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Application of Artificial Neural Network to Analyze Hexagonal Plate with Hole Considering Different Geometrical and Loading Parameters

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Abstract In the competitive nature of structural engineering, industry and its heuristic problem-solving needs, among other reasons, have contributed to the development of some advanced decision making tools. A step ahead from soft computing techniques, now artificial intelligence has proved itself as an efficient tool for solving the problem in construction industry over old tedious analytical methods. In this study, Artificial Neural Network is compared with finite element techniques in order to find the stress, strain and deflection in plates with holes. For approaching the complexity of the problem, hexagonal plates with holes and different geometrical and loading parameters have been taken as specimens. Finite element analysis for 81 cases are carried out using the software based on finite element method (FEM), ANSYS Workbench 15.0 software. Using these data of FEM analysis an Artificial Neural Network has been trained. The successfully trained network is further used for analysis of four new cases which are also validated by using FEM based software. It was found that most of the results were quite close to the FEM results. Such a technique can be used to reduce the computation time and labour.

Keywords Artificial Neural Networks; Finite Element Analysis; Hexagonal Plate; ANSYS

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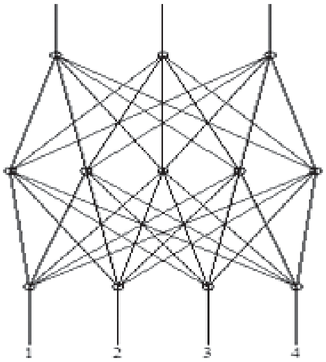
1. INTRODUCTION

Regardless of the powerful analysis software now available, the development of methods of approximate solution is very important. Although, these analysis software allow us to find out the numerical solution of various problems, including the problems of structural analysis. The need of approximate methods which would provide solutions in the form of simple analytic expressions is there. One of the method is artificial neural network also known as ANN. These are a functional abstraction of the biologic neural structures of the central nervous system.

ANNs are powerful pattern recognizers and classifiers. Garrett [1] has given an interesting engineering definition of the ANN as: “a computational mechanism able to acquire, represent, and compute mapping from one multivariate space of information to another, given a set of data representing that mapping.” Their computing abilities have been proven in the fields of prediction and estimation, pattern recognition, and optimization. Neural networks have been used for various structural analysis like fully stressed design of trusses, buckling behaviour of plates, stress concentration factor analysis for membranes etc.

In Figure 1, artificial neural network consisting of an input layer with four nodes, one hidden layers with five nodes, and an output layer with three nodes is shown. State function is summation function. Among transfer functions like sigmoid, modified sigmoid, hyperbolic tangent, Gaussian and modified Gaussian, hyperbolic tan-gent function has been used. Then, a training algorithm is needed that is back- propagation algorithm over here. Neurons are the processing elements of network. Neuron consists of a set of weighted input connections, a bias input, a state function, a nonlinear transfer function, an output. Figure 2 shows the structure of a neuron.

Further, Initialization method of threshold and initialization method of weight factor are to be chosen between zero or random, in our research, we have chose random.



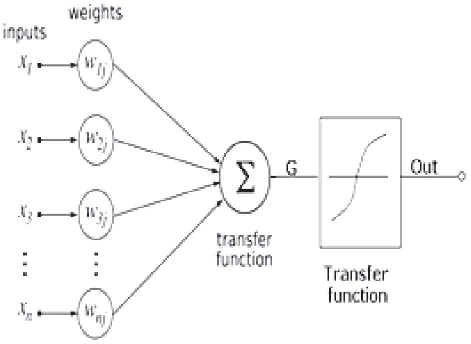


Figure 1: Neural Network Structure. **Figure 2:** Structure of Neuron.

P. Emmanuel Nicholas *et al.* [2] proposed a novel approach to study neural network based buckling strength prediction of laminated composite plate with central cut-out, The laminated composite plates with holes analyzed using finite element analysis by optimizing the parameters like thickness, orientation, material and the stacking sequence to obtain the desired characteristics for these structures. They showed that using finite element analysis makes the process more tedious job and thus proposed to construct the artificial neural network to predict the buckling behaviour of the composite plate. Hojjat Adeli [3] presented the first journal article on neural network application in civil/structural engineering in 1989.

In many previous research papers, membrane with holes or cutouts analysed using finite element software like ANSYS [4], ABAQUS etc., also the stress field around circular holes in plates with arbitrary thickness has been studied but most of the researches only plane loading is considered. However, it seems difficult to locate a work that quantifies the use of ANNs for analysis of equivalent stress, strain and directional deformation in a hexagonal plate subjected to vertical surface pressure without performing finite element analysis. The artificial neural network is used as an alternative analysis tool to analysis plates with hole since it can handle uncertainty through the probability method.

While comparing the artificial neural networking method with finite element method we have taken hexagonal plate with hole, it is to make problem much complex and to increase the number of variables. Different shaped plates with different shaped holes are used in industry to match the needs. Thus, it becomes necessary to use the method which excels in dealing with arbitrary shapes in less time and computational cost.

In some of the following research papers finite element analysis have been performed for plates and membranes with cut-outs. Zuxing Pan et al. [5], dealt with a complex variable method and proposed stress functions to obtain the solution for stress distribution around rectangular hole in finite plate subjected to uniaxial tension. They analyzed effect of hole sizes, hole orientation and plate's aspect ratio on stress distribution. Jeom Kee Paik [6] examined the ultimate strength of metallic plates with central circular cut-out under shear loading. The influence of boundary conditions on the buckling load for rectangular plates of various cut-out shape, length/thickness ratio, and ply orientation was examined by Buket Okutan Baba [7]. Boundary conditions considered were clamped, pinned and their various combinations. The plates were subjected to in-plane compression load. The results of experimentation were validated using numerical analysis by ANSYS. A.V Singh [8], presented the results of their study which was based on generalized work–energy method for rectangular plates with circular cut-out. Optimum design of holes and notches by considering fatigue life were presented by Hwai Chung Wu et al. [9]. V.G. Ukadgaonker et al. [10] gave a general solution for bending of symmetric laminates with holes considering any shape of hole in symmetric laminates subjected to remotely apply bending or twisting moments. Moments around circular, elliptical, Triangular, square, rectangular and several irregular shaped holes in cross-ply and angle ply symmetric laminates are obtained.

In this study, artificial neural network has been employed for analysis of maximum equivalent von Mises stress, strain and directional deformation in equilateral Hexagonal plate with different geometrical and loading patterns. Plates, having different size concentric holes are analyzed. Finite element analysis for 81 cases are carried out using ANSYS Workbench 15.0 software. Using these data of FEM analysis an artificial neural network has been trained. The successfully trained network is further used for analysis of five new cases which are also validated using ANSYS Workbench 15.0 software.

2. STRUCTURAL MODELING AND ANALYSIS

Modeling, meshing and analysis contours of plate are shown in Figure 3. Plate is a of five sided polygon having concentric hole. Size of edges of plate, thickness, size of hole diameter and loading pressure are varying parameters. In Table 1, isotropic elastic constants values are shown, these have been used as elemental properties. Other, in-use entities for finite element modeling is provided in Table 2. A total 81 cases are generated, and these are stated in Table 3.

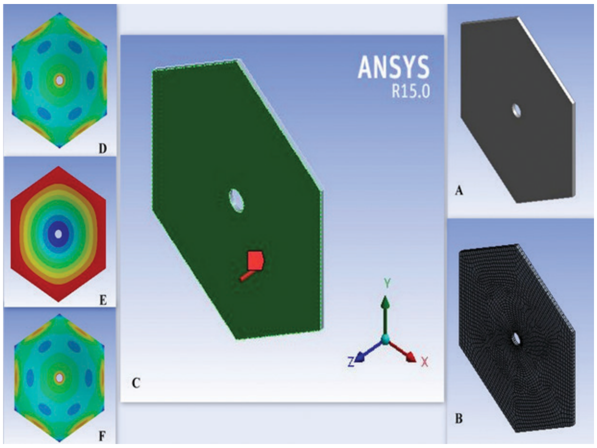


Figure 3: Modelling, Meshing and Analysis of Plate.

Table 1: Isotropic Elastic Constants.

Young's Modulus (MPa)	Poisson's Ratio	Bulk Modulus (Pa)	Shear Modulus (MPa)
2E+5	0.3	1.6667E+5	7.692E+4

Table 2: Entities for Finite Element Modeling

Sr. No.	Parameters	Value
1	Material	Structural Steel
2	Polygon	Hexagon
3	Hole	Single and Concentric
4	Support condition	All fixed Edges
5	Loading	Surface Pressure in –Z direction
6	Meshing Element	Eight nodded hexahedral element
7	Meshing Inflation	Automatic (Program Controlled)
8	Relevance	0
9	Relevance center	Fine
10	Meshing smoothing	Medium
11	Span angle center	Fine

Table 3: Input for Finite Element Models.

	Input for ANSYS					Input for ANSYS			
Sr. No.	Edge Dimension (mm)	Hole Dia. (mm)	Thickness of Plate (mm)	Pressure Applied (MPa)	Sr. No.	Edge Dimension (mm)	Hole Dia. (mm)	Thickness of Plate (mm)	Pressure Applied (MPa)
1	500	50	10	0.3	42	750	75	20	0.7
2	500	50	10	0.5	43	750	75	30	0.3
3	500	50	10	0.7	44	750	75	30	0.5
4	500	50	20	0.3	45	750	75	30	0.7
5	500	50	20	0.5	46	750	100	10	0.3
6	500	50	20	0.7	47	750	100	10	0.5
7	500	50	30	0.3	48	750	100	10	0.7
8	500	50	30	0.5	49	750	100	20	0.3

	Input for ANSYS			
Sr. No.	Edge Dimension (mm)	Hole Dia. (mm)	Thickness of Plate (mm)	Pressure Applied (MPa)
9	500	50	30	0.7
10	500	75	10	0.3
11	500	75	10	0.5
12	500	75	10	0.7
13	500	75	20	0.3
14	500	75	20	0.5
15	500	75	20	0.7
16	500	75	30	0.3
17	500	75	30	0.5
18	500	75	30	0.7
19	500	100	10	0.3
20	500	100	10	0.5
21	500	100	10	0.7
22	500	100	20	0.3
23	500	100	20	0.5
24	500	100	20	0.7
25	500	100	30	0.3
26	500	100	30	0.5
27	500	100	30	0.7
28	750	50	10	0.3
29	750	50	10	0.5
30	750	50	10	0.7
31	750	50	20	0.3
32	750	50	20	0.5
33	750	50	20	0.7
34	750	50	30	0.3
35	750	50	30	0.5
36	750	50	30	0.7
37	750	75	10	0.3
38	750	75	10	0.5
39	750	75	10	0.7
40	750	75	20	0.3
41	750	75	20	0.5
50	750	100	20	0.5
51	750	100	20	0.7
52	750	100	30	0.3
53	750	100	30	0.5
54	750	100	30	0.7
55	1000	50	10	0.3
56	1000	50	10	0.5
57	1000	50	10	0.7
58	1000	50	20	0.3
59	1000	50	20	0.5
60	1000	50	20	0.7
61	1000	50	30	0.3
62	1000	50	30	0.5
63	1000	50	30	0.7
64	1000	75	10	0.3
65	1000	75	10	0.5
66	1000	75	10	0.7
67	1000	75	20	0.3
68	1000	75	20	0.5
69	1000	75	20	0.7
70	1000	75	30	0.3
71	1000	75	30	0.5
72	1000	75	30	0.7
73	1000	100	10	0.3
74	1000	100	10	0.5
75	1000	100	10	0.7
76	1000	100	20	0.3
77	1000	100	20	0.5
78	1000	100	20	0.7
79	1000	100	30	0.3
80	1000	100	30	0.5
81	1000	100	30	0.7

Geometry of the plates are created in workbench itself and linear elastic analysis is performed. Automatic inflation is selected during meshing. In these models, fixed edge support condition is provided. Varying loading pressure is acting in negative Z direction where plates are lying in X-Y plane.

In Figure 3, A is showing the model view, B is the meshed structure, in C, Loading has been shown and in D, E, F, contour of variation in maximum equivalent von Mises stress, strain and directional deformation are shown respectively.

3. FINITE ELEMENT ANALYSIS

Finite element analysis has been performed using ANSYS Workbench 15.0 and results for following parameters are recorded,

1) Maximum Equivalent von Mises Stress
2) Maximum Equivalent von Mises Strain
3) Directional Deformation in Z – Direction

Output results are tabulated in Table 4. These values have been used as training data for artificial neural network, in the next section.

Table 4: Data Recorded as Output of Finite Element Analyses

	Output from ANSYS				**Output from ANSYS**		
Sr. No.	**Maximum Equivalent von Mises Stress (MPa)**	**Maximum Equivalent von Mises Strain $*10^{-5}$ (mm/mm)**	**Maximum Directional (-z) Deformation (mm)**	**Sr. No.**	**Maximum Equivalent von Mises Stress (MPa)**	**Maximum Equivalent von Mises Strain $*10^{-5}$ (mm/mm)**	**Maximum Directional (-z) Deformation (mm)**
1	558.36	279.18	10.58	42	732.52	366.26	15.538
2	930.59	465.3	17.513	43	139.97	69.987	1.9938
3	1302.8	651.42	24.518	44	233.29	116.665	3.323
4	140.06	70.032	1.3293	45	326.61	163.3	4.6522
5	233.44	166.72	2.2155	46	1242.6	621.39	53.801
6	326.81	163.41	3.1017	47	2071	1035.7	89.668
7	62.344	31.172	0.39841	48	2899.4	1449.9	125.53
8	103.91	51.954	0.66402	49	310.93	155.49	6.7463
9	145.47	72.735	0.92963	50	518.21	259.14	11.244
10	538.31	269.16	10.705	51	725.5	362.8	15.741
11	897.18	448.6	17.842	52	138.67	69.347	2.0198

	Output from ANSYS				Output from ANSYS		
Sr. No.	**Maximum Equivalent von Mises Stress (MPa)**	**Maximum Equivalent von Mises Strain *10^{-5} (mm/mm)**	**Maximum Directional (-z) Deformation (mm)**	**Sr. No.**	**Maximum Equivalent von Mises Stress (MPa)**	**Maximum Equivalent von Mises Strain *10^{-5} (mm/mm)**	**Maximum Directional (-z) Deformation (mm)**
12	1256.1	628.04	24.979	53	231.12	115.58	3.3664
13	135.08	67.544	1.3542	54	323.57	161.81	4.7129
14	225.14	112.57	2.257	55	2322.4	1161.2	164.23
15	315.2	157.6	3.1598	56	3870.7	1935.4	273.71
16	60.136	30.069	0.40574	57	5418.9	2709.6	383.2
17	100.23	50.115	0.67623	58	583.96	292	20.567
18	140.32	70.16	0.94672	59	973.27	486.66	34.278
19	508.76	254.38	10.829	60	1362.6	681.33	47.99
20	847.94	423.97	18.049	61	259.69	129.85	6.1123
21	1187.1	593.56	25.268	62	432.82	216.42	10.187
22	127.42	63.71	1.3694	63	605.94	302.99	14.262
23	212.36	106.18	2.2824	64	2275.1	1137.6	165.97
24	297.31	148.66	3.1953	65	3791.9	1895.9	276.61
25	56.721	28.361	0.41017	66	5308.6	2654.3	387.25
26	94.535	47.268	0.68361	67	571.11	285.56	20.783
27	132.35	66.175	0.95705	68	951.85	475.94	34.638
28	1297	648.54	52.373	69	1332.6	666.31	48.493
29	2161.7	1080.9	87.289	70	253.97	126.99	6.1761
30	3026.4	1513.3	122.2	71	423.29	211.65	10.294
31	324.45	162.23	6.5679	72	592.61	296.31	14.411
32	540.76	270.39	10.946	73	2260.9	1130.5	67.77
33	757.06	378.55	15.325	74	3768.1	1884.2	279.62
34	144.64	72.322	1.9661	75	5275.3	2637.8	391.46
35	241.06	120.54	3.2768	76	558.35	279.18	21.013
36	337.49	168.75	4.5876	77	930.58	465.29	35.022
37	1254.9	627.45	53.106	78	1302.8	651.41	49.03
38	2091.5	1045.8	88.509	79	248.3	124.15	6.2443
39	2928.1	1464.1	123.91	80	413.83	206.92	10.407
40	313.94	156.97	6.6593	81	579.36	289.68	14.57
41	523.23	261.62	11.099				

4. APPLICATION OF NEURAL NETWORK

The input, output data given in Table 3 and Table 4 are used for training of the neural network. A 4-5-3 size back propagation neural network has been trained. The input parameters are edge dimension, hole diameter, thickness of plate and pressure applied and output parameters are maximum equivalent von Mises stress, maximum equivalent von Mises strain and directional deformation in negative Z direction. For ANN, an in-house developed software has been used. The error tolerance is kept 0.03. It took 86830 epochs to converge to this tolerance. Thus trained network is used for complete analysis of four new cases of model plates, given in Table 5.

Validation of results has been presented in Table 6. Percentage (%) variation is carried out between the analyzed parameters artificial neural network and ANSYS Workbench. Graphical representation of analyzed parameters for new cases model plates are shown in Figure 4, Figure 5, Figure 6 and these figures also include percentage (%) variation between ANN and ANSYS results. It can be observed that averages of absolute positive percentage (%) errors are 3.605, 3.921, and 7.705 for maximum equivalent von Mises stress, maximum

Table 5: New Model Cases for Validation.

Sr. No.	New Cases Edge Dimension (mm)	Hole Dia. (mm)	Thickness of Plate (mm)	Pressure Applied (MPa)
A	600	60	25	0.4
B	700	70	20	0.45
C	800	80	15	0.5
D	900	90	10	0.55

Table 6: Validation of Results.

Sr. No.	Model	Maximum Equivalent vonMises Stress (MPa)			Maximum Equivalent vonMises Strain $*10^{-5}$ (mm/mm)			Directional Deformation in (-Z) Direction (mm)		
		ANN	ANSYS	%	ANN	ANSYS	%	ANN	ANSYS	%
1	A	172.0455	172.17	0.07226	86.7942	86.084	0.825005	1.910345	1.883	1.452220
2	B	445.2113	410.37	8.49024	223.5143	205.19	8.930408	8.350346	7.5869	10.06268
3	C	1104.777	1058	4.42131	552.6227	529	4.465542	36.64148	33.992	7.794416
4	D	3415.076	3464.9	1.43796	1706.67	1732	1.462446	217.9328	195.44	11.50881

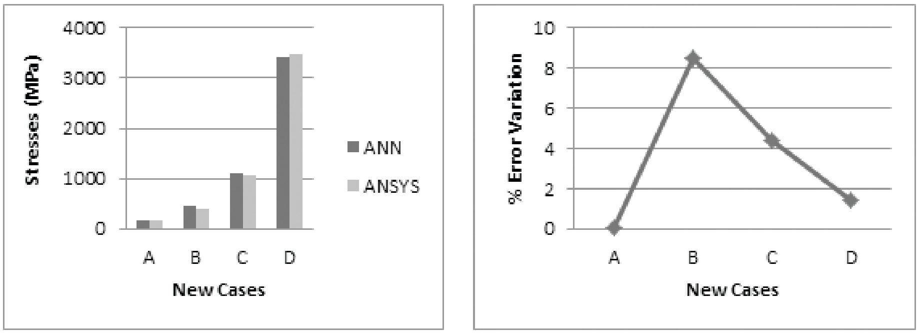


Figure 4: Model Case 1 - Max. Equivalent von Mises Stress and its % Variation for ANN and ANSYS.

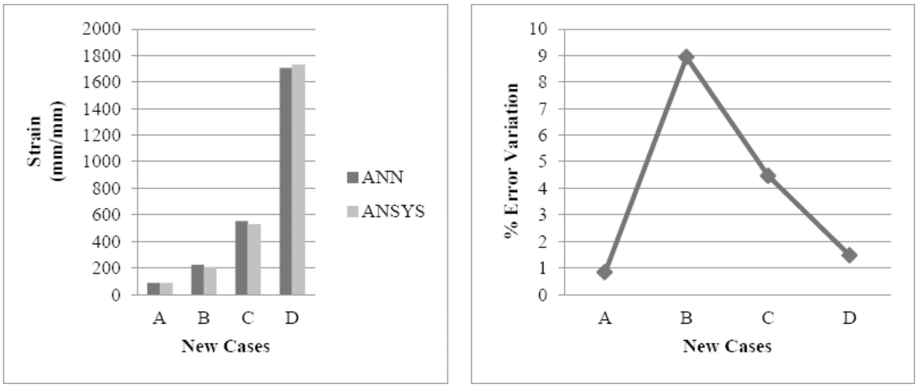


Figure 5: Model Case 2 - Max. Equivalent von Mises Strain and its % Variation for ANN and ANSYS.

equivalent von Mises strain and directional deformation in negative Z direction respectively which are small values. Thus it has been proved that the use of artificial neural network can avoid the lengthy and tedious complex modeling and analysis using costly FEM software.

Furthermore, correlation analysis of ANSYS and ANN results have been also carried out and shown in Figure 7, Figure 8 and Figure 9.

These regression maps are between ANSYS as observed values and ANN as predicted values. The more variance that is accounted for by the regression model the closer the data points will fall to the fitted regression line. Theoretically, if a model could explain 100% of the variance, the fitted values would always equal the observed values and, therefore, all the data points would fall on the fitted regression line. It can be observed that the sum

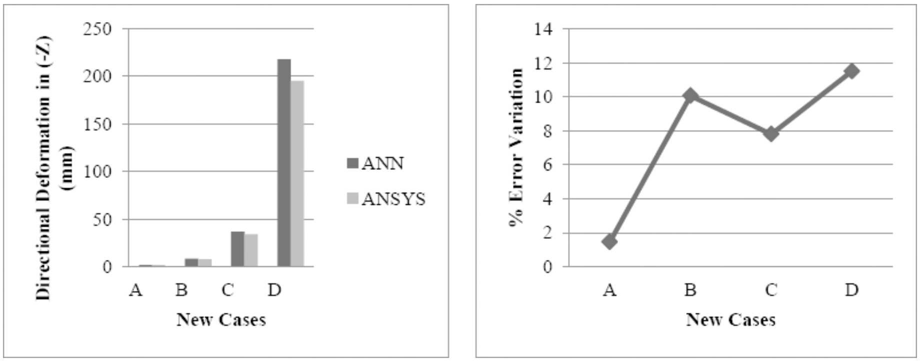


Figure 6: Model Case 3 - Directional Deformation and its % Variation for ANN and ANSYS.

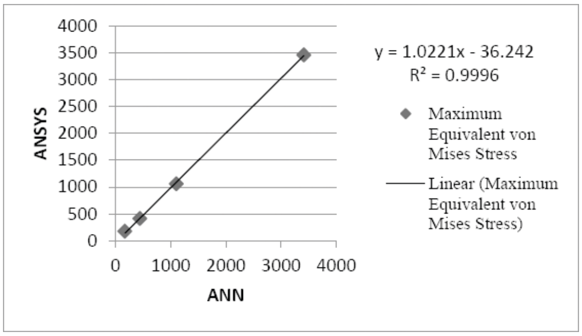


Figure 7: Regression Analyses for Max. Equivalent von Mises Stress between ANN and ANSYS for New Models.

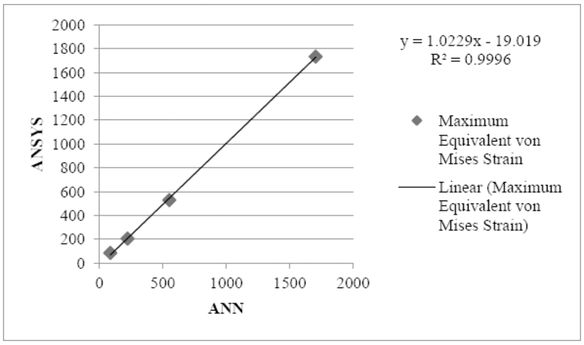


Figure 8: Regression Analyses for Max. Equivalent von Mises Strain between ANN and ANSYS for New Models.

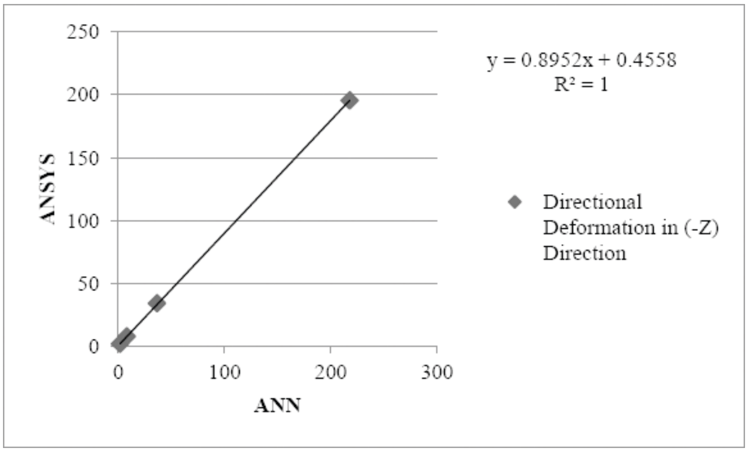


Figure 9: Regression Analyses for Max Directional Deformation in -Z Direction between ANN and ANSYS for New Models.

of squared residuals (R^2) for all three output parameters are very close to 1 that accounts for 100 % of the variance. Hence it can be proved that neural network predictions are close to FEM results.

5. CONCLUSION

In this study, linear elastic analysis of steel plates is performed, and results have been predicted using artificial neural network. The differences calculated between the maximum equivalent von Mises stress, strain and directional deformation by ANN and ANSYS are quite low. The average variation for all type of outcomes is about 5%. This could be further reduced if hidden layers used in higher numbers in neural network but that would in-crease the computation time a little so here, in this study a balance is made between the accuracy and time of computation. We have found that Artificial Neural Network (ANN) is a very powerful tool for linear elastic analysis of steel plates even with concentric cut-outs. Artificial neural network approach is easier and faster than approach adopted by software based on finite element method. It takes lesser time to compute the results. Using ANN, dependency upon costly analysis and design packages can be avoided.

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