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Optimum Concrete mix Design using Heuristic Techniques

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Abstract— This paper surveys the application of soft computing techniques in concrete mix design. Within this context, different methods as well as their fusion are reviewed in order to examine their capability.

Index Terms— Artificial Neural Network,Binary Evolution techniques,Concrete mix design,Fuzzy Logic,Genetic algorithm,Optimization,.

1 Introduction

Optimal design methods assist engineers to evolve the best possible design in terms of cost, weight or reliability or a combination of all these. Recent advances in computing scenario resulted in high performance computing at relatively low cost. This has made engineers to choose non traditional optimization techniques by minimizing approximations, assumptions and considering engineering aspects.

Mix design is the determination of ingredients of concrete. The task of optimization is the selection of most suitable ingredients from the database. To arrive at mix designs for concretes with special properties that cannot be obtained from conventional concrete, a large number of trial mixes are required to select the desired combination of materials. This leads to wastage of materials which detrimental to the environment. Also the experimental work needs a lot of effort, time and money, the need for utilizing new methodologies and techniques to reduce this effort, save time and money is urged. Hence now a day different soft computing techniques are employed to arrive at the optimal mix design which reduces the number of trial mixtures with desired properties in the field test. Experimental investigations can be carried out and to verify the proposed mix design. The design of concrete mix and the design process is not amenable to precise mathematical formulations. It is practically impossible to achieve the design strength of the mix in the field and what is realized in field is somewhere around the design strength.

This is due to uncertain behavior of constituent materials, impreciseness and vagueness in various parameters involved in the design (like degree of control, types of exposure, shape of aggregates etc…) and approximations in codal guidelines. Due to this, the process of mix design turns out to be approximate. It is thus essential to formulate approximate procedure of mix design in a way that is more natural, humanistic and more scientific.

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This paper gives an overview of the different soft computing techniques available for optimum concrete mix design.

2 Heuristic Techniques

2.1 Genetic Algorithms (GA)

Genetic algorithm that is a global optimization technique modeled on biological evolutionary process and can be used to find a near optimal solution to a problem that may have many solutions. Genetic algorithm, which is first formalized as an optimization method by Holland, is a global optimization technique for high dimensional, nonlinear, and noisy problem and a stochastic search technique based on the mechanism of natural selection and natural genetics. The general form of genetic algorithm, is composed of three major processes, i.e., selection, crossover, and mutation.
GA has been used for optimization problems on structural Engineering, water resources engineering and Engineering materials fields.

2.2 Artificial Neural Network (ANN)

Artificial intelligence has proven its capability in simulating and predicting the behavior of the different physical phenomena in most of the engineering fields. Artificial Neural Network (ANN) is one of the artificial intelligence techniques that have been incorporated in various scientific disciplines. Neural networks are powerful tools that are bestowed with the capability of realizing non-linear functions.
ANN has been used in modeling rainfall run off process and ocean waves, open channel hydraulics, tunnel construction and structural Engineering problems.

2.3 Fuzzy Logic

Fuzzy logic is a relatively new concept in science applications.

Hitherto, fuzzy logic has been a conceptual process applied in the field of risk management. Its potential applicability is much wider than that, however, and its particular suitability for expanding our understanding of processes and information in science and engineering in our post-modern world is only just beginning to be appreciated.

3 Review

This review may be considered as a valuable guide for researchers who are interested in optimal concrete mix design. Also the opportunities offered by fuzzy logic, artificial neural networks and genetic algorithms for further improvement can be explored

3.1 Genetic algorithm in mix proportioning of high-performance concrete [7]

High-performance concrete (HPC) is defined as concrete that meets special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices.HPC had been widely used in large-scale concrete construction that demands high strength, high flow ability, and high durability. To obtain such performances that cannot be obtained from conventional concrete , a large number of trial mixes are required to select the desired combination of materials that meets special performance. Chul-Hyun Lim, et al [7] had suggested that GA can be applied for high-performance concrete mix design to reduce the number of trial mixtures with desired properties in the field test. Experimental and analytic investigations were carried out to develop the design method for high-performance concrete mixtures and to verify the proposed mix design.

By applying the genetic algorithm for design of high-performance concrete mixtures, the number of trial mixtures with desired properties in the field can be reduced. This method is a new and alternative method to the current design method that has no exact design criteria.

3.2 Modeling Strength of High-Performance Concrete Using an Improved Grammatical Evolution combined with Macro genetic Algorithm Equations[8]

In this study a method is proposed to estimate the compressive strength of HPC incorporating improved grammatical evolution [GE] into the genetic algorithm [GA], called GEGA. The GE is a recently developed evolutionary programming type system. It is used to automatically discover complex relationships between significant factors and the strength of HPC. This method is transparent and can enhance our understanding of the mechanisms of HPC strength. GA was used afterward with GE to optimize the appropriate function type and its associated coefficients. In addition, macroevolution algorithm was processed to improve search efficiency during the GA optimization procedure. The case study includes over 1,000 examples of HPC for which experimental data were available. This novel model, GEGA, can obtain a highly non-linear mathematical equation for predicting the HPC's compressive strength. The results show that GEGA has lower estimating errors, which outperforms another evolutionary strategy called genetic programming and two popular types of traditional multiple regression analysis.

The main contribution of this paper is to provide an improved real-coded GEGA, to create the potential to predict the compressive strength of concrete. This model developed easily cooperate with the nonlinear problem of HPC that have several significant factors including water-to-binder ratio [*W/B*], age of testing [*T*], coarse aggregate [CA], and fine aggregate [FA].An equation, was obtained using GEGA to reveal the mixture mechanisms in detail. This result shows that the improved GEGA uses real-number coding which is an efficient and robust system identified model.

3.3 Analytic Formulae for Concrete Mix Design Based on Experimental Data Base and Predicting the concrete Behavior Using ANN Technique [3]

In this work,an experimental investigation of concrete properties is made using two of the locally most common types of cements. Slump, compressive strength, rebound number and ultrasonic pulse velocities were investigated for 64 mixes. The main parameters were type of cement, cement content, water content, and fine/coarse aggregate ratio. Data base was established for the mix proportions and corresponding properties.Analytic formulae are proposed for utilizing the collected data base for concrete mix design. Also, using the experimental data base presented in this study,a numerical approach, using one of the artificial intelligence techniques, is adopted to simulate the concrete behavior for different mix proportions. Artificial Neural Network (ANN) technique has been developed to simulate the concrete slump and concrete compressive strength for different mix proportions at different ages for the two types of cement and then predict the concrete behavior for different mix proportions at ages rather than those investigated in the experimental work.

The results of this study showed that ANN was capable of identifying relationship between different uncertain parameters with multiple input/output criterions. The designed ANN models were very successful in simulating and predicting the concrete slump and concrete compressive strength for different mix proportions at different ages for the two types of cement.

3.4 A Fuzzy-Neuro Model for Normal Concrete Mix Design [1]

In this study made by M.C.Nataraja et al., the Neural network is trained to learn experimental data that pertains to 28-day compressive strength of concrete cubes v/s water cement ratio of three commercial brands of cements that are popularly used in India. The data for training and testing of the net is generated through the manual interpolation of graph which was available in the literature. The five layers of fuzzy inference schemes are for finding target mean strength, maximum w/c ratio, water content, sand content and the minimum cement content. To account for non-linearity involved in various inputs and consequent outputs, Gaussian and sigmoid membership functions are considered in all the five layers.

This clearly shows that, the conventional method, which is approximate, is tenable to be treated under the integrated soft computing concepts of fuzzy logic and neural nets. Thus providing a mathematical (fuzzy) standpoint for the mix proportioning. From the end user (engineers) point of view, outcome of the model is significant on following counts; Firstly, it provides a way to capture inherent vagueness in the design steps proposed by codes. Secondly, it offers flexibility for the mix design expert to decide appropriate value for ambiguous parameters like degree of control, type of exposure and shape of aggregates. Finally, the ANN module helps to capture experimental data and to use it expeditiously during the design of fresh batches of trial mixes.

3.4 Binary Superposition Method For SFRC[3],[4]

The reinforcing effect of steel fiber on concrete relies on the bond between them which is formed by the certain cement paste wrapping steel fiber. The bond strength relies on the strength and thickness of cement paste. If the cement paste is made of the same water to cement ratio as that of concrete, the properties of concrete would not be affected by the added cement paste wrapping steel fibers. Therefore the mix design of SFRC can be divided into two parts: one is the added cement paste and the steel fiber, another is the base concrete. The total volume is maintained constantly and superposed by the two parts, the water to cement ratio of cement paste is the same as that of base concrete.

The binary superposition method for mix design of SFRC is proposed in the paper. The principle is to keep constant water to cement ratio and provide sufficient cement paste wrapping steel fibers to strengthen the boundary surfaces of steel fibers with base concrete, the volume of cement paste is determined by the average thickness of cement paste specially designed covering the surface of steel fibers. The formulas for mix design are given out based on the absolute volume method for mix design of ordinary concrete. The reason of the effect coefficient of steel fiber on splitting tensile strength of SFRC affected by the strength grade of SFRC should be further studied.

In the second part of the study[4] on binary superposition mix design method for steel fiber reinforced concrete (SFRC), which introduces the experimental results of flexural tensile strength and flexural toughness of SFRC. Based on the test, the effects of fraction of steel fiber by volume and average thickness of cement paste wrapping steel fibers on flexural tensile strength and toughness of SFRC are analyzed. The effect coefficient of steel fiber on flexural tensile strength of SFRC is suggested on the basis of the formula specified in current technical specification for fiber reinforced concrete structures. The flexural toughness of SFRC raises with the increase of fraction of steel fiber by volume, but less affected by the average thickness of cement paste wrapping steel fibers.

The results show that the flexural tensile strength and flexural toughness of steel fiber reinforced concrete are increased with the increase of fraction of steel fiber by volume. Meanwhile, the flexural toughness indexes of steel fiber reinforced concrete reach to the values of ideal elasto-plastic materials, the loading capacity in large deformation of steel fiber reinforced concrete beams also increases. The flexural tensile strength and flexural toughness of steel fiber reinforced concrete are affected by the average thickness of cement paste wrapping steel fibers, but the constant effect on steel fiber reinforced concrete in different strength grade should be further studied.

3.5 Compuer Aided Design For Optimum Concrete Mixtures[5]

Cheng Yeah showed that using neural networks and optimization technologies, it is possible to apply analytical methods to search for the optimum mixture of concrete composition, a mixture with the lowest cost and required performance, such as strength and slump. The concrete mixture design problem is first transformed into an optimization formulation, including objective function and constraint functions, appropriate for application of optimization technologies. Then the functions in the formulation, including strength and slump, can be modeled using a modeling module based on neural networks. Finally the optimization formulation can be solved using an optimization module based on nonlinear programming and genetic algorithms. These modules are integrated in a Computer-Aided Design (CAD) system. To evaluate the system, it was used to obtain a set of optimum concrete mixtures with wide ranges of workability (5–25 cm in slump) and strength (25–55 MPa in compression). It was found that (1) the modeling module can generate rather accurate models for compressive strength and slump for concrete, (2) the optimization module can generate the lowest cost mixtures for wide range of required strength and slump and their combinations, and (3) the dependence of required strength and slump on the design parameters meets expectations.

3.6 Optimization of concrete mix based on fresh properties using GA [6]

This paper presents a method for optimizing concrete mixture proportions according to the required performances Proportioning problems cannot be solved by the usual methods that consist in searching for the best solution with a single objective function, such as linear programming problems and nonlinear programming problems. The reason of this impossibility is that various performances are required of concrete corresponding to the environments in which the concrete is used, and it is impossible to express the plural requests in a single objective function. It follows from the feature of proportioning problem mentioned above that a proportion problem is classified as a multi-criteria optimization problem and it is of vital importance to formulate a way to solve the multi-criteria optimization problem.

The results show that Genetic algorithm system integrating the concept of Pareto optimality can be used for solving the multicriteria optimization problem in concrete mix proportioning from the vast combinations of sorts of content and proportions of mixture to explore. This system is maintained by suitable fitness evaluation, reasonable reproduction and correct prediction formulas. Also it reveals that with precise modelling the effect of admixtures on concrete performances, can be studied.

4 Conclusion

With the advent of sophisticated Computers and software Concrete mix design can still be improved and can be optimized which will lead to better tomorrow in sustainable environment.All the soft computing techniques discussed in this paper provide a very effective search in their own way. Hence their combination could also be possible if their concept is understood clearly.

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