Artificial Intelligence in Structural Engineering- Review

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Abstract **- The term Artificial Intelligence is becoming more and more popular nowadays is due to its ability to process things and learn things in the same as the human brain does and at the same time rectify and learn from its mistakes. Artificial Intelligence gives more benefits like decreasing the chances of error, giving more efficient solutions to problems which humans cannot solve manually as, it can make tasks easier and less time consuming. In field of engineering specially in structural engineering AI can give more accurate design parameters when testing is not possible, will provide more accurate computational and statistical efficiency. The main purpose of this review article is to study different applications of AI in structural or civil engineering, steps involved in the development of these systems, different types of AI methods, AI in structural engineering, and finally their shortcomings and solutions to overcome are discussed.**

Index Terms **- Artificial Intelligence; Structural Engineering; Expert Systems; Artificial Agents; AI Application.**

1.INTRODUCTION

AI is made up of two words, first “Artificial” means it can be anything that is made up by human beings is termed as artificial, second “Intelligence” the ability to understand, think, and learn(fig1). By combining these 2 words it can be said that AI is the mental capacity display by the machines or robots excluding humans or other animals. Any device which becomes aware of its environment and takes actions that will lower its chances of error and maximize its chances of success at some goal is known as "Artificial Intelligence".

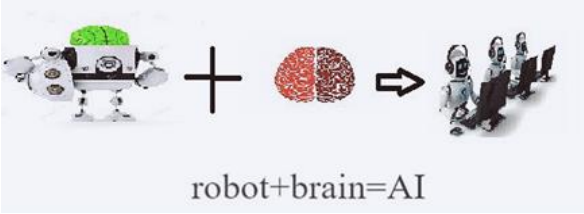

Fig.1

John McCarthy a Computer Scientist coined the term Artificial Intelligence in the year 1955 (The Mercury News, Assessed on 15 September 2020).

Main aim of AI is to make difficult things easier and less time consuming by making systems that behave like the human brain and can learn from their mistakes and can give outcomes intelligently and independently. Objective of AI is to break the barrier between humans and robots and give them the power to make decisions based on their previous and current situation’s data saved.

The Construction industry is growing at a very high speed. AI in structural infrastructure helps in making building designs more quickly and error-free. While the construction / structural community has seen a nerve breaking growth in the use of different types of AI methods in different and diverse areas, the present review paper concentrates on different expert systems that have been developed for the use of structural engineers, their applications, different types of AI methods that have gained most attention over the past years (Salehi, H., Burgueno, R. 2018).

Various works have been done on the topic Artificial Intelligence in civil engineering. Researchers have dealt with mainly 3 types of AI methods in structural engineering: Picture Recognition (PR); Machine Learning (ML); Deep Learning (DL). Internet of Things (IoT) for the Structural Health Monitoring system (SHM) (Salehi, H., Burgueno, R. 2018). The development of different Expert Systems to be used in str. Engineering is mentioned and their uses in different areas are also mentioned. Rules to be followed for making these Expert Systems have also been described by many authors (Adeli, 1986)

The development of an expert system for the analysis of concrete, design of RCC and steel components, use of the artificial neural network (ANN), and behaviour and modelling of fibre-reinforced concrete proved out to be an important step in AI in Str. Engineering

(Singh, 2018). Using AI in bridge engineering is a new technique therefore, researchers have explained the steps involve in designing a bridge using AI methods are explained using a flow chart and how to retrofit the bridge when required (Reich,1996). Different methods by different people about different experiments on AI in civil engineering were discussed, a three-prediction model was put forward using Artificial Neural Network (ANN). They are ANN, Gene Expression Programming (GEP), and Non-Linear Regression analysis (NLR). They used a huge amount of database which contains 269 shear tests results and the genetic programming to predict the shear capacity of FRP-reinforced concrete beams that are without strips. The final result shows that ANN model defines and predict the parameters accurately (Dede et al., 2019). It is very important to now our future with and without AI, hence past, present, and future was described with examples (Haenlein, Kaplan, A. 2019). Using intelligent agent mechanism, a portal frame structure has been designed. ADLIB project using (ZEUS AGENT) (Anumba et al. 2002).

Seven AI methods were defined and used to analyse a truss element for their damage detection and the conclusion is made that Least Square Support Vector Machine (LS-SVM) is the best AI method for damage detection of a structure (Ghiasi et al. 2015). Researchers used crack identification method, cracks were identified using convolutional neural network it was found out that cracks with different background show much better result of about 99.7% accuracy than the result of cracks with the same background colour (Chen et al., 2019). AI techniques like machine learning algorithm and neural network approaches has been used to increase the potential of sustainable building by predicting and modelling the elastic properties of a material, compressive and bond strength of concrete, development of Cementous concrete, predicting material efficiency, producing optimised designs assesses the economy of the structure by looking at the material reuse properties etc. (Amicoa et al., 2019). Machine Learning (ML) is a technique which requires specific steps to be followed to get a good result from ML. There were 7 steps which to be followed to get a result which is less in error percentage. Careful task analyses and clever problem formulations can transform difficult to manageable problems Intimate understanding of ML techniques can be used to map problem characteristics into ML techniques that can address them (Reich,1997). Different applications of neural networks in structural engineering and other branches of civil engineering are there like, Neural Network Algorithm increases the accuracy of the results by giving a good starting idea. The author conclude that Neural Network model gives more trustworthy results than any other model (Adeli, 2001). R. D. (Vanluchene, Sun, (1990) in this article, they explain how neural network works in structural engineering are defined and a new area of neural network where additional study is required NNICE is described briefly. The compressive strength of concrete was tested using different artificial neural network techniques particularly by the Levenberg–Marquardt network based on different parameters like bulk density, etc. The results show that the assessment of the compression strength of concrete by the Levenberg– Marquardt network, is a viable method (Hola, Schabowicz, 2004). The shortcomings of AI in the coming future are discussed like AI has the potential to eliminate or drive down the wages of low-skilled jobs, so measures are needed to maintain equality and spread the economic benefits broadly (Bundy, 2016). The author main focus is on how to make construction automatic by combining BIM and AI to 3-D printing (Tan, 2018).

The construction industry is among one of the world biggest industry and its contribution to the world GDP is one-tenth of the total. It can be increased by making changes in the construction procedure by making use of AI techniques and giving more opportunities to such technological work in the field of structures. The construction industry has the most potential to generate employment and remove unemployment and provide work to as good as 7% of the total employed person of the whole world. This industry has the potential to increase the economy of any country as the economy directly depends upon the infrastructure. Therefore, it is very necessary to make our construction industry more updated with the use of AI in this.

Even though the above articles mention and highlight the different applications of AI in different fields of civil engineering. They are mainly focused on their past and current uses, even though many debates are going on, on the uses of AI and their current future aspects (Salehi, Burgueno, 2018). This review paper

presents a brief look into what future will look like with AI and what its short comings are.
The pattern of this revies paper deals with: section 2 presents application of AI section 3 explains expert system, section 4 provides types of AI methods, section 5 explains different expert systems for structural engineering, section 6 gives the shortcoming and their solutions, finally section 7 gives the conclusion.

2.APPLICATIONS OF AI IN STRUCTURAL ENGINEERING

Artificial Intelligence (AI) deals with machines or robots doing human work and humans just giving the right input. The implementation 0f AI has done a great job in different fields especially in computer engineering but in civil or construction engineering its speed of growth is slow. Mainly because the process of laying brick and mortar work, brick making, aggregate mixture are quite the same from decades and century, now due to advances in technology it pace has been increased. Now a technology revolution has come in this area, especially Artificial Intelligence. AI is being used correctly and sincerely then AI has a whole lot of applications to be used in structural and construction areas. The following are the few areas in which AI can benefit engineers on the site:
1.Quality Assurance - One of the most important thing while making a structure is "quality". By making use of AI based software, effectiveness and efficiency of the materials can be achieved. Technologies like Image Recognition (IR) can be used, with the help of drones can collect the images of the site or structure from any angle an Engineer wants and then can identify the areas where the cracks occur or the areas of danger and can compare it with the other technical drawings or drafts. Next, by Reinforcement Technique, the trial-and- error method used by AI algorithms can be used to identify the best practice to follow. Furthermore, by use of AI the 3-D models of buildings can be created and compares it with the original model to check for any defects.
2.Optimizations in Designs – Many construction companies like Apis cor, Cazza, Branch technology, Zhuoda Group etc. and contractors are using AI-based software systems which work in pre-given input data which works in supervised learning which has inputs of much architectural data, and their solutions for any design of work, recommendations for any problem, criteria for different places are different. For example – a site on earthquake zone 4 the data provides by this system will be different from a site of earthquake zone 2. In this way, engineers can decide which plan or design is best suited for a particular place.

3.Management – AI has many divisions, Machine Learning (ML) is one of them. Through ML, a robot is trained by applying simulation tools to do the tasks with much more precision and within the available time frame. These robots can be designed for predetermined work which does not require human intelligence, like material testing, examine the quantity or quality of impurity present in the materials, and usual maintenance of the structure etc. AI tools like "Alice" which helps in finding an optimal plan by, "STACK" is an AI tool for estimating a project design, "Autodesk BIM 360" helps professional Architects and Engineers to plan, design and construct a model within one 3-D model and helps in managing a structure when there is no human around.

4.Maintenance – One of the subsets of AI is Machine Learning. By using AI algorithms systems can be made supervised and information can be feed into them regarding particular data. Through this data, the AI systems can follow the structural life cycle, the material used, execution speed, project timeline and provide the management in all aspects of it like ensuring uninterrupted project flow, can take care of management to make sure there is no break in the structure.

5.Risk Control – For risk control another AI subset Artificial Neural Network (ANN) is used. ANN is said to have organised data which is used to provide relevant conclusions. ANN helps the engineers to predict their most likely to occur failure and assess them by coming up with an appropriate precaution. Through the use of the Naive Bayes algorithm, the construction companies can introduce their clines with the risk factor before it happens and changes the design of the structure as per the need. AI techniques can also be used to save their stock prices from falling by coming up with better business strategies.

3.EXPERT SYSTEM

The expert system is a piece of software or an application which gives us advice of an expert and helps in making a precise decision by analysing its database. Ex- a spelling checker in a computer or a laptop. Fig.2 shows a typical diagram of how an expert system works.

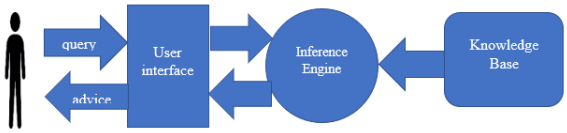

Fig.2. the architecture of an Expert System

Raw user

In the above diagram, it is shown that a raw user gives an input in the form of a query to user interface system like our computer or any system then inference engine which acts like a brain developed by Artificial Intelligence, it takes the input and then checks for its solution in its knowledge base system. Knowledgebase system has all the interconnected information which is compulsory to solve a particular problem. Ex- for a beam problem all parameter like depth of the beam, reinforcement provided, no of strips etc were already added in knowledge base system.

An Expert system should consider the following three important factors:

1. To present the best possible knowledge of expertise.
2. To make a set of rules for different problems that is what inference mechanism should be used.
3. To separate the knowledge and inference engine.

To develop the best expert system following five steps are to be followed:

1. Identification – to describe the problem with as much precision as possible, we must determine the exact nature of the problem.
2. Formulation – analysing and understanding the problem.
3. Designing – various AI techniques are used to solve a particular problem, and the problem is focused on its proposed solution.
4. Implementation – it prototypes a program and evaluates the results and checks were the correct technique chosen?
5. Testing – it shows were the results implemented correctly or not.

To recommend a solution the knowledge base system uses the common method of representing knowledge, that is, IF-THEN type rules and frames. The general form of the rule is:

Rule #N
IF (data1…….data n)
THEN (goal1 with fact a1)
……
……
(Goal n with the fact an)

Where N is the unique rule no. for identifying the rule.

Ex- for IF-THEN type rule is:

IF beam reinforcement to be provided, AND
Mu > Mu, lim AND
Xu > Xu, max AND
Ast, min > Ast

THEN the section to be designed is for doubly reinforced section. To recommend a solution the inference engine uses calculations that resemble human thinking, they are:

1. Forward chaining
2. Backward chaining

1. Forward chaining mechanism- is also known as a data-driven control strategy. In forwarding chaining mechanism, the data or the output are already available and from them, we have to conclude and asserts new facts. If the no. of possible conclusions is more of large, then forward chaining mechanism is recommended. It works from the initial state and reaches the goal state.

2. Backward chaining mechanism- it is also known as goal-driven strategy. In back chaining mechanism the goal state or conclusion is already given and we have to work backwards to determine what facts must be asserted so that the goal can be achieved. This process works backwardly. If the value of the result is known and is small then backward chaining mechanism is efficient.

4.TYPES OF AI METHODS

As AI is gaining acceptance in every area mainly due to its application and more precession in giving inputs. AI has many methods but, will discuss the ones which are emerging as more authentic and efficient tools in the field of structural engineering, these are pattern recognition, machine learning, deep learning and neural networks (Salehi, Burgueno,2018). AI is divided into machine learning then machine learning

is divided into deep learning and neural network. This section will give deep understanding about the uses of these noted AI methods and provides a technical ground about their background. Fig.4 shows the growing graph of different AI methods in the past years.

4.1 pattern recognition:

In pattern recognition (PR) the main goal is to systematize the object into number of groups or divisions i.e., placing the object to correct group based on the measurements or features of the object. The chief intention behind the PR is that using an intellectual technology to help humans to solve and recognise ambiguous data and place them under a particular classification. The ambiguous data could be anything like any image, sounds, hand gestures, videos, text, or it can be any statistical data. The components of pattern recognition are shown in fig.3. In the first step i.e., input, information is given then sensors sense the physical features of the input and converts it into the characteristic features that contains set of quantities. Then in segmentation process the image or input is segmented of and separated in small-small pieces to put them into batches where their most likely to be fit. In the feature extraction stage, the features of the input data are examined and the special attributes that are only present in that input data were checked and considered for example- in case of input data of beam the features extracted were the length and depth of the beam, grade of steel and concrete used, depth of the beam, etc. therefore ascertaining the size, amount or degree marked in the standard units for each feature is known as feature extraction. Now, the features which were selected and taken during the feature extraction process is passed on to classifier. Classifier is a machine which does the act of classification and this process is called as classification. Here on the basis of features it categorises them according to their properties. The last part is post-processing, it checks for any error if possible and corrects them, then the final decision or output is shown. Pattern recognition has many applications in, any fields like machine vision, computer aided diagnosis, speech recognition, character recognition, manufacturing (3D images), finger print recognition, industrial automation like identifying the defective pieces from the good ones etc.

Fig3. Pattern followed by PR

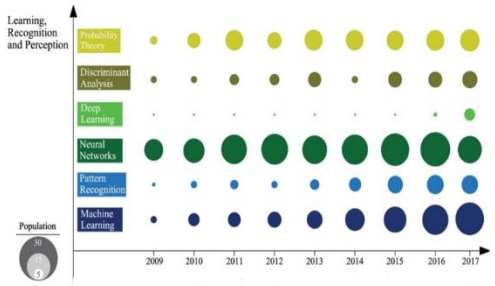

Fig.4. Research publications on the use of different AI branches in structural engineering (Salehi, Burgueno, (2018).

In the above fig it can be easily understood that the use of most of the AI techniques increased in the following years. The use of ML and Neural Networks has shown the most remarkable increase, the work on Neural Network is still going on and scientists show more interest towards that area. There is a close competition between ML and Neural Networks Further, deep learning architectures, e.g., convolutional neural networks (CNNs), are gaining remarkable attention among the research community over the last few years (Salehi, Burgueno, (2018).

These observations motivated the authors to concentrate this review article on the uses of AI techniques in structural engineering fields as they can come out as the new computational intelligence paradigms in structural engineering.

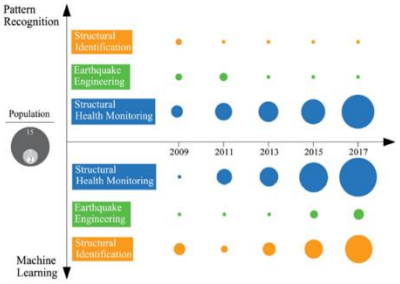

Fig.5.Research publications on the use of machine learning and pattern recognition (Salehi, Burgueno, (2018).

The above diagram displays how the population shifts from PR to ML in the recent years. ML is given more importance than PR in every field specially in SHM due to its prediction closer to the accuracy. Moreover, PR is an engineering application of ML. All ML

systems are applied in PR systems to increase their efficiency. therefore, the above diagram shows a shift from PR to ML.

Application in structural engineering

Pattern recognition is being used in many fields of structural engineering like structural health monitoring system (SHM), damage detection, earthquake engineering and seismic design, structure reliability, structural identification, and performance evaluation of any structure (Salehi, Burgueno, (2018).

From most of the studies it is clear that PR is mostly used for SHM and damage detection. According to Sohn H. sensors which can measure the limit of vibrations and strain of a structure were sent to the structure then they will respond according to the environmental and operational conditions of the structure, then these signals can be treated as patterns. These patterns are easily read by PR learning and the structural health and damage can be detected.

4.2 Machine Learning:

Machine learning term given by Arthur Samuel in the year 1959. Machine learning comes under AI which means machine is capable to learn the things on its own and rectify its mistakes through its previously saved data, just like human being machine will acquire knowledge by its experience, no need to make any extra program, no need to explicitly programmed by the programmer. When data is small so the best option is to train the model or to use some learning algorithm on the model, is known as machine learning. The more accurate the algorithm is the more accurate the results shown by the machine learning. Nowadays ML is being used in many fields such as computer science, probability and statistics, financial market, theory and philosophy (Salehi, Burgueno, (2018).

There is a slight difference between machine learning (ML) and picture recognition (PR). In PR the main function is to classify the image into different categories while in ML the main area of work is to make the machine learn from its past experience and make it capable of taking its own precise decisions. Comparing the uses of both ML and PR, we will see a huge difference in the shift from PR to ML especially in the field of structural health monitoring (SHM) Fig.5. ML has three types of learning which are described below:

4.2.1. Supervised learning

Here we already have, already tagged data set which means we have a supervisor in the form of data, we have both input and output available and on the basis of the tagged data we create a model and give the new input and checks weather the coming result is valid or not. For example, for any election the exit polls are the tagged data or training data which contains information about which party will get how many votes, using the algorithm data new input was given based on the actual data then the output was compared if it matches with the training data then the data is well classified.

4.2.2. Unsupervised learning

It contains only input data through the sensor and on their basis, it makes clustering or data and then slowly-slowly moves towards the actual output. In this it learns on its own by its clustering and association of data. Training is not done. Most of the machines first comes under unsupervised learning and then we have to make them supervised.

4.2.3. Reinforced learning

This type of learning works on “reward” and “penalty” policy. Here an agent performs an action in the environment and on the basis of that action it gets some reward and some penalty and then on the basis of this reward and penalty it makes some policy for next time and works accordingly whenever this same problem will occur.

Application in structural engineering

Machine learning is being used for:

damage detection - Machine Learning is used for locating the damage in structure, amount of damage that occurs, material stability, etc.by using visual or sensor data

SHM – By using a sensor and giving the input to sensor like mode shape, stress and tension, spectrum, damping, cracking, wind profile, etc. and as output we get acceleration and displacement, temperature, humidity. From these an engineer can predict weather a damage might be caused or it has already damaged, then we have to retrofit it. ML systems can give warnings for required repairs or evacuations.

Soil content of the site- from the help of satellite images we can see the soil moisture map prepared by geotechnical department, and soil estimation for the

structured site can be performed. Soil moisture estimation through remotely sensed data or even satellite images, can be done with increased accuracy using ML. Classifying the soil type and its class is one of the problems that can be easily tackled with ML by using both sensory and visual data.

Site safety monitoring- With the help of ML we can access the video data collected from the work sites to identify the unsafe worker behaviour and if they are not wearing hardhat, not wearing boots, if the workers not wearing the fluorescent jackets etc. (Drmsriram, 2018, Assessed 23 October 2020).

4.3 Deep Learning:

Deep learning comes into form when there was a discussion going on about artificial neural networks in the year 2000 then Igor Aizenberg gave the term deep learning (DL). In DL the features of the input were picked out by neural network without any intervention by humans. DL has many neural networks i.e., the process by which DL works is similar to that of a human brain neuron. In DL it consists of number of hidden layers by increasing the no of layers it also deeper the network. DL includes Convolutional Neural Network (CNN), Recurrent Neural Networks (RNN), Deep Belief Nets (DBN) etc. among them CNN is the most used deep learning technique because it uses the concept of visual cortex of animal (Salehi, Burgueno, (2018).

Deep learning is used in fields like customer support, medical care, self-driving cars, etc. when we have a massive amount of data then deep learning is mostly recommended.

Application in Structural Engineering

Earthquake prediction is the most used application of DL by considering a factor called von Mises yield criterion. The scientist at Harvard University use deep learning to teach a computer to perform viscoelastic computations, which are used in the prediction of earthquakes. This application helps to improve the calculation time of earthquake by 50,000% times.

5.USE OF ARTIFICIAL AGENTS IN STRUCTURAL ENGINEERING

Various works has been done on developing an Expert System in various fields like, application of Expert System in education has been discussed by O'Shea and Starfield et al. point out how engineering concepts can be mastered through the development of simple Expert Systems (Adeli, (1986).

Following are the expert systems that have been studied in the recent review papers.

1. HI-RISE

Proposed by Maher and Fenves at Carnegie- Mellon University (Adeli, (1986). This is an expert system which is designed for initial designing of rectangular shaped commercial and residential buildings with height more than 10 stories. The language use in this intelligent agent is PSRL it is a frame-based production system language developed at Carnegie-Mellon University (Adeli, (1986). The basic benchmark for selecting a structural system depends upon economy, structural integrity, durability. HI-RISE gives the best possible design for a particular structure.

2. WAVE

Given by Jain and A.K Aggarwal, here the system works with the user for write definitions of different loading patterns, foundation systems, and structural configuration of the structures which are located at marine sites.

3. CAD (Computer Aided Design)

Known as Computer Aided Design, it is now beingused for many decades for the detailed engineeringof 3-D or 2-D drawing of physical components, butit is also used for layout of products, designing of tools and machinery, drafting and designing of all types of buildings.

4. SICAD (Standard Interfaces in Computer Aided Design)

Standard Interfaces in Computer Aided Design, Proposed by Lopez. Its function is to reinforcing the engineering standards in CAD programs. In this the rules are treated as the internal part of SICAD and not a part of CAD. SICAD simplifies the design process by using the online maps, data-base of notes and automatic calculations tools.

5. SASE

It was tutored at National Bureau of Standard for Structural Analysis it checks whether the newly constructed buildings are made accordingly to the given standards or the existing ones are correct and consistent and follows the machine processing standards. This AI expert system helps in replacing the manual version of the engineering standards.

6. SPERIL

Given by Ishizuka, this AI intelligent system helps in detecting the structural damage subjected to seismic excitation. This expert system is present in the form of C language and based on rule-based system. The obtained information from different accelerographs and visual examination of an earthquake damage buildings were saved in this expert system and according to them it performs.

7. DURCON

Proposed by Clifton, it is designed for selecting the correct constituents of concrete open to harsh environmental conditions. It shows the worsening of concrete based on 4 factors- sulphate attack, corrosion of reinforced steel, concrete-aggregate reaction, and defrosting.

6.MERITS AND DEMERITS OF USING AI

The merits or advantages of using AI in Structural Engineering are -

1. It has the capability of making the work easier and much simpler.
2. It enhances the safety of roads by using PR technique
3. It decreases the labour work at the site.
4. It can predict precise and much faster response to disaster of any kind.
5. It will help in improving the standard of living of the people.
6. Error reduction will be very high.
7. The AI software will have much more mental alertness and decision-making power much higher than humans.
8. With so many advantages, it also has some eye-opening disadvantages which must be considered while we are planning to enhance our knowledge on the AI. Some of the disadvantages of this extra-ordinary artificial intelligent systems are written below.

DEMERITS: The following are the cons of including AI in the field of Structural Engineering.

1. Exploitation- Improper or half knowledge of this can lead to the exploitation of this technology. The public or private institutions must hire employees which already knows how to work in this technology, or must provide assistant to the newly hired employees.
2. Ethics- As AI is developed by humans only so, therefore the moral principles should be checked. Privacy, security, and safety should be integrated in the initial designing process of the systems. Technical terms should be needed for good intentions shown by the system.
3. Accountability- systems should be able to provide a reasonable solution for their outputs. For ex- a doctor just cannot consider the diagnosis given by a computer without any logical reasoning, Doctor should be accountable for any consequences.
4. Employment- various studies has shown that the AI has the capability of eliminating the wages of low skilled jobs thus increasing the rate of employment even though the effect may not be long term but, there is a need to address this issue and maintain the equality, and social readjustment to this new technology. And there is a high need for producing new jobs with cooperating humas and machines in it.

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8.CONCLUSION

This paper provides a systematic study about AI in structural engineering. The first sections give a detail introduction about the AI and the methodology used in this review paper. Second section presents some current applications of AI in the field of Structural Engineering. Many studies are still going on, on the uses of AI therefore third section provides an information about how to make an expert system in order to apply AI in different fields. In the fourth section it shows different types of AI and their applications in Structural Engineering field. By using AI applications in Structural field, the structural safety can be drastically improved and also maintenance cost can be drastically decreased therefore section five demonstrates some experimentally approved expert system which can help in increasing the efficiency of

the work and decreasing the errors in the designing process.

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