

Optimum Design of Truss Structures using Neural Network

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ABSTRACT

The purpose of this paper is to verify the applicability of the prototype of the Neural Network base model for Optimum Structural Design (NNOSD) to search the optimum design in all cases immediately. NNOSD suggest the procedure of the optimum design and the proper values of the neural network variables (training pattern, number of hidden neurons, maximum training error, steepness coefficient, learning constant, momentum term, etc.) to reduce the computer time and to improve the accuracy. And the methods of the connection between NNOSD and the existing design system is presented.

The artificial neural network is used as an alternative design model of the warren truss since it can handle uncertainty through the probability method.

KEYWORDS: artificial neural network, shape optimum design, truss

1. INTRODUCTION

Even though the study have been developed based on the deterministic optimization technique, the application to practice have been conducted in a limited scope because of the fundamental problems that the deterministic optimization technique must express objective function and constraint as design variable and the partial derivative of objective function and constraint should be obtained with respect to the design variable.

The most important factors in considering is to develop mathematical model, or engineering model which has universality that can be applied in any circumstances and adoptability can be applied even in a new condition. Therefore, this study is to develop the optimum design technique which can obtain a reliable optimum solution with the least time and effort, even though minor errors are contained, because objective functions and constraints don't have to be expressed as design variables, by adopting artificial neural network, which are parallel calculation model similar to human brain, which can deal with uncertainty because probabilistic procedures are contained, which extensive and complex non linear relationship can systemize correlation without simplification process to develop a new engineering model to solve so that problems of deterministic optimization technique can be solved.

The validity of developed NNOSD (Neural Network Base Model for Optimum Structural Design) has been verified by conducting shape optimum design based on warren truss beam.

2. NEURAL NETWORK THEORY

The neural network algorithm for structural design is error back-propagation training algorithm which is a typical neural network suitable in solving multi variable non linear problem.

The error back-propagation training algorithm has a structure of multi-layered perceptron as shown in Fig. 1, and are being operated in the sequence of training stage and recall stage.

First of all, in training phase, input and objective pattern consist of various input and output pairs. After output is computed with respect to input pattern, connection weight is adjusted in a manner that difference between expected value and output value is being reduced. After the adjusting phase, the optimum connection weight can be obtained by repetitive training using same procedure. In recall stage, if the input value is given, appropriate output value is computed by interaction with connection weight without repetitive computation.

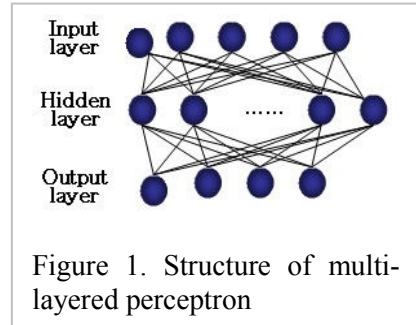


Figure 1. Structure of multi-layered perceptron

3. NEURAL NETWORK MODEL FOR OPTIMUM DESIGN

3.1 Pattern data for neural network train

Structural design was based on warren truss beam as shown in Fig. 2, analysis and design conditions are shown in Table 1. For accumulation of training pattern, analysis and design have been conducted by varying L, length of beam, D, depth of beam, and w, uniformly distributed load.

Table 2 shows steel pipes which were used in the process of designing members of warren truss beam. Total of 38 pipes whose section area was ranging from 5.76 to 98 cm² were used, and the average difference between section areas was 2.49 cm².

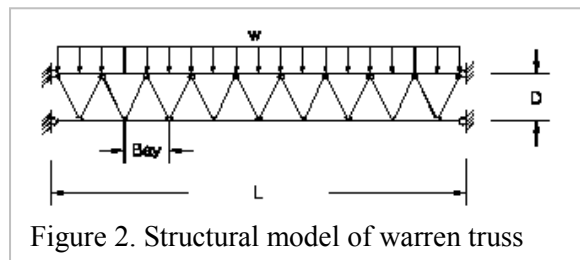


Figure 2. Structural model of warren truss

Table 1. Analysis and design conditions

Item	Design Condition	Remark
Bay	2 m	Constant
Member Group	Top Chord, Bottom Chord Web Member	3 Group, Pipe Section
Length	12 – 24 m	
Depth/Length	0.05 – 0.25	0.6 – 6 m
Load	1.2 – 2.4 t/m	Self weight is considered as another load case.

Table 2. Pipe for the warren truss design

No.	Label	Area(cm ²)	Area Difference(cm ²)
1	P60.5*3.2	5.76	-
2	P76.3*2.8	6.18	0.42
3	P76.3*3.2	7.02	0.84
...
36	P318*8	78.04	8.91
37	P355.6*8	87.36	9.32
38	P355.6*9	98.00	10.64
Average			2.49

3.2 Selection of Design Variable in neural network

In this study, the composite method, Com-39, which used 39 patterns as training patterns, and 63 test patterns, which are not overlapped with the training pattern, were used. The training result of

composite method showed 6-7% error which is in a reasonable range, and it has been selected as the training pattern which is used in structural design.

The remainder of neural network variables has been determined similar to the previous studies regarding the design variables of neural network in order to improve accuracy and reduce the repetition of calculation as shown in Table 3.

Table 3. Neural network variables

Variable Name	Possible Value	Proper Value
Training Pattern	-	Proposed Method
No. of Hidden Neurons	2 - 20	Sum of neurons on input and output layers
No. of Hidden Layers	Above 1	1
Initial Weight Strength	Under 0.1	Under 0.1
Max. Training Error	0.5 – 0.0001	$\frac{1}{2}$ (min. value of the desired output) 2
Steepness Coefficient	0.1 – 7.0	0.1 – 1
Learning Constant	0.1 – 9.0	0.3 – 0.7
Momentum Term	0.1 – 20.0	0.2 – 1.0

3.3 Proposal for the optimum design model of neural network

The number of neuron in the input and output layer can be determined based on the analysis variables in the proposed problem to be approximated and the value of result. In case analysis variable(number of neuron in the input layer) is large, the number of training pattern can increase too much to generate those. In that case, the variables can be grouped so that the appropriate variables only can be considered. The minimum unit of neural network structure consists of 3 neurons in the input layer and one neuron in the output layer.

[Stage 2: selection of training pattern]

In general structure, training pattern can be selected based on the upper and lower value of each variable(2n points per n design variable), the central point of each plane(2 points), and the central point of design space(1) using hypercube method. If design result depending on the change of design variable comes out irregularly, composite method using hypercube method and hexahedron method are to be selected.

[Stage 3: generation of expected value in training pattern]

Expected value can be determined using implementation of structural analysis based on the value of variable corresponding to selected training pattern or collection of experimental result. If the ratio of maximum value to minimum value among generated expected value is larger than 2-20, input space can be divided by adjusting the scope of variable value. In case input space can not be divided, next step should be proceeded.

[Stage 4: Calculation of maximum allowable error]

Maximum allowable error can be computed using eqn.(1) that is minimum value among scaled expected value.

$$E_{max} \leq 1/2 (\text{min. value in exp. Value})^2 \quad (1)$$

[Stage 5: determination of maximum repetition number]

As maximum repetition number is to limit the number of training repetition when converging speed is slow or converging is impossible, it can be determined differently depending on the type of problem.

[Stage 6: number of neuron in the hidden layer]

The number of hidden layer is 1, and the number of neuron in the hidden layer can be assumed as an initial minimum value by using the sum of neuron numbers in input and output layers. But, if the ratio of maximum to minimum value among generated expected value is larger than 2-20, the number of neuron in hidden layer increases by the degree that the maximum allowable error computed in stage 4 is less than 0.1. In this case, the proper number of neurons in the hidden layer to be increased depending on the maximum allowable error is different based on the scope of problems.

[Stage 7: activation function, training coefficient, momentum factor]

Repetition number of training is depending on the coefficient of slope(λ) in activation function, training coefficient(η), and momentum factor(α).

[Stage 8: Implementation of training]

If the training is not successful within the maximum repetition number using the neural network structure obtained in above stage 1-7, the value of α and η can be reduced gradually based on experience. If the training is not successful using $\alpha = 0.0$ and $\eta = 0.0$, one need to go back to stage 6 to increase the number of neuron, or in some cases, need to increase the number of hidden layer. Meanwhile, whenever new training is started, the value of initial strength should be randomly determined.

[Stage 9: test]

Test is to be conducted using a test pattern which was not used in the trained neural network. If the error of test result exceedingly occurs more than 10%, the training pattern should be increased based on the test pattern that encountered larger error after going back to stage 2.

[Stage 10: test pattern to search optimum design]

In test pattern, the value in the input layer corresponding to the given condition is a constant value based on given condition, and the value of input layer as per design variable to look for optimum value can be obtained by the series of test patterns that are increased by a small interval.

[Stage 11: selection of optimum design pattern using sorting method]

Printed expected value corresponding to the objective function among expected values is to be sorted in ascending order, then the test pattern of minimum printed value can be selected as an optimum design pattern, and the value of input layer corresponding to the design variable to be optimized can be used as an optimum solution.

If the optimum value corresponding to the minimum value of objective function can not be obtained, stage 11 should be repeated. Then the test pattern that subdivided the adjacent interval next to the test pattern of minimum printed value should be prepared and iterate until the optimized solution can be obtained.

4. OPTIMUM DESIGN EXAMPLE USING NEURAL NETWORK OPTIMUM DESIGN MODEL

Optimum design has been conducted to obtain the minimum beam depth with minimum self weight using the warren truss in Fig. 2 under the given design condition using neural network optimum design model.

According to stage 1, the number of hidden layer has been selected as 1, and the number of neuron in the hidden layer is 4 which is the sum of neuron number in the input layer and the output layer. Fig. 3 shows a neural network structure that consists of 3 neurons in the input layer, 4 neurons in the hidden layer and one neuron in the output layer.

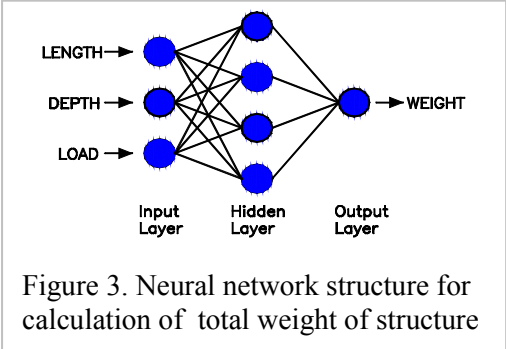


Figure 3. Neural network structure for calculation of total weight of structure

Based on stage 2, 39 training patterns were used utilizing composite method combining hypercube and hexahedron methods, according to stage 3, the result of structural design was used as a expected value of training pattern.

In stage 4-7, variables were assumed as, maximum allowable error; 0.025, maximum repetition number; 10,000, number of neuron in hidden layer; 1, coefficient of slope; 1.0, training coefficient; 0.5, and momentum factor; 0.5.

Training has been conducted based on stage 8, but it was not converged, but the training has been completed with the repetition number of 10,000 after adjusting the allowable training error to 0.004. In stage 9, it was confirmed that the average error of test pattern was less than 10% as shown in Fig. 4-6.

The output result of neural network for test pattern, which is the weight of structure, is shown in Fig. 4. In the figure, when maximum allowable error shown with mark '■' is 0.004, even though total weight of structure which is a result of structural design shown with mark '◆' analyzed using MIDAS

program shows an average error of 9.77%, but it predicts approximately similar trend of total weight of structure based on the beam depth.

Even though the test pattern is much different from the trained pattern, the error of 10% in the structural design using neural network may be considered a reasonable result. In shape optimization looking for optimum beam depth, the curve shape of objective function as per the optimum design variable rather than design error is more important. The optimum could be obtained using the similar curve shapes that are the minimum values of the curves.

In terms of prediction of minimum beam depth, 10th test pattern of MIDAS shows 0.78m, but the 8th test pattern of neural network shows 0.75m. In the result of calculation that was analyzing based on varying maximum allowable error considering that the prediction of neural network changes depending on maximum allowable error, other curves show that '▲' represents maximum allowable error of 0.006, 'x' 0.008, and '*' 0.001. When maximum allowable error was 0.008, the same result was generated with the optimum design using MIDAS.



Figure 4. Result of optimum design with Beam length of 14m, load of 2.2 tonf/m

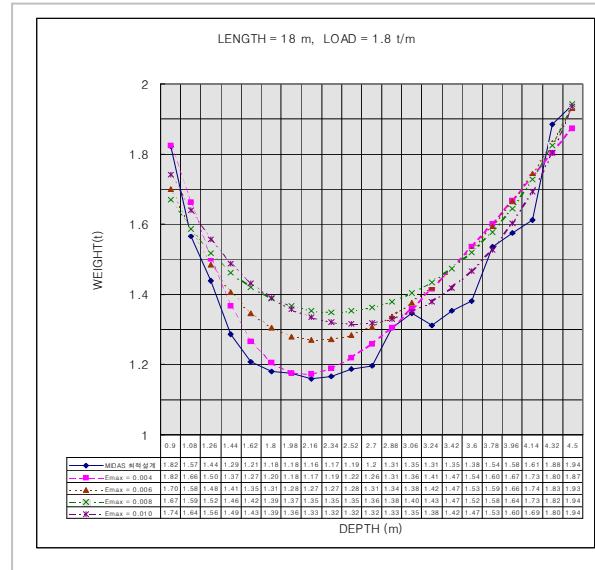


Figure 5. Optimum design result with beam Length of 18m, load of 1.8t/m

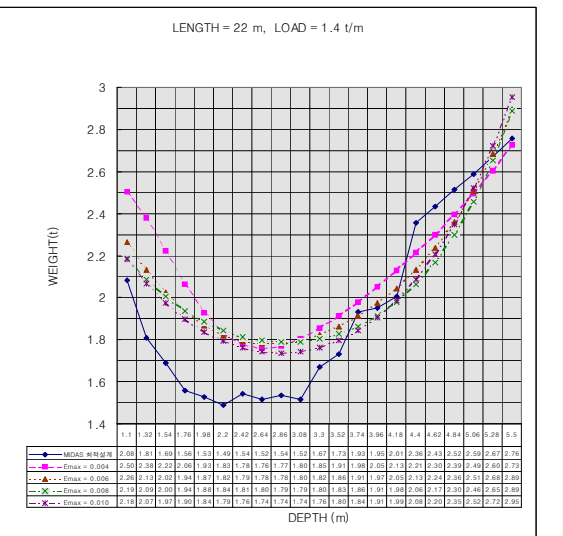


Figure 6. Optimum design result with beam Length of 22m, load of 1.4t/m

To obtain the maximum allowable error of neural network for the reduction of error in the optimum design result, the total weight calculation of the structure is shown in Fig. 5 and 6 using the quite different cases, middle of beam length(18 m), middle of distributed load(1.8 t/m), long beam(22m), small distributed load(1.4 t/m), which are different condition and are not training pattern.

The optimum prediction of beam depth is tabulated in Table 5 using Fig. 4-6, which shows that the more maximum allowable error is applied, the easing curve shapes form with less curvature, and with larger error of calculation value of objective function, the minimum values move toward the center of optimum design variable, and the error of optimum values increases.

The maximum allowable error of neural network converged for the first time was about 0.004 which was less than the exact solution of MIDAS and the optimum result showed smaller error.

Table 5. Comparison with the optimum depth by the manual design(MIDAS) and the neural network

Design Condition	Manual Design	Neural Network			
		E max =0.004	E max =0.006	E max =0.008	E max =0.0010
L=14 m W=2.2 t/m	1.96 m	1.68 m	1.82 m	1.96 m	2.10 m
L=18 m W=1.8 t/m	2.16 m	2.16 m	2.16 m	2.34 m	2.52 m
L=22 m W=1.4 t/m	2.20 m	2.64 m	2.64 m	2.86 m	2.86 m

In this study of warren truss, the scope of beam depth used in training pattern was the ratio of 0.05-0.25 based on beam length, which is equivalent to the beam depth of $L/20 - L/4$. Because the range of the pattern was extensive, the change of curve was varied. If we select the design variable to be used in the training in a practical scope, and increase the number of training pattern, better result of optimum design can be obtained in the future.

5. CONCLUSION

In the result of using neural network optimum design model(NNOSD) in the shape optimum design of warren truss beam, error range was about less than 10%, and findings are summarized as follows.

This study formulated the preparation of test pattern, and 11 stages of general method to obtain optimum solution using the technique of total search sorting in ascending order.

Even though warren truss has irregular design pattern in obtaining beam depth based on optimum design variable, optimum design solution was obtained within the error range of 9.05%.

The maximum allowable error was close to the curve shape of exact solution, and the error was negligible in the search result of optimum solution.

The proposed neural network optimum design model can be connected to the existing design system without revision by transferring the part of design data mutually. The proposed methods of connections are hierarchical connection, mutual connection and hybrid connection that combined the two methods.

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