Applications of Artificial Intelligence in Bridge Engineering: Review

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ABSTRACT

The integration of artificial intelligence (AI) in bridge engineering has revolutionized the industry, transforming the way bridges are designed, constructed, and maintained. AI's potential to analyze vast amounts of data, identify patterns, and make predictions has far-reaching implications for improving bridge safety, reducing construction costs, and enhancing sustainability. This review paper explores the use, significance, and application of AI in bridge engineering, highlighting its benefits and future directions.AI is being increasingly used in bridge engineering to Analyze structural health. AI models predict traffic patterns, enabling engineers to design bridges that can accommodate increasing traffic volumes, reducing congestion, and improving safety.The significance of AI in bridge engineering lies in its ability to Improve safety. AI-powered systems can detect potential hazards, reducing the risk of accidents and fatalities.AI optimizes bridge design, construction, and maintenance, reducing costs and improving project timelines. AI helps minimize environmental impacts by optimizing material usage, reducing waste, and improving bridge durability.AI-powered systems assess bridge conditions, identifying areas that require repair or replacement. AI-powered systems monitor construction progress, identifying potential delays and enabling proactive mitigation strategies.As AI continues to evolve, its applications in bridge engineering are expected to expand, with potential areas of research in various aspects and structural parameters.

Keywords: Bridge engineering, Artificial intelligence, models, IOT, structural parameters

1. INTRODUCTION

Artificial intelligence (AI) is a field of science and engineering concerned with the computational understanding of what is commonly called intelligent behavior, and with the creation of artifacts (software, robots etc...) that exhibit such behavior. [1,2]

The field of artificial intelligence (AI) [3,4] consists of long-standing intellectual and technologicalefforts addressing several interrelated scientific and practical aims, important ones are:

- Constructing intelligent machines, whether or not these operate in the same way aspeople do;
- Formalizing knowledge and mechanizing reasoning, both commonsense and refined expertise, in all areas of human endeavour;
- Using computational models to understand the psychology and behaviour of people, animals, and artificial agents;
- Making the working with computers as easy and helpful as working with skilled, cooperative, and possibly expert people.

Al has been around since the 1950s, and since then, it has fuelled many visions, dreams, and hopes. The details of realizing the promises included: a machine that will assist in its own programming (that is, a machine that learns), a machine that will be creative by evolving its programmers randomly through mutations (that is, achieving creativity by genetic programming), and the improvement in the hardware. In this chapter, Al is seen simply as a collection of mainly symbolic computational techniques developed in Al research such as: heuristic search, constraint propagation, inductive learning that will match the functionalitydesired by the engineering task at hand. [5,6,7]

AI applied to bridge engineering has developed into a large collection of studies specializing in solving various engineering subtasks. In a few cases, these studies were conducted closely with practitioners and in most others without such involvement. Even when the tasks addressed were significant, such as the conceptual design of bridges, the knowledge utilized was rather limited. [8,9,10]

Bridge engineering is characterized by the following

- For some tasks, there are no experts or there is significant historical knowledge that is available and therefore, rule based expert systems could not be coded.
- Some of the bridge engineering tasks are coupled with their solutions retire diverse and intricate knowledge.
- Bridge engineering evolves continually by the introduction of new loading requirements, new materials, new structural forms, new quality construction methods,and other technologies such as smart or intelligent structures.

2. AI Research In Bridge Engineering

Most of the reported works on Al techniques for bridge engineering has focused mainly on design (preliminary) and maintenance because of their relative importance in bridge engineering. Design has large impact on the success of any bridge and it is also considered to be the creative or artistic of all the tasks. This isolation permitted the use of Al techniques for attempting to solve this isolated task. However, the design applications have always drawn information generated by the other tasks. The second issue-maintenance has been pursued because it constitutes the most acute problem in bridge engineering. [11,12]

2.1 Decision to Commission

There seems to be no work on the applications of Al techniques to this task. Nevertheless, there are numerous studies dealing with risk evaluation of large construction projects. The work cited refers to encoding of interdisciplinary knowledge on risk management for a large construction project into a system and using it over a long period of time by industry. [13]

2.2 Design

There have been several applications of Al techniques in bridge design. Starting from the conceptual design to the aesthetics of bridges many issues have been addressed. In the conceptual design, the precise location of the bridge at the site is determined together with is form and major components. Some of the published research works coveringthis task are highlighted below [14]

- A commercial rule based expert system that takes care of preliminary design of bridges was implemented.
- Dynamic constraint satisfaction algorithm that can handle continuous variables thatsupport early stages of preliminary design of bridges has been implemented.
- Using the knowledge of algorithmic procedure prevalent in Japan, minimum costselection of superstructure and substructure of bridge was done.
- An expert system was developed to address precise site selection through theintegration with a geographic information system.
- An expert system for the conceptual design of bridges was developed. The knowledge for the system was garnered from several experts.
- Preliminary design of bridges was modelled as a mapping from a large number of input parameters to a large number of outputs by a artificial neural network.
- An expert system for the preliminary design of cable-stayed bridges. This experimental system showed that learning from existing designs can result in knowledge that can be used to synthesize bridges of a similar type. The system was implemented using two machine-learning tools integrated with a detailed numerical analysis programmed.
- An expert system was developed for selection of bridge superstructure.
- An expert system integrated with analysis tools was developed to design several types of trussed bridges. The expert rules were constructed by learning from simulations.
- A system was developed for designing highway bridges including their drawing production.
- Expert system was developed for the design of bridge abutments and piers.
- A rule and frame based shell was integrated with a finite element analysis programmed for analyzing alternative designs. It also included visual scanned images for assistingits use in practice and education.
- A system was developed to design bridge foundation using commercial expert systemtool.

2.3 Analysis

The analysis of bridge is basically a quantitative procedure which is based on sound technical principles. However, the practical execution of the analysis involves expertise and heuristics. Several Al based applications have addressed this issue.[15]

- A system that integrates heuristics extracted from many sources was developed todetermine the dynamic response of highway bridges.
- A generic tool for building design critics was developed and used to implement abridge design critic and a constructability critic for reinforced concrete bridges.
- Several systems were developed for assisting designers in designing against fatigue.

2.4 Monitoring

This task involves the continuous checking of the structure conditions. Following are the development of applications of AI in this area.[16]

- A blackboard system was developed to monitor the bridge in-situ. This system contained knowledge about interpreting measured signals from radar sensors. A preliminary experiment with data collected suggested that the approach could be useful for the analysis of bridge deck deterioration.
- A system that can provide early warning against collapse. This system compares the dynamic response of the bridge due to normal loading to a predetermined bridge signature.
- A neural network model for in-situ dynamic analysis of bridges.
- An expert system was developed for monitoring of a cable-stayed bridge. The systemcan also detect faults in its instrumentation.
- A real time neural network system for monitoring single spanned bridges and reducing the mid span deflection.

Added to this. significant work has been done on Al applications to bridge maintenanceincluding support for inspection, evaluation, retrofits, and scheduling activities.

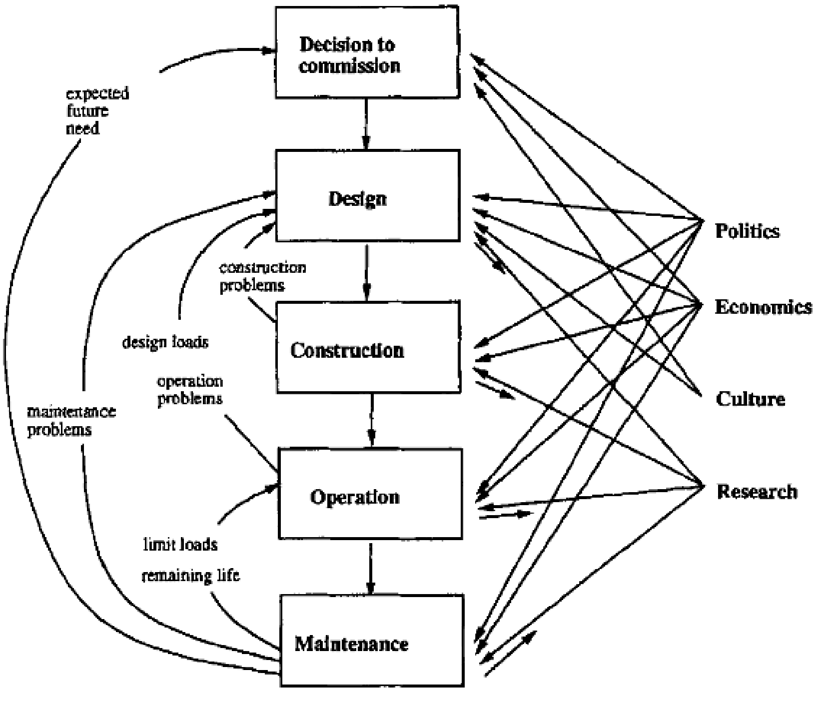

Figure 1: The life-cycle flow of information of a bridge.

3. AI And Related Techniques

There are other computational techniques that need to be integrated together with Al. It is desirable that all these new tools need to be integrated together with existing tools used presently by practioners. The emerged tool should be able to address information modelling. information analysis and information communication [17] The information modelling facility should be used to model information originating from various data acquisition tools, such as sensors The major technologies for supporting this facility are:

- Databases for storing product models and other information related to bridges.
- User interfaces.
- Multimedia technologies.

Some Al techniques that can play a supportive role will include:

- Knowledge representation techniques.
- Knowledge acquisition tools.
- Machine learning techniques.

The information analysis facility is to facilitate the user to extract pieces of knowledge from theenormous amount of data. The Al related technologies that play a major role in this context are:-

- Machine learning concepts and tools.
- Natural language processing for extracting information from textual information.

The information communication facilities rely on having compressed information into usable, comprehensible pieces of knowledge that can be transferred. These pieces can be in the form of sets of heuristic rules, relationships between parameters of design and bridge performance. Networking and distributed database technology can provide the means for people to communicate and share the information stored.[18,19]

4. Neural Networks For Prediction Of Scour Depth Around Bridge Piers

The depth of scour is an important parameter for determining the minimum depth of foundations as it reduces the lateral capacity of the foundation. It is for this reason that extensive experimental investigation has been conducted in an attempt to understand the complex process of scour and to determine a method of predicting scour depth for various pier situations. To date, no generic formula has been developed that can be applied to all pier cases to determine the extent of scour that will develop.[20]

The mechanism of flow around a pier structure is so complicated, that it is difficult to establish a general empirical model to provide accurate estimation for scour. Interestingly, each of the proposed empirical formula yields good results for a particular data set, an alternative approach, artificial neural network (ANN) has been extensively used to estimate the equilibrium and time dependent scour depth with numerous reliable database. Numerous ANN models, multi-layer perceptron using back propagation algorithm (MLP/BP) and radial basis function using orthogonal least-squares algorithm (RBF/OLS). Bayesian Neural Network (BNN) and Single Artificial Neural Network (SANN) were used.

The equilibrium scour depth was modeled as a function of five variables; flow depth, mean velocity, critical flow velocity, mean grain diameter and pier diameter. The time variation of scour depth was also modeled in terms of equilibrium scour depth, equilibrium scour time. Scour time, mean flow velocity and critical flow velocity. In all the published works, the training and testing data were selected from the experiments and from valuable references.

Scour is a local phenomenon that takes place in the vicinity or around a structure (piers,piles, abutments etc.) in flowing water, due to modification of flow pattern, results in increase of local shear stress. This, in effect, dislodges the material on stream bed, results in local scour.

River flow past a pier or an abutment causes three-dimensional flow separations-a system of vortex pairs developed in separated flow. Between them, the primary vortex is more dominating, wraps round the pier in the form of horse shoe-vortex. The magnitude and strength of this vortex depends on the geometry of pier and the magnitude of approaching velocity.[21]

The estimation of correct depth of scour below the stream bed is very important, because it determines the depth of foundation. The phenomenon of bridge pier scour is of paramount concern to hydraulics engineering profession, because without this detailed knowledge, bridge failures can occur. As per National Bridge Register (NBR) of America, out of 577,000 bridges, more than 26,000 of them have been found to be scoured critical, due to erroneous prediction of scour depth during engineering design. In this context, Indo-Gangitic belt of the Indian sub-continent is interwoven with mighty rivers like Indus, Ganga, Brahamaputra and their innumerable tributaries. The alluvial is so deep that in some cases even up to a depth of 100 metres no rock strata are found. Moreover the river beds are highly errodable. In order to protect the bridge piers against scouring the foundations have to be taken very deep. In the bridge across river Ganga at Varanasi, the maximum depth of scour estimated was around 60 m.[22]

Artificial Neural Network (ANN) models are attractive in the domain of estimation of local scour around bridge piers. This is due to their adoptive nature where learning by examples replaces or making functions in search of solutions. This architecture renders computational models more attractive in domains of very little or incomplete understanding of the problem to be solved but where broad training data base is accessible. From the literatures it appears that ANNS provide higher level of accuracy in solving a particular problem in comparison with experimental and theoretical results. ANN may therefore be a viable alternative in the prediction of local scour depth around bridge piers, provided reliable data base is available.

5. Application of ANNs in Prediction of Scour around Bridges

The prediction of depth of scour is an important parameter to decide the depth of foundation It is for this reason that extensive experimental investigation are undertaken to understand the complex process of scour. Till date, no generic formula has been developed that can be applied to all pier environment to determine the extent of scour. As explained above, mumerous empirical formulae have been developed to predict the scour, each varies significantly, highlighting the fact that there is lack of knowledge in estimating scour depth in obtaining a universal solution. This gap may be bridged through Artificial Neural Network Models,

ANN has been widely applied in various areas of hydrology and water resource engineering. ANN was used to predict the flow conditions when interfacial mixing in stratified estuaries commences. The neural network results were compared to the semi-theoretical solution based on a combination of results from flow theory, turbulent flow theory and interfacial friction experiments. Although neither of the two solutions was perfect in every respect, they were sufficiently close to one another. Engineers can now compute the critical velocity at which interfacial mixing commences at a particular location in a stratified estuary or fjord.[23]

Different networks were developed to predict the scour depth based on the input parameters of wave height, wave period, water depth, pile diameter, Reynold's number, maximum wave particle velocity, maximum shear velocity. Shield's parameter and Keulegan- Carpenter number. The neural network was able to provide a better alternative to the statistical curve fitting with a weight matrix developed to predict non-dimensional scour depth from the input of wave height, wave period, water depth and pile diameter

6. CONCLUSIONS

It has been demonstrated that the feasibility of training an ANN for accurately predicting transient water levels in a complex multilayered ground-water system under variable state, pumping, and climate conditions. The ANN was trained to predict transient water levels in response to changing pumping and climate conditions. The trained ANN was validated with ten sequential seven-day periods and the results compared against both measured and numerically simulated ground-water levels. The results indicate that the ANN technology has the potential to serve as a powerful prediction and management tool for many types of ground-water problems: ANN models are attractive in the area of estimation of local scour around bridge piers.This is because of their adaptive nature where learning by example replaces programming ormaking functions in solving problems. This feature renders computational models very appealing in domains, where one has little or incomplete understanding of the problem to be solved but where training data examples are available. It has been proved that ANN provided a higher level of accuracy in solving a particular problem when compared to experimental and theoretical results. ANN may therefore be a viable alternative in the estimation of local scour depth around bridge piers, provided a reliable database is available.Combining AI with IoT sensors to create real-time monitoring systems that can detect potential hazards and optimize bridge performance. Developing AI-powered decision support systems: Creating AI-powered systems that can provide engineers with data-driven insights to inform design, construction, and maintenance decisions. In conclusion, the use of AI in bridge engineering has the potential to transform the industry, improving safety, efficiency, and sustainability. As AI continues to evolve, its applications in bridge engineering are expected to expand, driving innovation and shaping the future of infrastructure development.

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