Lecture Notes in Civil Engineering

N. Vinod Chandra Menon
Sreevalsa Kolathayar
Hugo Rodrigues
K. S. Sreekeshava *Editors*

Recent Advances in Civil Engineering for Sustainable Communities

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Preface

In an era defined by rapid urbanization, increasing environmental concerns and the necessity to create sustainable communities, the field of civil engineering stands at the forefront of innovation and progress. The pursuit of sustainability has never been more crucial, as we face the challenge with the consequences of climate change, population growth and resource constraints.

This volume presents the select proceedings of the G20 C20 International Conference on Interdisciplinary Approaches in Civil Engineering for Sustainable Development (IACESD 2023) which showcase the remarkable diversity of thought and expertise that defines the field of civil engineering today. The main emphasis is on the vital mission of creating sustainable communities that will benefit not only our present but also the generations to come. The volume brings together a diverse array of cutting-edge research, methodologies and insights from leading researchers in the field. It explores the latest advancements in civil engineering that are not only transforming our urban landscapes but also nurturing environments where people can thrive while minimizing their ecological footprint.

We extend our heartfelt gratitude to all the authors, presenters, participants and reviewers who contributed to the success of the G20 C20 International Conference on Interdisciplinary Approaches in Civil Engineering.

We thank all the staff of Springer for their full support and cooperation at all the stages of the publication. We hope that this book shall be beneficial to students, academicians, professionals and researchers.

Kollam, India — Prof. N. Vinod Chandra Menon
Surathkal, India — Dr. Sreevalsa Kolathayar
Aveiro, Portugal — Dr. Hugo Rodrigues
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Contents

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Dr. Sreevalsa Kolathayar pursued M.Tech. from IIT Kanpur, Ph.D. from IISc, and served as International Research Staff at UPC Barcelona Tech Spain. He is Associate Professor at the Department of Civil Engineering, National Institute of Technology Karnataka (NITK) Surathkal, India. He has authored five books, edited twelve books, published over 100 research articles, and holds two patents. He is on the Editorial Board of several international journals. In 2017, The New Indian Express honored him with South India's Most Inspiring Young Teachers Award. He received the ISET D. K. Paul Research Award from the Indian Society of Earthquake Technology for the best Ph.D. thesis on Earthquake Risk Reduction in India. He received the "IEI Young Engineers Award" from The Institution of Engineers (India) in 2019. He is on the roster of two technical committees of ASCE Geo-Institute and is Member of the Working Groups of BIS CED 39 for three IS codes. Dr. Sreevalsa has eight funded R&D projects and completed over 50 civil engineering consultancy projects.

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Recent Advances in Civil Engineering for Sustainable Communities: An Introduction

N. Vinod Chandra Menon, Sreevalsa Kolathayar, Hugo Rodrigues, K. S. Sreekeshava, and C. Bhargavi

1 Introduction

In the pursuit of creating resilient and sustainable communities, the field of civil engineering has witnessed remarkable strides driven by innovation and interdisciplinary collaboration. This introduction provides an overview of the key thematic areas that are poised to redefine the future of urban development, encompassing the fusion of Geographic Information Systems (GIS) and Building Information Modeling (BIM), the emergence of Smart Structural Systems, the challenges and opportunities presented by fasturbanization, breakthroughs in building materials, the critical assessment of soil and ground water quality, the transformative role of artificial intelligence in engineering solutions, the integration of numerical methods for fluid flow modeling and the revolutionary potential of 3D printing technology within the construction industry. Through this compilation, we embark on a journey to uncover the transformative potential of these advancements, as they collectively contribute to the creation of sustainable communities that stand resilient in the face of evolving challenges.

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2 Building Materials

Advancements in material technologies have evolved over the period of the growth of sustainable construction practices. A study on metal matrix composites and their applications has been a notable contribution toward this field of study. The structural appropriateness and their tensile properties were studied along with the modulus [1–3]. A study on Repair Effectiveness of damaged RC beams with circular openings using CFRP sheet by Srihari et al. discusses about the application of CFRP in arresting shear cracks and enhance the durability of the beam.

Another paper in the volume by Dhanalakshmi et al. entitled Investigation on Compressive Strength of Fibre Reinforced Concrete using Artificial Neural Network deals with incorporating marble sludge powder in concrete as partial replacement of cement. The samples prepared are tested for their mechanical properties. ANN models are developed to predict the properties using feed-forward back-propagation techniques. Further, Saad et al. in their paper titled Conventional and Ensemble Machine Learning Techniques to Predict the Compressive Strength of Sustainable Concrete developed various machine learning models including decision tree (conventional machine learning model) and random forest, AdaBoost and gradient boosting (ensemble machine learning model). As compared to all the models, gradient boosting model fared better in both training and testing phases. Comparative study on the various machine learning models was a significant input to this study as it discusses about nodes, determinations and predictions [4]. Ensemble machine learning algorithms were further used by Toaha et al. in their paper titled Optimizing Sustainable Construction Materials with Machine Learning Algorithms: Predicting Compressive Strength of Concrete Composites to predict the property of limestone and calcined clay. Again, the gradient boosting model predicted the results with high efficiencies. Taking a step forward, Gaurav et al. in their paper titled Prognosis of Concrete Strength: The State of Art used different machine learning algorithms such as XGBoost, CAT-Boost, LightGBM, etc., to predict the strength. The outcome indicated that the CAT-Boost outperformed its other counterparts. Ensemble machine learning models were used to predict the porosity of SCM-blended concrete composites by Saad et al. The study indicated that the random forest model was subpar when the models were examined under model efficiency parameters. Their paper titled Ensemble Machine Learning Models to Predict the Compressive Strength and Ultrasonic Pulse Velocity of Sustainable Concrete in the same volume presented and compared the ultrasonic pulse velocity tests' results of fly ash-based concrete.

Classification of fly ash as Class F, Class C and Class P based on the chemical constituents in concrete matrix has been long known. The study titled Group Indexing of Fly Ashes using Unsupervised Learning and Fuzzy Clustering Techniques by Jayaram et al. uses unsupervised machine learning techniques such as k-means, k-medoids and fuzzy c-means to classify fly ashes. The results indicated that the cluster by fuzzy logic approach proved to be optimal. Incorporating indexing equation and attribute values makes it convenient to find the index and the associated properties of that index and the same has been emphasized in relevant studies previously [5, 6].

Bio concrete is among the very new concepts being introduced into the materials industry and the same has been discussed by Mithanthaya et al. in their paper titled Experimental Study on the Strength Properties of Concrete Incorporated with Bacteria. It was noted that the strength and durability of concrete significantly improved thus contributing to a sustainable future. Sumathi et al. took a step forward and studied about the self-healing properties of bacteria-based cement mortar with eggshell powder and jute fiber. They also studied the uncracked and pre-cracked specimens and their rate of crack healing. Microstructure study including SEM analysis and XRD analysis was performed. Srivathsa et al. studied the incorporation of various nanomaterials and their impact on the microstructure and the strength characteristics of concrete in their paper titled Experimental Study on Strength and Durability Characteristics of Mortars with TiO_2 Nanoparticles. About 3% of TiO_2 indicated to provide better resistance toward alkalinity and acidity up to 28 days of curing.

3 GIS, BIM and Smart Structural Systems

A notable paper in this context is ELA and AAR Dynamics of Glaciers in Chandra Basin, Western Himalayas by Geetha Priya et al. The study focusses on the estimation of ELA and AAR for selected glaciers in Chandra basin for two hydrological years using high-resolution multispectral datasets from Indian Remote Sensing Satellites (IRS-6) and Landsat-8. The glaciers of Himalaya play an important role in water cycle and any variations can impact water availability for the needy. The monitoring process can facilitate better understanding and management of the available resources. A crucial study on this previously indicated that climatological conditions and topography influence the effect of ELA [7] and a study carried out on 10 glaciers in Chandra basin in Lahaul-Spiti, HP, India, also enhanced the information for this study [8]. An overview about the utilization of machine learning models and their applications in infrastructure development, landslide susceptibility modeling, etc., has been provided in the paper titled GIS Applications and Machine Learning Approaches in Civil Engineering by Sasmita et al. Strategies in allocating resources and risk assessments can be accomplished by using these models. Arati Reddy et al. in their paper titled Analysis of Urbanization Induced Flooding in the Koramangala–Challaghatta Valley of Bangalore City using Remote Sensing and GIS have studied the satellite data along with digital elevation model data and survey of India toposheets. Flooding due to urbanization and its controlling and mitigation factors are discussed.

The strength of any structure must be assessed in order to decide its durability. One of the notable papers in this volume titled Structural Health Monitoring by simultaneous measurement of Strain and Temperature using Different materials by Somesh Nandi et al. provides an overview of the fiber Bragg grating sensors (FBG) that can be utilized at elevated temperatures up to 200 °C for different materials in both theoretical and experimental studies. Utilization of fiber optic sensors for being one

of the most reliable sensing systems and their susceptibility under extreme weather conditions are some of the prominent studies performed earlier [9, 10]. Study on regular and irregular plan has been performed in an integrated approach of Architectural and Structural Configuration and their Seismic Performance was studied by Kalyana Rama et al. Building information modeling Edificius along with STAAD Pro Connect were used for architectural and structural designing, respectively. Detailing was done using RCDC tool. The recent advancements in approach toward integration of various tools to result in ideal construction in seismic prone zones is shown to be a successful attempt in the field for resilient community. Another study on elevated water tank subjected to seismic vulnerability was presented in the paper titled Time period Determination for Shaft Type Elevated Water Tank by Jyothsna Sree et al. The study mainly focused on the stiffness determination from analytical formula and interpretation using software model.

Applications of artificial intelligence and robotics in construction industry have contributed toward a safe and sustainable advancement. The paper titled 3D Mapping and Exploration using Autonomous Robots and Neural Radiance Fields (NeRF) by Sudhanva et al. utilizes this exploration tool to revolutionize the civil engineering practices.

Sireesha et al. presented a paper titled Assessment of Soil Salinity in the East Upputeru Catchment of Andhra Pradesh using geospatial techniques based on integrated conventional and Geographic Information System (GIS) approach. Based on the outcomes, agricultural experts can take up strategical and economical decisions to use surface water, monitor drainage systems to ensure maximum capacity. Soil and water assessment tool has been utilized to ensure a sustainable urban plan is developed using soil and water quality assessment tools and GIS in the paper by Shwetha et al. titled Land use Landcover Modelling for Urban Area of Bengaluru Region. The potential impacts of different land use policies and planning strategies can be evaluated by means of this model.

4 Numerical Methods and 3D Printing

Finite element method for one-dimensional Darcy–Brinkman–Forchheimer fluid flow model by Mallikarjunaiah et al. discusses the discretization of fluid flow model using competent damped Newton's method type linearization with Lagrange's finite elements. Kemparaju et al. studied the time-independent MHD slip flow of USM fluid across an elongating surface using fluids that are transported through pipes with varying flow rates in their paper titled Effect of partial slip on mass transfer flow of non-Newtonian fluid due to unsteady stretching sheet. Earlier studies in the same areas have given contradictory results as compared to the results of this study [11–13]. Numerical Modelling Investigations of Hydraulic Jump Characteristics over a chute spillway by Urvi et al. discusses about simulation using SST K-omega turbulence model, in which characteristics and dissipation of energy of hydraulic jump are investigated.

3D printing and its advancements in the recent scenarios have gained lot of interest. Few of the contributions in this volume provides with the review of the 3D printing technologies and their applications with reference to the construction industry. The potential economic advantages, increased productivity and futuristic significance is discussed in the paper titled A Review on Impact Assessment of 3D Printing Technology in the Field of Modern Construction by Ravikanth et al. Kiruthiga et al. in their paper titled A short review of 3D printing from construction perspective discusses about the advancements in productive manufacturing, design optimization and overcoming the disadvantages faces by traditional construction methods. Contribution of 3D printing technology to construction sector has been studied from various perspectives that also includes ubiquity and futuristic approach [14, 15].

5 Soil and Ground Water Quality Assessment

IoT Enabled Monitoring of Prefabricated Drain Performance for Ground Improvement-A Review by Shrivastava et al. studied the improvement techniques of the soil's strength and facilitate reduction in its compressibility. An IoT-enabled system is used to monitor the drains real time to enhance the performance and reduce construction costs.

Arduino Uno is used to implement IoT-based intelligent agricultural engineering integrated farming in the paper titled IoT Driven Civil Engineering Solutions for Smart Integrated Agriculture in Controlled Environment by Hamsa et al. This farming system monitors and controls soil moisture, humidity, climatic conditions, pH, etc., and the same can be utilized to decide the crop pattern. Further, one of the studies in the volume showed that modification of irrigation, deciding fertilizer application, maximizing resources and raising yields can be done based on recent real-time information and analysis of soil conditions using ESP32 microcontroller technologies. This paper titled Temperature and soil parameter monitoring system by Pallavi et al. proposes the ability to alter sectors by providing real-time information. Notable studies on watershed models which describe the real-world system have been done and concluded that model simulations comprise few uncertainties [16]. A small change in model parameters by switching the SWAT code for growth and dormant seasons enhanced the model performance [17]. The study has been carried forward by Yashas et al. in their contribution titled Towards Selection and Improving the Performance of the SWAT hydrological model: A Review where they discuss about various parameters including sensitivity analysis, calibration techniques and superiority of the SWAT model.

Contribution toward the geotechnical aspects of the Civil Engineering community plays a vital role in advancement toward sustainable society. Soil and their properties can be predicted with various soft computing techniques and show the way forward for the geotechnical aspects and designs. Prediction of compression index, CBR values and standard penetration test N-values are the prominent contributions to this volume. Akshaya et al. in their paper titled Machine Learning Methods for Predicting

Soil Compression Index have used 359 data from diverse soil condition and trained the model to estimate the index properties like liquid limit, natural moisture content, initial void ratio and plasticity index. Ghani et al. in their paper titled Prediction of Soaked CBR Value of Sub-base Soil using artificial Intelligence model developed a predictive model for evaluating California bearing ratio value of soaked soil and the comparison between conventional and hybrid AI models. The paper titled Comparative Study of Various Machine Learning Models for Estimating Standard Penetration Test *N*-value by Shaik et al. uses ANN, XGBoost, ElasticNet, Lasso Regression, Extra Trees, Bayesian Linear Regression, Ridge Regression, etc., to estimate the standard penetration test *N*-values and compared with existing empirical equations.

Smart watering: Revolutionizing Irrigation with AR and IoT by Sumanth et al. combines the utilization of augmented reality and IoT to enhance the efficiency and accuracy of systems incorporating drip irrigation. Moisture sensors are used along with other electronic tools to measure the moisture content and automate the supply of water required for the irrigation purposes. Usage of the low-cost soil moisture sensor and the microcontroller [18] was studied previously and the same has been integrated in this study.

Study on spatial variation of the parameters of water quality can contribute toward protecting environmental geology and managing the same. The paper titled Evaluation of Spatial Variation for terrain parameters associated with surface and ground water quality necessary for sustainable geo-environmental conditions by Rao et al. utilizes analytical hierarchy process model approach to evaluate the watershed in the area in order to facilitate action plans for maintaining sustainable geo environment conditions.

6 Urban Transport Planning

Infrastructural development and urbanization play an important role in economic growth of the society. The standard of living and technological requirements has always posed a problem with respect to climatic changes and depleting fossil fuels. Overcoming all the problems caused by different facets of infrastructural development and working toward a sustainable society is one of the main objectives of urbanization. A study titled Impact Analysis of Modal Shift on Transport Ecological Footprint in Bengaluru by Ann et al. presented a model to estimate the footprint in both private and public modes and the impacts of shifting from private to public transport systems. Metro Rail development is an advantage to the growth and enhancement of the nation. But, one of the problems faced during the construction include the traffic diversions and the cost associated with such diversions. The above problem has been discussed by Chaitanya et al. in their paper titled An analysis of the cost associated with the diversions caused by Metro Rail construction work. The cost of diversion was estimated in both distance- and time-related scenarios for period from 2016 to 2022. The cost turned out to be more than 6% of actual cost of construction. This leads to decreased benefit to cost ratio. Intelligent Transport System (ITS) with EV

infrastructure for sustainable mobility by Joshi et al. presents an idea of connecting vehicles in real time using wireless technologies in order to facilitate people and goods movement in safe and efficient way and overcome the challenge such as traffic congestion, pollution, etc. The study also compares electric and conventional vehicular systems. Smart warning systems [19] and traffic monitoring systems [20] have been previously studied in this context.

Another important criterion of urbanization includes the pedestrian crossings and their contributions toward vehicular delay. Relations between crossing rules, vehicles volume, funds etc., are studied. The model calculated a delay in vehicular traffic which was very close to the on-site conditions. Incorporation of simulations and modeling techniques can facilitate in better decision making and identify optimal conditions. Identification of deficiencies and problems faced in the uncontrolled traffic junctions and implementation of signals, markings, etc., to regulate maneuvers at junctions is presented in the paper Analysis of traffic data at uncontrolled junction and recommending suitable remedies for the junction-A case study at Veera Savarkar flyover Junction–Yelahanka New Town, Bengaluru by Sreenatha et al.

Bibang et al. demonstrated a comparison between Ortho mosaic images generated using drone-based Pix4D and satellite map images. The paper also emphasizes on the drone-based survey's advantages that include cost effective, accurate and timely data for decision making and development of sustainable infrastructure. Another notable contribution in this volume discusses about the construction practices, work anatomy and job satisfaction levels along with the correlation among them in the paper titled Investigate the correlation among work autonomy and fringe benefits towards job satisfaction among construction professionals in Chennai by Kiruthiga et al.

Advancements of computer technology have played an incredible role in how the reality-based system works. Interior Design App using Augmented Reality by Pranav Ram et al. discusses an augmented reality-based android app that can create 3D models that can be arranged and be visualized how it will look in the real world.

Resilience of a society toward the disasters that may occur is an integral part of the urbanization process. Athiqullah et al. have presented the paper titled Urban Resilience Assessment of Kandahar City, Afghanistan, where they discuss the lack of awareness, low income of people and degraded conditions of infrastructure that can cause high vulnerability toward natural hazards. They proposed the strategies to enhance the urban resilience and take up necessary measures.

The paper titled A Machine Learning Based Intelligent Inventory System for Construction Industry by Manoj et al. discusses about an alternative inventory management system to track, organize and optimize the equipment and supplies of construction using machine learning algorithms.

The study titled A Conceptual Approach to Apply Agile Management in Construction by Nithish et al. discussed about implementation of APM, its applicability to multiple industrial domains and its flexible approach in the construction industry. The study also emphasizes the advantage of APM over traditional project managements and its advantages when both are hybridized.

7 Summary

The advancements collectively underline the potential for creating communities that thrive in an ever-changing world. The integration of forward-looking approaches, such as sustainable building materials, soil and water quality assessment, advanced numerical methods and 3D printing, reflects a commitment to constructing not just structures, but resilient and environmentally conscious communities. Ultimately, this compilation not only reflects the current strides in civil engineering but also paves the way for a holistic approach to global challenges through creative engineering solutions.

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Building Materials

Investigation on Compressive Strength of Fibre-Reinforced Concrete Using Artificial Neural Network

A. Dhanalakshmi, M. Shahul Hameed, K. Valarmathi, and C. Rajendra Prasath

1 Introduction

Building practices that are friendly to the environment are an essential component of human civilization [1–4]. Because of technological advancements and the fast growing need for increasingly complex building structures, there is a need for more durable building materials that are able to survive adverse environmental conditions [5–9]. This is owing to the widespread availability of concrete's basic components, its simple and straightforward manipulation, and its relatively low price. However, in order to satisfy the ongoing and unending demands placed on an infrastructure that is in a state of constant evolution, more robust and long-lasting building materials are required [10–13]. The addition of suitable mineral additives in optimal quantities can improve the performance of concrete by enhancing its durability properties [14–19]. This is one technique to improve the performance of concrete. It may be possible to achieve greater economic viability and sustainability through the utilization of waste marble sludge powder produced by manufacturing facilities such as marble cutting plants [20–23]. This is because it will lessen the burden that is placed on the environment as a result of the manufacture of concrete and garbage [24]. In addition, this will reduce the strain that is placed on the environment. One type of polymers is polypropylene. A structure of molecules known as a polymer is one that is made up of several identical subunits [25, 26]. The primary objective of this investigation is to explore use of MSP in concrete as a partial replacement for cement with the polypropylene fibre addition and to determine the effect that this has on both the mechanical characteristics of concrete and the cement and mortar that are used in

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the mixture. In addition, this investigation will examine how the addition of marble sediment powder affects these characteristics. Techniques from machine learning are used to make a prediction about the compressive strength of concrete that has when marble sludge powder added to it. Artificial neural network (ANN) does not need such particular equation form. Relatively, it requires enough data about what goes in and what comes out [27]. Also, it can keep retraining itself with fresh data, making it easy for it to adapt to new data. ANN is being looked into to figure out how to fix the issues with missing or wrong details [28, 29]. In this investigation, water cement ratio, cement, MSP, fine aggregate, coarse aggregate, polypropylene fibre, water and superplasticizer are used as input and targeted compressive strength is the output.

2 Materials and Methods

2.1 Materials

53 Grade of Ordinary Portland Cement (OPC) was utilized as the binder material. As an alternative to cement, the powder made from marble sludge was utilized. In this work, M-Sand is used as fine aggregate. The coarse material utilized was 20 mm in size. A combination of fine aggregate (FA) and coarse aggregate (CA) was used. It is necessary to make use of a water-reducing super plasticizer (SP) in order to get the desired level of workability. During this particular study project, Glenium B233 and polypropylene fibre of 12 mm length and 0.02 mm diameter was utilized. For the purposes of mixing and curing, water from the tap was used.

2.2 FRC Mix Proportion

The mix proportion of FRC were calculated as per IS 10262 (2009). For this study, we chose to focus on 0.35 and 0.4 w/c ratios. Table 1 provides the recommended concrete design mix proportions based on the chosen water binder ratios. Cement replacement with marble sludge powder ranged from 0 to 25% by weight.

3 Experimental Investigation

3.1 Compressive Strength

When a load is applied gradually to a solid, the material's compressive strength is the highest compressive stress it can withstand before cracking. The procedures used in this analysis were those outlined in IS 516. The cubes are arranged so that the casting

Table 1 Mix proportions of fibre-reinforced concrete (kg/m^3)

Mix id	w/c ratio	Cement	MSP	FA	CA	Fibre	Water	SP
FRC1	0.35	429	0	1300	700	2.14	150.15	12.87
FRC2	0.35	407.55	21.45	1300	700	2.14	142.64	12.87
FRC3	0.35	386.1	42.9	1300	700	2.14	135.13	12.87
FRC4	0.35	364.65	64.35	1300	700	2.14	127.62	12.87
FRC5	0.35	343.2	85.8	1300	700	2.14	120.12	12.87
FRC6	0.35	321.75	107.25	1300	700	2.14	112.61	12.87
FRC7	0.40	401	0	1300	700	2.01	160.4	12.03
FRC8	0.40	380.95	20.05	1300	700	2.01	152.38	12.03
FRC9	0.40	360.9	40.1	1300	700	2.01	144.36	12.03
FRC10	0.40	340.85	60.15	1300	700	2.01	136.34	12.03
FRC11	0.40	320.8	80.2	1300	700	2.01	128.32	12.03
FRC12	0.40	300.75	100.25	1300	700	2.01	120.3	12.03

face and the testing face are perpendicular to each other, and the weight is gradually applying to the opposing faces of the cube specimen. The stress is applied axially and increased gradually, with no sudden impacts. When calculating compressive strength, the greatest force applied to the specimen is recorded and then divided by the specimen's cross-sectional area. Compressive strength was evaluated using concrete cubes of 150 mm on a side. To determine the optimal dosage, the age of curing 7, 14, 28, and 56 days was followed. Water binder ratios of 0.35 and 0.40, as well as percentage replacements ranging from 0 to 25%, were examined for optimal dosage and long-term efficiency. Compression strength of FRC specimens are shown in Fig. 1.

Fig. 1 Compression testing of a cube specimen

4 Results and Discussion

4.1 Compressive Strength

Figure 2 shows the results on cubes made with varying percentages of marble sludge powder used as a partial replacement for cement. As the graph shows below, the replacement of 10% cement with marble sludge powder boosts the compressive strength, whereas replacement of 20 and 25% of cement with marble sludge powder causes the strength to begin declining. The micro-filler effect of marble sludge powder, which aids in generating a denser mix by filling the spaces, may account for the increased strength.

The characteristics of both the transition zone and the cement matrix are improved as a result of the filler effect. Concrete's compressive strength is mostly attributable to the cementing substance that may have been reduced at 20 and 25% replacement levels, leading to a weakening of the material. At 15% replacement, compressive strength increases for both the 0.35 and 0.40 w/b ratios. Compressive strength increased slightly after 14, 25, and 56 days of cure compared to 7 days of curing for the same amounts of cement substitution by marble sludge powder.

5 Regression Analysis in Concrete

In a typical scenario, if it is possible to maintain the optimal conditions for casting, testing, and curing, the trends for strength ratios should be the same no matter what kind of specimen is being looked at. Even if the same concrete is used to make the samples and tests, it is hard to keep the same conditions when making the samples

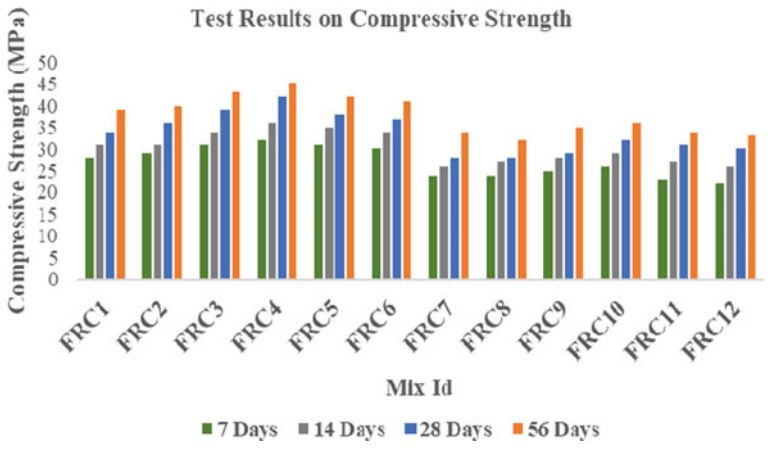

Fig. 2 Test results on compressive strength

and testing them. This is one of the reasons why unique occurrences can happen in the real world. Because of this, it was found that the strength of one type of concrete is not the same as the strength of the other types of concrete samples that were tested. So, the ratios of strengths can be used to make a general formula for the regression analysis of compressive strength for concrete that includes marble sludge powder. Since the strength ratios are being used to figure out the relationship, the type of specimen that is used will not change the relationship.

5.1 Artificial Neural Network Model

This section deals with an artificial neural network (ANN) model is presented in order to conduct a regression analysis of the effect of concrete that will be identified when marble sludge powder is used as a partial cement substitute. Figure 3 refers ANN structure model for FRFC.

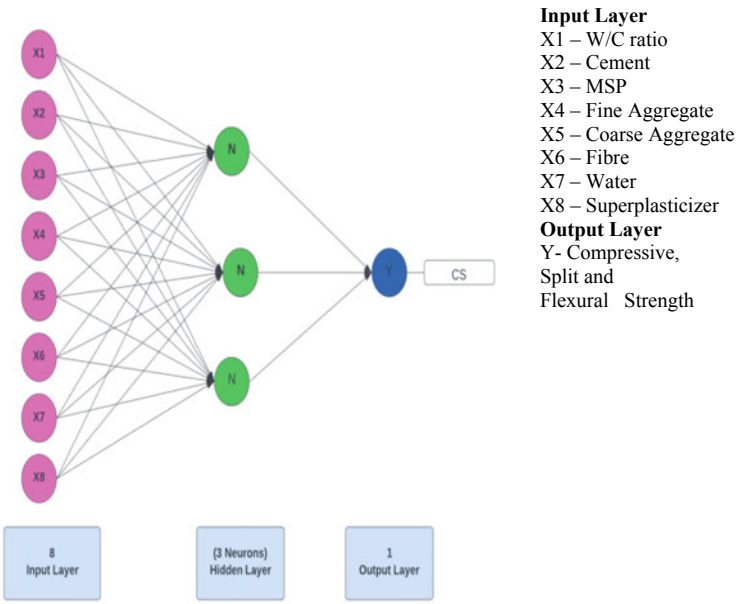

Fig. 3 ANN structure model

5.2 Regression Analysis Model Using ANN

The results of Figs. 4, 5, 6, 7, 8 and 9 were gotten from MATLAB Software. In this investigation, two-layered feed-forward network ANN structure was performed and the structure is shown in Fig. 4. The Table 2 refers the specifications of ANN technical parameters. Figure 5 shows the performance state of mechanical strength parameters. The obtained minimum gradient of 0.26172 is at epoch 8 for compressive strength.

Figure 6 refers the training state of mechanical strength parameters. In this training, validation, testing, and best parameters were analysed and find out the best validation performance ranges. The compressive strength attained MSE in the range of 10^2–10^0, and the best validation is achieved at epoch 9 of 6.4918.

Figure 7 shows the error histogram analysis of concrete mechanical strength. It is the error findings between targeted values and predicted values after training a feed-forward neural network using machine learning techniques. Totally, 12 data

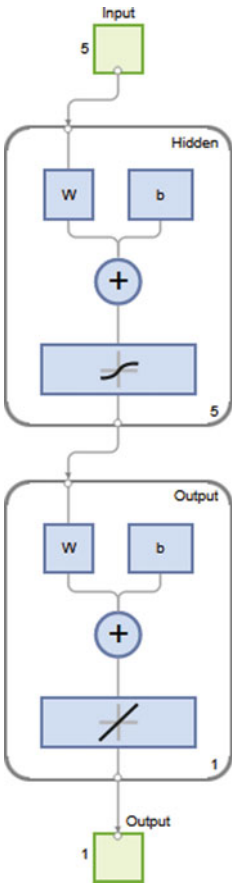

Fig. 4 Feed-forward neural network

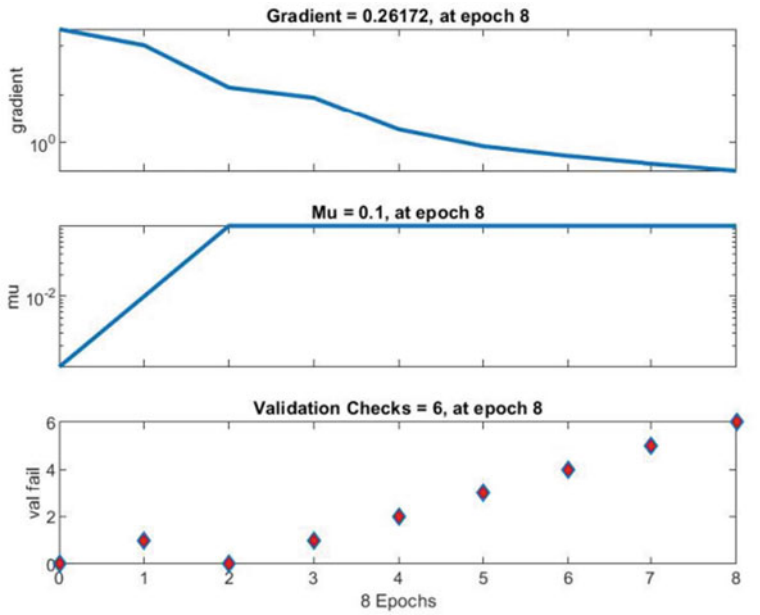

Fig. 5 Performance state of compressive strength at epoch

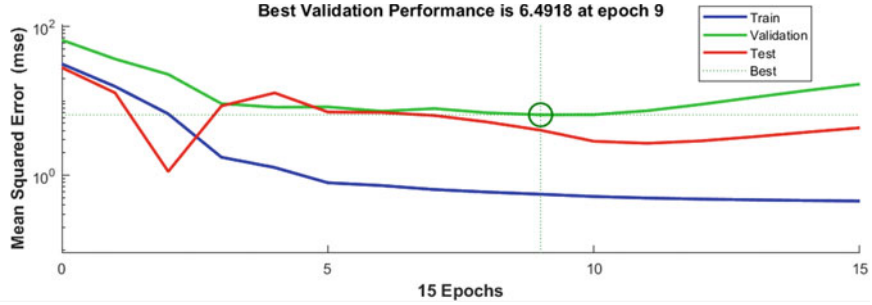

Fig. 6 Training state of compressive strength

were analysed. From the analysis, error values of compressive strength indicate that the error of 0.606 for 3 instances, error of 3.473 for 2 instances, and one instance with an error of − 8.515 was achieved.

The relationship between experimental data and the training, validation, and testing sets of compressive strength of fibre-reinforced concrete employing marble sludge powder is depicted in Fig. 8. The mechanical parameters of the fibre-reinforced concrete are estimated using the suggested ANN model utilizing the experimental database to demonstrate its effectiveness.