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DAMAGE LEVEL PREDICTION OF MULTI-STORY STEEL STRUCTURE IN SUMATRA USING BACKPROPAGATION NEURAL NETWORK

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ABSTRACT: Sumatra is one of the Indonesia islands that is prone to earthquakes both tectonic and volcanic. The research aims to predict the damage level of a multi-story steel structure due to the earthquake in Sumatra Island using the Backpropagation Neural Network (BPNN). The study used the steel structure building that received earthquake loads from ten capital cities of the province on Sumatra Island. The structure analysis used the finite element software while the BPNN method used the MATLAB Programming. The input data were the responses of the structure such as displacement, velocity, and acceleration while the output was damage level of the steel structure model. The model of BPNN has the potential accuracy to predict the damage level of steel structural more than 95%. According to the simulation result, 98,5% data could be predicted correctly by the BPNN method, and the best Mean Squared Error (MSE) is 0.028. These results have shown that BPNN can predict the damage level of multi-story steel structure in all the capital cities of the province on Sumatra Island.

Keywords: Backpropagation Neural Networks, Damage Level, Earthquake Load, Mean Squared Error, Response of Structure

1. INTRODUCTION

All the coastal areas of Sumatra are in the Pacific Ring of Fire. Sumatra is one of the Indonesia islands that is prone to earthquakes both tectonic and volcanic. The characteristic of strong Indonesian quakes as occurred in Aceh on December 26, 2004 (measured 9.3 on the Richter Scale) and in Padang City on September 30, 2009 (with 7.9 on the Richter Scale) is very dangerous to the structure of buildings on these areas [1]-[2]. The collapse due to the sudden release of energy from within that creates a seismic wave. Earthquakes often occur in the location areas that are close to volcanoes and also in the regions that are surrounded by vast oceans. When this wave reaches the surface of the earth, its vibrations can be damaging or independent of source power and focal distance, besides the quality of the building and the quality of the soil in which it stands. Ordinary earthquakes are caused by the movement of the earth's crust (the earth's plates). Base on [3] the scales are used to measure the strength and magnitude of earthquakes is the Richter Scale and MMI (Modified Mercalli Intensity. However, in designing a structure, the necessary earthquake record data is in the form of Peak Ground Acceleration (PGA) units (g). The PGA is accelerogram, that is, a graph of surface acceleration comparison with time or duration during an earthquake. This accelerogram data will be an input quake parameter for a design or structural analysis.

The construction of high rise buildings is currently overgrowing. When the building goes higher, it tends to have a lower rigidity so that deformation of the structure is higher if the earthquake load is active. This excessive deformation can damage structural components. Steel structure building is a construction made from the arrangement of steel rods. Each part of the steel is connected using a joint such as bolts, nail or weld. The steel frame structure has advantages compared to concrete structures and wooden structures. Therefore, the higher the tensile strength of steel, the lighter steel and more flexible when compared with concrete structures.

Therefore, the design of a building structure must meet the requirements written in the Design Codes and Standards and be well planned to minimize the occurrence of errors. In the Indonesian National Standards on Earthquake Resilience Procedures for Building Constructions, the construction of a building structure can be well designed and take into consideration earthquake loads that may occur. The requirement of quantity is outlined in [4] which the number of the mode of modal shall be sufficient to obtain the modal participating mass ratio at least 90% of the actual mass in each mode. Through the non-linear time history analysis, behavior and response of steel structure due to dynamic loading can be known in detail [5]-[6]. However, this method takes a relatively long time to process the finite element analysis compared with the static non-linear method.

It is necessary to develop a smart learning process in predicting the damage level of steel structures in different quake locations rapidly. Therefore, the study aims to identify damage level the steel structure due to earthquake load quickly based on the time history of an earthquake using the Backpropagation Neural Network (BPNN).

According to FEMA 356 [7], the performance level of a building structure for primary members (P) and secondary members (S) must be at six levels of structural performance as shown in Fig.1, which are:

1. *Immediate Occupancy* (IO), that is, there is no significant damage to the structure so that its strength and stiffness are almost the same as before the earthquake.
2. *Damage Control*, in these circumstances the structure is at the safety level (safe limit) of the structure.
3. *Life Safety* (LS), in this situation there is damage to the structural components. The stiffness of the structure is reduced but has not experienced structural collapse. Structures that are in this state can still be used when the repair has been done.
4. *Limited Safety*, in this case, the structure is defined as being in the condition between the occupant's safety structure and the prevention of collapse. In this situation, there is "much structural damage," because it is no longer safe to be inhabited due to limited structural strength.
5. *Collapse Prevention* (CP), defined as a state of post-collapse damage. Damage occurs in structural and nonstructural components.
6. *Structural Performance not Considered*, buildings that have been damaged in their nonstructural parts are classified at this level of performance.

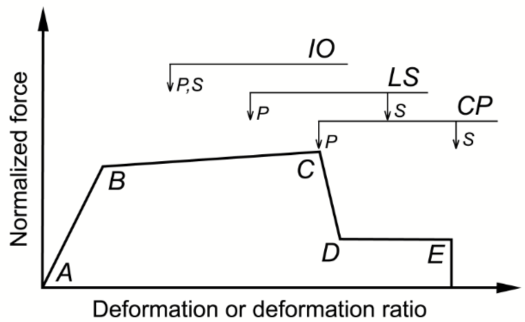

Fig.1. Acceptance criteria of componen deformation

Currently, most of the earthquake-resistant buildings are planned with procedures written in the building codes. In this study, building structure was analyzed using a non-linear time history method to find out the structure behavior due to earthquake load. This time history analysis is a structural analysis method that reviews the structure response over time to earthquake vibrations. In general, analysis using the time history of earthquake requires a relatively long time duration. One solution to rapid prediction is using the Backpropagation Neural Network (BPNN). Based on previous research, the BPNN method has been successfully used in various fields of Civil Engineering for making predictions such as [8], [9] and [10]. The previous study has resulted in the BPNN accuracy reaches 96% to 98% to predict the damage level of drift story of concrete building [11] and bridge structure [12]. The study suggests that BPNN deserves to be applied as a tool for predicting in the Civil Engineering world. However, the number of research that discusses the estimation of damage to structures of multi-story steel buildings is still relatively small. Therefore, this study aims to predict the extent of damage to building structures that occur due to earthquakes. Consequently, the matters discussed in this study include the level of damage to the multi-story steel portal that happens in a building model that has a height variation.

2. BACKPROPAGATION NEURAL NETWORKS

Knowledge of biological neuron cells in the brain has inspired the development of a computing system called Artificial Neural Network (ANN). The artificial neural network is a system that has a working system like the human brain. This system can model a complicated thing between input and output to determine a particular pattern. The architecture and operation of ANN can be described in the form of mathematical and computational models for data classification, clusters, and non-parametric regression or as simulations of biological neural models.

Backpropagation Neural Network (BPNN) is one of the training methods on ANN, where the characteristics of this method are to minimize the error on the output produced by the network. The BPNN training is conducted to develop the ability of memorization and generalization in weights. The strength of BPNN to memorize is the way to remember and take the learned pattern incorrectly. What is meant by generalization capability is the ability of BPNN to provide an acceptable response from similar data and input patterns to a model previously studied by the previous system. Most of the training for feedforward networks use gradients from the activation function to determine how to manage the weights in minimizing performance. The gradient is estimated by using a technique called backpropagation. The advantage of using this BPNN method is that it is possible to obtain information from a complex set of data and solve problems that are unstructured and difficult to define. The standard backpropagation training algorithm will drive the weights with the negative gradient direction. The fundamental principle of the backpropagation algorithm is to fix network weights by making the activation function go down quickly.

Backpropagation could be estimated errors with gradient descent on each network located on the architecture of the Artificial Neural Network. BPNN consists of three layers; input, hidden and an output layer. Each neuron in the hidden layer it will receive information from the input layer neuron multiplied by the weight of the tissue entering the neuron and summed.

3. RESEARCH METHODOLOGY

The models of the structure are three multi-story steel building. The structure models refer to the requirements by SNI 1729-2015 Indonesian specification for structural steel building [13]. The dimensions of the structural elements used are as follows:

1. Modulus of Elasticity: 200.000 MPa
2. Shear Modulus: 80.000 MPa
3. Poisson's ratio : 0.3
4. Steel density : 7.850 Kg/m^3
5. Yield strength : A36 - 240 MPa

Table 1 Properties of Steel Structure Model

Story of Model	Beam	Column	Height (m)
5	WF 300x150	H 350x350	18
10	WF 300x150	H 350x350	35.5
15	WF 300x150	H 350x350	53

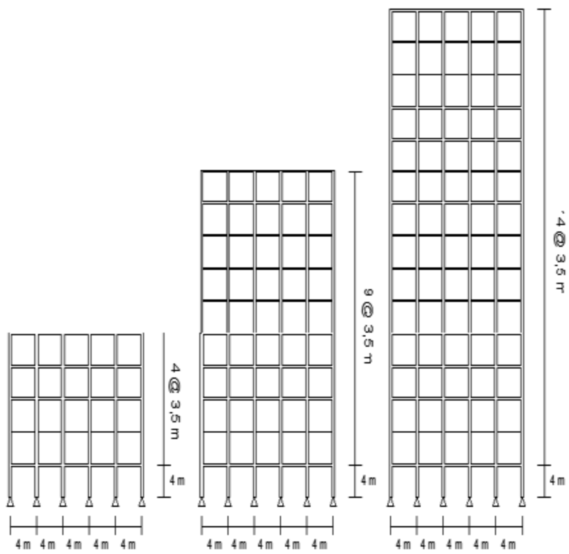

Fig 2. The steel structure model with various height.

The structure of the building under observation is a steel portal which has the same floorplan starting from the ground floor (base) to the roof (rooftop), as shown in Fig 2. Elevation between floors is 4 meters for the ground floor and 3.5 meters for the next level. The regular building shape with X and Y direction is not symmetrical as shown in Fig 3.

The earthquake load used is in the form of a time history response record. Adjustment of the scale used is determined based on the planning standards of seismic resistance of Indonesia SNI 1726-2012 [4] with medium soil conditions. The earthquake data in all provincial capitals on the island of Sumatra in Table 2.

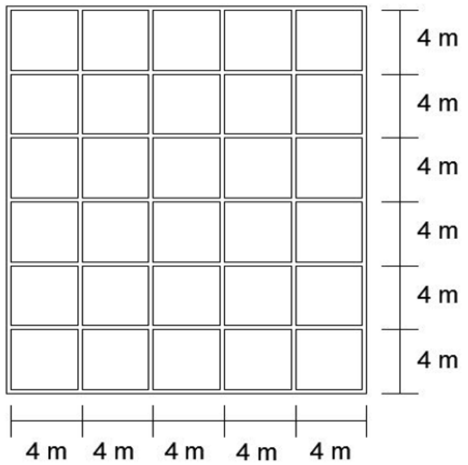

Fig 3. The layout of the steel structure building

Table 2 PGA value of Capital City of Province in Sumatra Island

No.	Capital City of Province	PGA
1	Banda Aceh	0,621g
2	Medan	0,231g
3	Padang	0,515g
4	Pekanbaru	0,214g
5	Tanjung Pinang	0,023g
6	Jambi	0,105g
7	Bengkulu	0,519g
8	Palembang	0,146g
9	Pangkal Pinang	0,026g
10	Lampung	0,356g

The time history analysis of earthquake is done by modeling the steel structure by the data that will be used into the finite element software. Following is the flowchart of the analysis steps with the finite element software, as shown in Fig 4. Meanwhile, the BPNN architecture model for this study is shown in Fig. 5.

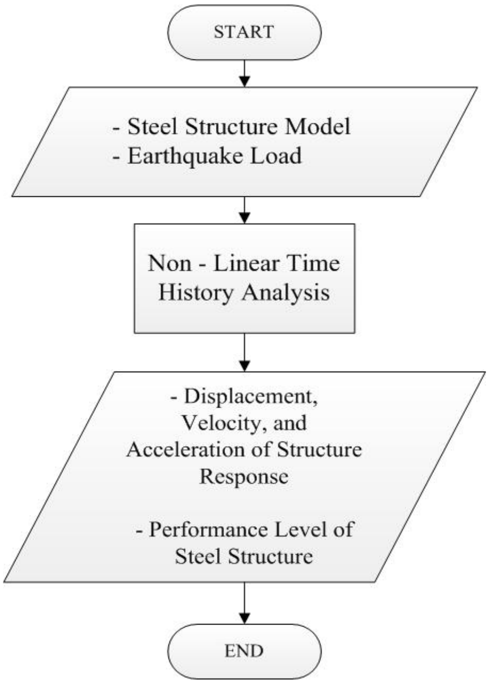

Fig 4. Flowchart of the finite element method for the study

Input layer consists of the height of the steel structure building, displacement, velocity and acceleration of structural response in X and Y direction. The output layer includes the building condition after received earthquake load; Safe as index 1, Immediate Occupancy as index 2, Life Safety as index 3 and Collapse Prevention as index 4.

The procedure of the study used the BPNN method as shown in Fig 6

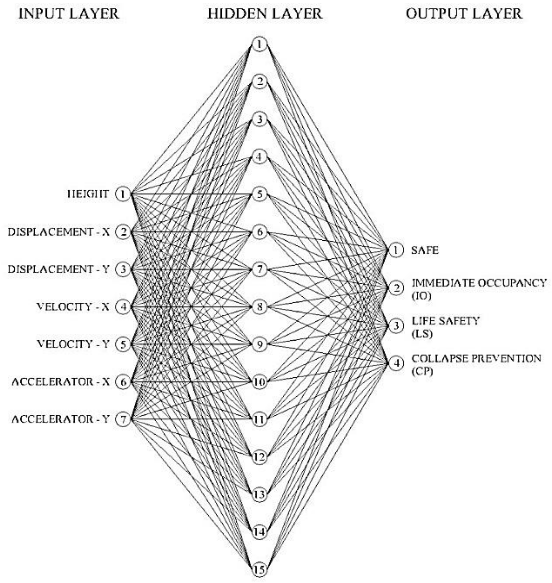

Fig 5. The BPNN architecture model

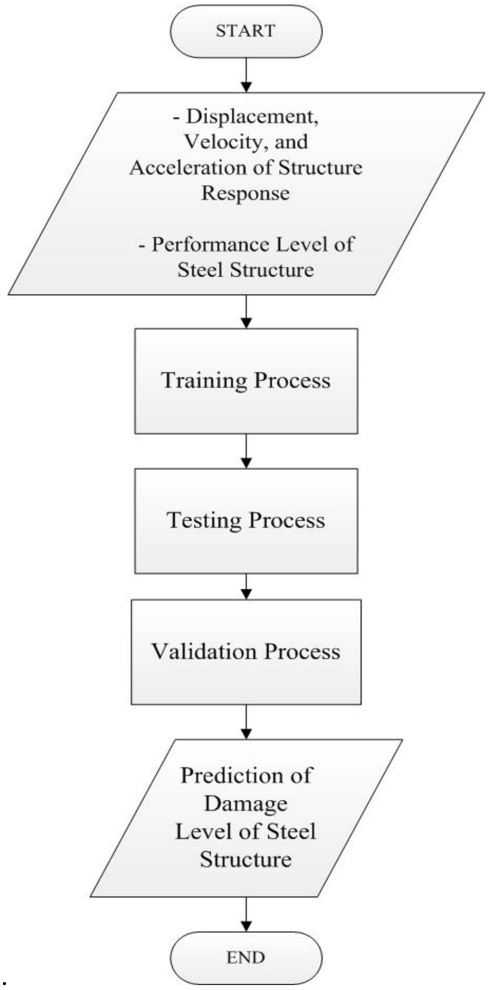

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Fig 6. The BPNN method for the study

4. RESULTS AND DISCUSSION

Finite element analysis resulted in the time history of displacement, velocity, and acceleration at the top of the steel structure. The most considerable displacement value occurred in Banda Aceh City was 0.102 meters in X-direction. Meanwhile, the displacement value of the Y-direction was 0.112 meters. The smallest displacement value happened in Tanjung Pinang City was 0.006 m for the X direction and 0.007 m for Y-direction.

The most considerable velocity value occurred in Banda Aceh City was 0.957 m/s for the X-direction and 0.926 m/s for Y-direction. The smallest velocity value happened in Tanjung Pinang City was 0.057 m/s for the X-direction and 0.055 m/s for Y-direction.

The most considerable acceleration value occurred in Banda Aceh City was 13.832 m/s^2 for X-direction and 9,555 m/s^2 for Y-direction. The smallest acceleration value in Tanjung Pinang City was 0.820 m/s^2 for X-direction and 0.583 m/s^2 for Y-direction.

Backpropagation Neural Network (BPNN) method was used with the following input parameters: displacement, velocity, and acceleration in X and Y-direction. Whereas the predicted output parameters are Safe as 1, Immediate Occupancy as 2, Life Safety as 3 and Collapse Prevention as 4 for the label. The training process on the system was done as a whole to facilitate the learning process. The learning process was delivered repeatedly and gradually with 21 hidden layers. After the completion of the training process, the total iteration (epoch) obtained was as much as 7675 epoch by using the Tan Sigmoid method. The best validation performance of Mean Squared Error (MSE) is 0.028227 as shown in Fig 7.

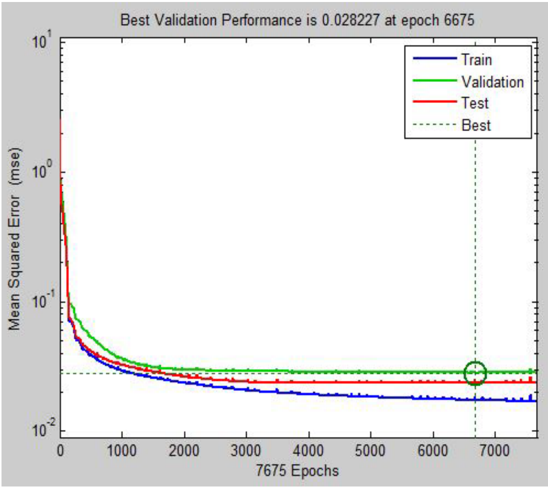

Fig 7. The best performance of MSE (MSE)

Based on the above results, the trained BPNN method has been able to predict the extent of structural damage very well. The result indicated how closely located the distribution of the target points and the prediction to the diagonal line of Regression (R) that is 0.98499. In other words, the predicted results are close to 100 percent of the actual state as shown in Fig 8.

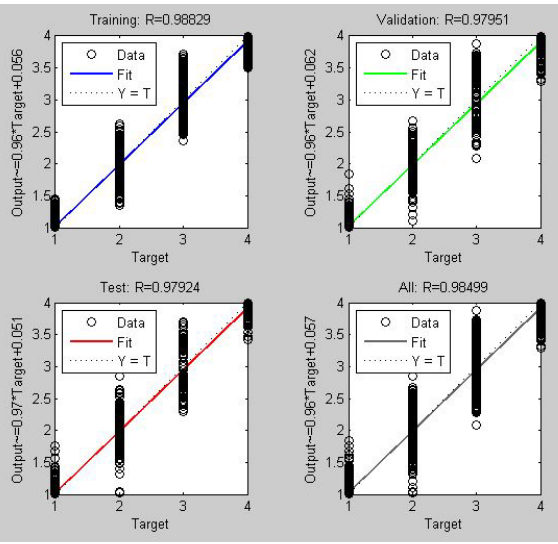

Fig 8. The best performance of Regression (R)

5. CONCLUSION

The displacement of a structure will increase the height of the structure due to the earthquake. The same is true for the velocity and acceleration which will also increase with the height of the building structure. Out of the ten provinces on the island of Sumatra, Banda Aceh City shows the most significant damage level due to the scaled earthquake and has the most substantial displacement is 0.102 m for the X-direction and 0.112 m for Y-directions in comparison to the other provinces. The smallest displacement values occurred in the city of Tanjung Pinang with 0.006 m for the X-direction and 0.007 m for the Y-direction. Based on the average of Regression which is 0.95573, it can be concluded that the designed ANN has a high correlation and accuracy.

6. ACKNOWLEDGMENTS

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