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Prediction of temperature difference effect in the buckling of a bi-material column with interface crack using ANN and FE

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ABSTRACT

Buckling is one of the most complicated concepts in mechanical engineering. Buckling often happens by compressive loads on thin structures. Thermal gradient between two ends of a column may cause a deflection in it. This will add an extra deformation to the one provided by compressive loads on the column. This phenomenon occurs when two ends of the column are at different temperatures, which can be seen at various structures. Because of the considered temperature gradients, the critical load of the column will decrease. In the current paper, various columns are modeled and the effect of thermal gradient and compressive load and other parameters on the Bi-material columns are studied. In other words, influences of compressive load and temperature gradient on critical load of Bi-material columns with interface crack are investigated. Effect of change in each parameter on critical load of column and crack opening was investigated. First, the thermal gradient was only applied to the model and in the next step; only the effect of mechanical loading was studied. Furthermore, artificial neural network (ANN) was used to extend the results to a bigger range of temperature conditions through the columns. Based on the results, ANN and finite element results are in a good agreement and the thermal effects may have a significant role in buckling of the column.

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1. Introduction

Buckling is a phenomenon that can cause instability in the loaded specimen. For instance if the load applied to a structure part increases, instability may occur on a point and its displacements begin to increase unmorally. The best example for buckling is a thin column which is under axial loading. In this state if even a little non-axial load is applied to the column, corresponding displacements will increase rapidly and buckling will happen. Buckling may occur in a big range of states in elastic or plastic regions. This means that the induced stresses in a body (near or far from yield stress region) are able to cause buckling. A large number of research studies have focused on buckling and optimum designing with respect to this phenomenon. There have been many studies associated with

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the area of static buckling under several types of loading (axial compression, external pressure, internal pressure, transverse shear or bending, thermal loading). Koitor (1974) highlighted the initial imperfection. Also some design codes (such as Eurocode 1995) are available for all static loadings. Research on the shear buckling behavior of corrugated plates has been initiated by Easley and McFarland (1969). Seismic design of steel buildings is based on design procedures (ICC 2000, BSSC 2000, AISC 2001) that improve the high ductility of steel components. Such design procedures involve certain structural components specifically detailed to respond to seismic forces by deformation that occurs by earthquake, inputting energy beyond their elastic limit.

The buckling of bi-materials is among the interesting subjects for engineers and designers. Sometimes simple materials are combined together in order to make a composition that has better properties than the rudiment materials. These advanced materials are called Bi-materials. Bi-materials are mostly used in construction industries. It is important to study the properties of such materials according to the fact that their usage field is frequent. Linear analysis of buckling is called eigenvalues method. This can predict the critical loads in structures theoretically and provides good results in simple problems.

In the present work, effect of thermal gradient and compressive load on the critical load and eigenvalues in the Bi-material columns with an interface crack are investigated. Since many parameters can influence the buckling phenomenon, such as amount of axial load, size of specimen, thermal gradient, crack length, etc., the effect of each parameter is investigated. For this purpose, various bi-material columns with interface crack were modeled and analyzed in the finite element. Effect of each parameter on critical load of the column was separately investigated. Also, artificial neural network (ANN) was employed for extending the results for other ranges of temperatures and column sizes. It is shown that the temperature of column can play an important role in buckling of the column. Hence, it is important to consider this effect in designing process and find a way to reduce it.

2. Finite element modeling

For all simulation of the current study, ABAQUS (2003) was employed. In simulation of columns deformation and three dimensional shells were modeled. For modeling the Bi-material the column was divided into two equal parts with two different materials such as shown in Fig. 1.

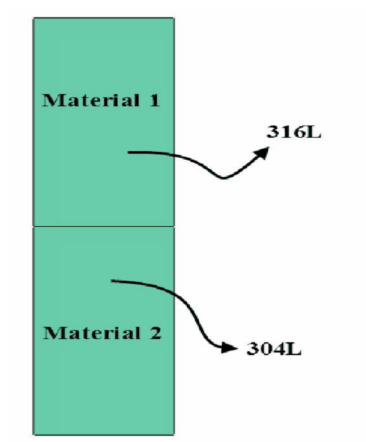

Fig. 1. A view of simulated column and material assignments.

The simulation was carried out in two main steps. First a coupled temperature-stress analysis was performed. Then a linear perturbation for buckling simulation was accomplished to derive the eigenvalues. Moreover, as shown in Fig. 2, a crack was also assigned along the interface line of materials.

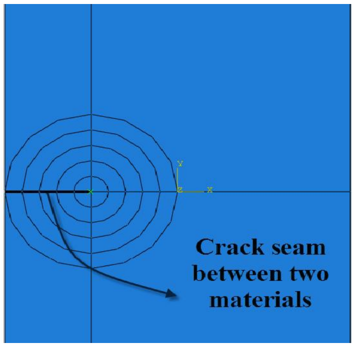

Fig. 2. Crack seam between the interface of the two materials

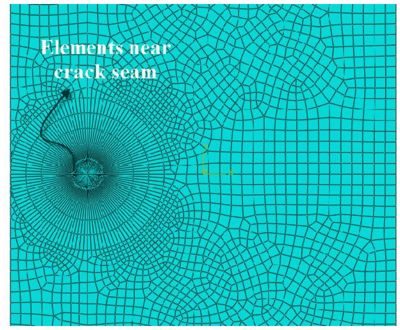

Fig. 3. Elements near the crack line

After defining interactions and temperature gradient between the two ends of column, meshing was done. Fine elements were assigned near the crack. Fig. 3 shows the mesh generated in the model.

At the end of the second step, the stresses and eigenvalues following the operations were predicted. Fig. 4 shows crack opening and distribution of stress after finishing the FE analyses.

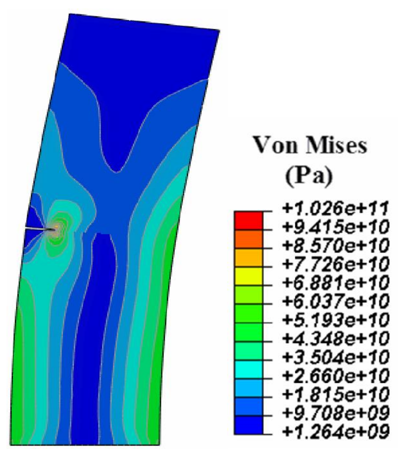

Fig. 4. Von Mises stress distribution in the analyzed edge cracked bi-material column

Fig. 5 presents the result of critical load for different mode numbers with and without considering crack and thermal gradients in the analyzed column. These results clearly indicated that both of these factors decrease the critical load but the effect of crack is more pronounced in decreasing the critical load.

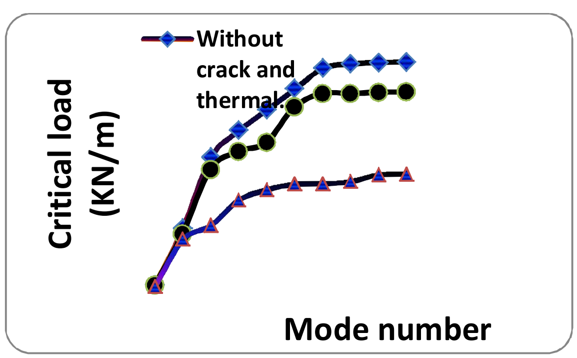

Fig. 5. The effects of crack and thermal gradient on the critical loads of different mode shapes

In addition, for further numerical investigations, parameters such as temperature gradient, applied load and crack length was changed in different models and variations of critical loads were evaluated. Temperature gradient between two ends of column was the first parameter studied and it was assumed that the temperature gradient varies in the range of 0-300 °C. This study showed that gain of temperature gradient causes reduction of critical load for the column. This advantage is clearly seen in Fig. 6.

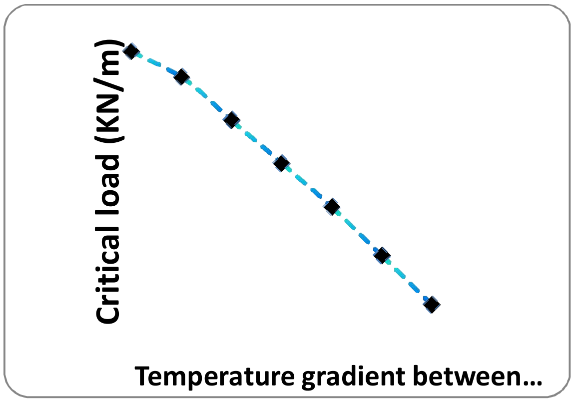

Fig. 6. The effects of thermal gradient on the critical buckling loads of investigated column

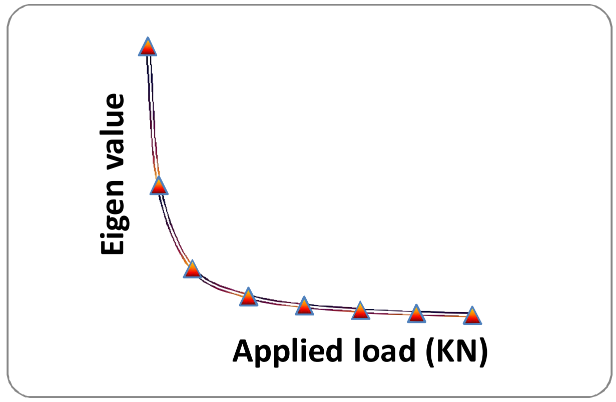

Fig. 7. Variation of eigenvalues by applied load

The other parameter examined is the change of applied loads to the column. This investigation shows how the eigenvalues decrease by increasing the applied load (see Fig. 7).

By multiplying the obtained eigenvalues with the applied load in each simulation, critical load will be achieved. As seen clearly in Fig. 8, these calculations show that the critical load is not dependent on the applied load. The crack length between two materials is another affecting parameter which was investigated. In the analyzed models the crack length was changed from 20 mm to 60 mm and results showed that by increasing the crack length, both strength of structure and critical load are decreased (see Fig. 9).

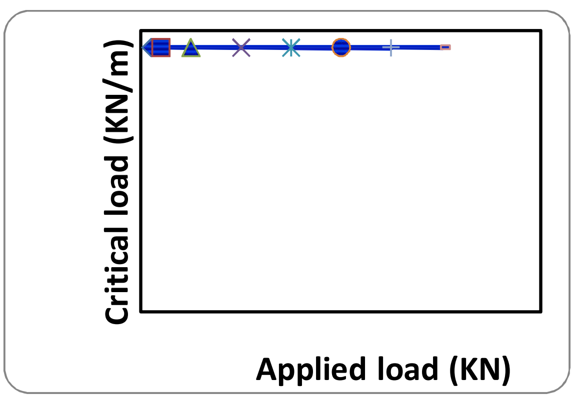

Fig. 8. Independency of critical load from the applied load

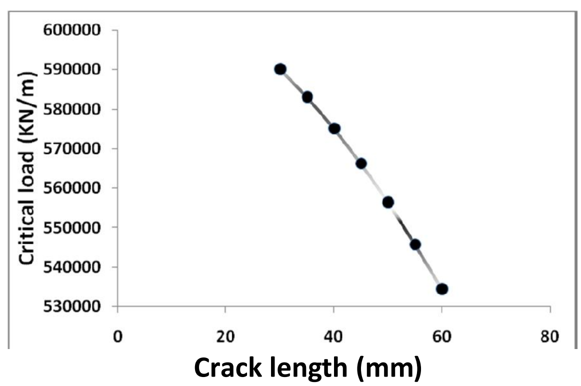

Fig. 9. Effects of crack length on the critical load of column

3. Comparison of FE results with ANN

Generally, the purpose of the ANN (Artificial Neural Network) is to constitute a mathematical structure that can be trained to obtain a set of outputs by a set of inputs by a mapping (Kim et al. 2004). Fig. 10 illustrates the general structure of an ANN.

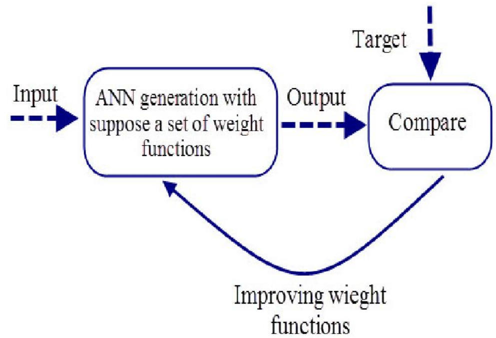

Fig. 10. General structure of an ANN

This ANN consists of the input layer, one hidden layer, and the output layer. Each layer consists of nodes or neurons and each node has a sigmoid activation function associated with it. The nodes in the hidden and output layers sum the weighted inputs from the sending nodes and apply this net input to the activation function. The output of the network is determined by applying the inputs and computing the output from the various nodes activations and interconnection weights (Al-Haik et al. 2005). To make an ANN, the first task is to determine the neural network topology, which includes the number of hidden layers, the number of PEs in each layer, and the connections between them. The number of neurons in the input and output layers is governed by the dimensionality of the problem (Sirat and Talbot 2001). In the current study, width of column and thermal gradient were considered as input layer and corresponding critical load was put as target layer. This means for achieving the critical loads in desired width (250 mm) that the previous simulations were performed with it, Simulations in two other widths was repeated and their width and obtained critical loads were applied as input layer and output layer of designed ANN, respectively. Various ANNs were trained with two hidden layers. At first hidden layer number of neurons was changed in range of 5-9 neurons. (Note that also other numbers of neurons were examined but this range showed more consistency with finite elements prediction). Results of each ANN have been presented in Fig. 11. These achieved critical loads are according to the temperature gradient in the same range in Fig. 6.

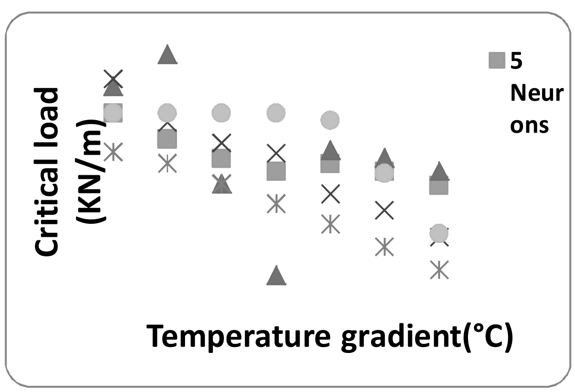

Fig. 11. Critical loads obtained by ANNs.

To find the best results, in Table 1 error percent of each ANN with finite elements results have been compared with the ANN and it was observed that 7 neurons are very close to the finite element simulation results. Fig. 12 also compares the FE and ANN results obtained for the critical loads of different temperature gradients which shows a good consistency between two sets of

Table 1. Discrepancy percent of each designed ANN with finite elements results

Neuron numbers	5	6	7	8	9
Discrepancy percent (%)	1.12	3.05	0.492	1.99	1.60

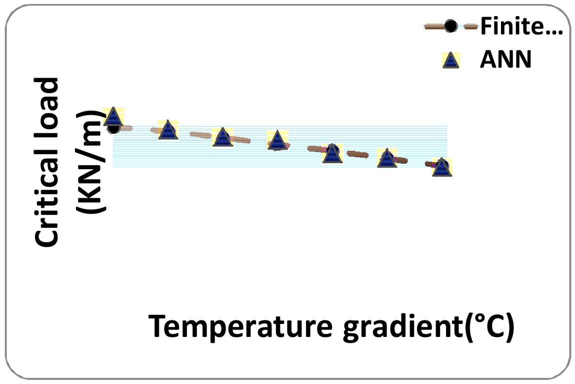

Fig. 12. Comparison the best ANN results with those achieved by finite elements in a range of temperature gradient

4. Summary

To complete the study, more than 50 models were simulated and a lot of ANNs were trained. Effects of different parameters including temperature gradient, crack length and applied loads on the buckling of column were investigated. This research shows that generally with increasing the temperature gradient between two ends of column and the crack length, critical loads are decreased. This phenomenon is justifiable by a microscopic decrease in molecular links in material strength by heating the component or initiation of crack in the column. However, the effect of crack was more pronounced than the influence of thermal gradient on the reduction of buckling critical load.

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