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Finite element analysis of vessels to study changes in natural frequencies due to cracks

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Abstract

When significant damage occurs in structures, there is a change in stiffness, which in turn affects the natural frequency. To study this, a study was conducted to analyse the effect of cracks on natural frequencies in two vessel structures. Finite element analysis has been used to obtain the dynamic characteristics of intact and damaged vessels for the first eight modes of these structures. Two kinds of vessel, boilers and storage tanks, were chosen and through-thickness cracks were analysed. Different cases were examined by changing the size and locations of cracks with the help of a FEM (Finite element model). Natural frequencies and mode shapes were analysed. The natural frequencies for different modes have been used as input pattern of ANN (artificial neural network) model. The output of the ANN model is a crack size for a particular location. It was found that as the crack size increased, natural frequency changed to a large extent, but the frequency was not reduced in the same manner for every position of damage for the same size of crack. It was also found that the reduction in natural frequencies depends upon the mode shapes of the structures.

Keywords: Natural frequency; FEM; Mode shape; Artificial neural network; Vessels; Crack

1. Introduction

Pressure vessels are needed in the oil, chemical, nuclear power and many other industries. In the process industries, application for such vessels includes paper and pulp mills, caustic soda plants, bleaching, water purification, sewage treatment, refineries, anti-freeze components, fertilizers, insecticides and refrigerants plants. The primary requirement of these vessels is to be leak proof, so it is important to detect cracks in pressure vessels and storage tanks before use. NDT techniques can be used to detect a flaw in the pressure vessel.

The existence of a crack causes changes in natural frequencies, mode shapes and structural damping. Since, the measurement of natural frequencies is easier than that of changes in structural damping, damage can be detected from dynamic analysis using natural frequencies and mode shapes. Examination of the change in natural frequencies allows an estimation of both the location and size of the crack [1–3]. The dynamic characteristics like mode shapes and natural frequencies can be estimated by both experimental and numerical methods [4,5]. Several researchers [6–8] used this fact for damage detection. As damage detection is an inverse, non-linear and non-unique problem, that generally does not have a feasible algorithmic solution or for which an algorithmic solution is too complicated to be found and handled, a different approach is required. Therefore, artificial neural networks (ANNs) [9,10], are used for automation of defect identification and tracking [11].

In the present work, boiler and cylindrical storage tanks were chosen as test structures. A FEM (finite element model) has been used to determine the dynamic characteristics of the intact and damaged structures up to eight modes of the structures. Different damage scenarios were obtained by changing the size of the defect at different locations. Natural frequencies and corresponding mode shapes were obtained by FEM. Different cases with different location and size of cracks were studied to see for which location the reductions in natural frequencies were significant. Natural frequencies corresponding to different crack sizes for a particular location were used as input patterns to an artificial neural network. The output of the ANN is a crack parameter (crack size).

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Nomenclature

a	size of crack	*h*	height of storage tank
c	distance of crack on cylindrical shell from bottom	*l*	effective length of boiler
C	distance of crack on boiler from right end	*w*,*k*	weights in neural network

2. Finite element modeling

In model dependent vibration-based analysis, it is important to have an accurate numerical model. For numerical analysis the models of intact and damaged structures of vessels were created using ANSYS software [12].

2.1. FEM of boiler with hemispherical ends

The specifications of the structure are as follows.

Internal diameter is 5 m, length is 18 m (cylindrical portion), thickness is 0.0254 m, effective length is 23 m, saddle width is 0.3048 m, and distance between two saddles is 14.3424 m. Effective length is the distance between two extreme ends of the boiler taking into account both the hemispherical and cylindrical portions. Material properties taken for the boiler structure are—modulus of elasticity: 210×10^9 N/m^2, Poisson's ratio: 0.28 and density: 7840 kg/m^3. Boundary conditions: all nodes at the area where saddles are attached were fixed.

2.2. Crack analysis of boiler

A finite element model is created with the specification of the original structure and meshing is done using eight noded shell elements. The number of elements is 1268. Two locations are chosen for creating cracks one at 11.5 m from both ends and the other 7 m from the right end. At each location, the size of the crack varies with the ratio of crack size to the effective length of the boiler (*a*/*l*) as 0.1, 0.2, 0.3, 0.35. Hence, a total of eight cases were analysed. Fig. 1 shows the finite element mesh of the boiler with a crack.

2.3. FEM of oil storage tank

The specification of the structure is as follows:

Internal diameter of cylinder: 5 m, thickness: 0.04 m, and height of the tank: 10 m.

Boundary conditions: cylindrical tank has its top portion and bottom portion closed and all degree of freedom at the bottom area have been made zero. The material properties taken were the same as in the case of the boiler.

Elements used are eight node shell elements and the number of elements is 588.

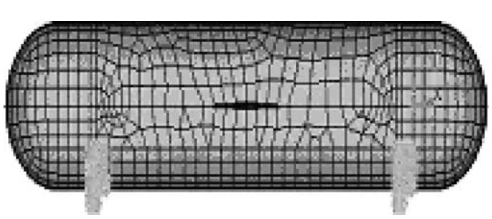

Fig. 1. FEM of boiler with a crack.

2.4. Crack analysis of storage tank

Through cracks were created vertically along the height. Three locations have been chosen—2.5, 5 and 7.5 m for creating cracks. For each location, the size of the vertical crack varies as the ratio of crack length to the height of the cylinder (*a*/*h*) varies as 0.1, 0.2, 0.3 and 0.4. A FEM of a storage tank with a crack is shown in Fig. 2.

3. Neural networks

A neural network is a powerful data modeling tool that is able to capture and represent complex input/output relationships [9,10]. The motivation for the development of neural network technology stemmed from the desire to develop an artificial system that could perform 'intelligent' tasks. A neural network acquires knowledge through learning and its knowledge is stored within inter-neuron connection strengths known as synaptic weights.

The true power and advantage of neural networks lies in their ability to represent both linear and non-linear relationships and in their ability to learn these relationships directly

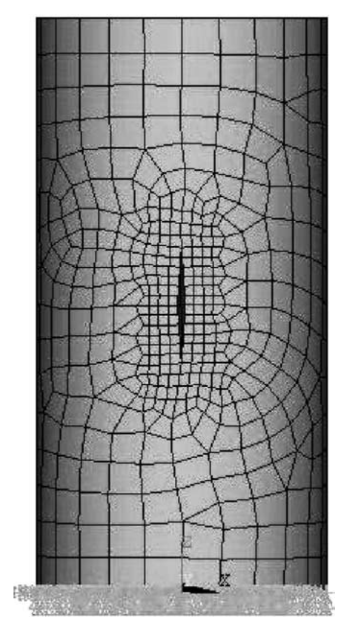

Fig. 2. FEM of storage tank with crack.