Prediction of Load at Which Nonlinearity Initiates in a Cantilever Beam

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Abstract: Nonlinearity is a frequent occurrence in engineering structures and its study is being more widely accepted over linear experimental modal analysis. Nonlinear systems exhibit extremely complex behaviour which the linear systems do not produce. Non Linearity can be induced by varying the geometry of the model and excitation like frequency, displacement. The cantilever system used for the experiment have two beams which are connected to each other. Hence in this system the resonance condition is the cause of the nonlinearity in the system. Both the beam interacts together to reach the resonance condition. At this condition the maximum deflection is obtained and lead to nonlinearity.

Index Terms—Nonlinear dynamics, Nonlinear normal modes, Modal analysis, Resonance.

1. Introduction

Nonlinear systems exhibit extremely complex behaviour which the linear systems do not produce. These phenomena include jumps, resonance captures, bifurcations, saturation, limit cycles, subharmonic, super harmonic and internal resonances, modal interactions and chaos. Non-linear normal modes of vibration for a cantilever beam are assessed considering both the continuous framework and finite element models. Non Linearity can be induced by varying the geometry of the model. Another way of introducing nonlinearity could be increasing the amplitude of input excitation. The thin beam used is the cause of nonlinearity in the system. The load level at which the nonlinearity behaviour initiates is obtained by using static analysis in Ansys.


2. Ansys code development

2.1. Geometric Modelling

A cantilever beam used in the experiment can be considered as a model and we can apply the same principle for the other cantilever structures having
the geometric nonlinearity such as aircraft wings, long bridges, helicopter blades, etc. The detailed dimensions of the part considered for the analysis is given in Table 2.1.

### Table 2.2: Dimensions of the beams

<table>
<thead>
<tr>
<th></th>
<th>Length(m)</th>
<th>Width(m)</th>
<th>Thickness(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main beam</td>
<td>0.7</td>
<td>0.014</td>
<td>0.014</td>
</tr>
<tr>
<td>Thin beam 1</td>
<td>0.04</td>
<td>0.024</td>
<td>0.001</td>
</tr>
<tr>
<td>Thin beam 2</td>
<td>0.15</td>
<td>0.024</td>
<td>0.001</td>
</tr>
</tbody>
</table>

The cantilever beam is having two parts, the main beam or the thick beam and the thin beam section. These two beams are joined together and the structure is modelled for 4cm thin beam as shown in fig 2.1 and 15cm thin beam as shown in fig 2.2.

2.2. Material Model

The material used for the analysis is Stainless Steel for the thin beam and mild steel for the thin beam. Since forced simulation takes place in a variable load condition, a very detailed force dependent, nonlinear material model is required for the simulation. The major properties required for the analysis are:

- **For Mild Steel**
  - Modulus of Elasticity - $210 \times 10^9$ N/m²
  - Poisson’s Ratio - 0.303
  - Density - 7850 Kg/m³

- **For Stainless Steel**
  - Modulus of Elasticity - $200 \times 10^9$ N/m²
  - Poisson’s Ratio - 0.305
  - Density - 7700 Kg/m³

3. Analysis using Ansys APDL 15.0

The analysis using Ansys is done to obtain the frequencies in which the non-linearity is occurring. The main focus is on the first three modes. 4cm and 15cm thin beam were used for the modal analysis and results are as shown below:

3.1. Modal Analysis of 4cm Thin Beam

The first mode obtained for the cantilever beam of length 0.7m attached to 4cm thin beam which is shown in Fig 3.1.
The second mode obtained for the cantilever beam of length 0.7m attached to 4cm thin beam which is shown in Fig 3.2.

The third mode obtained for the cantilever beam of length 0.7m attached to 4cm thin beam which is shown in Fig 3.3.

### 3.2. Modal Analysis of 15cm Thin Beam

The first mode obtained for the cantilever beam of length 0.7m attached to 15cm thin beam which is shown in Fig 3.4.

The second mode obtained for the cantilever beam of length 0.7m attached to 15cm thin beam which is shown in Fig 3.5.

The third mode obtained for the cantilever beam of length 0.7m attached to 15cm thin beam which is shown in Fig 3.6.

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Natural Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference Paper Value</td>
</tr>
<tr>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>145</td>
</tr>
<tr>
<td>3</td>
<td>395</td>
</tr>
</tbody>
</table>
4. Result and Discussions

In Ansys the static analysis is done for the small displacement and the large displacement and if there is any variation in it shows that there is presence of the non-linearity. Non linearity is observed and load level is obtained by using static analysis is done in the Ansys. In thin beam of having length 4cm the non-linearity starts at load 11.2N as shown in fig 4.1 and from the reference paper [4] the value obtained by them while numerical calculation is 11.7279N.

Fig. 4.1 : Prediction of load level in 4cm thin beam

The table 4.1 shows the load values obtained for the reference paper and obtained value of load in Ansys.

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Reference Paper Load(N)</th>
<th>Obtained Value of Load(N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.7279</td>
<td>11.2</td>
</tr>
</tbody>
</table>

From this we can understand that similarly we can predict the load for the 15cm thin beam as shown below in fig 4.2.

Fig. 4.2 : Prediction of load level in 15cm thin beam

5. Conclusions

The cantilever system used have two beams which are connected to each other. Hence in this system the resonance condition is the cause of the nonlinearity. Both the beam interacts together to reach the resonance condition. Hence maximum deflection is obtained and lead to nonlinearity. The first modes of the both beam have excited at same time to get the interaction. The actual load obtained was a little high because the thin beam used has higher width. The beams have to deflect and the geometric nonlinearity come into effect when the thin beam deflect much more due to the resonance created. The static linear analysis of the cantilever beam have been done and the load level is compared with the load value of the reference paper [4]. Thus the load value at which the nonlinearity is initiating for a specific system is identified. Thus it could be inferred that this technique can be applied to any cantilever structure and the load at which nonlinearity excited can be predicted.

6. Acknowledgements

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7. References