# APPLICATION OF EMERGING ARTIFICIAL INTELLIGENCE METHODS IN STRUCTURAL ENGINEERING-A REVIEW

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**Abstract -** *The aspiration of the work presented in this paper was to collect, organize, and write the knowledge and experience about structural analysis-based design improvements into a knowledge base for a consultative advisory intelligent decision support system. The civil engineering problems are not repetitive, as the problem definition is always influenced by a number of factors like financial modes, importance of structure and site conditions and so on Therefore, although the use of computers in structural analysis started almost four decades ago, the profession has not been able to make use of computers fully, especially, for structural design and planning. This is mainly because of problem specific nature, need for logical reasoning, feasibility constraints and use of past experience required in actual design process and planning. Expert systems have capabilities to incorporate some of these requirements for programming a machine for solving a design problem. Artificial Intelligence (AI) is a very versatile and potential technology in the field of computer technology, which enables computer users in various fields to solve problems for which algorithmic approach cannot be formulated and which normally requires human intelligence and expertise. Expert Systems (ESs) and Artificial Neural Networks (ANNs), the best known manifestations of AI, have today gained immense credibility and acceptance in many professional fields. Artificial neural networks are biologically inspired in the sense that neural network configurations and algorithms are usually constructed with the natural counterpart in mind.*

***Key Words***: Artificial Intelligence (AI), Structural Engineering, Civil Engineering, Pattern recognition (PR) Expert Systems (ESs) Artificial Neural Networks (ANNs)

## 1. INTRODUCTION

Artificial intelligence (AI) is proving to be an efficient alternative approach to classical modelling techniques. AI refers to the branch of computer science that develops machines and software with human-like intelligence.[1] Compared to traditional methods, AI offers advantages to deal with problems associated with uncertainties and is an effective aid to solve such complex problems.[3] In addition, AI-based solutions are good alternatives to determine engineering design parameters when testing is not possible, thus resulting in significant savings in terms of human time and effort spent in experiments.[3] AI is also able to make the process of decision making faster, decrease error rates, and increase computational efficiency. Among the different AI techniques, machine learning (ML), pattern recognition (PR), and deep learning (DL) have recently acquired considerable attention and are establishing themselves as a new class of intelligent methods for use in structural engineering. There are various advantages of artificial intelligence approaches in different fields of civil engineering. For example, the minimization of total weight for a steel, concrete, and composite structure can be obtained using genetic programming, estimating of energy consumption based on the available data can be obtained using artificial neural network, and optimal work schedules for the activities of a construction management can be made by using met-heuristic optimization algorithm. In particular, hybrid artificial intelligence studies in the fields of structural engineering, construction management, hydrology, hydraulic engineering, geotechnical engineering, environmental engineering, transportation engineering, coastal and ocean engineering and materials of construction.

[4]Artificial Intelligence is a term that describes the ability of a computational entity to perform activities in a fashion that usually characterizes human thought. By deploying appropriate models, algorithms and systems, the ultimate goal of AI is to completely replicate intelligent human behaviour. Thus, many scientists remain doubtful that true AI with inherent, apparently intelligent behaviour, can ever be developed because machines are not "mental" and can, as a result, neither incorporate intrinsic meaning nor a true intelligence. However, with the rapidly increasing advancements in modern sciences, the search for AI has taken various directions comprising a multitude of AI-related technologies and methods. Engineering design is a very complex, iterative process. Physical and mathematical modelling simulations and analyses are computationally intensive but offer immense insight into a developing product. Structural engineering analysis plays an important role in this process, as the results of such analysis are often used as basic optimization parameters to improve the design candidate being validated and analysed. The number of iterations/cycles that are needed to reach the final design solution depends directly on the quality of the initial design and the appropriateness of the subsequent design changes.

Computer Aided Design (CAD) software is extensively applied in performing various design activities, such as modelling, kinematics, simulations, structural analysis or just drawing technical documentation. Nowadays, the software can be so complex, and offers such an extensive assortment of different options, that one can easily be confused.[5] This is the reason for the relatively low level of control over these systems. Computer aided design (CAD) has increased by orders of magnitude the power of design tools available to the engineer. Advantages of CAD include the reduction of computation time and therefore its cost, the elimination of the amount of tedious and error-prone detailed calculations done by the engineer, and the ability to develop and analyze much more complete models of structures. All present applications of the computer to structural design deal with later stages of the design process, namely, analysis, proportioning and drafting. With the advancements of a section of computer science called artificial intelligence it is now conceivable to create a knowledge-based system to automate or assist in the early, preliminary stages of the structural design process. The purpose of this report is to explore the potentials of such a system.

## 2. STRUCTURAL ENGINEERING BACKGROUND

Design can be viewed as the general process in which an idea is developed into detailed instructions for manufacturing a physical product [7].The design process starts with a definition of a need. The activities that follow can be grouped into four phases:

1. Synthesis : the clarification of the input parameters and their interaction to create a structure that will meet design requirements.
2. Analysis: the modeling and solving of equations to predict the response of a selected structure.
3. Evaluation: the activity of placing a worth on the structure where worth may be cost, safety, or energy consumption.
4. Optimization: the search over the range of possibilities to improve the design as much as possible.

Today, CAD in structural engineering involves almost exclusively analysis, proportioning of structural components, and production of drawings and schedules. There are very few applications to conceptual and preliminary design. Conceptual and preliminary designs are considered the creative aspects of design. Yet, generally the preliminary design process is not new design but redesign, where redesign involves the application of existing structural ideas to a particular design. New design implies the development of a new structural configuration, e.g. new concepts in structural design. Redesign actually is the application of a set of rules to assign values to predefined variables. Thus, it appears that preliminary structural design process may be placed in a knowledge based system, where IF THEN rules are used to instantiate values in a data structure.

A knowledge based program is developed using the knowledge of experts. Once the program is developed there should be close interaction between the designer and the computer. The computer should be able to respond to queries on the design process as well as accept additional information. Since a design prepared by the computer follows a limited number of rules, close supervision by the designer is necessary. In this way the designer will realize inadequacies in the existing set of rules and make revisions or additions to the rules when necessary.

## 3. ARTIFICIAL INTELLIGENCE BACKGROUND

Artificial intelligence is the study of ideas which enable computers to do the things that make people seem intelligent." [10] Ideas are being developed to facilitate the creation of knowledge-based systems using the experience and knowledge of experts. The description of some of the applications of artificial intelligence is as follows. Knowledge based systems can do geometric analogy tests Knowledge based systems acquire knowledge or learn ideas similar to the way people learn. The study of how knowledge based systems learn can provide insight into the way people learn and vice versa. Learning new concepts may be through sequences. Learning may also be done through the acquisition of procedural knowledge. Knowledge based systems can understand simple drawings, simple language, and do expert problem solving.[8] There are programs capable of doing integration problems (MACSYMA), understanding mass spectrograms (DENDRAL), and helping physicians diagnose and treat bacterial infections (MYCIN). Knowledge based systems can also do industrial work (i.e., robotics) and model psychological processes. One approach to the development of knowledge based systems is heuristic programming. (Heuristic is defined as serving to guide or discover).A model may be developed in the form of a goal tree. Some existing applications of artificial intelligence techniques are AGE and SACON. AGE is a knowledge based program for building knowledge based programs. AGE is an attempt to formulate the knowledge used in constructing knowledge based programs and put it at the disposal of others. This is a development in 'knowledge engineering, the process of writing application programs using primary artificial intelligence methods. SACON is a knowledge based consultant for structural analysis. SACON is an "automated consultant, it advises engineers in the use of a general purpose structural analysis program, MARC.MARC offers a large choice of analysis methods.

SACON is an example of the use of AI techniques in structural design in the analysis phase. The study and development of knowledge based systems should enable the structural designer to incorporate AI techniques into the other phases of design. In the preliminary design of a structure for example bridges, the first step is the definition of a need, eg . A roadway between two points. The preliminary design can be separated into two parts: first, the horizontal and vertical alignment and second, the selection of an alternative structure or structures. For this example, we assume that the alignment is determined before the designing engineer is involved.

Some of the constraints on the alignment are the cost of property, the earthwork involved, and who will be affected. The second part, the selection of alternatives, will be discussed in terms of artificial intelligence techniques. The selection of alternative structural types, such as simply supported steel, pre-stressed concrete, tied arch, or truss, depends on span lengths and their ratios, i.e., the comparison of the lengths of adjacent spans. The selection of component types (e.g., deck vs. through truss, plate girder vs. box beam, etc.) depends on span lengths as well as available vertical clearance. Finally, material type (eg. steel vs. Prestressed concrete beams) depends largely on relative costs. The span lengths are estimated in preliminary design by the application of alignment and clearance constraints and cost analysis. It is these constraints that will generate the rules to be executed in a knowledge based system. The resulting facts, i.e., span lengths and types, and component types, material and preliminary specifications could be processed and stored into frames. The frame representation may be viewed as a network data base, where a frame containing a level of information is linked to adjacent levels. The highest level frame would contain general information common to all alternatives. As a particular alternative is developed, lower levels of frames are instantiated with data. It may be possible to develop more than one alternative within a frame structure by duplicating frames and changing certain data within these frames.

### 3.1 Expert Systems for Analysis and Design

Developing an inference mechanism demands very high programming skills particularly for developing a general expert system shell, which can be used for diverse types of applications. This is not an easy task particularly for those who are not familiar with much programming. The procedure outlined in IS: 10262 - 1982 known as Indian Standard (IS) code method. This facility was found very useful particularly for developing expert systems for concrete mix design as most of the knowledge available for mix design can be easily put in tabular form. Because of all these features it was further used for development of expert systems for the design of concrete mix for flexural strength and also for selecting concrete constituents based on A. C. I. Method. The developed expert systems eliminate the tedious procedure of referring to charts, graphs and tables of IS codes and help the user to arrive at final quantities of cement, water, sand and coarse aggregates per cubic meter of concrete. Expert systems were developed to determine safe bearing capacity of soil, to select suitable foundation and to design isolated footing subjected to axial load only or to an axial load and moment or a combined slab footing as the case may be. Also many authors developed a knowledge based expert system to determine the nature of loading on the rectangular column and to calculate slenderness ratio for the type of column, i.e. axial, uniaxial or biaxial and thus to fire rules related to design of that particular type of column. Further, expert system was developed to arrive at optimal design of T-beam floors. For developing knowledge base, in the rule form, available design charts for the cost of materials and magnitudes of imposed loads for different spans of slab were used and to obtain optimal design section. Problems of design of singly reinforced section were chosen for the optimal design. For simplicity, an optimal design polynomial was considered for the development of an expert system with the design constraints as equilibrium constraints, bending moment constraint and beam width/depth ratio constraint. The objective function considered was the cost of beam, which included cost of steel, concrete and shuttering. Some of the salient features which offered a suitable base for development of rule based expert system are menu driven navigation, simple English-like rule syntax, the ability to execute external DOS programs and good interface capabilities to external programs such as spread sheets, databases and batch files. Particularly, the facility of induce command that automatically creates a knowledge base from a table contained in a data base was found very much suitable in transforming directly the tabular information available in design codes.

### 3.2 ANN in Non-destructive Testing

Two popular methods, namely, Schmidt test hammer method and Ultrasonic pulse velocity method were considered to study, for the first time, the feasibility of using Artificial Neural Network (ANN) for correlation of Non Destructive Testing (NDT) parameters to the strength of the structure. As there is no direct relation between rebound number and concrete strength or pulse velocity, the development of an ANN simulator seems to be the natural choice for such problems because predefined mathematical relationship among the variables is not required in an artificial neural network. The feed forward back propagation training algorithm was selected for the preparation of program for its simplicity and good generalization capabilities. A study of training and recall results for both the concrete hammer and ultrasonic tests indicated that the neural networks are able to learn examples of NDT and give reasonable predictions of concrete strength for any new value of rebound number or pulse velocity. To facilitate rapid assessment of flexural behavior, multi-layer feed forward ANNs were trained to learn the relationship between input and output data generated from the available experimental data. The error correcting back propagation algorithm was used to map the relationship. The flexural behaviour of two different types of steel fibre reinforced concrete beam problems were modelled using neural networks. The results obtained for both the problems were found to be in excellent agreement with the actual experimental values. The engineering importance of the whole exercise was thus demonstrated by predicting the behavior for new test values without performing any expensive and time consuming experiments. A generalized delta rule was used to train the networks based on the existing experimental results for two different types of deep beam problems, i.e., FRC deep beams with and without reinforcement. In the case of FRC deep beam without reinforcement, four inputs (length of beam, shear span, span/depth ratio and percentage fibre content by weight) were related to five outputs (first cracking load, failure load, maximum average shear stress, maximum experimental moment at failure and theoretical maximum moment) using one hidden layer with 7 nodes.

### 3.3 ANN in Predicting Large Deflection Response

Recently, feasibility of using neural networks to evaluate large deflection response of fixed immovable rectangular plates subjected to patch loading has been investigated. The error back propagation algorithm with sigmoidal function in the range 0 to 1 was used to map the relationship between the inputs-plate aspect ratio, the patch size and pressure coefficient and the 8 outputs, namely, the central deflection, bending and membrane stresses in the x and y directions at key locations of the rectangular plate.

## 4. CONCLUSION

Developed expert systems for analysis-design, concrete technology, design of R.C.C. and structural steel components and use of artificial neural networks in non-destructive testing, behavior modeling of fibre reinforced concrete beams, and predicting large deflection response of rectangular plates were discussed clearly the advantages of using AI in these areas. Developed expert systems in the field of concrete technology are not only used by engineers during their laboratory work of concrete technology, but are also used in commercial testing of material for arriving at proper concrete mix for compressive and flexural strengths. Developed artificial neural networks for the non-destructive testing are also used in the field for commercial testing work for finding strength based on rebound number and pulse velocity while using concrete hammer and ultrasonic concrete tester respectively. The preliminary design process relies heavily on the expert's ability to identify and analyze situations, and to evaluate alternatives. This ability is developed through personal experience and the passed on experience of other experts. Since it is impossible for an expert to pass on all the knowledge he has gained from experience, the departure of an expert (from an office or the field of engineering) means the loss of some of that experience. The development of knowledge based systems will permit not only the retention of expertise, but also its logical extension, as well as access to the expertise by other structural engineers.

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