COMPUTATIONAL MODELING WITH FEM AND WAVELET TRANSFORMS TO HELP IN THE DETECTION OF DAMAGES IN NUCLEAR POWER PLANTS

R.S.Y.C.Silva\textsuperscript{1}, L.M.Bezerra\textsuperscript{1}, L.A.P.Peña\textsuperscript{1}
\textsuperscript{1}Department of Civil Engineering, University of Brasilia, Brasilia, BRAZIL- 70910900
E-mail of corresponding author: ramon@unb.br

ABSTRACT

In the nuclear industry, due to radiation, some structures, like beams, columns and pipeline inside the complex Nuclear Power Plant (NPP) are very difficult to inspect and, moreover, to determine the location of a potential crack. In such inaccessible zones, it should be very helpful, if one could detect a potential damage just knowing signals like, stress, displacement, or deformation distribution along part of the structure, for example. Nowadays, many researches are trying to establish numerical formulations to help in the detection of the location of a damage using numerical techniques associated to finite element or boundary element methods, among others. With a previous detection of the location of a crack, the region for inspection can be significantly reduced, and the prices of such examination task substantially reduced. This paper presents simple applications of the Wavelet Transforms for the detection of damages in structures. Different Wavelet Transforms are applied to the displacement or mode shape responses of simple structures under static or modal analysis. Using finite elements from ANSYS software, the modeling of damage is simulated by deleting some finite elements from the mesh. The static response (in displacement) of the damaged structure is employed in the analysis to detect the location of damages using two mother-Wavelet and the locations of cracks were successfully detected. It is also important to notice that such numerical technique may also be applied for health monitoring of NPP structures under operations. The results of all the analyses are presented and discussed in this paper.

INTRODUCTION

In the last decades, scientists have showed a large interest in researches associated to damage detection in structures. Such researches include the intensive use of numerical methods to help in the non-destructive techniques of structural performance monitoring and pathology detection \cite{6} in civil, aerospace, and also nuclear engineering. Although the literature on damage recognition is predominantly focused on methods that utilize frequency or stiffness variation information converted in structural signatures, a new formulation based on signal analysis \cite{1,2,4} methods that uses wavelet transform is promising. Generally, the numerical methods make the comparison of signatures obtained before and after the onset of damage, and these signatures are defined in terms of displacements, frequencies, mode shapes, stress, among others. However, it should be very significant important that the indication of damage position could be showed without comparing structural signatures but just based on the response of damaged of the actual structure.

WAVELETS THEORY

Considering a signal $f(x)$ of interest in the space domain. The value of the wavelet function in terms of two parameters “a” and “b”, named, respectively, dilation and translation can be generated from the mother wavelet $\psi(x)$, as:

$$\psi_{a,b}(x) = \frac{1}{\sqrt{a}} \psi \left( \frac{x - b}{a} \right)$$

(1)

Moreover, the wavelet coefficient $c_{a,b}$ obtained after the integral of the signal $f(x)$ multiplyed by the function $\psi_{a,b}(x)$ in Eq. (1) and integrated, as in Eq. (2), is defined as:
\[ C_{a,b} = C_{a,b}(x_o) = \int_{-\infty}^{\infty} f(x) \Psi_{a,b}(x_o) \, dx \] (2)

The wavelet coefficients above represent how the signal \( f(x) \) correlates to \( \Psi_{a,b}(x) \). These coefficients are very sensitive to any discontinuities or singularities present in \( f(x) \). Considering this sensitive property and the verification that damage can cause loss of stiffness and consequently changes in the displacement signal \( f(x) \), a formulation can then be conceived to detect damage. Any small disturbance generated in the signal \( f(x) \) of the corresponding displacement or vibrating mode shapes of a structure with damage will create very large amplitudes in the wavelet coefficient \( C_{a,b} \). This perturbation on \( C_{a,b} \) due to a damage is used in this research to detect damage [3]. During computation of the wavelet coefficient \( C_{a,b} \), the analysing wavelet is shifted smoothly all over the full domain of the signal \( f(x) \) [5].

**NUMERICAL STUDY**

This section presents the finite element model of cantilever beams cracked used in this research subjected to static and modal analyses and also errors noises in the response signals. The beams were modeled using the element PLANE42 of ANSYS11.0 program.

The element PLANE42 has four nodes and three degrees of freedom by node: translations in x, y and z directions. The signals of static response obtained in ANSYS were analysed in MATLAB program to compute the wavelet coefficients.

**Static Analysis**

The cantilever beam was submitted to a load \( F=500\,\text{kN} \) in the free end and to a transverse crack \( a^* = 0.025\,\text{m} \) positioned at \( d=0.125\,\text{m} \) from the clamped end, see Fig. 1. The material and geometric properties of the beam analyzed are shown in Table 1.

![Fig. 1: Schematic model of cantilever beam](image)

**Table 1: Geometric and materials properties of cantilever beam**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Symbol</th>
<th>Value</th>
<th>Unity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam width</td>
<td>B</td>
<td>0.10</td>
<td>m</td>
</tr>
<tr>
<td>Beam height</td>
<td>H</td>
<td>0.10</td>
<td>m</td>
</tr>
<tr>
<td>Area</td>
<td>S</td>
<td>0.01</td>
<td>m²</td>
</tr>
<tr>
<td>Moment of inertia</td>
<td>I</td>
<td>8.333x10^{-6}</td>
<td>m⁴</td>
</tr>
<tr>
<td>Beam length</td>
<td>L</td>
<td>0.50</td>
<td>m</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>E</td>
<td>200.00</td>
<td>GPa</td>
</tr>
<tr>
<td>Density</td>
<td>( \rho )</td>
<td>7850.00</td>
<td>Kg/m³</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>( \nu )</td>
<td>0.30</td>
<td>-</td>
</tr>
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</table>
The finite element model of cantilever beam was discretized in 4000 elements and 4509 nodes, the crack was simulated deleting some elements from the mesh and the boundary conditions were applied in the all nodes of left end restricting the degrees of freedom x, y and z, see Fig. 2.

[Image: Finite element model of cantilever beam]

The nodal displacements of beam with crack and without crack are presented in the Fig. 3.

[Image: Deflection of cantilever beam]

The wavelet transform was applied in the signal of displacements obtained in the nodes of bottom line of beam using the wavetoolbox of MATLAB to compute the wavelet coefficients for two different mother-wavelet: biorthogonal6.8(bior6.8) and daubechies2(db2). The Figs. 4 and 5 shows the results of these wavelet transforms.
The two mother-wavelet were able to detect the exact position of damage (node 125), moreover, the graphics presented little perturbations in the ends due to geometric discontinuities.

Static Analysis with Noise

For evaluate the effect of noise in the damage detection process, 1% of noise, corresponding to 1% of the average value of the signal, was added in the static signals and the results are presented in Figs. 6 and 7.
Comparing the Figs. 4 and 5 with the Figs. 6 and 7, one observes that the introduction of noise caused an increase in the disturbances along of signal, but nevertheless, the crack was detected.

MODAL ANALYSIS

In the modal analysis, the three mode shapes were computed and the first mode shape was used in the application of wavelet transforms, as can be seen in Figs. 8,9 and 10.
The results of the modal analysis show that the application of wavelet transforms in the modal signals, like mode shapes, could be used in the damage detection process, furthermore, the modal signals transformed presented less disturbances than static ones.

**CONCLUSIONS**

This paper presented a mathematical methodology associating finite element analysis and wavelet transform for the solution of the inverse problem of damage detection. The signals used in this research were static and modal signals. Such methodology can be applied to help in non-destructive techniques for the detection of structural damages and even for structural performance monitoring. Throughout all the examples shown in this paper, the wavelet transform was applied to static displacement or mode shape signals and the results showed an effective way to detect the position of the simulated damages. Signal noises were introduced on the data corresponding to a percentage of the data average. Even with noises up to 1%, the wavelet transform was able to detect the damage on the examples analyzed. The main advantage of the methods presented here is that it can indicate the position of damage just from the response of damaged structure not comparing signatures from the structure before and after the damage.

**REFERENCES**


