Excitation force is set to 100kHz due to effects of load only occurred at low frequency region.Wave propagation speed increases withan increase in strain valuesapplied onplate under extension load. This is due to the increase in the platestiffness. Nevertheless, this condition did not work for plate under bending. Results of ABAQUS in space-time domain are able to provide obvious difference between various load applied on plate but not the 2D FFT curves. Center frequency of excitation force cannot be set lower, which is the limitation of the proposedapproach.

Keywords : *Guided wave propagation, loaded plate, symmetrical mode, asymmetrical mode, finite element method*

1.0 INTRODUCTION

The application of guided wave in structural health monitoring is still an open problem due to the difficulties in extracting accurate and reliable information from the complex damage signal, especially for real structure shaving complex geometry and boundary conditions. During in-situ monitoring, structures are exposed to load variety that are unavoidable. Thus, load changes may mask the damage-induced signal or produced false alarm unless compensation is performed. Hence, effects of load on guided wave propagation have become the concern in this research.The wave propagation behaviours are described using dispersion curves. Effects of load on dispersion curves are obvious only at low frequency region and negligible at high frequency region [1-3]. Previous study also shown that the effects of load is stronger forasymmetrical mode A_0 compared to the symmetrical mode S_0 [3].

There is no analytical solution available for the wave propagation behavior in loaded plate. Therefore, finite element method (FEM) is used in this work to study the behavior of guided wave propagations in loaded plates. Studies on effects of load to rod, plate or rail have been done by earlier researchers [1-3]. However, they have concentrated only on uni-axial load. This work on the other hand looks into the behavior of guided wave propagations under both uni-axial load and bending load conditions. The effects of asymmetrical load to guide wave propagation in plates need to be investigated as they might occurs in practical application.

In the FEM analysis, 1mm thick aluminum plate is used in the 2D simulation using ABAQUS software. The load is assumed to be coming from thin piezoelectric

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transducer which can be simplified as point loads acting at the edges of the transducer. Displacements for multiple points located at a distance away from the point loads are monitored. From the point displacements calculated in FEM, the dispersion curves showing the guided wave propagation behaviour is plotted using two-dimensional fast Fourier transform (2D FFT) approach [5]. Lastly, the limitations of the proposed approach is discussed.

2.0 VERIFICATION OF THE PROPOSED FEM APPROACH

As there is no analytical solution for loaded plate, semi-analytical finite element (SAFE) method [4] is used calculate the dispersion curves to verify the FEM approach proposed here. However, the SAFE method is suitable only for uni-axial load. Thus, a plate under uni-axial load is simulated in ABAQUS for the verification purpose.

However, the result obtained from ABAQUS is in space-time domain. Hence, it cannot be directly overlapped with the SAFE solution (that is in frequency domain) for verification purposes. The 2D FFT is required to convert the space-time domain into the frequency domain. In the literature,there are several dispersion curves available i.e phase velocity versus frequency, group velocity versus frequency, and wavenumber versus frequency. The wavenumber-frequency dispersion curve is the easiest dispersion curve to be extracted from ABAQUS simulation results.

An ABAQUS simulation is made for an aluminium plate that has a thickness of 1 mm and a length of 250mm that is exerted with extensional load of 0.1% strain (uni-axial load equal to 70MPa). A pulse with center frequency of 100kHz is then excited in the plate to induce the A_0 mode. Points from distance d = 50 mm to 150 mm are monitored with interval e = 1 mm which translates to 101 monitored points. The SAFE dispersion curve is then overlaped with the dispersion curve obtained using the 2D FFT approach based onthe ABAQUSresults. Figure 1 shows that both curves intersect perfectly, hence verifying the proposed procedure. The result is concentrated at 100 kHz which is the center frequency of the pulse.

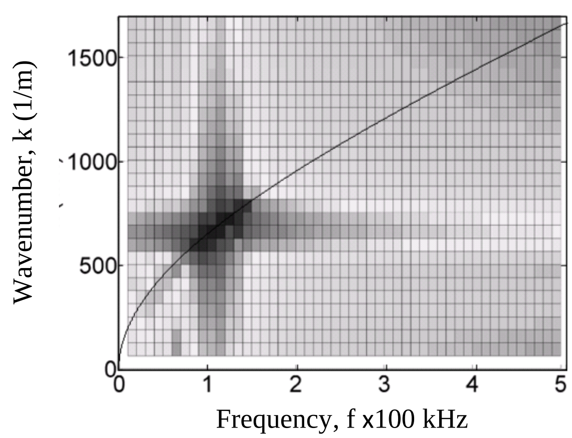

Figure 1: Overlaping of dispersion curve provided by SAFE (straight line) and ABAQUS

3.0 FEM SIMULATIONS FOR DIFFERENT LOADING CONDITIONS

After the verification of the FEM procedures, similar ABAQUS simulations are continued for the guided wave propagation in plate with different loading condition. The modeling of the plate in ABAQUS are shown in Figures 2 to 6. The length of plate under uni-axial load (extension load) is 250mm, while plate length of 500mm is used for plate under bending load. The monitored points interval e = 1mm is taken with 101 monitored points from the excitation force point i.e. d =50 to 150mm. The excitation force is set as a pulse at 100kHz since the effect of loads are obvious only at low frequency region [3]. Only A_0 mode is excited as the effects of load on other modes are negligible [3]. Displacement at the monitored points along x-axis (U1) and y-axis (U2) are used in the 2D FFT. The FEM analysis of the loaded plate consists of static and explicit steps. Static step is used to induce the uni-axial and bending load conditions while the explicit step is used to excite the A_0 mode in the plate. After the static step simulation, the calculated data are then exported to the explicit step for further simulation.

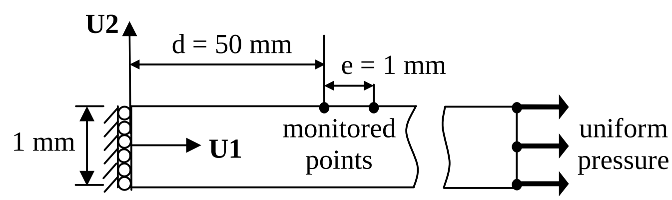

Figure 2: Plate under extension in static step with uniform pressure pulling outward to simulate the uni-axial loading.

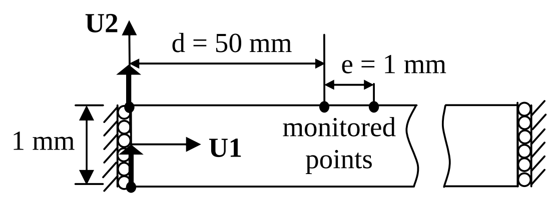

Figure 3: Plate under extension in explicit step,excited with anti-symmetrical mode, A_0

Two different patterns of bending loads are applied in this research to see if it would cause any differences in the wave propagation on the plate, as shown in Figures 4 and 5.

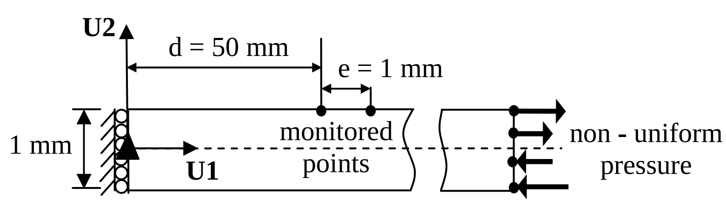

Figure 4: Plate under bending in static step with asymetrical pressure applied.

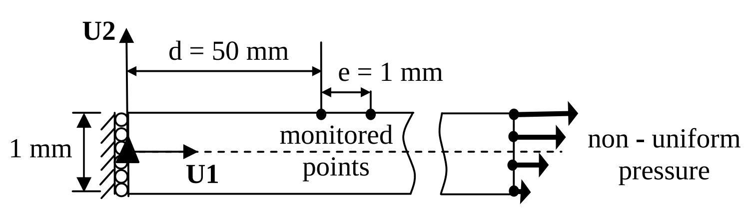

Figure 5: Plate under bending in static step with asymetrical pressure applied.

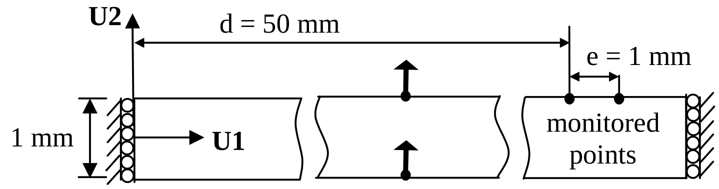

Figure 6: Plate under bending in explicit step,excited with anti-symmetrical mode, A_0

4.0 RESULTS AND DISCUSSIONS

As mentioned earlier, the results obtained directly from ABAQUS is in space-time domain, as shown in Figures 7 to 9. Figure 7 provides a zoom view at one of the peaks of the amplitude of U1 displacement in time domain for plates with conditions of (i) unload, and (ii) uni-axial (extension) load. The curves are smooth and the order shows that higher load would cause the wave to propagate faster in the plate. Wave propagation speed increases with strain values applied on the plate. The 0.1% strain line (70MPa) always lead all the other lines due to its highest strain value, followed by 0.08% strain (56 MPa) line, 0.06% strain (42 MPa) line, 0.04% strain (28 MPa) line, 0.01% strain line (7 MPa) and 0% strain line (unload). However, Figure 8 shows that the wave propagation speed did not increase with strain values for plate under bending (load pattern as in Figure 4) with pressure values of 1kPa (0.00000143% strain), 10kPa (0.0000143% strain), 910kPa (0.0013% strain), 980kPa (0.0014% strain) and 1.08MPa (0.00154% strain).

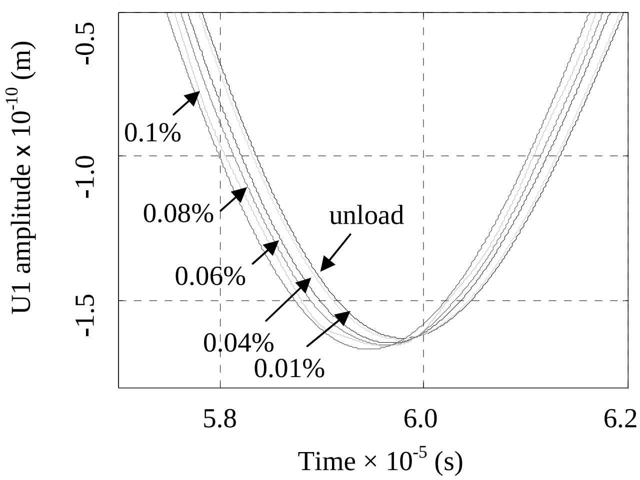

Figure 7 : Zoom views of U1 amplitude peaks in time domain for plate under no load and plate under uni-axial (extension) load with various strain values at d=50mm.

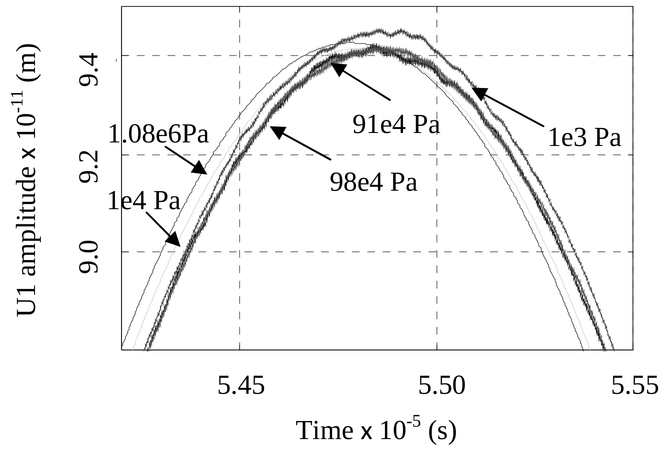

Figure 8 : Zoom views of U1 amplitude peaks in time domain for plate under bending (load pattern as in Figure 4) with various strain values at d=50mm.

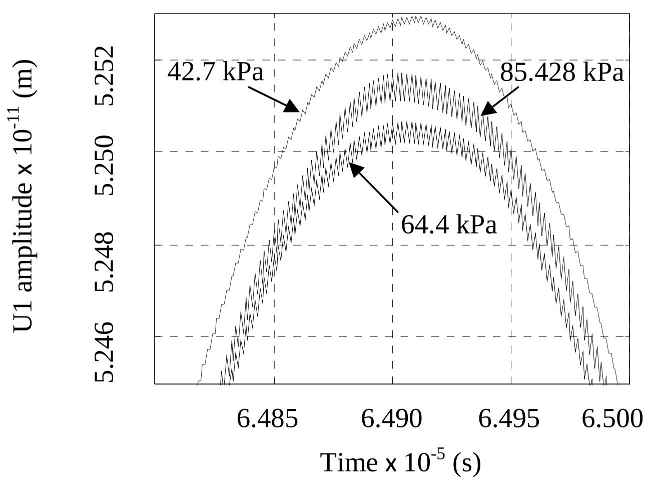

Figure 9 : Zoom views of U1 amplitude peaks in time domain for plate under bending (load pattern as in Figure 5) with various strain values at d=50mm.

Figure 9 shows that the wave propagation speed did not increase with strain values for plate under bending (load pattern as in Figure 5) with pressure values of 42.7 kPa (0.000061% strain), 64.4 kPa (0.000092% strain) and 85.428 kPa (0.000122% strain). Plate under bending load initially contains stresses along the plate length and hence caused instability in the displacements obtained for certain strain values.

The displacement results obtained from ABAQUS in the space-time domain are exported to Matlab for the 2D FFT process that transform the data to dispersion curves in wavenumber-frequency domain. The dispersion curves for plate under extension and bending loads with various strain values are similar with each other as shown in Figures 10 and 11. The difference between dispersion curves for these strain values are not obvious as the excitation frequency is not low enough. However, the frequency of the excitation pulse cannot be set lower due to the limitation of the finite element method implemented in ABAQUS. If lower value of frequency is selected, numerical instability would occur.

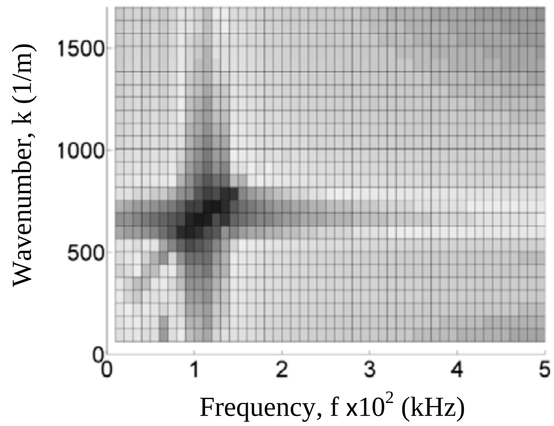

Figure 10 : Amode Dispersion curve of wavenumber, k (1/m) versus Frequency, f (kHz) for plate under extensional with 0.1% strain (70MPa)

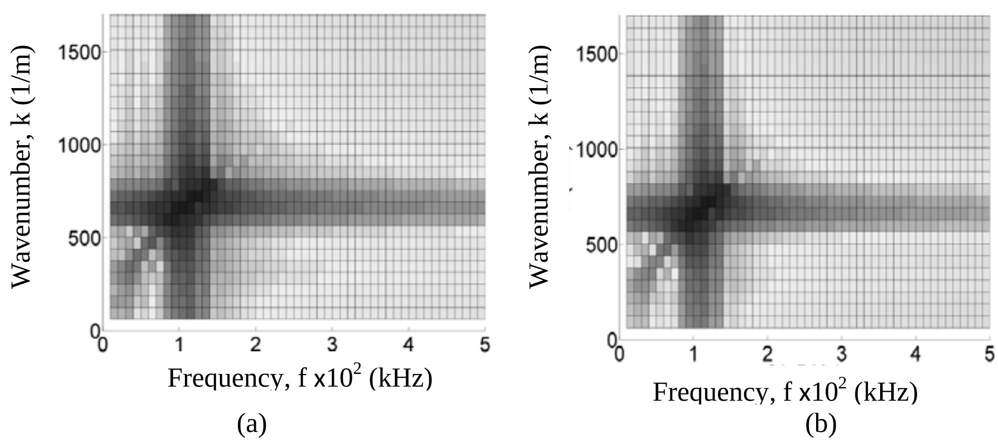

Figure 11 : Antisymmetrical mode dispersion curve of wavenumber, k (1/m) versus frequency, f (kHz) for plate under bending (a) pattern in Figure 4 with 1.08MPa (0.00154% strain) and (b) load pattern as in Figure 5 with 85.428 kPa (0.000122% strain)

5.0 CONCLUSIONS

Wave propagation speed increases with the increase of strain values for plate under extension load. This is due to the increase in the platestiffness during uniform increment of strain applied on plate during uni-axial loading. However, wave propagation speed did not increase with the increase of the strain values for plate under bending. From theprevious results in [3,4], effects of load on wave propagation only can be observed in low frequency region. Hence, the center frequency of the excitation pulse is set at 100kHz in order to observe the load effects on the wave propagation. The displacement results from ABAQUS in space-time domain are able to show obvious differences for various strain values. However, the dispersion curves obtained from the 2D FFT procedure are unable to showthese differences. It is believed that center frequency of the excitation pulse need to be lower than 100kHz in order the see the difference in the dispersion curves. However, due to the limitation of the proposed finite element method, this can not be done due to numerical instability. For future research, this FEM approach could be extended for modelling loaded 3D waveguide such as loaded rod and loaded rail. The analysis for loaded rod could be used to verified the approach with available analytical solution of loaded beam model. Furthermore, torsion load may also be considered.

ACKNOWLEDGEMENTS

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