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Study of Pneumatic Tire Deformation under Foot Print Loads and Inflation Pressures by Neural Network Model and 2D Finite Element Analysis

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ABSTRACT

There are many attempts to apply artificial neural networks in mechanical engineering field. In this work an attempt has been made to apply the artificial neural networks in the analysis of automotive tires. The study of tire performance and deformation are challenging owing to the non-linearity associated with geometry as well as composition of material. The tire material is a cord-rubber composite, its properties anisotropic in nature. The present attempt is to analyze the tire using artificial neural network. The tire deformation under various inflation pressures has been modeled by artificial neural network. To train the network, the experimental data has been used. It has been found that the artificial neural network can effectively be used in the analysis of pneumatic tires. The artificial neural network is employed to analyze the displacement of side wall of the tire for various pressures. The pressures are given as the input and the artificial neural network is trained with the displacement of 'x' and 'y' as the output target. The ultimate purpose of a finite element analysis is to create mathematical behaviour of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. This model comprises all the nodes, element material properties, real constants, boundary conditions, and other features that are used to represent the physical system. In ANSYS terminology, the term model generation usually takes on the narrower nurturing of generating the nodes and elements that represent the spatial volume and connectivity of the actual system. Thus the model generation means the process of defining the geometric configuration of the model nodes and elements.

1. Introduction

This deals about a tire and its application. There are also brief notes on how tires are made, numbers and markings on the sidewall. The discussion gives how tire supports a car, why heat builds-up in tire.

➢ *The Bead Bundle*

The bead is a loop of high-strength steel cable coated with rubber. It gives the tire the strength it needs to stay seated on the wheel rim and to handle the forces applied by tire mounting machines when the tires are installed on rims.

➢ *The Body*

The body is made up of several layers of different fabrics, called plies. The most common ply is fabric or polyester cord. The cords in a radial tire run perpendicular to the tread. Some older tires used diagonal bias treads, tires in which the fabric run at an angle to the tread. The plies are coated with rubber to help them bond with the tire material or tire composite and to seal in the air. A tire strength is often described by the number of plies it has. Most car tires have two body plies. By comparison, large commercial jetliners often have tires with 30 or more plies.

➢ *The Belts*

In steel-belted radial tires, belts made from steel are used to reinforce the area under the tread. These belts provide puncture resistance and help the tire stay flat so that it makes the best contact with the road.

➢ *Cap Plies*

Some tires have cap plies, an extra layer or two of polyester fabric to help hold everything in place. These cap plies are not found on all tires; they are mostly used on tires with higher speed ratings to help all the components stay in place at high speeds.

➢ *The Sidewall*

The sidewall provides lateral stability for the tire, protects the body plies and helps keep the air from escaping. It may contain additional components to help increase the lateral stability.

➢ *The Tread*

The tread is made from a mixture of many different kinds of natural and synthetic rubbers. The tread and the sidewalls are extruded and cut to length. The tread is just smooth rubber at this point; it does not have the tread patterns that give the tire traction.

2. How Tires Support a Car

Under inflation can cause tires to wear more on the outside than the inside. It also causes reduced fuel efficiency and heat buildup in the tires. It is important to check the tire pressure with a gauge at least once a month.

Over inflation causes tires to wear more in the center of the tread. The tire pressure should never exceed the maximum that is listed on the side of the tire. Car manufacturers often suggest a lower pressure than the maximum because the tires will give a softer ride.

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But running the tires at a higher pressure will improve mileage. Misalignment of the wheels causes either the inside or the outside to wear unevenly, or to have a rough, slightly torn appearance.

Fig 1. A properly inflated tire and an under inflated or overloaded tire.

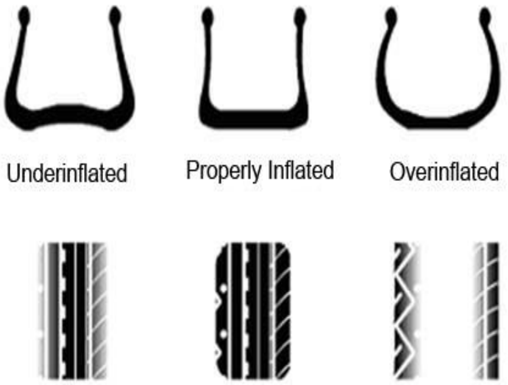

Fig 2. The wear patterns of an under inflated, properly inflated and over inflated tire.

Fig 3. Cross Sectional View of Tire.

3. Neural Networks

A neural network is a computational structure inspired by the study of biological neural processing. A layered feed-forward neural network has layers, or subgroups of processing elements. A layer of processing elements makes independent computations on data that it receives and passes the results to another layer. The next layer may in turn make its independent computations and pass on the results to yet another layer. Finally, a subgroup of one or more processing elements determines the output from the network. Each processing element makes its computation based upon a weighted sum of its inputs.

The first layer is the input layer and the last the output layer. The layers that are placed between the first and the last layers are the hidden layers. The processing elements are seen as units that are similar to the neurons in a human brain, and hence, they are referred to as cells, neuromimes, or artificial neurons. A threshold function is sometimes used to qualify the output of a neuron in the output layer. Even though our subject matter deals with artificial neurons, we will simply refer to them as neurons. Synapses between neurons are referred to as connections, which are represented by edges of a directed graph in which the nodes are the artificial neurons.

3.1Training Algorithm

The standard backpropagation algorithm is being discussed here. The form of data is an important factor in choosing the appropriate function. The algorithm is as follows:

Step 0: Initialize weights (set to small random values).

Step 1: While stopping condition is a false, do step 2-9.

Step 2: For each training pair do steps 3-8 Feed forward:

Step 3: Each input unit receives input signal x_i and broad casts this signal to all units in the layer above (the hidden units).

Step 4: Each hidden unit sums its weighted signals, applies it activation functions to compute its activation signal and send the signal to all units in the layer above (output units).

Step 5: Each input unit sums its weighted input signals, and applies its activation functions to compute its output signal. Back propagation of error:

Step 6: Each output unit receives a target pattern corresponding to the input training pattern, computes its error information term. Calculate its weight correction term and sends error to units in the layer below.

Step 7: Each hidden unit sums its error input, multiplies by the derivative of the activation function to calculate its error information term. Calculate its weight correction. Update weights:

Step 8: Each output unit updates its bias and weights. Each hidden unit updates weights.

Step 9: Test stopping condition.

An epoch is one cycle through the entire set of training vectors. Typically, many epochs are required for training a backpropagation neural net. The forgoing algorithm updates the weights after each training pattern is presented. The common variation is batch updating, in which weight updates are accumulated over an entire epoch before being applied. The mathematical basis for backpropagation algorithm is the optimization technique known as gradient descent. The gradient of a function is the direction in which the function increases more rapidly; the negative of the gradient gives the direction in which the function decreases more rapidly.

3.2 Choice of Initial Weights and Biases

The choice of initial weights will influence whether the net reaches a global minimum of the error and, if so, how quickly it converges. The updates of the weights between two units depend on both the derivative of the upper unit's activation of the lower unit. For this reason, it is important to avoid choices of initial weights that would make it likely that either activations or derivatives of activations are zero. The values for the initial weights must not be too large, or the initial input signals to each hidden or output unit will be likely to fall in the region where the derivative of the function has a very small value. On the other hand, if the initial weights are too small, the net input to a hidden or output unit will be close to zero, which also causes extremely slow learning.

3.3 How Long to Train the Net

Since the usual motivation for applying a back propagation net is to achieve a balance between correct responses to training patterns and good responses to new input patterns, it is not necessarily advantageous to continue training until the total squared error actually reaches the minimum. Weight adjustments are based on the training patterns; however, at intervals during training, the error is computed using the training –testing pattern. As long as the error for the training-testing patterns decreases, training continues. When the error begins to increase, the net is starting to memorize the training patterns too specifically. At this point the training is terminated.

4. Finite Element Analysis of Pneumatic Tire

Modulus of elasticity is a measure of the relative stiffness or rigidity of a material. The unit values are those of force per area because modulus of elasticity equals to Stress/Strain, and this only applies to the elastic portion of the stress-strain diagram, the modulus is indicated by the slope of the linear part of the line. Therefore, a material with a steep line will have a higher modulus and be more rigid than a material with a flatter line. Modulus is a reflection of the strength of the inter atomic or intermolecular bonds.

4.1Training Data

The data used for the present analysis are the work done and are given in Table 1.

4.2 2-D Analysis of a Pneumatic Tire

In this analysis, the plane 183, 8 node element has been selected as the meshing element. It has two degree of freedom in UX and UY directions, and the model is curved and non-linear.

4.3 Material Properties

The material property which is the function of temperature is called linear property. Typical non-thermal analysis with these properties requires only a single iteration. Conversely, if properties need a thermal analysis which is temperature dependant, then the problem is non-linear. Properties such as stress-strain data are called non-linear properties; analysis of these properties requires an iterative solution. In the present work, the model is divided into 16 elements the material properties like Young's modulus, shear stress and Poisson's ratio are given as the bulk properties in 2-D analysis.

4.4 Modeling of Pneumatic Tire

The ultimate purpose of a finite element analysis is to create mathematical behaviour of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. This model comprises all the nodes, element material properties, real constants, boundary conditions, and other features that are used to represent the physical system. In ANSYS terminology, the term model generation usually takes on the narrower nurturing of generating the nodes and elements that represent the spatial volume and connectivity of the actual system. Thus the model generation means the process of defining the geometric configuration of the model nodes and elements. In the present work, the model is generated in AutoCAD and the same has been imported in to ANSYS. The imported ANSYS model is divided into 16 elements. The model is shown in Fig. 4.

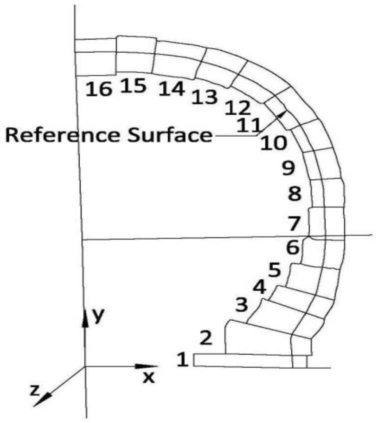

Fig 4. Tire cross section.

4.5 Meshing and Boundary Conditions

Mesh controls is to establish factors such as the element shape, mid side node placement and element size to be used in meshing the solid model, and is important for the entire analysis. The decisions made at this stage in the model development will profoundly affect the accuracy and economics of the analysis. Once the solid model, element of attributes and meshing controls have been built it is ready to generate finite element mesh. The mesh can be classified into two types, (i) free mesh (ii) mapped mesh. It is proposed to select free meshing, since the free mesh is more accurate than mapped mesh.

1. The element 1, 2 and 3 are fixed and axisymetric condition is applied until to the topmost node.
2. The internal pressure is maintained on 250 Kpa and external pressure is applied to elements 13, 14, 15 and 16, since only these elements are made in contact with road surface.
3. Static condition is applied to analyse the tire because the system is not time dependent.

The figure 5 refers to the 2D model after applying the boundary conditions.

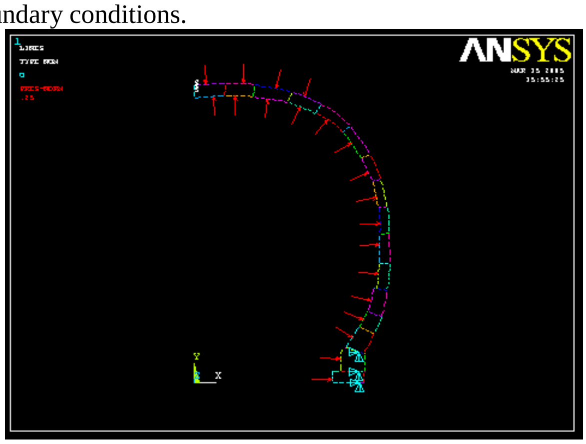

Fig 5. Boundary Condition for 2-D Model.

Table 1. Horizontal and vertical displacements (in mm) of the bias tire under footprint load.

Load	3777N (485 kgf)				4572N (465 kgf)			
Inflation	175 kPa		200 kPa		175 kPa		200 kPa	
Location	x	y	x	y	X	y	X	y
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	4.671	-2.60	3.823	-3.50	4.762	-3.30	4.675	-3.30
3	8.768	-3.60	7.764	-4.50	9.542	-4.80	8.818	-5.40
4	11.95	-3.90	10.65	-4.20	12.52	-4.50	12.24	-5.10
5	9.788	-4.30	10.31	-4.50	10.23	-5.60	10.93	-5.30
6	4.527	-22.1	5.215	-19.3	4.805	-26.0	4.782	-23.3
7	0.00	-22.5	0.00	-19.0	0.00	-26.5	0.00	-23.5

5. Results and Discussion

The input values are inflation pressures and the target values are the displacements in 'x' and 'y' directions. The experimental pressure ranges from 150 kPa to 250 kPa, and the neural network training pressure range is selected between 125 kPa to 275 kPa. The reason for selecting this range is that, it is very close to the actual values and hence the accuracy of the neural network will be the maximum.

Experimental displacement values of the bias and radial tire are trained in the neural network. The experimental pressure ranges from 150 kPa to 250 kPa, whereas the neural network is trained for the pressure range of 125-275 kPa. The displacement of the bias and radial tire are obtained through neural network for the pressure range of 125 kPa to 275 kPa and the displacement values are plotted in the Figs. 6 -11.

It is evident from the Figs. 6 -11, displacement measured by experimental method and the displacements obtained by the neural network are similar having the mean square error range of 0.002. From the trained net it is also possible to determine the displacement of the tire for any desired intermediate pressure. The displacement of the bias and radial tire for various pressure limits are plotted in the Figs. 12 and 13. The intermediate pressure of 200kPa is trained by neural network and is also plotted in the Figs.12 and 13 for bias and radial tire respectively.

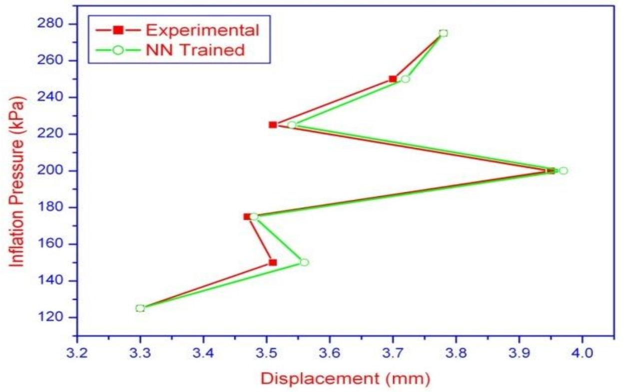

Fig 6. Displacement of the Bias tire at Crown.

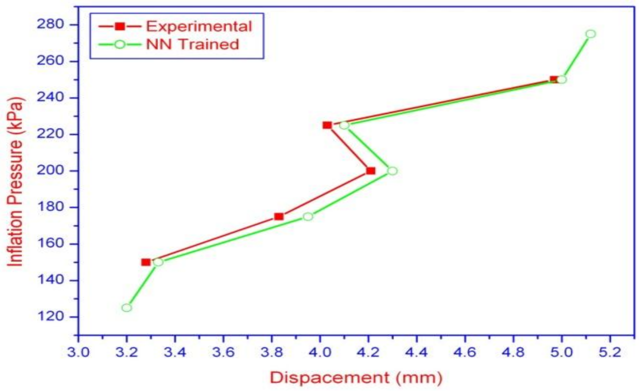

Fig 7. Displacement of the bias tire at Sidewall.

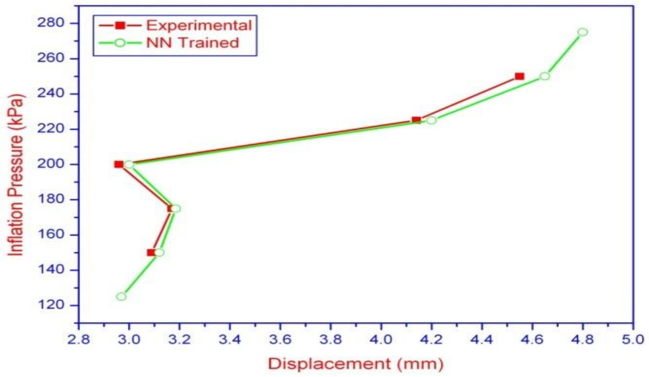

Fig 8. Displacement of the Radial tire at Crown.

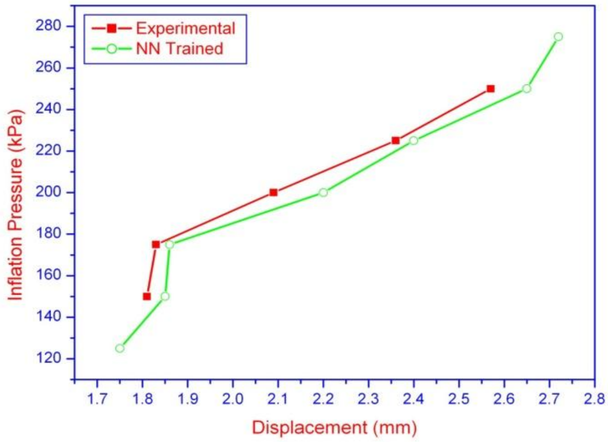

Fig 9. Displacement of the Radial Tire at Sidewall.

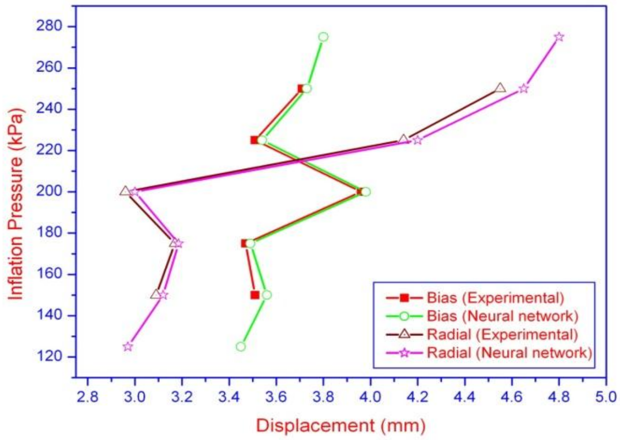

Fig. 10 Displacement of the Bias and Radial tire at Crown.

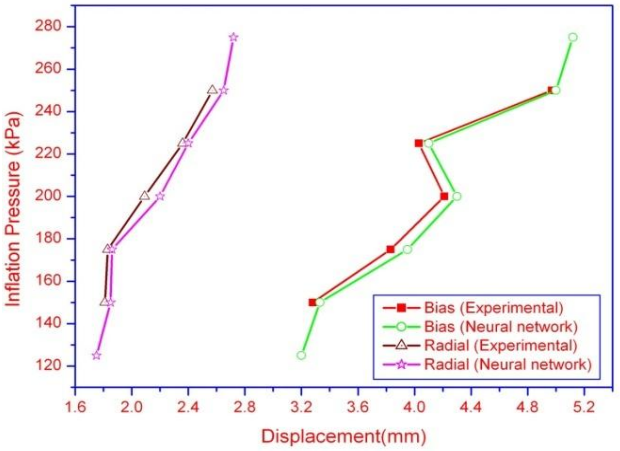

Fig 11. Displacement of the Bias and Radial tire at Sidewall.

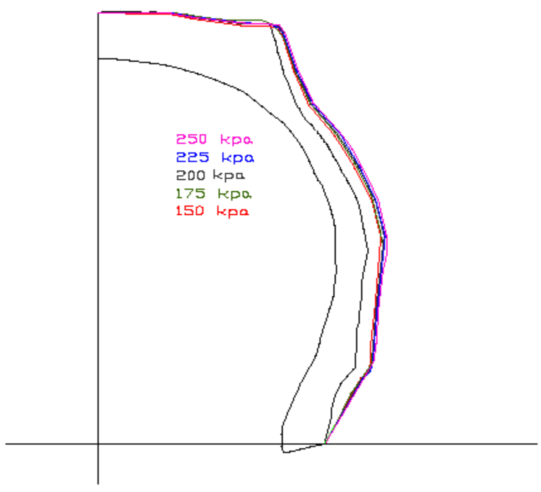

Fig 12. Tire geometry for various pressures of bias tire.

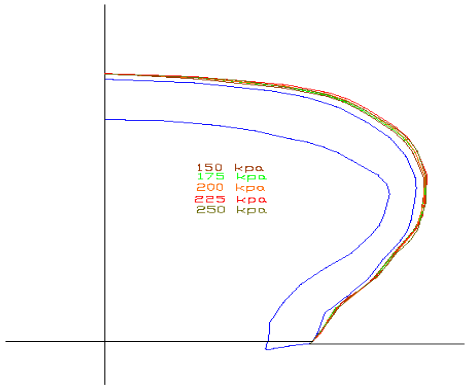

Fig 13. Tire geometry for various pressures of Radial tire.

By applying the boundary conditions, the resultant stress and strain are analysed. The resultant stress and strain along x, y and xy directions are also plotted in Figs.14 and 15 respectively. Out of all the nodes only one node '42' is taken for the future analysis considering all the elements. Stress developed by the finite element model for x direction, y direction and xy direction are captured and plotted in Figs. 16 to 18. The resultant stress and strain of the tire for a pressure load of 250 KPa, which are derived from the finite element analysis are further used in neural network model.

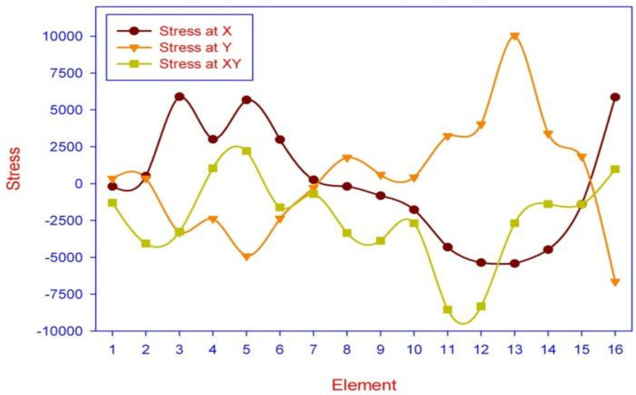

Fig 14. Stress (N/mm^2) at various element locations.

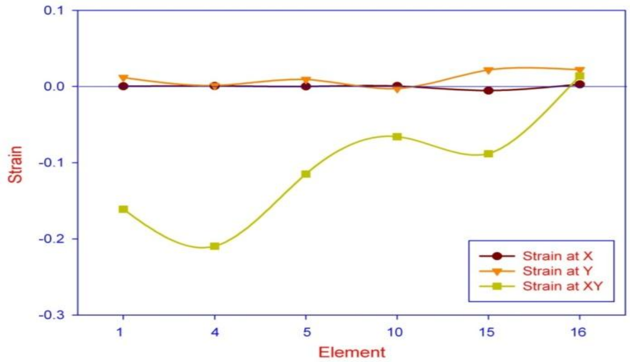

Fig 15. Strain at various element locations.

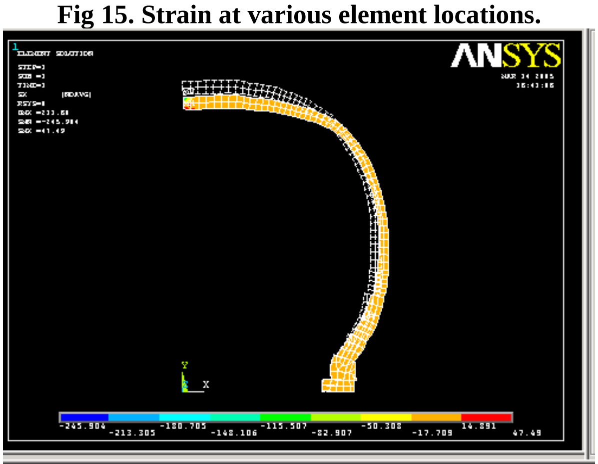

Fig 16. Stress in X direction for 2-D.

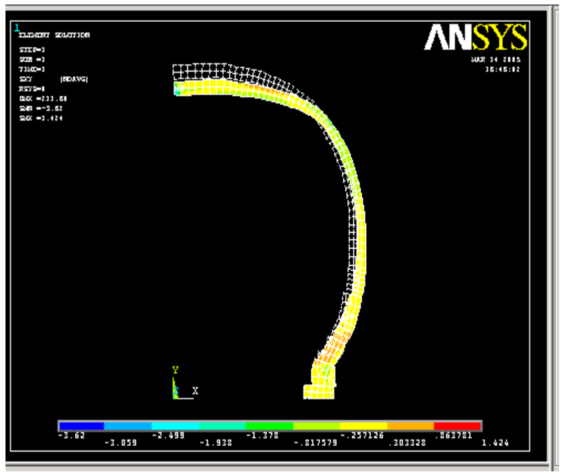

Fig 17. Stress in Y direction for 2-D.

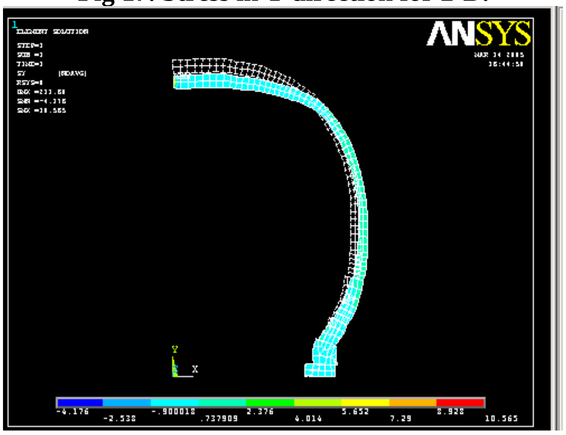

Fig 18. Stress in XY direction for 2-D.

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