Research Article

Optimization of Mix Proportions for Novel Dry Stack Interlocking Concrete Blocks Using ANN

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This paper proposes novel concrete interlocking blocks made of fly ash and GGBS which are an alternative for the conventional concrete blocks. The artificial neural network (ANN) technique is used to estimate the mechanical strength of interlocking blocks and is verified with experimental investigation. The ANN model is based on the Levenberg–Marquardt principle which is executed using MATLAB. The inputs are given in the percentage ratio of cement: fly ash: crushed stone aggregate (FA): coarse aggregate (CA) for the process of learning, testing, and validation. The selected model is subjected to several trials in terms of mean square error, containing 4 input, 2 sets of 10 hidden layers, and one output components. In this study, a total of 2600 blocks of different mixes were tested as per IS 2185-1 (2005) to assess 3, 7, 14, 21, and 28 days' strength. The experimental investigations were carried out in two phases. In the first phase, experimental investigations to identify the optimum mix proportions of cement, aggregate, fly ash, and ground granulated blast furnace slag to achieve desired compressive strength was carried out. In the second phase, the identified mix proportions were analysed using ANN to predict the compressive strength of interlocking blocks. The results indicate that the proposed ANN model developed to determine the mechanical strength and cost of interlocking blocks has excellent prediction ability.

1. Introduction

In the current scenario, the construction industry utilises the natural resources which is a threat for the environment. Compared to RCC framed construction, masonry construction is less expensive and faster [1]. To overcome the defects in the masonry system, the mortarless interlocking block system has emerged [2]. The key feature of the interlocking blocks is its curved grooves and protrusions that help to retain the blocks together so the mortar at each layer can be eliminated, thus saving materials, time, and manpower. Jaafar et al. [3] observed that the interlocking masonry has strength higher than conventional masonry in axial compression tests. In the system of interlocking blocks, the issue of shrinkage and continuous breaking of blocks does not happen. Few researchers discovered that interlocking blocks perform well in seismic regions [4, 5]. Anand

and Ramamurthy [6] discovered that when the interlocking block system is subjected to in-plane shear load, the interlocking blocks shift slightly, improving the energy dissipation under seismic loads. The seismic test on an unreinforced masonry block by Giamundo et al. [7] demonstrates that the interfaces between mortar and block are the weakest part of the wall, where cracks open and close. Due to physical and mechanical debasement of the mortar layer, numerous historical and old constructions built with mortar and blocks show a higher loss in structural performance. This issue can be avoided when interlocking bricks are employed, due to the elimination of the mortar layer. Ayed et al. [8] examined the contact behaviour of interlocking blocks and found that the interlocking joint behaviour is higher for the block having a rough surface rather than a smooth surface. This emphasizes the importance of surface texture of interlocking blocks.

FIGURE 1: ANN operational model.

FIGURE 2: Dry mix in the vibro compaction machine.

ANN is a numerical model that reproduces the neural system of the central sensory system. An ANN comprises of large numbers of interconnected neurons, and it decodes data utilizing the dynamic state approach for the output [9, 10]. ANN modelling is an advancement to the statistical regression approach. Every layer of neurons has an input or output of the previous neuron. The ANN system of operation is shown in Figure 1. Every input value X is multiplied by weight (W), and then, it is allotted a bias for the output:

$$\text{ANN output} = \sum_{i=0}^i X_i W_i - b, \quad (1)$$

where W_i is the weight, X_i is the input, and b is the bias.

The advanced feature of ANN is its capability of gaining knowledge directly from models and providing an excellent reaction to deficient undertakings. The ANN model utilized in this research provides the mix proportions for an optimized interlocking block at minimum cost.

1.1. Research Significance and Novelty of Proposed Interlocking Blocks. The mix proportions and the mechanical strength of

vibro compacted interlocking blocks have received less attention. As a result, tests on mix proportions with varying mix ratios have been conducted for the vibro compacted interlocking blocks. Furthermore, the effects of fly ash and GGBS are examined, along with their influence on the failure mechanisms. The concrete mix used to make vibro compacted interlocking blocks is not the same as the regular concrete mix. The vibro compacted load-bearing interlocking concrete blocks are manufactured using the dry mix with precise optimum water content, as shown in Figure 2. The interlocking blocks are manufactured by feeding the mixture through a hydraulic vibro compression press machine, which produces a high level of vibration and compression from the top, resulting in a compacted, high-strength block. It is difficult or impossible to manufacture blocks if the moisture content is excessive, as the block deforms during the removal of the mould from the vibro compaction machine. The percentage of fine and coarse aggregate plays a vital role in strength and texture of the blocks. If the percentage of coarse aggregate increases, the strength of the blocks will be higher but the texture of the blocks becomes porous, which leads to seepage of water inside the blocks, and it increases the cost of plastering. However, if the percentage of fine aggregate increases, the strength of the blocks reduces.

FIGURE 3: Interlocking blocks' wall connections.

FIGURE 4: ANN propagation model.

FIGURE 5: (a) Frasson's equipment. (b) Parts of equipment. (c) Molded cylinder specimens.

This study also highlights the effective replacement of river sand with crushed stone aggregate. Compared to natural river sand, the crushed stone aggregate has a higher fineness modulus index which provides good workability for the blocks [11]. Crushed stone aggregate is free from

sediment and clay particles which gives better abrasion resistance, higher unit weight, and lower permeability. Cost of interlocking blocks is highly influenced by cement content. To minimise the cost, supplementary cementations materials such as fly ash and GGBS are incorporated. Higher

TABLE 1: Properties of cement.

Material	Physical properties	Test result
Cement OPC 53 grade	Consistency (%)	27
	Initial setting time (min)	178
	Final setting time (min)	301
	Fineness dry sieving (%)	5.3
	Compressive strength N (mm^2)	18.7 MPa (3 days)
		39.5 MPa (7 days)
		56.2 MPa (28 days)

TABLE 2: Properties of coarse aggregate.

Material	Physical properties	Test result
Coarse aggregate	Specific gravity (g/cc)	2.80
	Soundness	2.58
	Moisture content	0.11
	Water absorption (%)	0.56
	Bulk density loose (kg/m^3)	1506
	Bulk density rodded (kg/m^3)	1750

TABLE 3: Properties of crushed stone aggregate.

Material	Physical properties	Test result
Crushed stone aggregate (FA)	Specific gravity (g/cc)	2.71
	Bulking (%)	9.56
	Moisture content	0.32
	Water absorption (%)	2.08
	Bulk density (kg/m^3)	1678
	Silt content	1.35
	Soundness	1.12

TABLE 4: Properties of fly ash.

Material	Physical properties	Test result
Fly ash	Normal consistency (%)	31.5
	Initial consistency setting time (min)	192
	Final setting time (min)	428
	Strength index with cement	56.2
	Dry density (g/cc)	1.3
	Plasticity	Nonplastic

FIGURE 6: Interlocking block dimensions in mm.

FIGURE 7: Caste interlocking blocks.

FIGURE 8: Test setup.

TABLE 5: Results of the compressive strength test.

Price (kg)	Rs. 8	Rs. 0.75	Rs. 3	Rs. 0.86	Rs. 0.75	Compressive strength (MPa)						Cost per block rupees (Rs.)
Mix	Cement %	Fly ash %	GGBS %	FA%	CA%	3 days	7 days	14 days	21 days	28 days		
Mix 1	2	8	0	30	60	3.22	4.69	5.40	6.63	6.03	14.18	
Mix 2	2.2	7.8	0	30	60	3.86	5.63	6.48	7.96	7.24	14.40	
Mix 3	2.5	7.5	0	30	60	4.64	6.75	7.78	9.55	8.68	14.74	
Mix 4	2.8	7.2	0	30	60	5.10	7.43	8.55	9.12	9.55	15.07	
Mix 5	3	7	0	30	60	5.88	8.56	9.87	10.13	10.54	15.29	
Mix 6	3.2	6.8	0	30	60	6.12	8.90	10.26	10.54	10.96	15.51	
Mix 7	3.5	6.5	0	30	60	6.36	9.26	10.68	10.96	11.40	15.84	
Mix 8	3.8	6.2	0	30	60	6.65	9.68	11.16	11.45	11.91	16.18	
Mix 9	4	6	0	30	60	6.70	9.67	11.74	12.11	12.65	16.40	
Mix 10	4.2	5.8	0	30	60	6.83	9.86	11.97	12.35	12.90	16.62	
Mix 11	4.5	5.5	0	30	60	6.97	10.06	12.21	12.60	13.16	16.95	
Mix 12	4.8	5.2	0	30	60	7.11	10.26	12.46	12.85	13.42	17.28	
Mix 13	5	5	0	30	60	7.25	10.47	12.71	13.11	13.69	17.51	
Mix 14	5.2	4.8	0	30	60	7.43	10.73	13.03	13.44	14.04	17.73	
Mix 15	5.5	4.5	0	30	60	7.55	10.89	13.22	13.64	14.25	18.06	
Mix 16	5.8	4.2	0	30	60	7.67	11.07	13.45	13.87	14.49	18.39	
Mix 17	6	4	0	30	60	7.89	11.21	13.62	14.22	14.85	18.61	
Mix 18	2	8	0	25	65	4.80	5.21	5.64	6.68	7.71	14.10	
Mix 19	2.2	7.8	0	25	65	4.88	5.29	5.72	6.78	7.83	14.32	
Mix 20	2.5	7.5	0	25	65	4.95	5.37	5.81	6.88	7.94	14.65	
Mix 21	2.8	7.2	0	25	65	5.03	5.47	5.93	7.02	8.10	14.98	
Mix 22	3	7	0	25	65	5.20	6.82	8.24	11.25	13.06	15.21	
Mix 23	3.2	6.8	0	25	65	5.28	6.92	8.36	11.42	13.26	15.43	
Mix 24	3.5	6.5	0	25	65	5.37	7.05	8.51	11.62	13.49	15.76	
Mix 25	3.8	6.2	0	25	65	5.48	7.18	8.68	11.86	13.76	16.09	
Mix 26	4	6	0	25	65	6.21	7.75	11.40	14.75	14.98	16.31	
Mix 27	4.2	5.8	0	25	65	6.30	7.94	11.69	15.12	15.35	16.54	
Mix 28	4.5	5.5	0	25	65	6.39	8.14	11.98	15.50	15.74	16.87	
Mix 29	4.8	5.2	0	25	65	6.47	9.36	12.82	16.58	16.13	17.20	
Mix 30	5	5	0	25	65	6.98	11.18	14.01	17.32	17.25	17.42	
Mix 31	5.2	4.8	0	25	65	7.08	11.35	14.22	17.47	17.42	17.64	
Mix 32	5.5	4.5	0	25	65	7.19	11.57	14.65	17.82	17.77	17.98	

TABLE 5: Continued.

Price (kg)	Rs. 8	Rs. 0.75	Rs. 3	Rs. 0.86	Rs. 0.75	Compressive strength (MPa)						Cost per block rupees (Rs.)
Mix	Cement %	Fly ash %	GGBS %	FA%	CA%	3 days	7 days	14 days	21 days	28 days		
Mix 33	5.8	4.2	0	25	65	7.77	11.81	15.23	17.91	17.86	18.31	
Mix 34	6	4	0	25	65	7.82	12.24	16.78	17.78	18.21	18.53	
Mix 35	2	8	0	20	70	4.69	5.09	6.20	7.01	9.04	14.01	
Mix 36	2.2	7.8	0	20	70	4.76	5.17	6.29	7.12	9.18	14.24	
Mix 37	2.5	7.5	0	20	70	4.86	5.27	6.42	7.26	9.36	14.57	
Mix 38	2.8	7.2	0	20	70	5.83	6.32	7.70	8.71	11.23	14.90	
Mix 39	3	7	0	20	70	7.25	7.52	9.85	10.05	12.55	15.12	
Mix 40	3.2	6.8	0	20	70	7.36	7.63	10.03	10.23	12.78	15.34	
Mix 41	3.5	6.5	0	20	70	7.47	7.75	10.21	10.42	13.01	15.68	
Mix 42	3.8	6.2	0	20	70	7.58	7.86	10.46	10.62	13.27	16.01	
Mix 43	4	6	0	20	70	7.66	8.95	11.99	13.87	14.70	16.23	
Mix 44	4.2	5.8	0	20	70	7.77	9.08	12.17	14.08	14.92	16.45	
Mix 45	4.5	5.5	0	20	70	7.89	9.22	12.35	14.36	15.22	16.78	
Mix 46	4.8	5.2	0	20	70	8.01	9.36	12.60	15.51	16.44	17.12	
Mix 47	5	5	0	20	70	8.21	9.23	13.61	16.12	16.87	17.34	
Mix 48	5.2	4.8	0	20	70	8.33	9.37	13.81	16.36	17.12	17.56	
Mix 49	5.5	4.5	0	20	70	8.46	9.51	14.02	16.61	17.38	17.89	
Mix 50	5.8	4.2	0	20	70	8.59	9.65	14.16	16.77	17.55	18.22	
Mix 51	6	4	0	20	70	7.92	9.87	14.86	16.85	17.90	18.45	
Mix 52	2	0	8	25	65	7.10	7.21	8.10	8.24	11.12	16.85	
Mix 53	2.2	0	7.8	25	65	7.23	7.35	8.25	8.40	11.33	17.00	
Mix 54	2.5	0	7.5	25	65	7.37	7.48	8.40	8.55	11.54	17.23	
Mix 55	2.8	0	7.2	25	65	7.50	7.61	8.55	8.70	11.74	17.46	
Mix 56	3	0	7	25	65	9.02	10.21	13.51	13.97	14.76	17.61	
Mix 57	3.2	0	6.8	25	65	9.09	10.29	13.62	14.08	14.88	17.77	
Mix 58	3.5	0	6.5	25	65	9.16	10.37	13.73	14.19	15.00	17.99	
Mix 59	3.8	0	6.2	25	65	9.24	10.47	13.84	14.31	15.12	18.22	
Mix 60	4	0	6	25	65	9.45	11.50	13.97	14.14	15.71	18.38	
Mix 61	4.2	0	5.8	25	65	9.59	11.67	14.18	14.35	15.95	18.53	
Mix 62	4.5	0	5.5	25	65	9.74	11.85	14.39	14.78	16.18	18.76	
Mix 63	4.8	0	5.2	25	65	9.88	12.03	14.65	15.24	16.43	18.99	
Mix 64	5	0	5	25	65	9.87	12.51	14.87	13.42	16.93	19.14	
Mix 65	10	0	0	25	65	12.38	16.89	17.05	18.33	18.46	22.96	

TABLE 6: Summary of test results.

S. no.	Batch	Mix	Cement %	Fly ash %	GGBS %	FA %	CA %	Compressive strength (MPa)						Cost per block (Rs.)
								3 days	7 days	14 days	21 days	28 days		
1		MPF1a	2	8	0	30	60	3.22	4.69	5.40	6.63	6.03		14.18
2		MPF1b	3	7	0	30	60	5.88	8.56	9.87	10.13	10.54		15.29
3	MPF1	MPF1c	4	6	0	30	60	6.70	9.67	11.74	12.11	12.65		16.40
4		MPF1d	5	5	0	30	60	7.25	10.47	12.71	13.11	13.69		17.51
5		MPF1e	6	4	0	30	60	7.89	11.21	13.62	14.22	14.85		18.61
6		MPF2a	2	8	0	25	65	4.80	5.21	5.64	6.68	7.71		14.10
7		MPF2b	3	7	0	25	65	5.20	6.82	8.24	11.25	13.06		15.21
8	MPF2	MPF2c	4	6	0	25	65	6.21	7.75	11.40	14.75	14.98		16.31
9		MPF2d	5	5	0	25	65	6.98	11.18	14.01	17.32	17.25		17.42
10		MPF2e	6	4	0	25	65	7.82	12.24	16.78	17.78	18.21		18.53
11		MPF3a	2	8	0	20	70	4.69	5.09	6.20	7.01	9.04		14.01
12		MPF3b	3	7	0	20	70	7.25	7.52	9.85	10.05	12.55		15.12
13	MPF3	MPF3c	4	6	0	20	70	7.66	8.95	11.99	13.87	14.70		16.23
14		MPF3d	5	5	0	20	70	8.21	9.23	13.61	16.12	16.87		17.34
15		MPF3e	6	4	0	20	70	7.92	9.87	14.86	16.85	17.90		18.45

TABLE 6: Continued.

S. no.	Batch	Mix	Cement %	Fly ash %	GGBS %	FA %	CA %	Compressive strength (MPa)					
								3 days	7 days	14 days	21 days	28 days	Cost per block (Rs.)
16	MPG	MPGa	2	0	8	25	65	7.10	7.21	8.10	8.24	11.12	16.85
17		MPGb	3	0	7	25	65	9.02	10.21	13.51	13.97	14.76	17.61
18		MPGc	4	0	6	25	65	9.45	11.50	13.97	14.14	15.71	18.38
19		MPGd	5	0	5	25	65	9.88	12.03	14.65	15.24	16.43	19.14
20	MPC	MPCa	10	0	0	25	65	12.38	16.89	17.05	18.33	18.46	22.96

FIGURE 9: Smooth surface texture.

FIGURE 10: Grainy surface texture.

FIGURE 11: Cost and compressive strength of interlocking blocks at 28th day.

FIGURE 12: Comparison between actual and predicted values for 28 days strength.

quantity of fly ash retards the strength and setting time of blocks. Bheel et al. [12] carried out mechanical examination on fly ash, and the results indicated that fly ash improves the microstructure in concrete as the breaking of fly ash plerospheres changes the behaviour of mortar. Zhou et al. [13] found that the replacement of fly ash and GGBS results in delay in setting time of concrete, but the replacement of fly ash and GGBS improves the workability of concrete [14].

This interlocking block will be a suitable replacement for the conventional concrete masonry blocks. Inclusion of fly ash in the concrete makes interlocking blocks greener by lowering CO₂ emissions. These blocks can be assembled ten times faster by unskilled employees when compared with regular masonry construction and are easier to install as it does not require mortar. These are self-aligning and interlock both horizontally and vertically ensuring proper alignment. This proposed block provides 50% horizontal interlocking connectivity over each block, resulting in a higher shear capacity than standard

interlocking blocks, as illustrated in Figure 3. These blocks are more resistant to earthquakes due to the elimination of mortar for binding. These interconnecting blocks can be easily dismantled and reused.

The research findings include a list of various mix proportions and the mechanical strength of the blocks at various ages. The main objective of this study is to investigate and predict the performance of interlocking blocks with various dosages of fly ash, cement, and crushed stone aggregate. This study also highlights the effective replacement of cement with pozzolanic materials such as fly ash and GGBS. This research work addresses the optimum and cost-effective proportions for the manufacture of interlocking blocks which can be used for affordable housing. These research data will be useful for researchers and entrepreneurs who are interested in manufacturing vibro compacted hollow concrete blocks for affordable housing.

FIGURE 13: Comparison between actual and predicted values for 21 days strength.

2. Artificial Neural Network

The most commonly used artificial neural network utilized in the regression analysis is feedforward backpropagation. As demonstrated in Figure 4, for this research, four input and two layers of ten hidden node layers between input and one output are used. The input layer nodes do not perform any process, but it collects information from outside. Each artificial neuron present in the hidden layer or the outer layer collects a large number of weighted inputs, sends it to bias for summing and imposing an activation function, and then it transfers the data to output [15, 16].

In the ANN feedforward propagation, the data flow is from the input layer to the output layer, where the prediction in ANN is accomplished from the provided input values and specific weights [9, 17]. For the backpropagation, the weights are modified utilizing advanced training algorithms such as Levenberg–Marquardt (LM), scaled conjugate inclination, and Bayesian regularization to minimise the errors of predicted output values. This calculation is an augmentation of

quasi-Newton strategy where there is no need to compute the Hessian framework to take care of nonlinear least squares issues. The weights and bias (wb_{n+1}) can be determined utilizing the following equation [10]:

$$wb_{n+1} = wb_n - [J^n J + \mu I]^{-1} J^n e, \quad (2)$$

where J represents the Jacobian matrix, which represents first derivative of network error regarding weights and bias, e represents the vector of the network, and μ and I indicate the real number factor and identity matrix.

3. Experimental Study

The experimental investigation involves assessing of material properties and determination of the engineering properties of the interlocking blocks. The material proportions are considered according to Frasson's method to achieve the desired density. The texture of the mixtures as well as optimum water

FIGURE 14: Comparison between actual and predicted values for 14 days strength.

content with cohesion is also evaluated by casting specimens in Frasson's equipment, as shown in Figure 5.

For the experimentation, the choice of aggregate should pass through 9.5 mm sieve, it should be retained on 4.8 mm sieve, and the aggregate should be of cubical shape. The crushed stone aggregate must have a fineness of 2.20 to 2.80. Mix design methodology is based on moulding a 5×10 cm cylinder using a 5×13 cm tri-panel cylindrical mould, as shown in Figure 5(b). In addition to the cylindrical mould, the moulding equipment has a metallic base plate, which measures 7 cm in diameter and 2 cm height, and a compacting bar to compact the mortar. For moulding the specimens, first the materials need to be weighed to obtain the density of concrete after compacting. The materials should be placed in the tri-panel cylindrical mould and be divided in four equal parts in order to mould the specimen with four-layer filing. The first layer of the mix is filled in the cylinder, and it should receive 20 strokes with the compacting bar for proper compaction. The mould is again filled and compacted with 20 strokes, and this process is continued for 4 layers. The energy applied during the compaction needs

to be distributed equally among each layer in such a way that the specimen height reaches 10.2 cm to 10.5 cm after 80 stokes of compaction. The final height of the specimen is achieved by applying additional strokes on a stopper with a rubber hammer. Finally, the mould is unscrewed for demoulding. The physical examination on the freshly prepared mould is an excellent predictor for the final surface texture of the blocks. The texture of the specimen needs to be assessed visually for each type of mix proportion at optimum water content and density.

To determine the optimum water content for a given mix proportion, we need to assess the surface texture of the specimens following its removal from the cylindrical mould. When the water content in the mix reaches its optimal value, the surface of the specimen will start to become slightly humid. Moreover, the internal surface of the moulds and metallic base used for supporting the mould also starts to become humid. If the moisture content of the mixture is below this point, more energy will be required to compact the materials which leads to loss in productivity and wear of the vibro compaction machine. If the water content

FIGURE 15: Comparison between actual and predicted values for 7 days strength.

increases, it is difficult or impossible to manufacture blocks due to block deformation during the time of removal of the mould from the vibro compaction machine. From the experimental results, it is seen that an optimum water content of 4% to its total weight is required.

3.1. Selection of Materials. For casting of interlocking blocks, locally available raw materials such as fly ash, crushed stone aggregate, cement, and coarse aggregate were used. The properties of the materials such as cement, coarse aggregate, crushed stone aggregate, and fly ash are given in Tables 1–4.

3.2. Test Methods

3.2.1. Casting of Interlocking Blocks. An elaborate experimental work is carried out by casting 2600 interlocking blocks. The interlocking blocks are cast by feeding the

concrete mix into the moulds of the vibro compression machine which has a geometric size of 400 mm × 150 mm × 150 mm, as shown in Figures 6 and 7. The concrete mix is vibrated and compacted using a hydraulic press, and then, the blocks come out from the vibro compression machine. The density of the block ranges from 2380 to 2440 kg/m³.

3.2.2. Compressive Strength Test. A universal testing machine of capacity 1000 kN is used for testing the compressive strength of interlocking blocks. The interlocking block specimens were placed with their key facing upward so that the load will be transferred in the vertical direction of the block. Blocks are placed between the jaws, and load is applied gradually at the rate of 4.6 kN/sec. Special steel plates were placed to create horizontal platform for the interlocking blocks on the top to distribute the load uniformly, as shown in Figure 8.

FIGURE 16: Comparison between actual and predicted values for 3 days strength.

As per IS 2185-1 (2005), the compressive strength of any individual specimen shall not fall below the minimum average compressive strength by more than 20%. The compressive strength results provided in this investigation represent the average compressive strength of eight samples tested for each curing age.

4. Results and Discussion

The results of the compressive strength test of 65 mix proportions are given in Table 5, and the summarized mix proportions are given in Table 6. In addition to compressive strength, surface texture is also an important parameter in the production of interlocking blocks as there is no need for plastering when the surface looks uniform and smooth. From the results, it is seen that higher proportions of crushed stone aggregate with respect to coarse aggregate result in a smooth surface texture, as shown in Figure 9, but the compressive strength of the blocks gets reduced. Increase in coarse aggregate results in higher compressive strength

but the surface texture looks grainy, and it has lots of pores, as shown in Figure 10. From the tests conducted on specimens having fly ash as replacement, it is seen that mix proportions with 65% coarse aggregate and 25% crushed stone aggregate show the best smooth surface texture and higher compressive strength with optimal cost.

4.1. Influence of Fly Ash and GGBS on Interlocking Blocks. According to Indian Standard IS 2185-1 (2005), the average compressive strength for load bearing blocks should be between 3.5 and 15 N/mm². According to American Standard C90-14, the average compressive strength for load-bearing hollow blocks should be at least 13.8 N/mm².

There are several types of supplementary cementitious materials such as fly ash, GGBS, metakaolin, silica fumes, and rice husk. Among all the supplementary cementitious material, fly ash and GGBS have good pozzolanic nature and so they are utilized in this research for manufacturing of interlocking blocks. Fly ash increases the chemical resistance, durability, and workability of the concrete mix when

FIGURE 17: Comparison between actual and predicted values for cost (Rs.).

mixed at an optimum percentage. Figure 11 shows the results of compressive strength and cost of interlocking blocks with varying percentages of cement, fly ash, crushed stone aggregate, and coarse aggregates. From the results, it is seen that the MPF2b mix gives the required compressive strength and surface texture with an optimum cost compared to the standard mix with cement satisfying the codal specifications. Fly ash reacts slowly at the initial stages which gives less compressive strength. At later ages, due to its reactions with alkali and lime in the concrete mix, an additional cementitious compound is produced which helps to gain strength over time.

It is observed that replacement of cement with GGBS results in faster strength gain than fly ash. The experimental results shown in Figure 9 reveal that the mix proportion MPGb has the compressive strength required for load-bearing blocks as specified in the code.

Overall, results showed that the use of alternative materials such as fly ash and GGBS in the given ratio does not affect the quality and strength of the specimen. Replacement

of cement with GGBS and fly ash mix reduces the cost. Reduction in the cement content results in reduction in cost. These results can be used as guidelines for the manufacturing of interlocking blocks using cement, fly ash, and crushed stone aggregate with improved strength properties at optimum cost.

4.2. Artificial Neural Network Results. In the present study, the MATLAB neural network tool is utilized for predicting the cost and compressive strength of interlocking blocks. The utilization of ANN in predicting the compressive strength of concrete provides a quick and easy method to determine the optimal mix proportion for a desired strength. The accuracy of ANN prediction generally relies upon the network architecture selected, so various number of trials with several hidden node numbers were tested before the final architecture model is chosen. The input for the ANN model is the proportion of cement, fly ash, GGBS, coarse aggregate, and crushed stone aggregate; the

TABLE 7: Dimensions of the wall.

S. no.	Description	Length (m)	Height (m)	Width (m)
1	Brick masonry wall	3.6	3.2	0.23
2	Interlocking block masonry	3.6	3.2	0.2

TABLE 8: Cost of materials.

S. no.	Material	Rate	Unit
1	Red brick	8	Rs./no.
2	Interlocking blocks	22	Rs./no.
3	Cement	6	Rs./kg
4	Sand	0.6	Rs./kg
5	Brickwork labor	16	Rs./sq. ft
6	Interlocking block labor	8	Rs./sq. ft

TABLE 9: Construction cost using the brick and interlocking block.

Item	Description		Quantity	Unit	Cost (Rs.)
Brick masonry	Brick	Brick masonry wall			
		Quantity	1148	Nos.	9184
		Labor	123.84	sq. ft	1981.44
	Mortar	Mortar-cement	338.74	kg	2032.44
		Mortar-sand	1852.77	kg	1111.66
	Plastering	External-cement	79.42	kg	476.56
		External-sand	434.43	kg	260.66
		Internal-cement	52.95	kg	317.71
		Internal-sand	289.62	kg	173.77
Total		15538.25 (Rs.)			
Interlocking block	Interlocking block				
	Blocks	Quantity	280	Nos.	6160
		Labor	123.95	sq. ft	991.6416
Total		7151.642 (Rs.)			

variations in proportions of the above materials will have a significant effect on the strength and cost of interlocking blocks. The output results are compressive strength and cost.

Figures 12–17 show the regression plot for all the test data along with predicted values of compressive strength and cost. The algorithm is tested and validated. The overall regression value for 3, 7, 14, 21, and 28 days is above 0.98 indicating that the model fits best for predicting compressive strength at all ages. From the results, it is clear that the network is well trained as the predicted values of compressive strength for interlocking blocks are almost similar to the actual strength. So, this neural model can be used to find optimal mix proportions for the desired strength at optimum cost.

5. Cost Analysis

The dimension of the wall considered for cost analysis is given in Table 7. Interlocking blocks can reduce the construction cost of walls by more than 50%. Costing for blocks, labor, and material is given in Tables 8 and 9.

6. Conclusion

This research investigation provides a predictive model for determination of the optimum mix proportion for interlocking blocks using the artificial neural network algorithm. The ANN trained model using the Levenberg–Marquardt algorithm with 4 input 2 sets of 10 hidden layers exhibits good mechanical strength prediction on novel concrete interlocking blocks. Moreover, predicted ANN values are 98% accurate when compared to experimental results. In general, the proposed ANN model with cement, fly ash, GGBS, and fine and coarse aggregates as the architectural model has high capability and reliability in predicting the mechanical strength and cost of interlocking blocks. By adopting the ANN architecture model, there will be no need to develop and test large number of mix proportions for determining the mechanical strength. This developed ANN architecture simplifies the challenge of determining the interlocking blocks' mechanical strength and optimum cost for the mix proportion within the bounds of the ranges discussed in this study.

Based on the experimental investigation reported in this paper, following conclusions are drawn:

- (1) The best combination of strength and surface texture of the interlocking blocks can be achieved using 65% coarse aggregate and 25% crushed stone aggregate with 4% cement and 6% fly ash.
- (2) If the percentage of cement is less than 4% to weight of fly ash, brittle failure occurs in the interlocking blocks. The percentage of cement by more than 4% shows fracture failure in the interlocking blocks.
- (3) Interlocking blocks with GGBS reaches early compressive strength when compared to blocks with fly ash.
- (4) The innovative geometric design of the interlocking block provides better strength and stability eliminating the need for mortar resulting in faster and economical construction.
- (5) This proposed interlocking block system is more than 50% cost efficient compared to the conventional masonry system since the construction is faster and less manpower is utilized.
- (6) The experimental values are close to the predicted values showing a strong statistical correlation between the input and output values, and so this neural model can be used to find the optimal mix proportions for the desired strength at an optimum cost rather than performing lots of experiments.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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