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Optimization of mix proportions of compressed earth blocks with rice straw using artificial neural network

*Jason Maximino C. Ongpeng[1)], Emerson Gapuz[2)] and
Cheryl Lyne C. Roxas [3)]

[1)2)3)] *Department of Civil Engineering, De La Salle University, Manila, Philippines*
[1)] *jason.ongpeng@dlsu.edu.ph*

ABSTRACT

The use of compressed earth blocks (CEB) in construction is an alternative way of promoting sustainable engineering. Compressed earth blocks have many advantages in terms of material cost, embodied energy, thermal properties, sound and fire proofing. However, CEB have undesirable properties which can be eliminated by stabilization. This can be done by adding fibers and cement. In this paper, rice straw from Bauang, La Union, Philippines was used to stabilize CEB. Rice straw is a final waste product of rice harvesting. The practice of disposing rice straw is to burn it which harms the environment. To minimize this postharvest practice, this study investigates the effect of adding stabilizers rice straw and cement to the compressive strength of CEB under uni-axial compression test at an age of 7days and 28 days. Production of 250 CEBs was made having a dimension of 290mm x140mm x100mm with varying mixtures according to: a) fiber content of 0.0%, 0.25%, 0.75% and 1% by weight, b) fiber length of 4cm and 10cm, c) cement content of 0%, 5%, 10%, 15% and 20% by weight. In addition, artificial neural network (ANN) modeling was used to predict the compressive strength of CEB. As an alternative to construction material, baseline value of 2.50 MPa compressive strength was established and taken from Philippine National Standard (PNS) under conventional concrete hollow blocks used in the Philippines. Using acceptable model ANN 5-11-1, simulation was done to investigate the relationship of ingredients with compressive strength. It was found out that the cement and fiber content was directly and inversely proportional to the compressive strength, respectively. A mixture of cement content 9.16% or more achieved baseline value of 2.50MPa despite of the fiber content and length of rice straw.

[1) 3)]Assistant Professor
[2)] Graduate Student

1. INTRODUCTION

The use of sustainable materials is now a point of interest in engineering construction. Earth as a building material is increasingly being studied for its low environmental impact, low cost and its availability. Plant aggregates and fibers have been incorporated into the earth matrix in the aim of enhancing performance for thousands of years but scientific studies began quite recently (Laborel-Préneron 2016).

In using earth materials, few undesirable properties such as loss of strength when saturated with water, erosion due to wind or driving rain and poor dimensional stability. Today, these problems can be eliminated or controlled significantly by stabilizing the soil using lime, Portland cement and other pozzolans such as volcanic ash, fly ash and different ash materials. These materials enhance the engineering properties of the soil and producing an improved construction material.

In the Philippines, the most common agricultural wastes in the country are rice husk, rice straw, coconut husk, coconut shell and bagasse. Based on estimates by the Industrial Technology Development Institute (ITDI) of Department of Science and Technology (DOST), 250 kg of rice straw and 100 kg of rice hull are burned per ton of rice produced. This comes to a total of 5,073,880 tons of rice straw and rice hull burned every year.

To utilize these wastes, different studies investigate the effect of adding fibers in CEB as stabilizers. The study of (Donkor *et al.* 2015) assessed the feasibility of improving the CEB with polypropylene fibers. The integration of fibers improved the block ductility and deformability. Study was made to investigate the effect of adding date palm fibers in the mechanical properties and hygroscopicity behavior of compressed earth blocks (Tallah *et al.* 2014). The date palm fibers increased the compressive strength of CEB at 0.05% of fiber, 8% of cement and compaction pressure of 10MPa.

1.1 Compressed earth blocks

Compressed earth blocks are earthen bricks which is compressed by hand-operated or hydraulic machines. The CEB is the modern version of molded earth block which is used not only in the third world countries but also in developed countries. It can be molded through different solid shapes. It can be in a form of brick, brick with holes, or interlocking blocks.

A study on interlocking CEB showed performance of the blocks formed into walls to assess its behavior. According to the tests performed, ICEB walls can exhibit ductile behavior and stable hysteretic energy dissipation. A larger height-to-width ratio reduce the strength of the wall but increases the ductility of the wall. Introduction of a flange on one end enhances the strength of the wall when it is in tension (Qu *et al.* 2015). In Nigeria, a proposed outer shell layer was made to confine CEBs. The overall strength of the masonry units further increased with the presence of the outer shell (Egenti *et. al.* 2014). Another study investigated the performance of compressed stabilized earth blocks (CSEB) walls for extreme wind loads. The use of CSEB masonry for high-wind resistant dwelling structures is feasible. Wind loads representative of Category 4 hurricanes and EF3 tornadoes can be withstood by means of structural walls having conventional thickness (up to 400 mm) and roof tilt angle (up to 15°), provided that a rigid and well anchored horizontal diaphragm is used (Matta *et. al.* 2015).

In the Philippines, design recommendations for one story CEB structures was made to resist lateral earthquake force in a quadruplex residential house. The different tests show that the interlocking compressed earth blocks (ICEB) has a lower Young's Modulus E than conventional masonry. It exhibited higher strain at peak stress compared to the usual conventional concrete hollow blocks (CHB) (Kennedy 2013).

1.1.1 Advantages and Disadvantages of compressed earth blocks

Compressed earth blocks are significantly less expensive compared to the conventional CHB because the materials are locally available (Minke 2006). The blocks were made on site, eliminating transportation cost and fuel consumption. Compared to concrete, compressed earth blocks requires less energy to make. It promotes sustainable construction because it lessens the consumption of fuels, chemicals, or industrial process needed in manufacturing. The CEBs are also fire and noise resistant compared to wood wall panels or partitions (Hadjri *et al.* 2007). Another unique characteristic of CEB is the ability to balance and improve the indoor air humidity and temperature.

There are undesirable properties of compressed earth blocks. It reduces strength when saturated with water, eroded due to wind or driving rain and poor dimensional stability. These draw backs can be eliminated significantly by stabilizing the soil with a chemical agent such as cement or adding fibers.

A review of the environmental benefits associated with the earth construction from past to present is available from literatures (Pacheco-Torgal 2012). The study includes a review on economic issues, now-renewable resource consumption, waste generation, energy consumption, carbon dioxide emissions and indoor air quality. Investigations show that soil stabilization with gypsum shows to be much more cost effective than with Portland cement.

1.1.2 Stabilization of compressed earth blocks

The limitations of CEB can now be eliminated using stabilization process. Recent studies focused on how to improve the strength, durability and water resistance of compressed earth blocks. Stabilization comes in different processes. Physical stabilization focuses on modifying the characteristics of the soil. Mechanical stabilization is to increase the compressive pressure of the molding hydraulic press. Lastly, chemical stabilization uses binders such as cement, lime or fly ash to improve the strength and durability of the blocks.

Fibers have been used as reinforcement in previous studies such as straw and horsehair to provide tensile reinforcement for sunbaked bricks masonry mortar and plaster (Donkor *et al.* 2015). Natural and artificial fibers were used to reinforced soils that could improve the tensile and shearing stress, reduce shrinkage, and ductility. The study assessed the feasibility of improving the CEB with polypropylene fibers. The integration of fibers improved the block ductility and deformability. It showed that fiber proportion of 0.6%, enhanced the compressive strength of unreinforced CEB but exceedance of 0.6% of polypropylene fiber lowers the strength of the CEB. Another study suggested coal-ash and cassava peels as stabilizers for the CEBs. Coal-ash at 5% showed best performance in the compressive strength and flexural strength (Villamizar *et al.* 2012).

On the other hand, chemical binders as stabilizers such as cement, lime, and gypsum is important in the development of CEB. Results showed that increasing cement content will lead to a durable brick but it becomes uneconomical. Same is the case for lime but handling of lime is difficult. Gypsum is durable in terms of strength but cannot be used when it is under moist conditions (Alam *et al.* 2015).

1.2 Artificial Neural Networks

Artificial Neural Networks are becoming more frequent as computers become more powerful. They are a series of interconnected processing layers which mimic how the human brain processes information (Kostić *et al.* 2015). Each layer has some number of neurons with an associated weight. A certain disposition of the connection of these neurons produced a neural network model suitable for certain tasks. The Back Propagation Multilayer Perceptron (BPMLP) is the most popular neural network model often used, consisting of three adjacent layers, input, hidden and output (Chauvin 1995). Each layer contains several neurons as shown in **Fig.1** where there are five input nodes- soil content, cement content, straw content, length of straw, and age. This architectural model was used in this paper. The ANN is trained by presenting a set of input-output associated data based on learning or training process. The training process uses an algorithm, in which the ANN develops a function between the inputs and outputs.

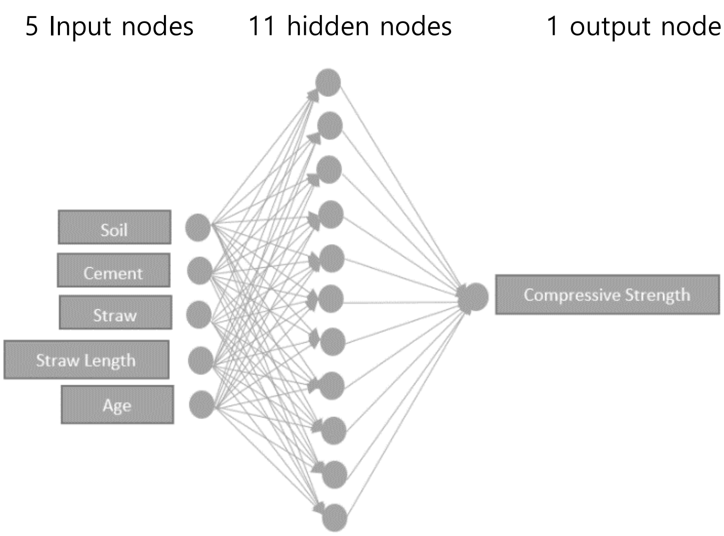

Fig.1. Optimum architecture ANN 5-11-1 model

In training process, neurons receive input from the external environment (x_1, x_2, ... x_n) and transmit them to the neurons in the hidden layer, which are responsible for simple and useful mathematical calculations involving the connections weight (w_{11}, w_{12} ..., w_{1n}), bias (b_1, b_1, …, b_n), and input values. The choice of transfer function is very important in ANN, and often nonlinear functions are required to arrive at a reasonable training process. Once, this function is applied, the final results are produced. Thereafter these results become the input to all neurons in the adjacent layer (the second hidden layer or output layer), and the calculation process is repeated through the layers until the output layer is adjusted close to the target values. This is an iterative process and stops when a target error is reached. Upon completion of a training process, the network should be able to give out the solution(s) for any set of data based on the general architecture that has been developed (Boukhatem *et al.* 2013).

Artificial Neural Networks was utilized in many field of prediction researches. A recent study used ultrasonic test results to predict compressive stress in concrete. (Ongpeng *et al.* 2017). Another study used ANN modelling to predict confined compressive strength of hybrid circular concrete columns (Oreta and Ongpeng 2011). In CEB, ANN was also utilized on rapid soil classification to aid its production (Sitton 2017).

In this paper, rice straw from Bauang, La Union, Philippines was used to stabilize CEB. This study investigated the effect of adding stabilizers rice straw and cement to the compressive strength of CEB under uni-axial compression test at an age of 7days and 28 days. Neural network modeling was used to predict the compressive strength of CEB. Using acceptable optimum model, simulation was done to investigate behavior of compressive strength with regards to the ingredients used in the production of CEB. In addition, baseline value of 2.50MPa compressive strength was established and used in this study as minimum strength. This was made to propose mixture of CEB as an alternative to conventional CHB commonly used in the Philippines.

2. MATERIALS AND METHODS

2.1 Materials

The materials used included local soil from Bauang, La Union, ordinary Portland cement (OPC), and rice straw obtained from the fields of Bauang, La Union. The location map of the study area is presented in **Fig.2**. This field is located in Region 1, located close to the North West of Luzon Island Philippines. The province produces rice as an agricultural product as of 2002. The five major commodities produced in this region shared 66.02% in the region's total agricultural output. Rice was the leading commodity with its 27.71% contribution and the region ranked 4th in production. Among the temporary crops, *palay* or rice was the major temporary crop in the region in terms of area planted. This crop accounted for 252.4 thousand farms with a combined area of 241.1 thousand hectares.

Fig.2. Map of the Philippines and La Union Province (Source: google map)

Before production, particle size distribution using ASTM D422 was made as shown in **Fig.3**. Results showed values of D_{10}= 0.28mm, D_{30}= 0.565m, D_{60}= 1.0mm, Cu (coefficient of uniformity) = 3.571 and Cc (coefficient of curvature) = 1.14. It can also be seen that this soil contains 5.20% gravels, 93.80% sands, and 1% fines. Since the coefficient of curvature (or Cc) obtained has a value between 0.5 and 2.0, it indicated that it is a well-graded soil. The specific gravity of the soil was determined using ASTM D854. In determining the plastic limit, liquid limit and the plasticity index of the soil, Atterberg limit tests based on ASTM D4318 was used. The value of the plasticity index is 9. The higher the PI, the greater is the shrink-swell potential. PI of 0–15%: Low expansion potential, PI of 15–25%: Medium expansion potential PI of 25% and above: High expansion potential. Thus, the soil is considered as low expansion potential as seen in **Table1**.

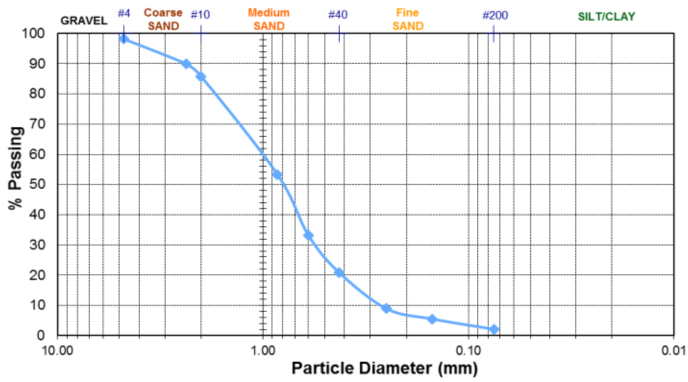

Fig.3. Particle size distribution of the soil

The straw was sun dried for 24hrs to avoid decomposition, and then stored into sacks. The lengths of the straw were cut into 4cm and 10cm length as shown in **Fig.4**. Rice straw contains 41%C, 0.5-0.8% N, 0.05-0.1%P, 0.3-0.2%K, 12% silica, and 10% lignin (IRRI Knowledge Bank 2003).

Table1. Soil Properties

Property	Composition
Liquid Limit (%)	50%
Plastic Limit (%)	41%
Plasticity Index (%)	9%
Gravel (%)	5.20%
Sand (%)	93.8%
Silt (%)	1%
USCS CLASSIFICATION	Poorly Graded Sand

a. 4cm fiber length

b. 10cm fiber length

Fig.4. Rice straw used as stabilizers in CEBs

2.2 Preparation of Specimens

This study investigated the effect of adding stabilizers rice straw and cement to the compressive strength of CEB under uni-axial compression test at an age of 7days and 28 days. The proportion of mix was based on the previous study (Grospe 2002) where the cement content used was 0%, 5%, 10%, 15% and 20% by weight. The proportions of the rice straw used was 0.0%, 0.25%, 0.5%, 0.75% and 1% by weight. The summary of the proportions of samples is shown in **Table2**. The total number of samples was 250 CEB. The nominal dimension of the compressed earth blocks is 290mm x 140mm x 100mm and weighs an average of 6.55kgs. The specimens were labeled as C % - S %, where C represents the cement content and S represents the straw content.

Table2. Design mix proportions

Proportions	Fiber Length Ave 4cm				
Cement	0%	0.25%	0.50%	0.75%	1%
0%	5	5	5	5	5
5%	5	5	5	5	5
10%	5	5	5	5	5
15%	5	5	5	5	5
20%	5	5	5	5	5
Proportions	Fiber Length Ave 10cm				
Cement	0%	0.25%	0.50%	0.75%	1%
0%	5	5	5	5	5
5%	5	5	5	5	5
10%	5	5	5	5	5
15%	5	5	5	5	5
20%	5	5	5	5	5

The soil for block production were prepared initially by air drying, the lumps were broken down manually and sieving was done using 3.175mm screen to remove unnecessary particles. The mixing procedure of CEB was done first by dry mixing the cement, soil, and fibers until it became consistent and uniformly distributed. After the dry mix, required amount of water was added gradually to obtain 40% water cement ratio.

Prior to molding and compaction, the materials were carefully batched by weight. The samples were then put into the mold and compressed using the CINVA RAM with a minimum compaction pressure of eight tons shown in **Fig.5**. After compaction, the specimens were removed from the mold and stored for curing for 28 days. Half of the period, the blocks was covered with plastic simulating wet curing. Then, the cover was removed to let the block dry out for another two weeks.

(A) Placement of soil (B) Compaction of soil (C) Block after compaction

Fig.5. Production of CEB

2.3 Testing Procedure

The CEBs were tested in accordance to ASTM C39. The universal testing machine at Saint Louis University, Baguio City was used. The ultimate compressive load at which the blocks fail was recorded.

2.4 Building the ANN Models

There were five input nodes for the ANN. These were: cement content (0%, 5%, 10%, 15%, 20%), soil content, straw content (0.0%,0.25%,0.50%,0.75%,0.1%) and straw length (4cm,10cm) and age (7day, 28day). The *Neural Network Toolbox* in MATLAB R2010a was used in constructing the ANN model. The compressive strength of the 250 samples were divided into three sets: 60% (150 samples) for training the neural network, 20% (50 samples) for validation and 20%(50 samples) for testing. The samples were randomly selected in MATLAB. Neural Network Fitting Tool (nftool) was used in this paper. It uses a two-layer feed-forward network with sigmoid hidden neurons and linear output neurons. The network was trained using Levenberg-Marquardt backpropagation algorithm (trainlm). The feed-forward backpropagation was used to generate the best model for the optimization of mix proportions of rice straw and cement because it gradually reduces the error between the model output and the target output by minimizing the mean square error (MSE).

Previous study suggested that the data be normalized at a range of -1 to +1 to speed up the training process and to improve the network performance (Boukhatem *et al.* 2013). The weights and bias are updated according to the Levenberg-Marquardt network training function. This is often the fastest backpropagation algorithm and highly recommended, though it requires more memory than other algorithms.

3. RESULTS AND DISCUSSIONS

3.1 Compressed earth block as an alternative to conventional concrete hollow blocks used in the Philippines

In categorizing CEB as alternative construction material, Philippine National Standard (PNS) was used as a reference to replace conventional concrete hollow blocks (CHB) with CEB. Seen in Table3 are the compressive strength values of CHB.

Table3. PNS Strength Requirement for CHB

Compressive Strength in MPa	**Type 1**		**Type 2**
	Class A	**Class B**	
Average of 5 units	6.9	4.8	2.5
Individual Unit	5.5	4.1	2.1

3.2 Compressive Strength Results of CEB

The results obtained from the compressive strength test for the 4cm and 10cm straw length are presented in **Fig.6 and Fig.7**, respectively. The cement content as chemical stabilizer played an important role in the development of compressive strength for both straw lengths used. Results showed close values to CHB PNS Type 2 non-load bearing CHB where 2.5MPa average compressive strength is required. In achieving 2.50MPa strength, the cement content of 10% or more with any combination of fiber content and length of fibers can be reached conservatively.

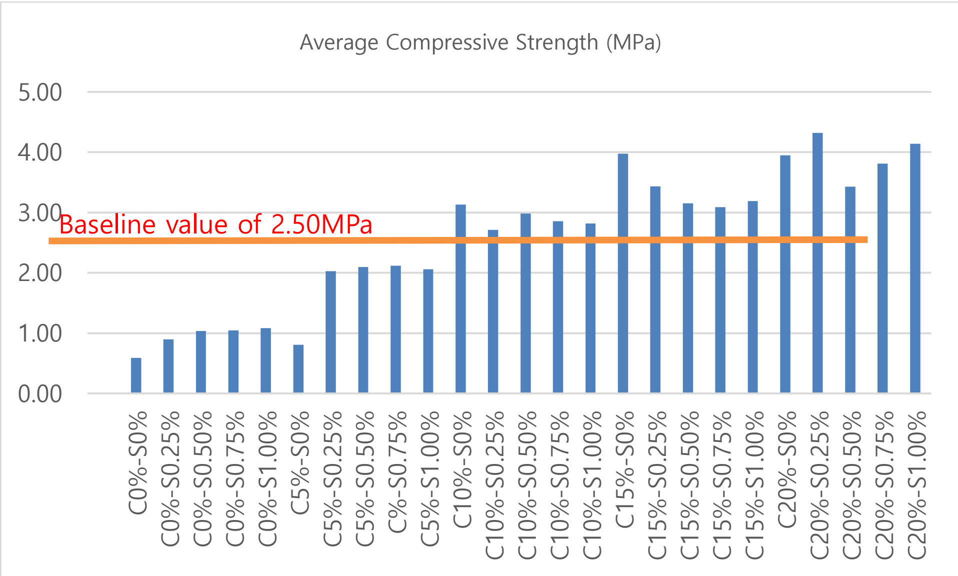

Fig.6. Compressive strength of variable C% and S% with 4cm length of fiber

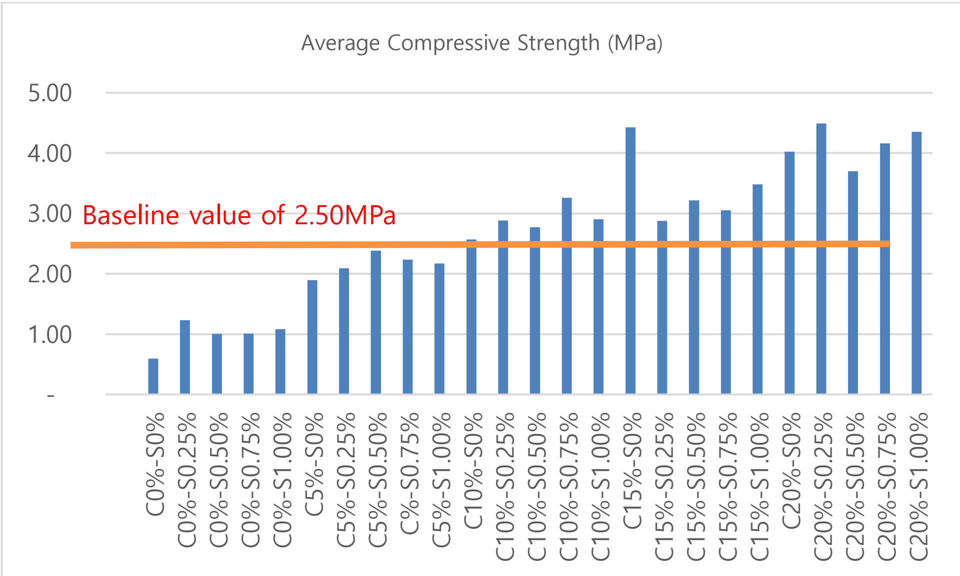

Fig.7. Compressive strength of variable C% and S% with 10cm length of fiber

3.3 Development of the Artificial Neural Network Model

The optimum neural network architecture is described in **Fig.1**. It has five input parameters (soil content, cement content, straw content, straw length and age), one hidden layer with 11 neurons and one output parameter (compressive strength). After training, the architecture ANN 5-11-1 (5-input variables, 11-hidden layer, 1-output layer) was found to be the best model in terms of Pearson correlation coefficient (R) in testing as seen in **Table4**. It can be noted that some models had higher R, but upon simulation, it behaved in contrast with theory. Hence, ANN 5-11-1 was taken as the optimum model since it had good R for testing and performed well under simulation.

Table4. Trained, validated and tested models for CEB

ANN Architecture			Pearson correlation coefficient (R)		
Input Layer	Hidden Layer	Output Layer	Training	Validation	Testing
5	4	1	0.929	0.867	0.867
5	5	1	0.914	0.895	0.88
5	6	1	0.948	0.899	0.854
5	7	1	0.941	0.935	0.832
5	8	1	0.941	0.93	0.925
5	9	1	0.949	0.932	0.908
5	10	1	0.949	0.876	0.895
5	11	1	0.953	0.9514	0.914

3.4 Simulation of ANN 5-11-1

The strength of CEBs are affected by many internal and external factors. It can be seen that the compressive strength is sensitive to the type and quantity of each ingredient. In order to verify the relationship between the input-output parameters, a model-based parametric study was applied.

It was observed from experimental results that chemical stabilizer using cement played significant role in the increase of compressive strength. Simulations were made by holding 4 input parameters constant at its median values and one significant parameter varied from minimum to maximum values. This process will carefully produce proper investigation on the effect of the specific ingredients being studied.

Shown in **Fig.8** is the simulation of varying cement content to investigate the behavior of the compressive strength. By ratio and proportion, the cement content to achieve the baseline value of 2.50 MPa for CEB as an alternative to CHB is 9.16% cement content.

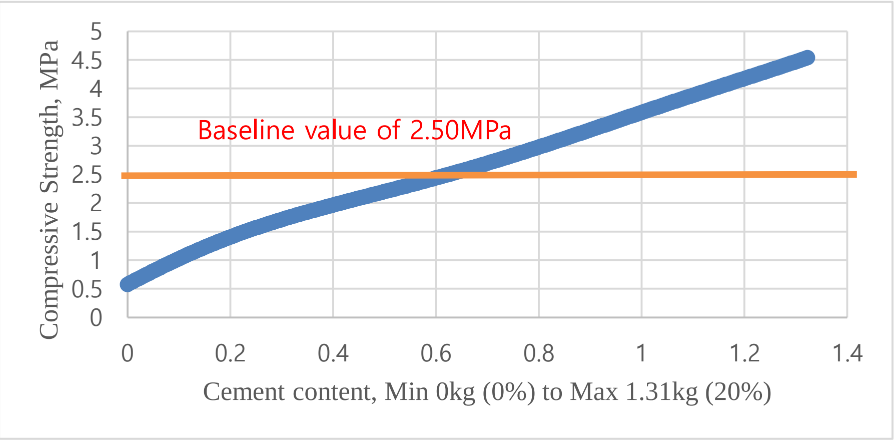

Fig.8. Simulation of ANN 5-11-1 with varying cement and remaining four input parameters held at its median value

In addition, simulation using varying fiber content and straw length was done in **Fig.9 and Fig.10**. The compressive strength of CEB decreases as fiber content and straw length increases. The median value of cement content was set at 10%. In line with this, simulation showed that despite of the decrease in strength as fiber content and straw length increases, it can still achieve the minimum strength of 2.50MPa to make CEB as an alternative material according to PNS type 2 CHB.

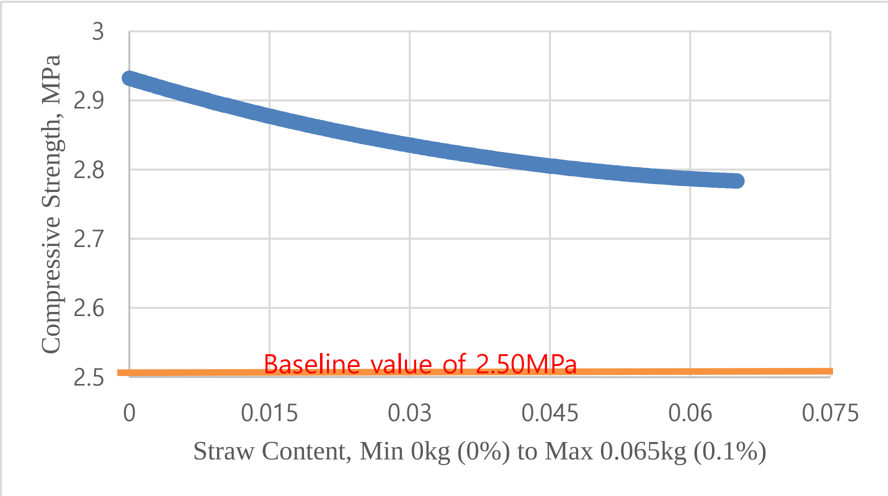

Fig.9. Simulation of ANN 5-11-1 with straw content and remaining four input parameters held at its median value

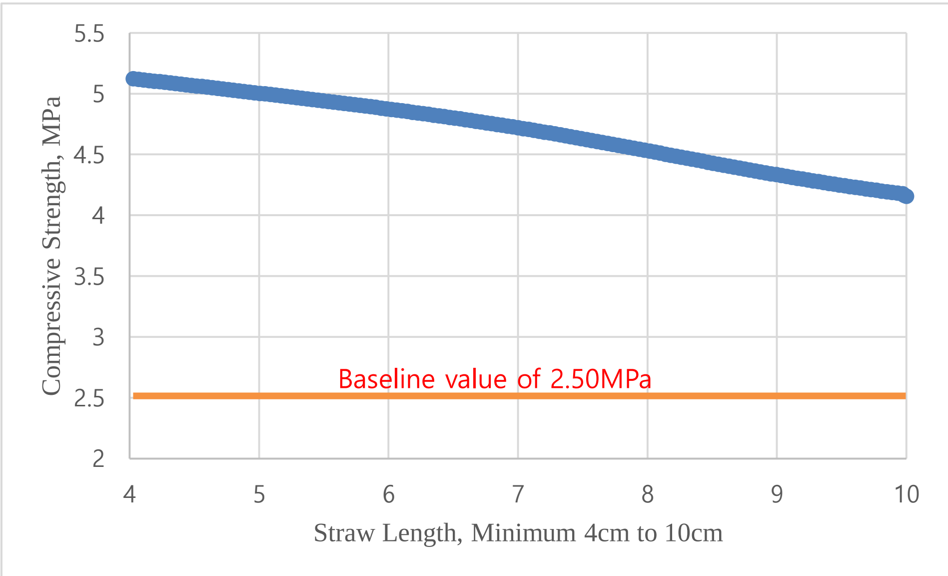

Fig.10. Simulation of ANN 5-11-1 with varying cement and remaining four input parameters held at its median value

3. CONCLUSIONS AND RECOMMENDATIONS

Optimizing the proportions of stabilizers in compressed earth blocks (CEB) is a very important process to explore it as an alternative material in construction. In this study, an optimum artificial neural network ANN 5-11-1 composed of five input parameters (soil, cement, straw, straw length and age), one hidden layer with 11 neurons and one output parameter (compressive strength)5input was generated and used to simulate the CEB with varying rice straw and cement content. The ANN network was trained using 250 samples from experiments. Based on simulations, the ANN model allowed us to investigate the influence and significant ingredients with the compressive strength. In addition, CEB can be used as an alternative construction material having 9.16% cement content and any addition of fiber content and length of fibers. Future studies on the positive effects of fibers against mechanical and environmental degradation can be made to maximize fiber content.

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