Artificial Neural Networks (ANNs) to Predict the Behavior of Reinforced Linear Pavements with Geosynthetics - Comparision with the Finite Element Method

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ABSTRACT: Studies carried out in recent years have demonstrated the effectiveness of "geo-synthetics" materials on the behavior of linear pavements after they have been reinforced with these materials, as well as through experimental-numerical comparisons. However, in most cases, the error (or deviation) observed by these comparisons is difficult to readjust. This is why neural networks seems to be an alternative solution for facilitating this readjustment. In this paper, we propose a study of a set of linear pavements in Algeria, in high-traffic areas, by collecting databases derived from practical experience in the field. The results obtained from the application of the neural network method (ANNs), using Python software, will be compared with the results obtained using the finite element method (FE) using Ansys/Workbench software. It seems that the parameterized RNA method is more accurate in predicting the behavior of linear pavements by determining their bearing capacity, despite the advantage given by the finite element method.
KEYWORDS: linear pavement, reinforcement, geo-synthetic, RNAs, analysis.

1.INTRODUCTION

Algeria is strategically located in the north of the African continent, bordering on the Mediterranean. It has a very extensive road network, with 135,000 km of roads and motorways (Ministry of Public Works, 2021), spread throughout the country. Given the extent of these infrastructures and the intense traffic that uses them, we are often faced with problems of deterioration and damage (cracks, splinters, rutting, deformation, tears, etc.), which occur in the surface layers and pavements of these infrastructures (Fig.1). It is therefore necessary to assess and diagnose these infrastructures in order to maintain them, with reinforcement if necessary. The rehabilitation of linear road pavements (roads, motorways) and airport pavements (airfields), using innovative materials known as "geo-synthetics", has emerged as a popular method in recent years, particularly for flexible and sometimes rigid pavements (Zornberg. 2017).

Figure 1. Degradations of Rutting in road

However, the evaluation of these infrastructures, before or after their reinforcement, over time is carried out by several processes: visual inspection, experimental investigation (non-destructive testing), and numerical simulations using finite elements (FE) or analytical analysis.
Unfortunately, the analytical tools and, to a lesser degree, the numerical tools used to analyzed such pavements (in particular finite element analysis (FE)) are costly in terms of calculation, which makes them slow to provide an answer, such as the prediction of their bearing capacity and their behavior in the event of major hazards. An empirical solution is therefore proposed, involving the development of an artificial neural network model of the performance (ANNs) of linear pavements or other infrastructure elements (adjacent layers, interfaces), developed from experimental results or from experts in the field (Abdessemed et al. 2014). Recent research on the monitoring of the static and pseudo-dynamic behavior of linear infrastructures reinforced with geosynthetics has shown the effectiveness of the latter on the bearing capacity of the pavement and its longevity (Medjdoub et al. 2023) In the present study, new empirical approaches for simulating the behavior of flexible pavements (asphalt concrete) reinforced with geogrids (families of geo-synthetics) are developed, using the "Python" software, from available experimental data by applying artificial neural networks (ANNs). Given known combinations of input and output data, the neural network can be trained to extract underlying features and relationships from the data. Then, when a separate set of input data is provided to the trained network, it produces an approximate but reasonable output. Neural networks are highly non-linear and can capture complex interactions between the input and output variables of a system without any prior knowledge of the nature of these interactions (Flood et al. 2001). Using input data, the bearing capacity is estimated by predicting the value of the equivalent thickness of the pavement, both reinforced and unreinforced. A comparison of the results using the finite element method is carried out using the Ansys/Workbench software, to see the difference in the calculations.

2. NEURAL NETWORK AND APPLICATION FOR PAVEMENT

2.1 Neural network

The artificial neural network (ANN) has emerged as the most widely used and preferred AI method, with 52% of studies relying on it (Baghbani et al. 2022). By definition, a neural network is a functional abstraction of the biological neural structures of the central nervous system (Oztas, 2006). It can exhibit a surprising number of features of the human brain. Neural networks can provide meaningful responses even when the data to be processed contains errors or is incomplete, and can process information extremely quickly when applied to real-world problem solving (Lippman. 1988). Neuro informatics architectures can be integrated into physical hardware (or machines) or neurological languages (or programs) capable of thinking and acting intelligently like human beings.

Among the different architectures and paradigms, the back-propagation network is one of the simplest and most applicable networks, used to perform high-level human tasks such as diagnosis, classification and decision-making, planning and scheduling. It’s one of the most popular learning (training) algorithms. Consequently, for a given input model, an activation flow is transmitted from the input layer to the output layer via the hidden layers. In recent years, the use of artificial neural networks (ANNs) has increased in many areas of engineering. In particular, ANNs have been applied to many geotechnical engineering problems and have demonstrated a certain degree of success (Shahin et al. 2001).

Then, errors in the output are initiated. The neural network modeling process has five main aspects: (a) data acquisition, analysis and representation of the problem; (b) determination of the architecture; (c) determination of the learning process (Fig.2); (d) training of the networks; and (e) testing of the trained network for generalization (Barai et al. 1997).

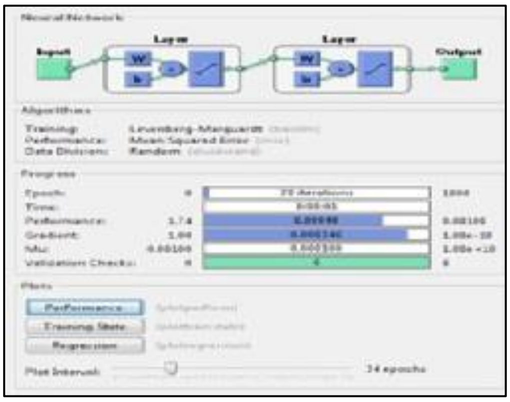

Figure 1. Learning of the network panel.

2.2 ANNs for predicting the behavior of linear pavements

The literature has shown that several research studies have investigated the prediction of linear pavement behavior using neural networks (ANNs). For example, Gopalakrishnan, presented a study on the prediction of critical responses of asphalt airport pavements from in situ (non-destructive) tests using structural models based on ANNs (Gopalakrishnan. 2006). The detection of damage to basic infrastructure using artificial neural networks has been studied by Zhao (Zhao et al. 1998). Estimation of the dynamic modulus "E" of hot mix asphalt layers for a flexible road was developed by a set of predictive models using artificial neural networks (ANNs) trained with different sets of parameters (Sakhaeifar et al. 2010). Recent studies have developed artificial neural network (ANN) models to predict the flexural stiffness and rutting depth of bituminous pavements (Qadir et al. 2020), or the prediction of the equivalent thickness of the pavement body reinforced with geogrids (Lina et al. 2023). Similarly, the work carried out by Gu F., aimed at developing a methodology for incorporating the geogrid material into the Pavement ME-Design software, in order to predict the performance of flexible pavements reinforced with geogrids, based on a large database of pavement responses and corresponding material properties (Gu et al. 2018). However, the application of neural networks in predicting the behaviour of a linear asphalt concrete pavement, before and after repair by geogrids, is few (see rare). For this reason, in this paper we focus on a parameterized analysis using ANNs to predict the behavior of linear asphalt concrete pavements after reinforcement of their layers, by insertion with geogrids, and making a comparison with the finite element (FE) method.

3. PREDICTION GEOGRID-REINFORCED PAVEMENT BEHABIOR WITH ANNS

3.1 Implementing geogrid-reinforced pavements

The performance of geogrid-reinforced roads depends on many factors, including geogrid type, pavement thickness, loading conditions, and environmental factors. Accurately predicting behavior is critical to the design and maintenance of durable pavements. When geogrid is placed beneath the pavement, it distributes a load of traffic more evenly across the subgrade. This reduces stress on the soil and helps prevent cracking and other types of damage. Implementing a geogrid is relatively straightforward and can be done with light equipment. First, it is important to clean and level the paved surface. The geogrid is then spread over the surface and secured with staples or nails. Care must be taken to ensure that the geogrid is properly stretched and free of wrinkles and deformation. Finally, a layer of asphalt is applied to the surface to seal the geogrid and form a strong and durable pavement (Al-Qadi et al. 2012).

3.2 Neural Network Architecture and data pre-processing

The collected data underwent several pre-processing steps to ensure its suitability for training the ANN model. Initially, the data was carefully examined for missing values or outliers. Missing values, if any, were handled through appropriate techniques such as imputation or exclusion based on the extent of missingness and the impact on the overall dataset. Outliers, which could potentially skew the model's performance, were identified and treated using statistical methods or domain knowledge. Next, the data was standardized or normalized to bring all variables to a similar scale, preventing any particular variable from dominating the training process due to differences in their magnitudes. This step allowed for a fair comparison and effective training of the ANN model. Feature selection techniques were applied to identify the most relevant variables contributing to pavement behavior prediction, reducing dimensionality and potentially enhancing model efficiency. Finally, the dataset was split into training, validation, and testing subsets, ensuring the model's performance evaluation on unseen data. The training set was used to train the ANN model, the validation set to fine-tune hyper parameters and prevent over fitting, while the testing set provided an independent evaluation of the model's performance. The research made extensive use of various Python tools and libraries, in particular Pandas, to facilitate data analysis and pre-processing. Drawing on the power of Pandas. The library's intuitive and versatile data structures made it possible to organise and manipulate all the data efficiently. This allowed us to filter, sort and aggregate data seamlessly, while its powerful indexing capabilities facilitated data alignment and integration. The database of collected values: Critical Truck Weight (P), Traffic Count (N) and Physical Quality of the Roadway (ICBR), were fed into the Python code in "data.csv" format. After executing the code, Python generated this table based on the relationship:

$$e = \frac{100+\sqrt{P}(75+\log(\frac{N}{10})}{\frac{ICBR}{5}} \quad (1)$$

Python code that has been developed utilizes three inputs and one output based on the provided database. Using this code, we were able to obtain results for the variable "e" with different values of ICBR (Input Current Bias Resistance) and N (Fig.2).

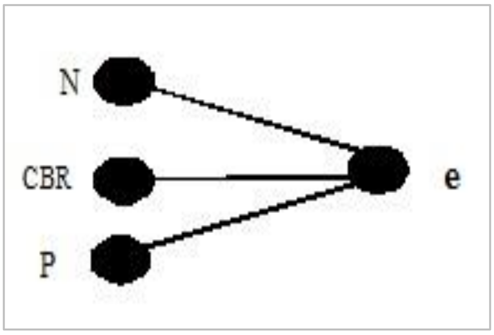

Figure 2. Neural network architecture

4. RESULTS FOUND AND DISCUSSION

4.1 Prediction of equivalent thickness using ANNs

These results show, in the graph below, for all the examples taken from the database, that the equivalent thickness of the pavement body decreases with the increase in the CBR index. Both before and after reinforcement of the flexible pavement with geogrid. (Fig.3).

The curve, in terms of performance, shows a reduction in the mean absolute error from approximately 3×10-2 m. seconds (for a network with zero hidden neurons) to 10-4 m. seconds (for a network with 20 hidden neurons), which shows a clear regression in the absolute error throughout the training of the network. Therefore, beyond the point where performance stops for the set of test observations (20 hidden networks), there is no advantage in training a neural network beyond this point where its performance stops improving for the set of test observations. From the point of view of the number seen, we note that the performance curve for the test observations appears to be on a slight downward trend, even after 20 hidden neural networks have been trained. This indicates that the additional improvement in the performance of the network could have been achieved as well in the hypotheses, it had been allowed to continue, albeit by a small amount.

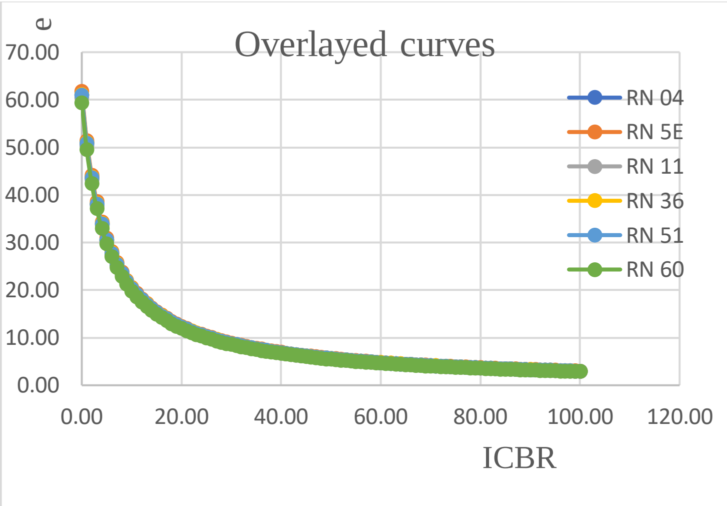

Figure 3. Overlayed curves of the projects

After the addition of two layers of geogrid, the thickness values "e", observed a reduction of 30% compared to the thickness of the original layer (without reinforcement).

4.2 Results of numerical analysis

The modeling results consisted of using real case studies to calculate (predict) the behavior of the flexible pavement. The calculation parameters are: the load P, the dimensions of the pavement in "3D", the type of soil (ICBR value), the mechanical characteristics of the surface layers of the pavement body, the average thickness of the pavement (determined by predicting the calculation using neural networks (ANNs)). We used the same real case studies as in our previous calculations, for unreinforced pavement and then for pavement reinforced with layers of geogrid.

The results found in terms of stresses showed that the geogrid, in addition to its separation role, reduces the tensile stresses and consequently reduces the thickness of the reinforced pavement. The value found for the stress before reinforcement is : 4.716 MPa, compared with 4.102 MPa (after reinforcement), a reduction of 14.97% (Figs 4a & 4b). This gives an advantage to pavements reinforced with these geo-synthetics in terms of longevity.

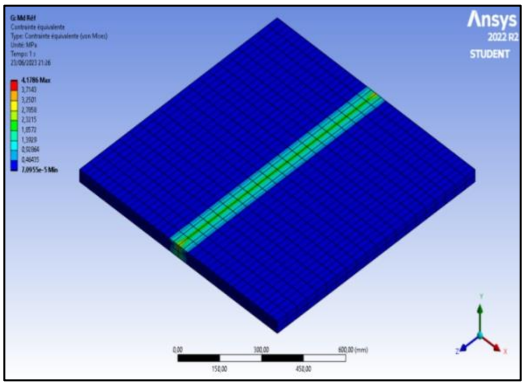

Figure 4a. Unreinforced pavement

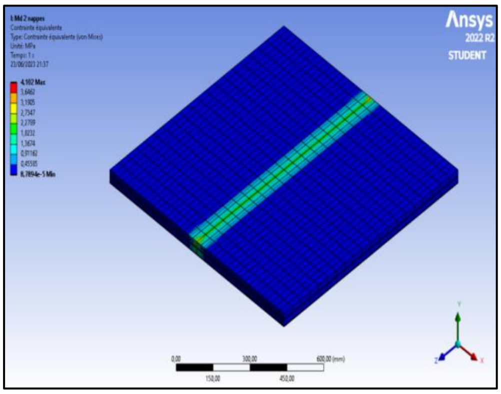

Figure 4b.Pavement reinforced with 2 layers

CONCLUSION

At the end of this analysis, which consisted first of all of gaining a good understanding of geosynthetic products and, more specifically, geogrids and their application in the pavement structure of linear infrastructures (roads and aircraft runways), with the prediction of their behaviour over time by measuring their bearing capacity (equivalent thickness and stresses), by applying artificial intelligence with the method known as neural networks (ANNSs) and the finite element method (FE). In fact, the work carried out shows that quantitatively, while geogrids reduce stresses (the difference) by between 12 and 15% (experimentally or numerically (finite elements)), this difference is increased by the application of ANNs, by 30%, i.e. an error of almost 14%, which makes the application of neural networks more effective and efficient. The ANNs implemented are made up of three input layers, a hidden layer and a single output layer.

References

Abdessemed, M. & Kenai, S. 2014, Application of neural networks to the prediction of the behavior of reinforced composite bridges, Conference- ACEM14/ Seoul - 24-28 August in Busan, South Korea, pp.1-7

Al-Qadi, I. L., Dessouky, S. H., Kwon, J. & Tutumluer, E. 2012. Geogrid-reinforced low-volume flexible pavements: pavement response and geogrid optimal location. Journal of transportation engineering, 138(9), pp.1083-1090.

Baghbani, A., Choudhury, T., Costa, S., & Reiner, J. 2022, Application of artificial intelligence in geotechnical engineering: A state-of-the-art review. Earth-Science Reviews, 228, 103991. https://doi.org/10.1016/j.earscirev.2022.103991.

Barai, S. V., & Pandey, P. C. 1997, Time-delay neural networks in damage detection of railway bridges. Advances in Engineering Software, 28(1), pp. 1-10.

Flood, I., Muszynski, L., & Nandy, S. 2001. Rapid analysis of externally reinforced concrete beams using neural networks. Computers & Structures, 79(17), pp.1553-1559.

Gopalakrishnan, K. 2006, Prediction of airport flexible pavement critical responses from non-destructive test data using ANN-based structural models. Journal of Applied Sciences, 6(7), pp. 1547-1552.

Gu, F., Luo, X., Zhang, Y., Chen, Y., Luo, R. & Lytton, R. L. 2018, Prediction of geogrid-reinforced flexible pavement performance using artificial neural network approach. Road Materials and Pavement Design, 19(5), pp. 1147-1163.

Lina, B. & Abdessemed, M. 2023, Application of artificial neural networks (ANNs) to predict the behavior of reinforced linear Pavements with geosynthetics- comparison with finite element method, Master's thesis, Department of Civil Engineering, University of Blida1, Algeria, 126 pages.

Lippmann, R. 1987, An introduction to computing with neural nets. IEEE Assp magazine, 4(2), pp. 4-22. https://doi.org/10.1109/MASSP.1987.1165576.

Medjdoub, A. & Abdessemed, M. 2023, Tests on the Influence of Cyclic Loading and Temperature on the Behaviour of Flexible Pavement Reinforced by Geogrids with Numerical Simulation. Tehnički vjesnik. 30(2), Pp. 521-529. https://doi.org/1017559/TV-20220806010532.

Ministère des Travaux Publics. 2021, Atlas routier et autoroutier du réseau routier en Algérie, Guide d'utilisation, Direction des Routes et des Ouvrages d'Art, 335 pages.

Öztaş, A., Pala, M., Özbay, E., Kanca, E., Çagˇlar, N., & Bhatti, M. A. 2006. Predicting the compressive strength and slump of high strength concrete using neural network. Construction and building materials, 20(9), 769-775.

Qadir, A., Gazder, U., & Choudhary, K. U. N. (2020). Artificial neural network models for performance design of asphalt pavements reinforced with geosynthetics. Transportation Research Record, 2674(8), 319-326.

Sakhaeifar, M. S., Underwood, B. S., Kim, Y. R., Puccinelli, J. & Jackson, N. 2010, Development of artificial neural network predictive models for populating dynamic moduli of long-term pavement performance sections. Transportation research record, 2181(1), pp. 88-97.

Shahin, M. A., Jaksa, M. B., & Maier, H. R. 2001. Artificial neural network applications in geotechnical engineering. Australian geomechanics, 36(1), pp. 49-62.

Zhao, J., Ivan, J. N., & DeWolf, J. T. 1998, Structural damage detection using artificial neural networks. Journal of Infrastructure Systems, 4(3), pp. 93-101.

Zornberg, J. G. 2017, Functions and applications of geosynthetics in roadways. Procedia engineering, 189, 298-306. https://doi.org/10.1016/j.proeng.2017.05.048.

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