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DETERMINATION OF THE POSITION AND MAGNITUDE OF THE FORCE ACTING ON A COMPOSITE SANDWICH PANEL USING ARTIFICIAL INTELLIGENCE

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Abstract: *The paper presents the deformations that occur in a simply supported composite sandwich panel under the action of a concentrated force moving along the length of the beam. Taking into account the method of superposition of effects, the deflection of the beam under the action of its own weight are determined, over which the deflection given by the mobile concentrated force are superimposed. The results obtained analytically are compared with the results from the numerical method. Based on these results, an artificial neural network was developed to determine the position and value of the concentrated force. It can be used to create patterns so that the force localization and its value becomes a pattern recognition problem.*

Keywords: *composite materials, deflection, neural network*

INTRODUCTION

The bending loads on a straight beam lead to its deformation in the vertical plane, so that the longitudinal axis of the beam takes the form of a curve [1]. The vertical displacement of the center of gravity of the cross-section under the action of stresses is called the deflection [2].
Determining the deformed shape of the beam at any point on the beam can be determined if the deformed fiber equation is known. The deformed fiber of the beam is a continuous curve without inflection points [3, 4].
In the present paper, the deflections of a simply supported beam under the action of its own weight and a mobile force are analyzed both through an analytical and numerical calculation using the finite element method.
The obtained results represent the input data for the development and testing of an artificial neural network for locating the position and magnitude of the moving force acting on the beam.

1.THE SANDWICH PANEL MODEL

The considered beam is of the sandwich type, composed on the outside of 2 layers of structural steel (S235JR) with 1 mm thickness and the middle layer made of polyethylene with 3 mm thickness. (Figure 1).

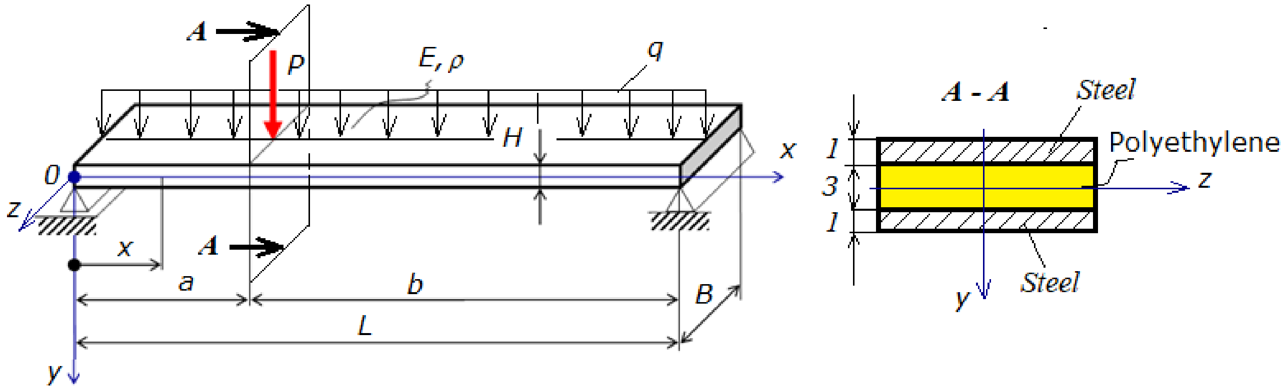

Figure 1: Simply supported sandwich panel.

The steel layers have the density ρ_s = 7800 kg/m^3 and Young's modulus E_s = 2.1·10^{11} N/m^2. The core has the density ρ_c = 952 kg/m^3 and Young's modulus E_c = 1.07·10^9 N/m^2. The length of the beam is L = 1 m, and the constant rectangular cross-section has the dimensions: B = 0.050 m and H = 0.005 m. The self-weight acts on the beam in the form of a uniformly distributed load q = 9.05 N/m with g = 9.81 m/s^2 – gravitational acceleration and a movable force with the values: P = 10 N; 20 N and 30 N, occupying the following positions on the beam: a = 0.1 m; 0.2m; 0.3 m; 0.4 m and a =$L/2$ = 0.5 m. For these cases, the deflections in the vertical plane are determined at 9 (nine) equidistant points on the beam (x = *0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9*).
Due to the symmetry of the support system, when the force acts at a distance greater than $L/2$, the arrow values will be considered in the mirror.

2.ANALYTICAL APPROACH

From the literature, it is known what the deflection of the beam under its own weight is:

$$v_q = \frac{q \cdot L^4}{24 \cdot (E \cdot I_z)_{eq}} \cdot \left(\frac{x}{L} - 2\frac{x^3}{L^3} + \frac{x^4}{L^4} \right) \quad (1)$$

and under the action of force *P:*

$$\begin{cases} v_P = \dfrac{P \cdot b \cdot x}{6 \cdot L \cdot (E \cdot I_z)_{eq}} \cdot (L^2 - b^2 - x^2)\ when\ 0 < x < a \\ v_P = \dfrac{P \cdot b}{6 \cdot L \cdot (E \cdot I_z)_{eq}} \cdot \left(\dfrac{L}{b}(x-a)^3 + (L^2 - b^2) \cdot x - x^3\right)\ when\ a < x < L \end{cases} \quad (2)$$

Through the algebraic summation of expressions (1) and (2), it is possible to calculate the deflection of the beam under its own weight on which a movable force *P* also acts, relation (3).

$$v_A = v_q + v_P \quad (3)$$

The equivalent stiffness of the beam $(E \cdot I_z)_{eq}$ is calculated with the relation [6]:

$$(E \cdot I_z)_{eq} = \frac{B}{12} \cdot [2E_s \cdot s^3 + 6E_s \cdot s(c+s)^2 + E_c \cdot c] \quad (4)$$

3.NUMERICAL INVESTIGATIONS

The software used is SolidWorks, and tetrahedral elements with an average size of 3 mm were used for mesh. For the boundary conditions at the ends of the beam, displacements of these surfaces along the *x0z* and *y0z* planes are canceled and displacements along the *x0y* plane, respectively rotations along the *z* axis, are allowed.

To obtain the deflections at the considered points along the length of the beam, the software allows to define sensors on the nodes of the mesh [7] with the indication of the node number, the measurement position, and the value of the deflection. Figure 2 shows the deflection values obtained from the numerical analysis for a force of *P* = 10 N applied at a distance of a = 0.1 m from the left support.

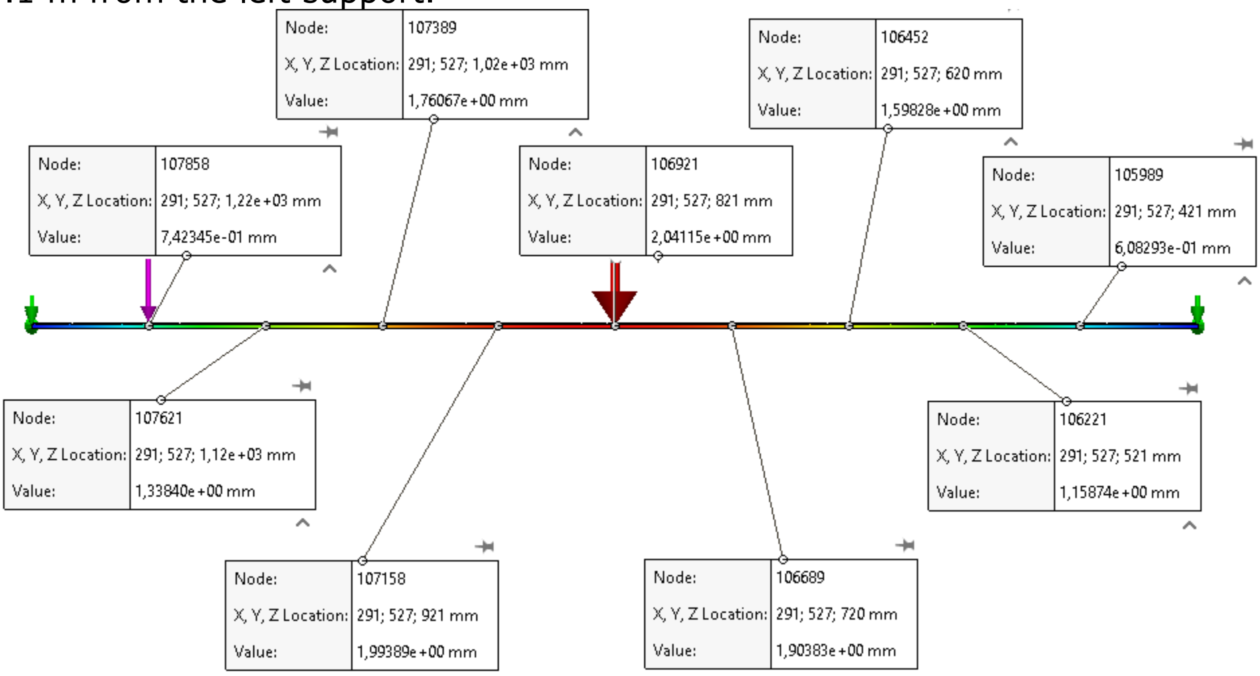

Figure 2: Deflections for *P*=10 N force applied at *a*=0.1 m from left support.

4.RESULTS

Tables 1 – 5 show the deflections obtained by applying the analytical and numerical method and the error obtained between the two methods. The notations used in the tables represent:

x[m] – the position on the beam where the deflection is determined;

v_A [m] – the value of the deflection obtained analytically with the relation (3);

v_{FEM} [m] – deflection value obtained by finite element method;

ε [%]– the error between the deflection values obtained by the two methods.

Tabel 1. Deflections for simply supported beam when force is applied at distance a = 0.1 m

	***P* = 10 N**			***P* = 20 N**			***P* = 30 N**		
***x* [m]**	**v_A [mm]**	**v_{FEM} [mm]**	**ε[%]**	**v_A [mm]**	**v_{FEM} [mm]**	**ε[%]**	**v_A [mm]**	**v_{FEM} [mm]**	**ε[%]**
0,1	0.7453	0.7424	-0.401	1.0598	1.0604	0.06	1.3742	1.3785	0.31
0,2	1.3587	1.3384	-1.50	1.9022	1.8762	-1.37	2.4456	2.4140	-1.29
0,3	1.7955	1.7607	-1.94	2.4748	2.4273	-1.92	3.1541	3.0938	-1.91
0,4	2.0409	1.9939	-2.30	2.7746	2.7125	-2.24	3.5082	3.4265	-2.33
0,5	2.0908	2.0412	-2.38	2.8090	2.7408	-2.43	3.5271	3.4405	-2.46
0,6	1.9516	1.9038	-2.45	2.5960	2.5306	-2.52	3.2404	3.1635	-2.37
0,7	1.6402	1.5983	-2.56	2.1643	2.1147	-2.29	2.6883	2.6254	-2.34
0,8	1.1840	1.1587	-2.14	1.5528	1.5181	-2.24	1.8316	1.8744	-2.46
0,9	0.6211	0.6083	-2.07	0.8113	0.7936	-2.18	1.0015	0.9789	-2.26

Tabel 2. Deflections for simply supported beam when force is applied at distance a = 0.2 m

	***P* = 10 N**			***P* = 20 N**			***P* = 30 N**		
***x* [m]**	**v_A [mm]**	**v_{FEM} [mm]**	**ε[%]**	**v_A [mm]**	**v_{FEM} [mm]**	**ε[%]**	**v_A [mm]**	**v_{FEM} [mm]**	**ε[%]**
0,1	0.9744	0.9611	-1.37	1.5178	1.4987	-1.26	2.0613	2.0363	-1.21
0,2	1.8090	1.7827	-1.46	2.8028	2.7654	-1.33	3.7965	3.7482	-1.27
0,3	2.3933	2.3469	-1.94	3.6704	3.6000	-1.92	4.9475	4.8531	-1.91
0,4	2.7047	2.6440	-2.24	4.1021	4.0088	-2.28	5.4996	5.3735	-2.29
0,5	2.7507	2.6836	-2.24	4.1288	4.0261	-2.49	5.5068	5.3685	-2.51
0,6	2.5494	2.4844	-2.55	3.7916	3.6922	-2.62	5.0338	4.9000	-2.66
0,7	2.1293	2.0793	-2.35	3.1425	3.0662	-2.43	4.1556	4.0531	-2.47
0,8	1.5295	1.4939	-2.33	2.2438	2.1893	-2.43	2.9580	2.8847	-2.48
0,9	0.7997	0.7812	-2.32	1.1685	1.1401	-2.43	1.5372	1.4990	-2.49

Tabel 3. Deflections for simply supported beam when force is applied at distance a = 0.3 m

	***P* = 10 N**			***P* = 20 N**			***P* = 30 N**		
***x* [m]**	**v_A [mm]**	**v_{FEM} [mm]**	**ε[%]**	**v_A [mm]**	**v_{FEM} [mm]**	**ε[%]**	**v_A [mm]**	**v_{FEM} [mm]**	**ε[%]**
0,1	1.1102	1.0909	-1.74	1.7896	1.7592	-1.70	2.4689	2.4275	-1.68
0,2	2.0924	2.0541	-1.83	3.3695	3.3102	-1.76	4.6466	4.5663	-1.73
0,3	28280	2.7728	-1.95	4.5399	4.4554	-1.86	6.2518	6.1380	-1.82
0,4	3.2287	3.1510	-2.41	5.1502	5.0273	-2.39	7.0717	6.9035	-2.38
0,5	3.2942	3.2043	-2.73	5.2157	5.0728	-2.74	7.1372	6.9412	-2.75
0,6	3.0541	2.9643	-2.94	4.8009	4.6678	-2.77	6.5477	6.3513	-3.00
0,7	2.5486	2.4766	-2.82	3.9809	3.8663	-2.88	5.4133	5.2560	-2.91
0,8	1.8284	1.7757	-2.88	2.8416	2.7575	-2.96	3.8547	3.7392	-3.00
0,9	0.9950	0.9271	-2.92	1.4790	1.4356	-3.01	2.0031	1.9418	-3.06

Tabel 4. Deflections for simply supported beam when force is applied at distance a = 0.4 m

***P* = 10 N**	***P* = 20 N**	***P* = 30 N**

x [m]	v_A [mm]	v_{FEM} [mm]	ε[%]	v_A [mm]	v_{FEM} [mm]	ε[%]	v_A [mm]	v_{FEM} [mm]	ε[%]
0,1	1.1646	1.1430	-1.85	1.8982	1.8622	-1.90	2.6319	2.5815	-1.92
0,2	2.2127	2.1707	-1.90	3.6102	3.5409	1.92	5.0076	4.9112	-1.92
0,3	3.0377	2.9777	-1.98	4.9592	4.8617	-1.97	6.8807	6.7456	-1.96
0,4	3.5432	3.4717	-2.02	5.7791	5.6645	-1.98	80.150	7.8573	-1.97
0,5	3.6630	3.5787	-2.30	5.9532	5.8162	-2.30	8.2435	8.0538	-2.30
0,6	3.4189	3.3353	-2.45	5.5307	5.3938	-2.48	7.6424	7.4523	-2.49
0,7	2.8630	2.7985	2-25	4.6098	4.5040	-2.29	6.3566	6.2095	-2.31
0,8	2.0574	2.0118	-2.22	3.2996	3.2243	-2.28	4.5418	4.4368	-2.31
0,9	1.0753	1.0518	-2.19	1.7197	1.6807	-2.27	2.3641	2.3096	-2.31

Tabel 5. Deflections for simply supported beam when force is applied at distance a = 0.5 m

		P = 10 N			P = 20 N			P = 30 N	
x [m]	v_A [mm]	v_{FEM} [mm]	ε[%]	v_A [mm]	v_{FEM} [mm]	ε[%]	v_A [mm]	v_{FEM} [mm]	ε[%]
0,1	1.1491	1.1259	-2.01	1.8672	1.8287	-2.06	2.5853	2.5315	-2.08
0,2	2.1933	2.1478	-2.08	3.5714	3.4962	-2.10	4.9494	4.8447	2.12
0,3	3.0377	2.9732	-2.12	4.9592	4.8534	-2.13	6.8807	6.7337	-2.14
0,4	3.5975	3.5199	-2.16	5.8878	5.7615	-2.15	8.1781	8.0031	-2.14
0,5	3.7988	3.7149	-2.21	6.2250	6.0897	-2.17	8.6511	8.4645	-2.16
0,6	3.5975	3.5115	-2.39	5.8878	5.7472	-2.39	8.1781	7.9829	-2.39
0,7	3.0377	2.9691	-2.26	4.9592	4.8464	-2.27	6.8807	6.7237	-2.28
0,8	2.1933	2.1434	-2.27	3.5714	3.4888	-2.31	4.9494	4.8342	-2.33
0,9	1.1491	1.1228	-2.29	1.9672	1.8235	-2.34	2.5853	2.5243	-2.36

From the above tables it can be seen (Figure 3) that the errors are small, up to 3%.

5.DEVELOPMENT OF THE NEURONAL NETWORK

In this section, based on the analytical calculation to determine the deflections of the sandwich panel simply supported beam, a Feedforward-Backpropagation artificial neural network is developed and tested which is trained to determine the position and value of a concentrated force acting on the bar [8, 9].
Feedforward networks, also called multilayer perceptrons (MLP), are machine learning models that involve training the network by approximating a threshold function in accordance with the input and output values. Based on these training values the model must find a hypothesis function that matches the threshold function or at least approximates it well. These models are called feedforward because the information flows from the function evaluated based on the input values, then through the intermediate calculations used to define the threshold function, and finally to the result.
The backpropagation algorithm is a supervised learning method for multilayer feedforward networks and aims to model a given function by changing the internal weights of each input to produce an expected output signal [10, 11].

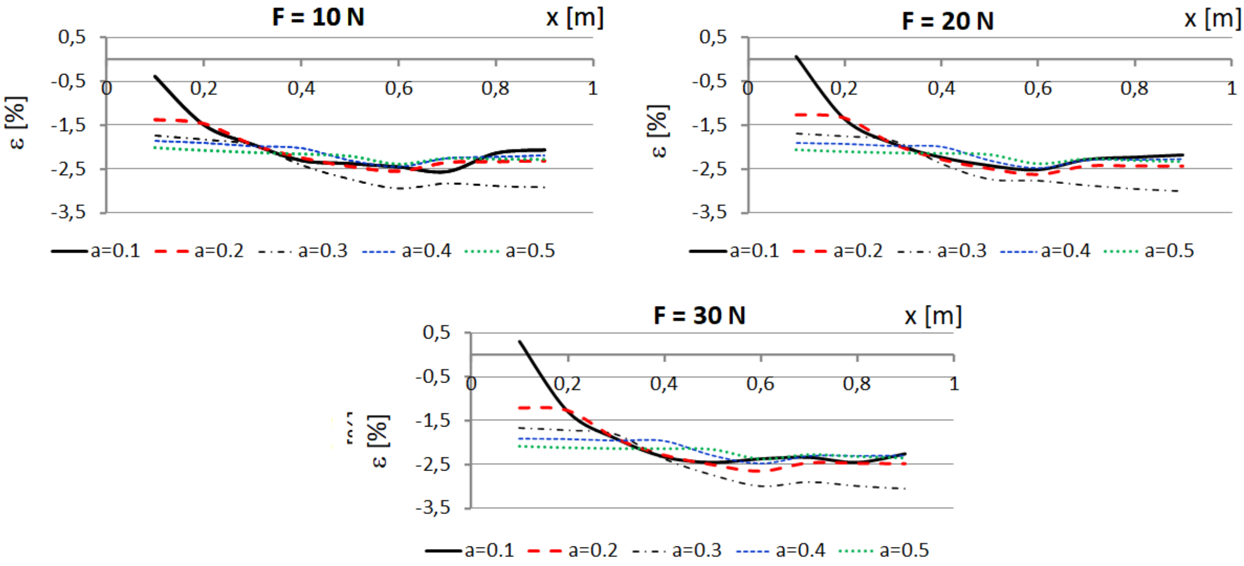

Figure 3: Deviations between numerically and analytically values.

In this paper, the artificial neural network was developed using the Matlab program based on the training data obtained by the method used in the previous section. The network parameters are shown in figure 4.

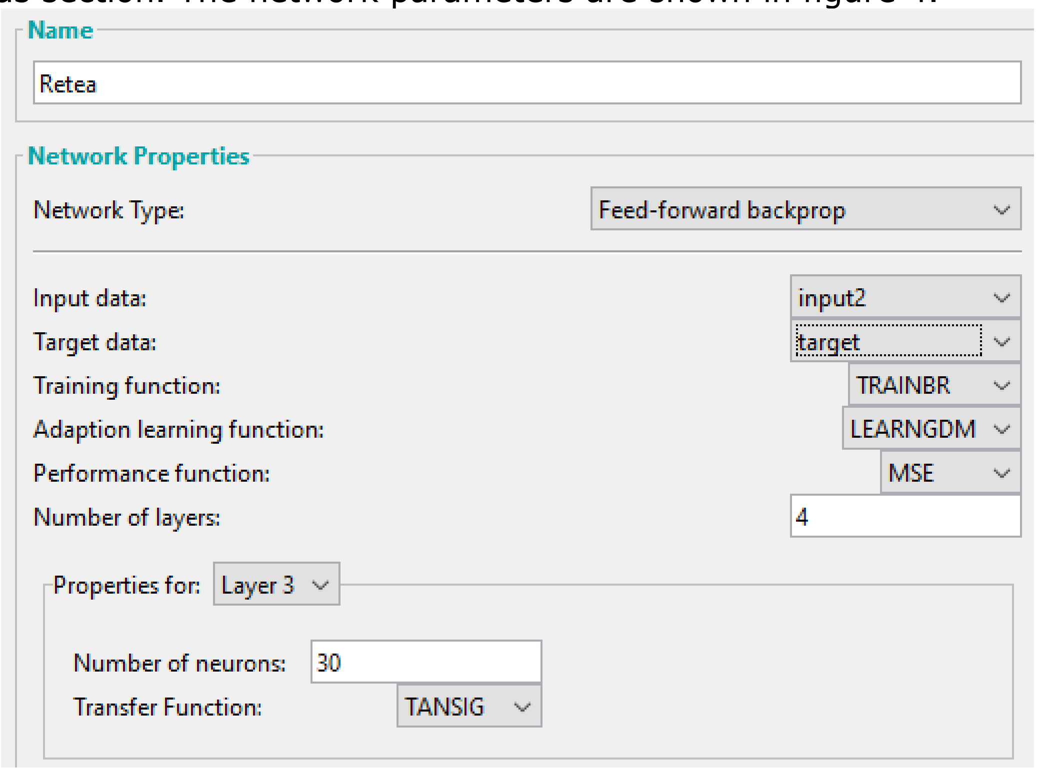

Figure 4: Network type and parameters used for training.

The training data consists of input values, namely the deflections value determined for 9 positions along the beam when a concentrated force of known position acts on it. Each set of input values was assigned two output values, which are position and force value, as shown in Tables 1 - 5. The performance obtained for the developed network is shown in Figure 5.

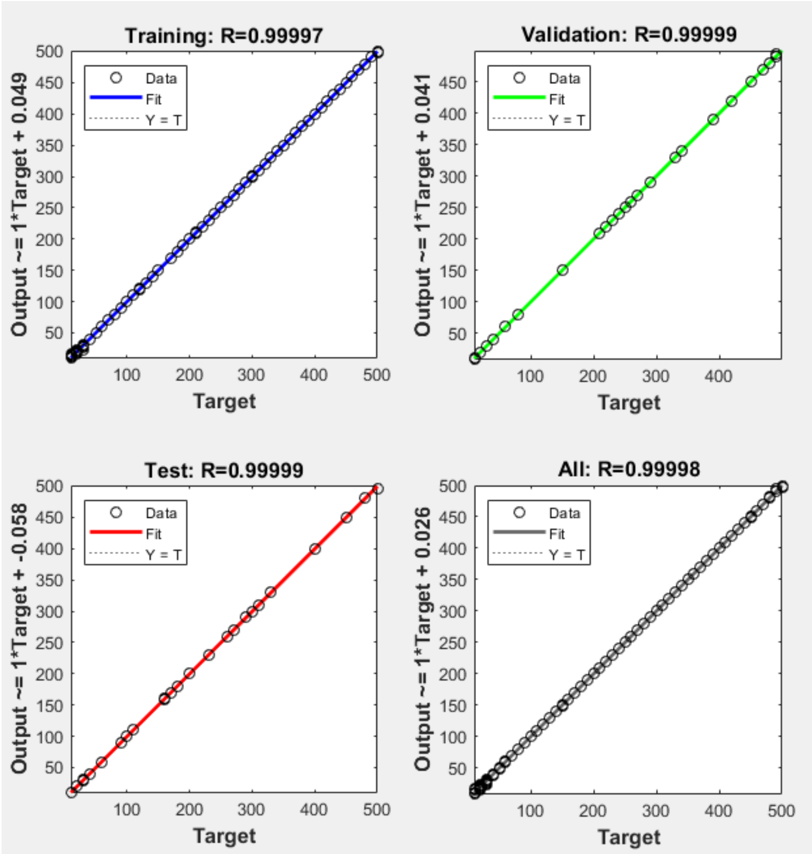

Figure 5: Neural network training results.

The accuracy of the mesh to determine the value and position of the concentrated force acting on the beam was tested by using the deflections obtained by FEM analysis in the SolidWorks simulation program. The same 9 sensor positions were considered for testing, but the positions where the force was applied were changed to not match the training data.

The results obtained as well as the precision of the developed neural network are presented in table 6. From this table it can be seen that the estimated values of the position and the force are very close to the real ones, the maximum error for determining the force being 4.1% and for position determination 0.47%.

Table 6. The results obtained by using the artificial neural network.

	FEM		Artificial neural network prediction			
Scen.	**Force value [N]**	**Force position [mm]**	**Force value [N]**	**Force error [%]**	**Force position [mm]**	**Position error [%]**
1	10	113	10.23	2.30%	111.40	0.16%
2	10	113	19.86	0.70%	117.20	0.42%
3	20	113	31.20	4.00%	110.50	0.25%
4	10	264	9.72	2.80%	266.40	0.24%
5	30	264	19.18	4.10%	267.80	0.38%
6	30	264	29.97	0.10%	265.80	0.18%
7	30	326	10.19	1.90%	330.70	0.47%
8	20	326	19.65	1.75%	329.10	0.31%
9	20	326	29.92	0.27%	327.40	0.14%
10	10	482	10.37	3.70%	478.20	0.38%
11	20	482	19.37	3.15%	485.80	0.38%
12	30	482	30.16	0.53%	481.40	0.06%

6.CONCLUSIONS

From the analysis of the data obtained from the analytical calculation using relation (3) and the numerical results, a very good correlation can be found between the two methods. The errors for the two methods are maximum 3%. The numerical calculation has a tendency to slightly under estimate the deflections.
The results obtained by using a neural network, namely the estimated value of the position and magnitude of the force acting on the sandwich panel simply supported beam, show that the neural network can be used successfully. Following the analysis of the estimated values, it follows that the largest error in the determination of the force value was obtained for Scenario 5, namely 4.1%. Regarding the highest error obtained in the force position estimation, it is 0.47% and was obtained for Scenario 7. From the prediction values presented, we can conclude that the developed method could provide reliable data regarding the loading degree of beam-type structures.

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