Artificial Intelligence and Machine Learning Applications in Civil, Mechanical, and Industrial Engineering

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Sinan Melih Nigdeli, Istanbul University-Cerrahpaşa, Turkey

This chapter presents a summary review of development of Artificial Intelligence (AI). Definitions of
AI are given with basic features. The development process of AI and machine learning is presented. The
developments of applications from the past to today are mentioned and use of AI in different categories
is given. Prediction applications using artificial neural network are given for engineering applications.
Usage of AI methods to predict optimum results is the current trend and it will be more important in
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This chapter reveals the advantages of artificial neural networks (ANNs) by means of prediction success
and effects on solutions for various problems. With this aim, initially, multilayer ANNs and their
structural properties are explained. Then, feed-forward ANNs and a type of training algorithm called
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Tuğba Özge Onur, Zonguldak Bulent Ecevit University, Turkey
Yusuf Aytaç Onur, Zonguldak Bulent Ecevit University, Turkey

Steel wire ropes are frequently subjected to dynamic reciprocal bending movement over sheaves or drums in cranes, elevators, mine hoists, and aerial ropeways. This kind of movement initiates fatigue damage on the ropes. It is a quite significant case to know bending cycles to failure of rope in service which is also known as bending over sheave fatigue lifetime. It helps to take precaution in the plant in advance and eliminate catastrophic accidents due to usage of rope when allowable bending cycles are exceeded. To determine bending fatigue lifetime of ropes, experimental studies are conducted. However, bending over sheave fatigue testing in laboratory environments require high initial preparation cost and longer time to finalize the experiments. Due to those reasons, this chapter focuses on a novel prediction perspective to the bending over sheave fatigue lifetime of steel wire ropes by means of artificial neural networks.

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Ivo Bukovsky, Czech Technical University in Prague, Center of Advanced Aerospace Technology, Czech Republic
Peter M. Benes, Czech Technical University in Prague, Czech Republic
Martin Vesely, Czech Technical University in Prague, Czech Republic

This chapter recalls the nonlinear polynomial neurons and their incremental and batch learning algorithms for both plant identification and neuro-controller adaptation. Authors explain and demonstrate the use of feed-forward as well as recurrent polynomial neurons for system approximation and control via fundamental, though for practice efficient machine learning algorithms such as Ridge Regression, Levenberg-Marquardt, and Conjugate Gradients, authors also discuss the use of novel optimizers such as ADAM and BFGS. Incremental gradient descent and RLS algorithms for plant identification and control are explained and demonstrated. Also, novel BIBS stability for recurrent HONUs and for closed control loops with linear plant and nonlinear (HONU) controller is discussed and demonstrated.

Chapter 5

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In this chapter, an application for demonstrating prediction success and error performance of ensemble methods combined via various machine learning and artificial intelligence algorithms and techniques was performed. For this reason, two single method was selected and combination models with Bagging ensemble was constructed and operated in the direction optimum design of concrete beams covering with carbon fiber reinforced polymers (CFRP) by ensuring the determination of design variables. The
first part was optimization problem and method composing from an advanced bio-inspired metaheuristic called Jaya algorithm. Machine learning prediction methods and their operation logics were detailed. Performance evaluations and error indicators were represented for prediction models. In the last part, performed prediction applications and created models were introduced. Also, obtained prediction success for main model generated with optimization results was utilized to determine the optimum predictions about test models.

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Osman Hürol Türkakan, Istanbul University-Cerrahpaşa, Turkey

Computer vision methods are wide-spread techniques mostly used for detecting cracks on structural components, extracting information from traffic flows, and analyzing safety in construction processes. In recent years, with increasing usage of machine learning techniques, computer vision applications are supported by machine learning approaches. So, several studies were conducted using machine learning techniques to apply image processing. As a result, this chapter offers a scientometric analysis for investigating current literature of image processing studies for civil engineering field in order to track the scientometric relationship between machine learning and image processing techniques.

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Ersin Namli, Istanbul University-Cerrahpaşa, Turkey

In this chapter, prediction applications of concrete compressive strength values were realized via generation of various hybrid models, which are based on decision trees as main prediction method, by using different artificial intelligence and machine learning techniques. In respect to this aim, a literature research was presented. Used machine learning methods were explained together with their developments and structural features. Various applications were performed to predict concrete compressive strength, and then feature selection was applied to prediction model in order to determine primarily important parameters for compressive strength prediction model. Success of both models was evaluated with respect to correct and precision prediction of values with different error metrics and calculations.

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Ravi Sharma, Symbiosis Institute of International Business, Symbiosis International University, India
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Innovation and technology are trending in the industry 4.0 revolution, and dealing with environmental issues is no exception. The articulation of artificial intelligence (AI) and its application to the green economy, climate change, and sustainable development is becoming mainstream. Water as a resource is one of them which has direct and indirect interconnectedness with climate change, development, and sustainability goals. In recent decades, several national and international studies revealed the application
of AI and algorithm-based studies for integrated water management resources and decision-making systems. This chapter identifies major approaches used for water conservation and management. On the basis of a literature review, authors will outline types of approaches implemented through the years and offer instances of the ways different approaches selected for water conservation and management studies are relevant to the context.

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Urbanization, industrialization, and increase in population lead to depletion of ground water quantity and also deteriorate the ground water quality. Madurai city is one of the oldest cities in India. In this chapter the ground water quality was assessed using various statistical techniques. Groundwater samples were collected from 11 bore wells and 5 dug wells in Post-monsoon season during 2002. Samples were analysed for physico-chemical characterization in the laboratory. Around 17 physico-chemical parameters were analysed for all the samples. The descriptive statistical analysis was done to understand the correlation between each parameter. Cluster Analysis was carried out to identify the most affected bore well and dug well in the Madurai city.

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Sina Dabiri, Virginia Tech, USA
Kaveh Bakhsh Kelarestaghi, ICF Incorporated LLC, USA
Kevin Heaslip, Virginia Tech, USA

Smart transportation is a framework that leverages the power of Information and Communication Technology for acquisition, management, and mining of traffic-related data sources. This chapter categorizes them into probe people and vehicles based on Global Positioning Systems, mobile phone cellular networks, and Bluetooth, location-based social networks, and transit data with the focus on smart cards. For each data source, the operational mechanism of the technology for capturing the data is succinctly demonstrated. Secondly, as the most salient feature of this study, the transport-domain applications of each data source that have been conducted by the previous studies are reviewed and classified into the main groups. Possible research directions are provided for all types of data sources. Finally, authors briefly mention challenges and their corresponding solutions in smart transportation.

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Hacer Yumurtaci Aydogmus, Alanya Alaaddin Keykubat University, Turkey
Yusuf Sait Turkan, Istanbul University-Cerrahpasa, Turkey

The rapid growth in the number of drivers and vehicles in the population and the need for easy transportation of people increases the importance of public transportation. Traffic becomes a growing problem in Istanbul which is Turkey’s greatest urban settlement area. Decisions on investments and projections for the public transportation should be well planned by considering the total number of passengers and the
variations in the demand on the different regions. The success of this planning is directly related to the accurate passenger demand forecasting. In this study, machine learning algorithms are tested in a real-world demand forecasting problem where hourly passenger demands collected from two transfer stations of a public transportation system. The machine learning techniques are run in the WEKA software and the performance of methods are compared by MAE and RMSE statistical measures. The results show that the bagging based decision tree methods and rules methods have the best performance.

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Sinem Büyüksaatçı Kiriş, Istanbul University-Cerrahpasa, Turkey
Tuncay Özcan, Istanbul University-Cerrahpasa, Turkey

Vehicle routing problem (VRP) is a complex problem in the Operations Research topic. School bus routing (SBR) is one of the application areas of VRP. It is also possible to examine the employee bus routing problem in the direction of SBR problem. This chapter presents a case study with data taken from a retail company for capacitated employee bus routing problem. A mathematical model was developed based on minimizing the total bus route distance. The number and location of bus stops were determined using k-means and fuzzy c-means clustering algorithms. LINGO optimization software was utilized to solve the mathematical model. Then, due to NP-Hard nature of the bus routing problem, simulated annealing (SA) and genetic algorithm (GA)-based approaches were proposed to solve the real-world problem. Finally, the performances of the proposed approaches were evaluated by comparing with classical heuristics such as saving algorithm and nearest neighbor algorithm. The numerical results showed that the proposed GA-based approach with k-means performed better than other approaches.

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Ramazan Ünlü, Gumushane University, Turkey

Manual detection of abnormality in control data is an annoying work which requires a specialized person. Automatic detection might be simpler and effective. Various methodologies such as ANN, SVM, Fuzzy Logic, etc. have been implemented into the control chart patterns to detect abnormal patterns in real time. In general, control chart data is imbalanced, meaning the rate of minority class (abnormal pattern) is much lower than the rate of normal class (normal pattern). To take this fact into consideration, authors implemented a weighting strategy in conjunction with ANN and investigated the performance of weighted ANN for several abnormal patterns, then compared its performance with regular ANN. This comparison is also made under different conditions, for example, abnormal and normal patterns are separable, partially separable, inseparable and the length of data is fixed as being 10, 20, and 30 for each. Based on numerical results, weighting policy can better predict in some of the cases in terms of classifying samples belonging to minority class to the correct class.
Chapter 14
An Exploration of Machine Learning Methods for Biometric Identification Based on Keystroke Dynamics

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Ömer Özgür Tanrıöver, Ankara University, Turkey

In this chapter, authors explore keystroke dynamics as behavioral biometrics and effectiveness of state-of-the-art machine learning algorithms for identifying and authenticating users based on keystroke data. One of the motivations is to explore the use of classifiers to the field keystroke dynamics. In different settings, recent machine learning models have been effective with limited data and computationally relatively inexpensive. Therefore, authors conducted experiments with two different keystroke dynamics datasets with limited data. They demonstrated the effectiveness of models on dataset obtained from touch screen devices (mobile phones) and also on normal keyboard. Although there are similar recent studies which explore different classification algorithms, their main aim has been anomaly detection. But authors experimented with classification methods for user identification and authentication using two different keystroke datasets from touchscreens and keyboards.

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Various optimization techniques have been utilized from the past to the present in order to solve engineering problems and obtain the optimized designs. These techniques consist of classical mathematical methods and these methods remain incapable in terms of optimally solving real-life problems that have a complex structure with more than one requirement at the same time or showing non-linear behavior. This situation shows the truth of need to new methods.

Nowadays, optimization techniques, which are advanced and more flexible structure, have emerged with the help of developing technology and computers. These methods are known as heuristic with initial situation, and metaheuristic methods that is one step ahead of them and they involve different algorithms. However, although they avail in solution of many problems, they require very long times in the process of determining of result in solution of multiple problems.

In order to solve this problem and to obtain fast and effective solutions in terms of different problems, using artificial intelligence (AI) and machine learning (ML) methods is a different and effective approach. Thereby, it is not necessary to have continuous optimization and the optimum values of multi models can be determined together and quickly. In this way, it is possible to determine the optimum value for multiple designs without the need for new and repeated optimization processes via the learner model. At the same time, the optimal values for various new models that have been constructed with the hybrid models to estimate results quickly and accurately.

Factors such as economy (minimum cost), feasibility for purpose and correct design, esthetic etc. have taken part besides providing of required safety, among principal aims of engineering designs. In the process of appearance of designs, to may providing of all such aims at the same time, often depend on experience of engineers. However, conditions must carry out, such as most correctly calculating of various variables that forming the design, correct and controlled material usage in a safe and economic design.

In this respect, optimization methods come in useful for most appropriately solved of various engineering problems. Especially, in nowadays, metaheuristics which are from advanced optimization methods, avail in terms of various problems such as determining the best section of a tool, minimization of structure/material cost, optimization of structure weight and management of projects. On the other hand, usage of artificial intelligence and machine learning techniques from today’s technologies, gradually increase in engineering areas. Many problems can be solved rapidly, accurately and effectively thanks to these methods, which provide for realization of various activities such as forecasting, inference, feature identification and at the same time while executing them, providing easiness and efficiency in terms of time, cost and effort.

With this purpose, the carry out of required/preferred conditions are ensured with resolving of various engineering problems with optimization operations which are realizing by use different methods and in
Preface

most appropriate values of problem parameters; predictable to make more quick and right with hybrid models which are created by using various AI and ML methods, in result of this process.

In recent years, machine learning and artificial intelligence applications are gaining importance, more and more. Especially, they can provide effective solutions for different problems in engineering applications. The main purpose of this book is to introduce concepts of artificial intelligence and machine learning, explaining methods of machine learning and introduce various engineering applications that performed with these methods. In this respect, various examples which were realized with AI and ML methods, will be reflected intended for various problems from basically civil engineering, mechanical engineering, industrial engineering, and other engineering fields. Thus, the book can be a guide for students, researchers and academics in various engineering fields.

Furthermore, a part of engineering problems in book is related to examples that is, optimum values obtained by optimization are trained with machine learning methods, and thus to minimize the time and effort required to generate new designs; and other part reflect of efficiency and speed in solving of problem with using alone of these methods, book provides new approaches in terms of ML methods usage forms.

The applications of artificial intelligence and machine learning, which have become widespread with advancing technology, are no longer limited to certain areas, in many countries, in the field of educations such as universities, research centers etc. are conveyed in various lectures or courses. Especially, it is thought a source that different applications can be seen together for undergraduate and graduate students.

In addition, the book tackled of artificial intelligence and machine learning concepts, which are from the most recent and technological methods and represented practices that performed in various engineering branches, are also suitable for using by researchers.

Artificial Intelligence (AI) applications are the most interesting and fruitful subject of new era. Most trendy applications of AI are related with technological devices like human-like robots, electronic devices, autonomous vehicles, drones, etc. There is no doubt that these technologies are the part of future life, but now, we also use AI in our basic life. We cannot realize that AI applications are responsible from a process.

The main scope of the book is to express AI application depending on prediction process via machine learning applications. Similar applications from life using AI and machine learning are also given. Engineering applications, especially civil engineering, mechanical engineering and Industrial engineering applications may critically need AI techniques for organization, planning and prediction.

The structure of the book as follows:

In Chapter 1, a review of AI and ML method are presented. The development of methods is given by the explanation of basic features. The development of applications from the past to today can be found. Prediction applications using artificial neural networks (ANNs) are also mentioned at the end of the chapter.

The main aim second chapter is to present ANN in more detail including multilayer ANNS, feed-forward ANNs and back-propagation. Two prediction problems for application of structural mechanics are presented. The first is prediction of optimum design of tubular columns. In this application, the optimum results of several cases of design were used in training and a metaheuristic algorithm called teaching learning based optimization (TLBO) is used for optimization. For the second application, the optimum design of I-beam is predicted for vertical deflection minimization. For optimum results used in machine learning, flower pollination algorithm (FPA) is used. At the end of Chapter 2, a code for optimum design of tubular column problem is also given.
In the third chapter of the book, a novel prediction proposal is presented for bending over sheave fatigue lifetime of steel wire ropes. In prediction, ANN is employed. For providing bending fatigue lifetime of steel ropes used in cranes, elevators, mine hoisting and aerial ropeways experimental methods are generally used, but bending over sheave fatigue testing requires high cost and time. For that reason, ANN methods have great advantages for this application.

Chapter 4 is related to nonlinear polynomial neurons and batch learning algorithms for applications such as plant identification and Neuro-controller adaptation. This application employs Ridge Regression, Levenberg-Marquardt and Conjugate Gradients for ML algorithms. Novel optimizer was also used and the comparison results were discussed.

As Chapter 5, an application of civil engineering is presented. In the presented retrofit applications, the shear force capacity of reinforced concrete (RC) beam is increased by carbon fiber reinforced polymer (CFRP) wrapping. In the presented, a methodology for optimization and prediction of optimum results are presented in the application.

Chapter 6 includes computer vision methods. In engineering, computer vision methods are used for detecting cracks on structural members, extracting information from traffic flows, safety analysis in construction processes, etc. Computer vision applications are supported via ML for image processing.

The applications of prediction in civil engineering continue in Chapter 7. In this chapter, prediction of high performance concrete (HPC) compressive strength is presented. The prediction is realized via generation of several hybrid model based on decision trees.

Chapter 8 is related to integrated water management resources and decision-making systems. The use of AI method and soft computing algorithms for water management is important, because water resources have direct and indirect inter-connectedness with climate change, development and sustainability.

As Chapter 9, a case study, is shortly presented for analysis of ground water quality by using statistical techniques. The case study is done for Madurai city in India.

Chapter 10 is related to the smart transportation. Application about probe people and vehicle-based data sources are presented. By using technologies, smart transportation is a formwork providing acquisition, management and mining of traffic-related data sources.

In Chapter 11, passenger demand prediction via ML methods are is presented. The rapid growth in vehicles and the need of easy transportation of people increases the demand for public transportation. In Chapter 11, a case study of Istanbul’s public transportation system is also presented.

Chapter 12 includes a clustering-based bus stop selection for bus routing problems. As an operational research topic, vehicle routing problem is a complex and important one. In chapter 12, it is possible to find methods such as K-Means, fuzzy C-Means, simulated annealing, genetic algorithm, saving algorithm, and nearest neighborhood algorithm.

Chapter 13 presents an ANN application for unbalanced control for chart pattern recognition. The automatic detection of abnormality in control data is more effective comparing to manual detection. A weighting strategy implemented with ANN was investigation.

Chapter 14 is “related with biometric” identification based on Keystroke dynamics. Several ML methods were compared and discussed.
Chapter 1
Review and Applications of Machine Learning and Artificial Intelligence in Engineering: Overview for Machine Learning and AI

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ABSTRACT
This chapter presents a summary review of development of Artificial Intelligence (AI). Definitions of AI are given with basic features. The development process of AI and machine learning is presented. The developments of applications from the past to today are mentioned and use of AI in different categories is given. Prediction applications using artificial neural network are given for engineering applications. Usage of AI methods to predict optimum results is the current trend and it will be more important in the future.

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Artificial Intelligence and Machine Learning

Alongside related to generally computer sciences and engineering disciplines, artificial intelligence (AI) is a field of science and technology, which has been formed by benefit many fields such as biology and genetics, psychology, language learning and comprehension, mathematics.

The field of artificial intelligence, which is accepted as a branch of a science, owing to seen as a field of research and technology at the same time, its various definitions are made in many different sources, until nowadays. Some of these are as follows:

1. This approach, which is human-oriented, should be an experimental science that includes hypothesis and experiences within (Russell & Norvig, 1995).
2. Artificial intelligence can be defined as effort developing of computer operations, which will ensure to can be found out the similarities of this structure, via be understood of human thinking structure (Uygunoğlu & Yurtçu, 2006).
3. McCarthy (2007) has remarked that of AI is a science and engineering discipline, which is generated intelligent machines, especially computer programming, too.
4. Luger (2009) defined AI as a computer science branch that is related to automation of intelligent behaviors.
5. AI is an expert system to understand intelligent beings, establish, and make productive, rapid and simple of the process of decision-making (Patil et. al., 2017).

Possible to say that, based on these different definitions, which is expressed for artificial intelligence technology: artificial intelligence is a technology, which is composing of computers, which are functioning similarly to intelligence structure and thinking behaviors of humans, intelligently thinking software or computer-controlled robots.

However, although this technology is a case, which is related to using of computers in order to understand of human intelligence, should not be limited to methods that are measurable only according to biological factors (McCarthy, 2007). On the other hand, in recent times, the main cause of importantly advancing of AI technology is developments in computer functions, which are integrated with human intelligence, such as reasoning, nominated ability of discernment, learning, solving problem etc.

Machine learning, which is seen as a subfield of AI’s, is a technology related to designing and developing of algorithms and techniques, which ensure devices to learn, such as computers (Olivas, Guerrero, Sober, Benedito & López, 2009). In this respect, machine learning concept express the generated changes in systems by tasks, which include the actions, which are realized with artificial intelligence, such as recognition, robot-controlling, detection/identification, prediction. Also, with occurring changes either, previously generated systems are developed, or new systems are synthesized. The structure of a typical AI tool, which expressed this case more clearly, shown in Figure 1.

This tool senses information coming from its surrounding and realizes a suitable modelling. Possible effects, which will be generated of models by being predicted, actions are calculated. Conversely, changes, which can occur in any of AI components seen in the figure, may be regarded as learning. Also, different learning mechanism may be run based on change of subsystems.

Definitions of learning concept in dictionary is gain of knowledge and success through study, understand or experience, become skillful and changes that occurred via experience in behavioral tendencies (Nilsson, 1998). Due to this reason, learning action has been happening in a long and iterative process,
and generates alterations, which ensure of obtaining certain attainments and experiences in result of this process, too. The development of many technological devices, such as computer etc. and becoming like humans are unavoidable with the help of various activities that will be carried. In this case, machine learning is considered as gain of experience or information of machines, such as computers, in result of variety events, develop various decision-making mechanisms, foreknow and predict the similar states, which may be lived in future.

As remarked, to be successful of learning process realized in devices, firstly how actualized learning actions of biologic alives, namely people and animals, and the features of processes should be understood properly. However, this information is insufficient alone and in terms of engineering, too, some vital information and calculations are needed (Nilsson, 1998). Some of these are as below:

1. Using of meta-level knowledge makes the control of strategies solving problem more advanced. Although, this is a very hard problem, investigation of some current systems can be relatively considerable as an area of research (Luger, 2009).
2. The programs can only learn behaviors and factors, which formation (mathematical or logical definition) of itself may be represented. However, unfortunately that, almost all of learned systems depend on very limited abilities about representing the knowledge (McCarthy, 2007).
3. Some tasks are not described well without a sample. Therefore, we can determine input-output couples for tasks. Yet, a clear relation may not be occurred between inputs and desired outputs.

4. Current amount of information of specific duties can be too much for open coding can be performed by people.

Development Process of Artificial Intelligence and Machine Learning

Machine learning technology is a branch of AI, that focuses on independent computers and machines, realized the conversion of these to smart entities. Various features belong to humans, such as physical, genetic, intelligence etc. are benefited to execute of this conversion.

Since the starting of discovery and usage of computer and various technological calculators, with continually developing of technology, development of more innovative and differentiated machines can be observed. But, by such these machines, as think, experience and learn lessons from mistakes, by making various comparisons like humans, could be possible in 20th century.

With this respect, one of the first studies entered to literature is cybernetics meaning communication science and automatic control systems between livings and machines developed by Arturo Rosenblueth, Norbert Wiener and Julian Bigelow in 1943. In 1948, Weiner’s famous book was published with this name, too. Grey Walter performed an experiment in Bristol, as based on opinion, that little count brain cells can cause to occur of complex behaviors, with autonomous robots, which are turtles called Elsie and Elmer, between 1948 and 1949. Also, in 1949, a simple and current rule was proved, for altering of connection weights between neurons, which ensure to realize the learning by Donald Hebb (Buchanan, 2006).

The real important developments about artificial intelligence in terms of machine learning were occurred in 1950 and after. One of these was, that Alan Turing published the Turing test, which is required for measuring of intelligent behaviors, in the book called Computing Machinery and Intelligence, in 1950. In this book, required conditions were discussed to be able think of a machine is intelligent. According to Turing, it must be thought that the machine was certainly smart in case a machine shamming human successfully compared to a smart observer (McCarthy, 2007).

The application in Figure 2 is a method, which was generated and named as a simulation game by Turing. In this test, a machine and human are brought to face opposite, and in a separate section other person called as querier is taken place. Querier cannot see directly any entities within test and talk with them. However, querier actually does not know which entity is machine or human, too, and can communicate with them using a device, like a terminal, which can write only text. From querier, distinguishing of human with computer is wanted based on given answers by entities existed in test, to ask questions, which are asked with just the device. When machine or human cannot be distinguished, it may be assumed as machine is intelligent, according to opinion that was defended by Turing.

Nevertheless, querier person is free for asking any question, which is regardless how deceptive or indirect, to reveal the identity of computer. For example, querier can want arithmetic calculation from both, by assuming a high probability that computer gives more accurate results than human. Contrary to this strategy, computer may need to know when it may be unsuccessful about find correct answer to a set of problems as these, to resemble human. Querier can want to ask about both of entity to answerback a poem or artwork, to find out her/his identity based upon human sensitive structure and, a strategy is required to that computer has information related to sensual formation of mankind (Luger, 2009).
In this respect, Turing Test is a significant application to measure similarity of machine to human. Emerging results showed that, machines have similarities to humans at high rate, but these results cannot be considered as right exactly. The clearest reason of this state is some features, which is coming from human creation, and such sensual and humanized features, that machines have not them. Therefore, machines cannot carry out everything as humanoid and consequently, the result that machines are more successful/superior than human may not be deduced through all kinds of application.

On the other hand, as from 1950s, in these days using of k-means algorithm started, which is one of commonly attracted clustering methods in machine learning and works to estimate the values of a complex and multidimensional dataset with help of its several average point (Olivas et. al., 2009).

Another study in this time is chess programs, which were written for von Neumann style traditional computers by Claude Shannon (1950) and Alan Turing (1953). Then, in 1951, Marvin Minsky and Dean Edmonds, who were graduate student in Mathematic Department of Princeton University, set up first neural network computer. Between the years of 1952-1962, Arthur Samuel wrote the first program, which can play game, with the aim of having the upper hand to a world champion by gaining adequate skill in checkers. Together with this period, which was started in 1952, idea was refuted that computers can carry out only said actions to themselves. Because this written program learned rapidly playing a game better than its designer did. Logic Theorist, which was written by Allen Newell, J.C. Shaw and Herbert Simon, was demonstration of the first functioning AI program (Russell & Norvig, 1995).

In addition, a simple neural network called perceptron was proposed by Rosenblatt in 1958 and seen as a milestone in machine learning history (Han & Kamber, 2006). Again, in 1958, McCarthy, who became in an important name of AI field, discovered LISP programming language that is the second oldest programming language is still used today. At the beginning of 1960s, Margaret Masterman and friends designed semantic networks for machine translation. In 1964, the thesis of Danny Bobrow in MIT presented that computers were good at understanding natural language as well as solving algebraic problems, too. Joel Moses demonstrated power of symbolic reasoning for integral problems through Macsyma program (a computer-aided algebra system) in doctoral thesis, which was published in MIT in 1967. This program is the first successful knowledge-based program in the field of math. Another event in actualized in this year, was designing of a chess program named MacHack, which is based on knowledge, and as good as can get degree of C-class in a tournament, by Richard Greenblatt from MIT (Buchanan, 2006).
In conjunction with even more adopting the approach of knowledge-based system, intelligibility problem of molecular structure was solved from acquired information with mass spectrometer developed by the team, which was consisted by Ed Feigenbaum, Bruce Buchanan and Joshua Lederberg in 1969. Program input was formed from molecule’s base (beginning) formula, and when created molecule was bombarded by cathode (electron) rays, mass spectrometer puts forth masses of molecule’s various part. For instance, mass spectrometer can include a density at m=15 corresponding to mass of methyl part. By producing all possible structures, which were interconnection with formula, with a simple version of the program, what will be able to happen of mass spectrometer for each part was compared with an original spectrometer by being predicted (Russell & Norvig, 1995).

In 1970 and after, more developments were experienced in fields of industry and neural networks with rising of machine learning capabilities. Especially, with designed machines and robots for space studies, aim of that these were simulated to human more, became widespread gradually.

Coming to 1980, anymore the first expert systems and commercial applications became developed, more and more. As examples to these, Hearsay-II speech-understanding system, which has blackboard model as skeleton structure, and was developed by Lee Erman, Rick Hayes-Roth, Victor Lesser, and Raj Reddy was presented. With respect to the middle of 1980s, Werbos expressed how to work neural networks by using together with back-propagation algorithm, first time in 1974. Pattern recognition, which is another technology, is an issue closely related to machine learning and, usage of neural networks for it, was explained by Bishop (1995) and Ripley (1996). On the other hand, Mitchell (1997) wrote a book covering many machine learning techniques, also get included of genetic algorithms and reinforcement learning. Again, in 1997, program called The Deep Blue defeated Garry Kasparov, which was then-current world chess champion that was one of the happened important developments. As for in the ends of the twentieth century, Rod Brooks improved Cog Project at MIT, which allowed a major progress on building a humanoid robot. With these advances, it is sighted that any machines and systems have abilities on human level and even come to grade that will rival with her/his. As an example of this, Cynthia Breazeal’s thesis, named Social Machines, describing Kismet, which is a robot possess face that can express own feelings, can be given. Also in 2005, Robot Nomad explored of Antarctica’s far areas, for searching meteorite samples (Buchanan, 2006; Witten, Hall & Frank, 2011).

**Artificial Intelligence and Machine Learning**

Machine learning improved with artificial intelligence technology can be used for many different applications in various areas. Performed applications and developments in these areas are explained as follows:

1. Expert Systems: These systems generate solutions to existing problems in a similar way to solve-style of any problem by an expert. When viewed from this aspect, expert systems were created through conversion to a format that computers can apply for solving of similar problems by gain information from a human expert.

*Dendral*, which is one of the oldest expert systems and is benefiting from domain knowledge about solving problems, was developed at the ends of the 1960s, at Stanford. Generally, structure of organic molecules is too big that increases the possibility of the probable number of structures for molecules is more. Therefore, this system was developed to determine the structure of organic molecules, with mass spectrometer information related to chemical bonds in molecules, and chemical formulas. Another system
that has a feature to be first is *Mycin*, developed in 1974. Mycin was improved by using expert medical information, in a way to present cure advices by diagnosing spinal meningitis and bacterial infections inside blood (Luger, 2009).

The other example is that in 1991 by Bell Atlantic, a system was developed, about required deciding to assign what kind of technician by the company as a result of that a customer reports a phone problem. System, which was developed with machine learning methods, has features of becoming an expert system, which provides savings more than ten billion dollars per year through carrying out this decision less faulty in 1999 (Witten et. al., 2011). *Internist* to diagnose of internal diseases, *Prospector* to determine kind of mineral deposits and possible locations, according to geographical information about a site, and *Dipmeter Advisor* to comment the results of oil well drilling, were also developed as machine learning methods (Luger, 2009).

2. **Robotics**: Besides, AI is an area, which is generated in order to perform the tasks and actions, which are carried out by people, with a better and quick performance; numbers and usage areas of robots, which are one of the practices developing with AI technology for fulfilling of these tasks, increase day by day.

   That is seen as, artificial intelligence technology and machine learning, which is a branch of it, are closely related with robotics technology. The reason is that, generally, artificial neural networks or other classification systems are used for variety tasks, which are required to control robots (Onwubolu & Babu, 2004). However, nowadays, structures with simple form, such as algorithms, all sort software, internet robots, and apps, which are AI tools, together with structures with advanced form, such as robots, driver-less vehicles, smart watches and the other mechanical devices exist. On the other hand, Floridi (2017) said, predicting that generated digital technologies and automations take place of employees, who are in fields such as agricultural and production sectors, and if in service industry, robots will come instead of humans. But even so, human performs a duty as an interface between, a vehicle and a GPS, documents in different languages, a finished meal and ingredients of it, or in cases such as diagnosing of disease, which matched with symptoms. Thus, robots replacing of humans are posing a danger.

3. **Gaming**: Gaming is one of the oldest fields of work of AI. In 1950, as soon as computers became programmable, the first chess program had been written by Claude Shannon and Alan Turing. Since that time, a resolute progression is at stake in game standard, reaching up to the point that today’s systems can challenge across to a world champion (Russell & Norvig, 1995).

   The largest of part first researches performed in this field was performed by using common board games, such as checkers, chess and fifteen crosswords. Because board games have specific features, which made them ideal topic for AI research. Many of games are played by using well-described set of rules. This condition makes easy to generate the field of research and save researcher from most complexities and uncertainness, which is in inherent of more less structured problems (Luger, 2009). The games, which are less abstract, such as football or cricket did not attract working ones in AI field attention much. As increasing number of competitors in games make more complex, and effect operating of the installed functions’ negatively.
Together with the advance technology, other many kinds, such as football, tennis, volleyball, which are composed according to human talent, physical capacity or humanoid responses like reflex, entered to study field of researchers alongside of intelligent games such as chess, checkers, which are more preferred as study field in beginning times, and obtained results became real-like values, besides seen of the usage AI technology in these kinds of game.

4. Speech Recognition with Natural Language Process: Natural language processing is a research and development field, which deals with written and talked (digitized and recorded) language and its data. Natural language processing known as science and technology of features and usage of human language, is mentioned as NLP technology and NLP was named from first letters of the words that “Natural Language Process” and emphasizes the origins of languages talked by people and the role of them about information processing. The substantial execution areas of theory, tool and techniques developed at NLP contain the topics that machine translation, text summarization, text mining and information extraction.

Otherwise, Olivas et. al. (2009) expressed that, NLP methods are able to process of manageable amount of data, like people make, and analyze big amounts of data easily. As an example of this that it combines of speech parts automatically is close to faultless performance, which belongs to an adequate human, can be given.

One of the first designs is Lunar system, which was developed by William Woods in 1973. This system is the first natural language program, which allowed to geologists for asking English questions about rock/stone samples bringing by Apollo Moon Mission, and was used by other people practically (Russell & Norvig, 1995). Besides, via this technology, especially, translating speech to text, that is belong to virtual assistants, which is an app existing in smart phones, and systems, which are automatically corrected of errors in messages and e-mails, are some of the modern-day developments (Biswas, 2018).

5. Finance, Banking and Insurance Applications: Made expenditures, banking actions and various financial activities reflect the various features of people, and the bank, credit and finance institutions benefit from new technologies besides of increasing the number of customers with income that will obtain, with the aim of providing satisfaction of these people, too.

Otherwise, Olivas et. al. (2009) expressed that, NLP methods are able to process of manageable amount of As an example of one of these technologies can be given that determining that a loan corporation will give which persons and how much credit. For this case, loan companies apply a decision procedure by calculating a numeric parameter according to obtained information from surveys, which are conducted to applicants. If this parameter exceeds the defined threshold previous, application is accepted. It is refused, in case of going down below of the second threshold (Witten et. al., 2011). On the other hand, in various sectors, the planning of sale timing by predicting next purchasing time of a product/service, and predicting of travel, flight, car or house buying operations, which will make, that when may be realized and at what rate possibility of occurring is exist, become possible (Maimon & Rokach, 2010).
6. Medicine and Health: Medicine and health science is the primary that of areas which are used most common of artificial intelligence and especially machine learning applications. They are used on diagnosing, and treating of many diseases, moreover, machine learning practices find place to themselves about recognizing of genetic and biological features and improving new technologies.

For instance, determining of the most proper medicine dose for a person in treatment of chronic diseases is generally occurred by trial and error. Machine learning methods are benefitted in order to happen of this process more rapidly, and identifying of medicine treatment as pertain to person (Olivas et. al., 2009). Also, these methods help for deducing of phenotype information from data of gene expression, determining of how will occur sequencing of protein and DNA, examination of pattern regulations on biological gene sequences, and with regard to generation of different gene patterns and find out recurrence frequency (Han & Gao, 2008; Maimon & Rokach, 2010; Olivas et. al. 2009).

7. Vision systems and image recognition technology: Systems, which are created by benefitting from sight sense and characters of alives within nature, are vision systems. These systems can perform position determination, image selection and combination, pattern and photo analogy, debugging and many processing like these with the image detection actions, mainly by using properties of sight sense and advantages.

If will be given an example to vision systems, vision system based on optical flow is one of these, which are used the aim of controlling of responses of airplanes during landing. In addition, these systems are intended for aims, such as, performing movement of mobile robots moving in an environment by detecting location of existing of barriers and free spaces here, monitoring of many astronomical bodies in space, determine of varying land cover because of abrupt changes in green zones by identify of damages, which are natural or man-made within ecosystems (Han & Gao, 2008; Russell & Norvig, 1995).

Except these applications vision systems are preferred frequently in various areas with many purposes that especially geographical positioning, face recognition, determining of vehicle route, detect of faulty products, which can be occurred during production activities, diagnosis of diseased/healthy cells etc.

8. Publication, web and social media applications: Increase of the spending time on the web and social media, and varying of carried out actions cause to create of a big data stack. Also, improving of the new technologies is becoming possible via using of the data consisted in cases such as people use social media accounts, benefit over vary internet sites in many scopes.

Particularly, one of these is seen that as sequencing of web pages by search engines. This problem can be solved via usage of machine learning depending on a training set creating with data, which is obtained in line with decisions, which are given previously by persons. In analyzing of training data, a learning algorithm can predict the relation level of query, thanks to determine of the features such as URL address content for a new query, whether take place in header label. On the other hand, machine learning applications used that the searched terms to select of interested adverts, choices of other users about advices to similar product on shopping of book, film/music CD etc. (Witten et. al., 2011).
Prediction Applications via ANNs

In various study fields, artificial neural networks (ANN) benefit on many topics such as feature extraction, clustering, classification, notably prediction and forecasting. In engineering science, which is the primary of these fields, ANNs can represent quite successful results, especially about predicting the values of design parameters in handled problems.

Also, in civil engineering, some studies were performed to able to rapidly predict parameter values belong to problem, for designing purpose of a model. One of these is a study that developed of a model which can predict salinity rate of Murray River in South Australia from 14 days ago, by used ANN and GA methods by Bowden, Maier and Dandy (2002).

In the study made by Atici (2011), benefited from ANNs besides multiple regression analyses to predict the compressive strength in different curing periods of concrete mixtures consisting various amounts blast furnace slag and fly ash, by depend on additives’ values and features which are obtained with ultrasonic pulse velocity and non-distructive testing. Momeni, Armaghani and Hajihassani (2015) used ANNs, by combining with particle swarm optimization (PSO) method with the aim of increasing network performance, to predict of the unconfined compressive strength of granite and limestone rock samples that are taken from an area in Malaysia.

Another study made in 2015, is developing of an ANN with aim of modeling of the rain-runoff relation in a basin, which has a semi-arid Mediterranean climate that in Algeria, by Aichouri et al. (2015). Veintimilla-Reyes, Cisneros and Vanegas (2016) were formed a model based on ANN, which is enabled to predict the water flow in Tomebamba River by with real time and for a specific day of year. In addition, model inputs are precipitation and flow information, which are occurred in determined stations, and these obtained according to real data, which was gotten from a system placed in stations.

On the other hand, Chatterjee et. al. (2017) determined the structural damages of multi-story reinforced buildings via ANN, which is used to train with PSO algorithm. Also, Cascardi, Micelli and Aiello (2017) were formed a model based on ANN about predicting the compression strength of reinforced circular columns, which are covered by wrap unremittingly with fiber reinforced polymer (FRP). In the study made by Shebani and Iwnicki (2018), ANNs were used to be able to predict the wearing rate of wheel and ray according to different wheel-rail contact cases, such as under dry, wet, oiled conditions and after sanding.

At the same time, that ANNs together with metaheuristic algorithms work well, and became to hybrid, too, besides, they are quite achieved in terms of prediction issues like these, enable to various applications that determined by predict of optimum parameters for design problems that are investigated.

For example, in the study carried out by Ormsbee and Reddy (1995), realize of optimum control of pumping systems, which will supply water, was aimed with handling of pump working times as decision variable, and problem of minimization of pump operate costs. Prediction data obtained from simulation model which is used intended for the purpose, was trained with a neural network, and then optimization of system control is provided by using of trained data at genetic algorithm. On the other side, performance was compared with genetic algorithm and artificial neural network methods, by developing a multi stages prediction model that is composed of firefly algorithm that is used to determine optimum values of parameters in model, which is used in prediction duration, with support vector machine for predetermining of daily lake level according to three different horizon line, in study that was carried out of by Kişi et. al. (2015). Sebaaly, Varma and Maina (2018) were developed a model combined of ANNs with genetic algorithm, by using a data set including information belonging to numerous asphalt mixture.
As seen from these examples, the use of AI methods, mainly ANNs are the increasing trend in science and engineering when the problem solving is too complex, impossible or the process need to much time.

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Chapter 2

Artificial Neural Networks (ANNs) and Solution of Civil Engineering Problems: ANNs and Prediction Applications

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ABSTRACT

This chapter reveals the advantages of artificial neural networks (ANNs) by means of prediction success and effects on solutions for various problems. With this aim, initially, multilayer ANNs and their structural properties are explained. Then, feed-forward ANNs and a type of training algorithm called back-propagation, which was benefited for these type networks, are presented. Different structural design problems from civil engineering are optimized, and handled intended for obtaining prediction results thanks to usage of ANNs.

MULTILAYER ARTIFICIAL NEURAL NETWORKS

Artificial neural networks (ANNs) are computer systems that realize the learning function, which is one of the most principal features of human brain. They carry out the learning activity by the help of samples.

On the other hand, this model is used in various applications such as prediction, classification, control problem in practice, besides it is a computational stencil composing from a group of artificial neurons (nodes (input, hidden and output neurons), which are connected to each other and have the weight value),

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based on biologic neural networks. In this regard, ANNs are an adaptive system, which can change its structure by based on internal or external information flowing along network along learning stage process. This learning or training is a process that the weights are determined (Olivas et al., 2009). In addition, weight value that is possessed of every connection between nodes reflect the effect of each neuron to output value, and nodes are processed according to these weight values. Therefore, information that will be occurred, take form respect to these weights, too.

Layer name is given to section that is existed altogether of more than one neuron cells. There are only input and output layers in the main structure of ANNs. However, in multilayer ANNs, a layer called hidden layer take part in addition to these, too. Input layer that is from these three layers, which composed the network structure, represents the training data and these data are processed at model continuously.

As well as, the second layer is hidden layer, neurons in this layer are presented to be trained by the data, and they are not open to directly intervention from environment/out. Although generally, only one hidden layer is used in practice, number of layers is arbitral, and are can be between 0 and a high number. Output values arranged with weight values produced by the last hidden layer, are transferred to units composing of output layer, and so, network spreads the prediction values generated for training data (Han & Kamber, 2006; Veintimilla-Reyes et al., 2016).

In this way, how compatible of obtained outputs with actuals is observed by comparing the ultimate results obtained in output layer and results that existed real, and error rate (variation) is investigated. Can be say that trained of network in a good way, in case variation between the actual output and output, which is obtained from neural network, is in an allowable limit (Ormsbee & Reddy, 1995). If this rate is not in an admissible level, the network structure is arranged again by making of required improvements. If required, the weights of connections can be modified, too. Operations are iteratively continued, and network structure is completed when error achieve to acceptable level at fewest. In follows, some positive and negative properties of artificial neural networks can be seen:

- This is to produce solutions properly to samples that their values are not known or not applied in previous by generalization through learn of the linear or nonlinear relationship between input and output data about any problem from current samples. Networks have ability of working rapid due to learning ability of networks, adaptability to different problems and network components’ structure that can be worked simultaneously. At the same time, they require less information and their implementation is easy (Uygunoğlu & Yurtçu, 2006).
- They can process the information coming from external based on its previous experiences and simplify the complex and time-consuming problems owing to mapping ability (Gholizadeh, 2015).
- Neural networks include long training times and thus, they are more suitable for applications that are possible long training. In network structure generally, many parameters, which were determined in the best way as experimentally are needed (Han & Kamber, 2006).
- They can solve problems containing uncertain models or data that possess to variables, which include many missing and noisy information. This error tolerance feature address to data mining problems, because real data are generally dirty, and they follow the open possibility structures desired typically by statistical models (Maimon & Rokach, 2010).
- When ANN structure is very small, desired function cannot be carried out; if when it is very big network, which learns all created samples from a large search area, will not generalize inputs that it does not know its value or see before, substantially. From this respect, neural networks show
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extreme/peak behavior in case that numerous parameters are existed in model (Russell & Norvig, 1995)

Feed-Forward Artificial Neural Networks

Multilayer feed-forward artificial neural networks compose from one input layer, one or more hidden layer and one output layer; and in this artificial neural network form named as ‘perceptron’, too, all nodes and layers are arranged the way that a flow to forward (Han & Kamber, 2006; Olivas et al., 2009). Therefore, the connections in a feed-forward ANN are single direction, and cycle does not consist. In these networks, every node can establish contact only with the nodes in next layer. Nodes have not connection with other/neighbor nodes in layers, which are taken place of themselves, or nodes in previous layer (Russell & Norvig, 1995).

Every neuron (node) in input layer, transform to outputs as the way that processed by taking given information, and thus, takes on an information-processing task. Knowledge that will be generated thanks to the linking paths between these neurons, can be produced and stored as connection weights, which are related to power of relationship between different nodes. Although, each neuron applies its function slowly and faultily, main structure of a neural network can carry out various tasks effectively and remarkable results can be obtained (Maimon & Rokach, 2010).

Figure 1 shows the structure of a feed-forward neural network composing from neurons that is arranged as three layers. Here, the current input layer by i, the related input neuron by j, the output neuron in next layer by k, are represented respectively, and input neuron by $X_i$, weight values of connections by $w_{jk}$ and the bias value by $b_{ij}$, are expressed respectively as i, j, k=1, 2,..., n.

Dependent variables expressed via neurons in output layer are predicted by means of neurons in input layer taking place in this network structure and corresponding to independent variables. Each input value is multiplied via inter-connection weights related to output node. Output value is obtained via processing of all obtained multiplication results by means of a activation function (Gandomi et al., 2013). As to in this process, hidden layer and its neurons are existed with the aim of that the information is evaluated according to various factors, learned, and rearranged by experiencing.

Figure 1. Multilayer feed-forward neural network (Chou et al., 2015)
Back-Propagation Algorithm

Like any artificial intelligence model, artificial neural networks have learning ability, too. The most common and efficient learning algorithm, which is used to train a multilayer artificial neural network, is known as back-propagation algorithm (Chou et al., 2015). On the other hand, in learning process, errors, which will be occurred between consecutive layers that in structure of artificial neural networks, can be spread to general of network differently. The most frequently preferred from these is back-propagation algorithm that is based on rearranging the error by spread to backwards.

As generally, back propagation algorithm using in multilayer feed-forward neural networks use the weight changes of connections to minimize the output error generated by function of network.

Cause of the ‘back-propagation’ name is that output node errors spread to backwards from output layer, the way that towards to hidden layer; and these errors are used in equation, which ensure the updated of hidden layer weights. These errors propagating to backward are determined as difference between real and predicted values, in output layer (Chong & Zak, 2001; Luger, 2009).

For each neuron in layers, obtaining a new output value/prediction (feed forward process) is shown in Figure 2, nonlinear logistic or sigmoid function operates net value as activated via tackled with weighted summation of the values ensured in result of multiplied of the output obtained from nodes connected to itself in the one previous layer with connection weights in between each other together with the threshold value (named as bias) as a net input value in that node. In this process, difference between real output with output value forecasted by network is error value, which will be transferred towards to input layer by back-propagation algorithm; outputs (inputs) obtained from the one previous layer; connection weights are expressed as error value, $y_n$ and $w_{nj}$ respectively (Han & Kamber, 2006; Chou et al., 2015).

The value, which is expressed as activation level (net), too, is obtained by sum up of the weighted summation ($\Sigma$) result and bias value ($\theta_j$), and the output prediction is carried out by processed of this value via activation (threshold) function indicated as $f$. These operation steps are calculated by means of below equations:

$$net = \sum y_n w_{nj} + \theta_j$$ (1)

Figure 2. Output prediction via activation of back-propagation algorithm for hidden or output layer node (Han & Kamber, 2006)
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\[ f(\text{net}) = O_j = \frac{1}{1 + e^{-\text{net}}} \]  \hspace{1cm} (2)

Error value presenting the difference between real output \((T_j)\) with value \((O_j)\) generated for any output layer node following of a calculation process as in Equation(2) by activation function, is \(\delta_j\); also, error value, which will be obtained for a node in hidden layer, is expressed as \(\delta_k\), these values are known as error propagating backwards on network, and calculated via following equations:

\[ \delta_j = O_j (1 - O_j) (T_j - O_j) \]  \hspace{1cm} (3)

\[ \delta_k = O_k (1 - O_k) \sum_f \delta_f w_{kj} \]  \hspace{1cm} (4)

Obtained errors are spread to weights on layer connections orderly. This operation is named as training of network, and in each of performed \(t\) cycle (iteration), updating of weights is carried out according to Equation(5) for between hidden-output node and Equation(7) for input-hidden node.

For hidden-output node:

\[ w_{kj}(t) = w_{kj}(t-1) + \Delta w_{kj}(t) \]  \hspace{1cm} (5)

\[ \Delta w_{kj}(t) = \eta \delta_j O_k + \alpha \Delta w_{kj}(t-1) \]  \hspace{1cm} (6)

For input-hidden node:

\[ w_{nk}(t) = w_{nk}(t-1) + \Delta w_{nk}(t) \]  \hspace{1cm} (7)

\[ \Delta w_{nk}(t) = \eta \delta_k y_n + \alpha \Delta w_{nk}(t-1) \]  \hspace{1cm} (8)

Existing in equation, \(\eta\) is learning speed (rate) of network, \(\alpha\) is parameter of momentum and \(\Delta w_{nk}\) is weight change occurred in a cycle.
ANNs PREDICTION APPLICATIONS FOR OPTIMUM DESIGNS

Tubular Column Cost Optimization via ANNs

The Cost Optimization Problem

In this part, the cost optimization problem of tubular column under compressive load, as shown in Figure 3, is tackled with. In problem, the aim is that finding out of the optimal center diameter \(d\) (cm) and thickness \(t\) (cm) belonging to section, which ensure the minimization of total cost including material and construction.

As seen in Figure 3, the axial compressive load \(P\) is applied to center of tubular column at A-A cross-section. Also column length is indicated with \(l\) (cm).

Also, the other components belonging to problem are design constants that are yield stress \((\sigma_y)\) taken as 500 kgf/cm², density \((\rho)\) taken as 0.0025 kgf/cm³ and modulus of elasticity \((E)\) taken as 850000 kgf/cm², besides the design variables are center diameter and thickness which will be optimized in order to minimize cost. Therefore, the objective function of the expressed optimization problem can be written as in Equation (9). Also, constraint functions are six for the design problem, but only two are concerned to design. The other four constraints are related with design variables’ minimum and maximum limit values. On the other hand, constraints functions are \(g_1\) and \(g_2\), and these are expressed that axial compressive load capacity of column, and euler buckling limit, respectively. All of the are formulated as follows:

\[ f(d,t) = 9.8dt + 2d \] (9)

\[ g_1 = \frac{P}{\pi dt \sigma_y} - 1 \leq 0 \] (10)

\[ g_2 = \frac{8Pl^2}{\pi^3 Edt \left( d^2 + t^2 \right)} - 1 \leq 0 \] (11)

Ranges of design variables subjected to optimization, can be seen in Equation (12) and (13).

\[ 2 \leq d \leq 14 \] (12)

\[ 0.2 \leq t \leq 0.9 \] (13)
Artificial Neural Networks (ANNs) and Solution of Civil Engineering Problems

During the optimization process, teaching learning based optimization method, which was developed by Rao et al. (2011), was used in order to obtain optimum values of center diameter and thickness by

Figure 3. Tubular column with A-A cross-section design parameters (Hsu & Liu, 2007)

Teaching Learning Based Optimization (TLBO)

During the optimization process, teaching learning based optimization method, which was developed by Rao et al. (2011), was used in order to obtain optimum values of center diameter and thickness by
ensuring the cost optimization for a large number of P-l data (written Matlab (2018) computer code for optimization process via TLBO is represented in Appendix). This algorithm was generated based on the teaching-learning process between a teacher with his/her students in a classroom. Also, algorithm considers the interactions of students each other them and effects of teacher to students with the aim of improving knowledge of both students and whole classroom in the direction of an iterative process. Therefore, teacher, which is seen as the most experienced person, affects student to reach to predetermined target, and increasing the knowledge level of whole classroom depending on teacher’s ability, is expected. (Temür & Bekdaş, 2016; Toğan, 2012).

This process is composed of two separate phases (teacher and learner phases) with TLBO. The first process is teacher phase, which take form according to education skill of teacher to increase grades of students. The second one is increased of knowledge level in result that sharing knowledge obtained by students and called as student or learner phase. These phases are formulated as Equation(14) and (15), respectively:

\[ X_{i,new} = X_{i,j} + \text{rand}(0,1)\left( X_{i,best} - (TF) X_{i,mean} \right) \]  

(14)

\[ X_{i,new} = \begin{cases}  
X_{i,j} + \text{rand}(0,1)\left( X_{i,a} - X_{i,b} \right) & \text{if } f \left( X_{a} \right) < f \left( X_{b} \right) \\
X_{i,j} + \text{rand}(0,1)\left( X_{i,b} - X_{i,a} \right) & \text{if } f \left( X_{a} \right) > f \left( X_{b} \right) 
\end{cases} \]  

(15)

In these formulas, \( X_{i,j} \) is old value of related design variable within initial matrix and \( X_{i,new} \) is new value of it. Also, \( X_{i,best} \) and \( X_{i,mean} \) are the best value with regards to objective function (so, is teacher solution) and average all candidate solutions of this design variable, respectively. \( TF \) value expresses the teaching force of teacher, so called as teaching factor taken as 1 or 2 randomly. Furthermore, \( X_{i,a} \) and \( X_{i,b} \) in equation of learner phase, are solutions selected as randomly from initial matrix, and \( f(X_{a}) \) and \( f(X_{b}) \) are objective function value of them, too.

**ANN Model and Its Training**

In this chapter that mentioned about Artificial Neural Networks (ANNs), the prediction applications performed by using ANN models for different problems, are investigated. One of this is the problem of cost optimization of tubular column. With this aim, optimization was carried out via TLBO, and then obtained results were operated in prediction process executing via ANN.

In this problem, reason of benefiting from ANN is an effective, rapid and make well convergence tool in order to predict of values. To achieve this, a type of neural networks was used. It is feed-forward networks trained with back-propagation training algorithm.

**Numerical Examples**

In numerical applications, firstly, 10000 data (composed form P-l random values) were produced during optimization process, and the optimum design variables for these data were obtained. This process was
Artificial Neural Networks (ANNs) and Solution of Civil Engineering Problems

realized by using axial force (P) ranging in 100-5000 kgf and the column length (l) ranging in 100-800 cm, as random. By this means, a dataset was created including different P-l design couples together with optimum design variables (Yucel, Bekdaş, Nigdeli & Sevgen, 2018).

Following the generating of dataset, training is done via artificial neural networks. In this way, two input nodes (P and l values) and three output nodes (d, t and the objective function is Min f (d,t)) were determined in order to construct ANN structure. This ANN model was trained owing to Matlab neural net fitting application existing in the machine learning toolbox. For this reason, number of hidden layer nodes are 10, which was used assigned as constant by this tool.

In Table 1, prediction error rates of trained main model are represented in comparison with optimum values, which were obtained via TLBO.

Moreover, by virtue of the prediction success of the main model, a test model was generated by using the same ranges of P and l outputs. Optimization values are shown in Table 2 for this model composed of 10 data.

The obtained optimum design variable predictions are taken part in Tables 3-5, as including min f (d,t). In addition, in these Tables, error metrics composed from mean absolute error (MAE), mean absolute percent error (MAPE) and mean-squared error (MSE) are expressed for design variables and objective function, by comparing TLBO-ANN.

<table>
<thead>
<tr>
<th>Optimum parameters</th>
<th>Error metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean absolute error (MAE)</td>
</tr>
<tr>
<td>d</td>
<td>0.127</td>
</tr>
<tr>
<td>t</td>
<td>0.021</td>
</tr>
<tr>
<td>Min f (d,t)</td>
<td>0.398</td>
</tr>
</tbody>
</table>

Table 1. Error rates and evaluation of success for main model

<table>
<thead>
<tr>
<th>P (kgf)</th>
<th>l (cm)</th>
<th>d (cm)</th>
<th>t (cm)</th>
<th>g1</th>
<th>g2</th>
<th>Min f (d,t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>171</td>
<td>551</td>
<td>4.2840</td>
<td>0.200</td>
<td>-0.8729</td>
<td>0</td>
<td>16.9646</td>
</tr>
<tr>
<td>1373</td>
<td>306</td>
<td>5.7978</td>
<td>0.200</td>
<td>-0.2462</td>
<td>-1.11x10^-10</td>
<td>22.9593</td>
</tr>
<tr>
<td>958</td>
<td>110</td>
<td>2.3883</td>
<td>0.255</td>
<td>-1.11x10^-10</td>
<td>-1.11x10^-10</td>
<td>10.7535</td>
</tr>
<tr>
<td>749</td>
<td>411</td>
<td>5.7669</td>
<td>0.200</td>
<td>-0.5866</td>
<td>-2.22x10^-16</td>
<td>22.8371</td>
</tr>
<tr>
<td>2043</td>
<td>701</td>
<td>11.5059</td>
<td>0.200</td>
<td>-0.4348</td>
<td>0</td>
<td>45.5635</td>
</tr>
<tr>
<td>433</td>
<td>568</td>
<td>5.9607</td>
<td>0.200</td>
<td>-0.7688</td>
<td>-2.22x10^-16</td>
<td>23.6043</td>
</tr>
<tr>
<td>3786</td>
<td>270</td>
<td>5.8814</td>
<td>0.409</td>
<td>-1.11x10^-10</td>
<td>-2.22x10^-10</td>
<td>35.3832</td>
</tr>
<tr>
<td>2702</td>
<td>217</td>
<td>4.7244</td>
<td>0.364</td>
<td>0</td>
<td>-5.55x10^-16</td>
<td>26.3062</td>
</tr>
<tr>
<td>2810</td>
<td>259</td>
<td>5.6466</td>
<td>0.316</td>
<td>-1.11x10^-10</td>
<td>0</td>
<td>28.8245</td>
</tr>
<tr>
<td>870</td>
<td>686</td>
<td>8.5318</td>
<td>0.200</td>
<td>-0.6754</td>
<td>-1.11x10^-10</td>
<td>33.7859</td>
</tr>
</tbody>
</table>

Table 2. Optimum results obtained via TLBO for test model
Artificial Neural Networks (ANNs) and Solution of Civil Engineering Problems

When we analyze the error results, we can see that these rates are very small and acceptable regard to determining of design variables’ values by used the main model. Because, the biggest error value was realized for thickness indicated as $t$ and is 8.776% in terms of MAPE.

Therefore, for test model, the calculating of $g_1$ and $g_2$ constraint functions are make possible owing to be reasonable and proper of prediction results. Calculations of constraints are represented in Table 6 and remarkable point is that only one value is exceeded the limitation:

Table 3. $d$ predictions for new samples via ANN

<table>
<thead>
<tr>
<th>P (kgf)</th>
<th>$l$ (cm)</th>
<th>ANN (10 neuron)</th>
<th>Error Values for TLBO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$d$ (cm)</td>
<td>MAE</td>
</tr>
<tr>
<td>171</td>
<td>551</td>
<td>4.3687</td>
<td>0.0847</td>
</tr>
<tr>
<td>1373</td>
<td>306</td>
<td>5.7872</td>
<td>0.0105</td>
</tr>
<tr>
<td>958</td>
<td>110</td>
<td>2.4948</td>
<td>0.1064</td>
</tr>
<tr>
<td>749</td>
<td>411</td>
<td>5.7955</td>
<td>0.0286</td>
</tr>
<tr>
<td>2043</td>
<td>701</td>
<td>11.4767</td>
<td>0.0293</td>
</tr>
<tr>
<td>433</td>
<td>568</td>
<td>5.8880</td>
<td>0.0727</td>
</tr>
<tr>
<td>3786</td>
<td>270</td>
<td>5.7367</td>
<td>0.1447</td>
</tr>
<tr>
<td>2702</td>
<td>217</td>
<td>4.7064</td>
<td>0.0180</td>
</tr>
<tr>
<td>2810</td>
<td>259</td>
<td>5.6852</td>
<td>0.0386</td>
</tr>
<tr>
<td>870</td>
<td>686</td>
<td>8.5527</td>
<td>0.0209</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>0.0554</strong></td>
<td><strong>1.2356</strong></td>
</tr>
</tbody>
</table>

Table 4. $t$ predictions for new samples via ANN

<table>
<thead>
<tr>
<th>P (kgf)</th>
<th>$l$ (cm)</th>
<th>ANN (10 neuron)</th>
<th>Error Values for TLBO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$t$ (cm)</td>
<td>MAE</td>
</tr>
<tr>
<td>171</td>
<td>551</td>
<td>0.197</td>
<td>0.0026</td>
</tr>
<tr>
<td>1373</td>
<td>306</td>
<td>0.228</td>
<td>0.0288</td>
</tr>
<tr>
<td>958</td>
<td>110</td>
<td>0.265</td>
<td>0.0098</td>
</tr>
<tr>
<td>749</td>
<td>411</td>
<td>0.219</td>
<td>0.0198</td>
</tr>
<tr>
<td>2043</td>
<td>701</td>
<td>0.187</td>
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<tr>
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<td>568</td>
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<td>2702</td>
<td>217</td>
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<td>0.0441</td>
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<td>2810</td>
<td>259</td>
<td>0.373</td>
<td>0.0564</td>
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<tr>
<td>870</td>
<td>686</td>
<td>0.198</td>
<td>0.0011</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>0.0254</strong></td>
<td><strong>8.7760</strong></td>
</tr>
</tbody>
</table>
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Conclusions

If observed error values are analyzed, it is seen that prediction model was improved by using ANN method, which is one of the most used and intelligent machine learning algorithms that is an efficient tool for determining of optimum values close to real/target data. So, the ANN model can be accepted as successful about optimizing of design variables rapidly, effectively and easily. For this reason, a prediction application for generated test model was realized and according to resultant of obtained predictions, these values are very close to real optimum data. Thus, differences, in other words, errors did not reach very big values.

According to error values, MSE metric is very small for both all design variables and objective function. Also, MAE is the same situation as MSE, because their values are between only 0.0254-0.1667.

Table 5. Min (f (d,t)) predictions for new samples via ANN

<table>
<thead>
<tr>
<th>P (kgf)</th>
<th>l (cm)</th>
<th>ANN (10 neuron)</th>
<th>Error Values for TLBO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min f(d,t)</td>
<td>MAE</td>
</tr>
<tr>
<td>171</td>
<td>551</td>
<td>17.2501</td>
<td>0.2855</td>
</tr>
<tr>
<td>1373</td>
<td>306</td>
<td>22.9529</td>
<td>0.0064</td>
</tr>
<tr>
<td>958</td>
<td>110</td>
<td>11.2577</td>
<td>0.5042</td>
</tr>
<tr>
<td>749</td>
<td>411</td>
<td>22.9484</td>
<td>0.1114</td>
</tr>
<tr>
<td>2043</td>
<td>701</td>
<td>45.7778</td>
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</tr>
<tr>
<td>433</td>
<td>568</td>
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<td>0.2642</td>
</tr>
<tr>
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<td>270</td>
<td>35.4033</td>
<td>0.0200</td>
</tr>
<tr>
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<td>217</td>
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<td>2810</td>
<td>259</td>
<td>28.8227</td>
<td>0.0018</td>
</tr>
<tr>
<td>870</td>
<td>686</td>
<td>33.9598</td>
<td>0.1739</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.1667</td>
<td>0.9378</td>
</tr>
</tbody>
</table>

Table 6. The constraint function calculations for new samples via ANN

<table>
<thead>
<tr>
<th>P (kgf)</th>
<th>l (cm)</th>
<th>g₁</th>
<th>g₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>171</td>
<td>551</td>
<td>-0.8737</td>
<td>-0.0443</td>
</tr>
<tr>
<td>1373</td>
<td>306</td>
<td>-0.3398</td>
<td>-0.1213</td>
</tr>
<tr>
<td>958</td>
<td>110</td>
<td>-0.0780</td>
<td>-0.1549</td>
</tr>
<tr>
<td>749</td>
<td>411</td>
<td>-0.6256</td>
<td>-0.1035</td>
</tr>
<tr>
<td>2043</td>
<td>701</td>
<td>-0.0780</td>
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<td>433</td>
<td>568</td>
<td>-0.7762</td>
<td>-0.0080</td>
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<tr>
<td>3786</td>
<td>270</td>
<td>-0.1231</td>
<td>-0.0802</td>
</tr>
<tr>
<td>2702</td>
<td>217</td>
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<td>-0.0991</td>
</tr>
<tr>
<td>2810</td>
<td>259</td>
<td>-0.1570</td>
<td>-0.1694</td>
</tr>
<tr>
<td>870</td>
<td>686</td>
<td>-0.6744</td>
<td>-0.0019</td>
</tr>
</tbody>
</table>
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Figure 4. Design variables and loads of I-section beam (Yang et al., 2016)

and the biggest one is belonging to Min f (d,t) predictions. Percentage errors, namely MAPE is ranging 0.9378-8.7760%. 8.7760% MAPE value is occurred for thickness (t). Reason of this, values of t variable is more precision so, predictions should be so close and similar to real values in the way of ensuring that errors are reducing.

Even so, to perform of calculating the constraint functions belonging to test model design couples can be validated by the success of the ANN prediction model. Therefore, constraints (g₁ and g₂) were calculated by using ANN predictions of new test samples. Obtained results are showed that prediction model is significantly successful due to that design constraints are proper to limitations. One design model, which was violated of limits for g₂, is existed. In this regards, error values of design variables can be neglected as independently (single).

This tool can be useful and efficient intended for determining design data for various usage fields, such as engineering, medical, science etc. Also, it is ensured optimization of cost, time especially effort. In future, ANNs models that are more preferred with the aim of preventing loss of time and effort with the other residuals, can be useful.

I-beam Section Optimization by Using ANN Optimum Predictions

Vertical Deflection Minimization of I-section Beam

The second problem is related to the minimization of vertical deflection, which is occurred in I-section beam.

This beam is acted from two loads composed from vertical load (P) and horizontal (Q) load, which are applied to midpoint of center axis of beam span, and middle axis point of beam web, respectively. From these loads Q was dealt with as constant 50 kN. However, the vertical design load symbolized as P was normally constant like Q in optimization but in present study, P values were determined in different ranges as randomly. This range is between 100-750 kN. Also, the beam span length (L) was determined between 100-350 cm, too. For the aim of this application, different optimum design models are benefited in training of artificial neural network model (Yucel, Nigdeli, & Bekdaş, 2019).

In this problem, design variables are composed from section properties, which are beam height (h), beam width, beam flange thickness (t_f) and beam web thickness (t_w), and all of them are denominated
Artificial Neural Networks (ANNs) and Solution of Civil Engineering Problems

in centimeters. The design loads (inputs for ANN model) and design variables of belonging to beam section (outputs for ANN model) are shown in Figure 4 (Yang et al., 2016):

While the optimum design variables were determined in optimization process realized by Flower Pollination Algorithm (FPA), targeted objective function is as in Equation(16). This function is concerned with optimization of section properties by ensuring the minimization of vertical deflection. In this equation, elasticity modulus symbolized with E, is 20000 kN/cm² and the moment of inertia (I) belonging to I-beam is formulated with Equation(17):

$$f(x) = \frac{PL^3}{48EI}$$  \hspace{1cm} (16)

$$I = \frac{t_w(h-2t_f)^3}{12} + \frac{bt_f^3}{6} + 2bt_f \left( \frac{h-t_f}{2} \right)^2$$  \hspace{1cm} (17)

Constraint functions are composed from g₁ and g₂, which are related with beam section area limitation (this cannot violate 300 cm²) and allowable moment stress limitation (this cannot be bigger than 6 kN/cm²), respectively. Formulations of constraints are shown as follows via Equation(18) and (19):

$$g_1 = 2bt_f + t_w(h-2t_f) \leq 300$$  \hspace{1cm} (18)

$$g_2 = \frac{1.5PWh}{t_w(h-2t_f)^3} + \frac{1.5Qlb}{2bt_w(4t_f^2 + 3h(h-2t_f))} \leq 6$$  \hspace{1cm} (19)

Also, design variables were handled within specific ranges intended for desired design conditions. For this purpose, the limits of design variables are determined in Equation(20)-(23).

$$10 \leq h \leq 100$$  \hspace{1cm} (20)

$$10 \leq b \leq 60$$  \hspace{1cm} (21)

$$0.9 \leq t_w \leq 6$$  \hspace{1cm} (22)

$$0.9 \leq t_f \leq 6$$  \hspace{1cm} (23)
Metaheuristic Method: Flower Pollination Algorithm (FPA)

Flower pollination algorithm (FPA) is known as a metaheuristic method, and in nowadays, preferred in an extent large for solving of various optimization problems.

This method was proposed by Xin-She Yang in 2012 (Yang, 2012) and in development process of algorithm, flowery plants are inspired for determining of optimization stages (Bekdaş, Nigdeli, & Yang, 2015). In this respect, FPA method is composed from two separate stages containing from cross pollination, which is realized between flowers of different plants coming from same type, and self-pollination, which is occurred between self-flowers of same plant, or a flower is one by one. Also, these stages are simulated as global search and local search in optimization.

During cross-pollination, pollinators move from one flower to another with one type of search flight, which is known as Lévy distribution rule as in Equation (25). Also, this flight formulation is as follows:

$$Lévy = \left( \frac{1}{\sqrt{2\pi}} \right) \int^{1.5} e^{-\frac{1}{2T}}$$  \hspace{0.5cm} (24)

$$X_{i,new} = X_{i,j} + Lévy \left( X_{i,best} - X_{i,j} \right)$$  \hspace{0.5cm} (25)

In these equations, Lévy and ε expressions are Lévy distribution and a value ranging 0 and 1 determined as randomly, respectively. $X_{i,j}$ is old value of $i^{th}$ design variable belonging to $j^{th}$ candidate solution within initial matrix. Also, $X_{i,new}$ is new solution value for concerned design variable and this updates iteratively during optimization. $X_{i,best}$ is the best solution, which ensure the minimum/maximum objective function. Self-pollination process performs with the equation as follows:

$$X_{i,new} = X_{i,j} + f \left( X_{i,m} - X_{i,k} \right)$$  \hspace{0.5cm} (26)

Here, $X_{i,m}$ and $X_{i,k}$ are two different candidate solution as m and k, which are determined as randomly ranging 0 and 1 for $i^{th}$ design variable.

In this study, too, flower pollination algorithm was benefited with the aim of optimizing of design variables belonging to I-section beam by ensuring of minimization the cost. In this regard, optimum values for design variables, which are beam height and width together with flange and web thickness of beam could be determined.

Artificial Neural Networks (ANNs) Model

As in the previous mentioned, ANNs are smart methods coming from machine learning and artificial intelligence. Because of they think, analyze and exhibit behavior like human, it is thought that ANNs are intelligent. In this direction, prediction application was carried out for determining of optimum values for I-section beam design by benefited from these advantages of artificial neural networks (ANNs). Owing to this, an effective and rapid prediction tool was developed via ANNs.
Artificial Neural Networks (ANNs) and Solution of Civil Engineering Problems

Firstly, optimum values of design variables are used for generating a dataset as training process. The training process was realized with Matlab R2018a program by using the neural net fitting application, besides 750 P-L design model was generating in optimization process for this aim. These are handled as outputs for ANN model and determined as randomly during optimization. Moreover, optimum values of design variables were selected as inputs in dataset. For this respect, main ANN training model could be created composing from vertical load (P) and span length of beam (L), together with section values of variables (h, b, t_w, t_f).

The aim of this process was predicting optimum designs for a new model. Therefore, a new test model was proposed containing ten different design combinations, and the prediction operations could be realized owing to obtained ANN prediction tool.

Determining of ANN Predictions belonging to the Test Model

Optimum values for test model containing 10 different designs can be seen in Table 7. Also, the optimum values determined via main ANN prediction model are taken apart in Tables 8-11.

Following the prediction of design variables, calculations of minimum objective functions were carried out. Objective functions determining via predictions with the their error metrics are taking part in Table 12.

CONCLUSION

According to tables including the optimum results for design variables within test model, error values are very small and, so predictions are close to real optimum values of h and b variables, especially h. However, h and b design variables have the same or very similar values for test model designs each other. With this reason, all prediction process should be analyzed by means of understanding and demonstrate of the success of ANN model.

Table 7. Optimum values belonging to designs within test model.

<table>
<thead>
<tr>
<th>L (cm)</th>
<th>P (kN)</th>
<th>h</th>
<th>b</th>
<th>t_w</th>
<th>t_f</th>
<th>Min f (x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>652</td>
<td>100.0000</td>
<td>60.0000</td>
<td>0.9000</td>
<td>1.7766</td>
<td>0.002018</td>
</tr>
<tr>
<td>350</td>
<td>520</td>
<td>100.0000</td>
<td>60.0000</td>
<td>1.6303</td>
<td>1.1733</td>
<td>0.049381</td>
</tr>
<tr>
<td>285</td>
<td>743</td>
<td>100.0000</td>
<td>60.0000</td>
<td>1.6833</td>
<td>1.1289</td>
<td>0.038774</td>
</tr>
<tr>
<td>150</td>
<td>200</td>
<td>100.0000</td>
<td>60.0000</td>
<td>0.9000</td>
<td>1.7766</td>
<td>0.001209</td>
</tr>
<tr>
<td>345</td>
<td>264</td>
<td>100.0000</td>
<td>60.0000</td>
<td>1.1171</td>
<td>1.5989</td>
<td>0.020572</td>
</tr>
<tr>
<td>100</td>
<td>690</td>
<td>100.0000</td>
<td>60.0000</td>
<td>0.9000</td>
<td>1.7766</td>
<td>0.001236</td>
</tr>
<tr>
<td>250</td>
<td>442</td>
<td>100.0000</td>
<td>59.9999</td>
<td>1.0635</td>
<td>1.6428</td>
<td>0.012915</td>
</tr>
<tr>
<td>310</td>
<td>675</td>
<td>100.0000</td>
<td>60.0000</td>
<td>1.9552</td>
<td>0.9000</td>
<td>0.049937</td>
</tr>
<tr>
<td>270</td>
<td>482</td>
<td>100.0000</td>
<td>60.0000</td>
<td>1.2077</td>
<td>1.5244</td>
<td>0.018465</td>
</tr>
<tr>
<td>220</td>
<td>355</td>
<td>100.0000</td>
<td>60.0000</td>
<td>0.9000</td>
<td>1.7766</td>
<td>0.006771</td>
</tr>
</tbody>
</table>
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Table 8. \( h \) predictions of designs within test model by using ANN.

<table>
<thead>
<tr>
<th>Predictions via ANNs</th>
<th>-</th>
<th>Error</th>
<th>Absolute error</th>
<th>Error %</th>
<th>Squared error</th>
</tr>
</thead>
<tbody>
<tr>
<td>h (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>99.9989</td>
<td></td>
<td>0.0011</td>
<td>0.0011</td>
<td>0.0011</td>
<td>0.0000</td>
</tr>
<tr>
<td>100.0121</td>
<td></td>
<td>-0.0121</td>
<td>0.0121</td>
<td>0.0121</td>
<td>0.0001</td>
</tr>
<tr>
<td>100.0283</td>
<td></td>
<td>-0.0283</td>
<td>0.0283</td>
<td>0.0283</td>
<td>0.0008</td>
</tr>
<tr>
<td>100.0045</td>
<td></td>
<td>-0.0045</td>
<td>0.0045</td>
<td>0.0045</td>
<td>0.0000</td>
</tr>
<tr>
<td>100.0061</td>
<td></td>
<td>-0.0061</td>
<td>0.0061</td>
<td>0.0061</td>
<td>0.0000</td>
</tr>
<tr>
<td>99.9984</td>
<td></td>
<td>0.0016</td>
<td>0.0016</td>
<td>0.0016</td>
<td>0.0000</td>
</tr>
<tr>
<td>99.9970</td>
<td></td>
<td>0.0030</td>
<td>0.0030</td>
<td>0.0030</td>
<td>0.0000</td>
</tr>
<tr>
<td>100.0279</td>
<td></td>
<td>-0.0279</td>
<td>0.0279</td>
<td>0.0279</td>
<td>0.0008</td>
</tr>
<tr>
<td>100.0029</td>
<td></td>
<td>-0.0029</td>
<td>0.0029</td>
<td>0.0029</td>
<td>0.0000</td>
</tr>
<tr>
<td>99.9942</td>
<td></td>
<td>0.0058</td>
<td>0.0058</td>
<td>0.0058</td>
<td>0.0000</td>
</tr>
<tr>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>-</td>
<td>0.0093</td>
<td>0.0093</td>
<td>0.0093</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

RMSE                  | - | 0.0141| -              | -      |               |

So, when analyzed of \( t_w \) and \( t_r \) variables, we can see that the error measurements are a bit considerable comparing to other variables. Nevertheless, not so big errors did not occur in these variables for test model. MAPE is 2.9681\% for \( t_w \) and 1.8968\% for \( t_r \), together with extremely small value of RMSE that is closely related with ANN success.

Table 9. \( b \) predictions of designs within test model by using ANN.

<table>
<thead>
<tr>
<th>Predictions via ANNs</th>
<th>-</th>
<th>Error</th>
<th>Absolute error</th>
<th>Error %</th>
<th>Squared error</th>
</tr>
</thead>
<tbody>
<tr>
<td>h (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>59.9968</td>
<td></td>
<td>0.0032</td>
<td>0.0032</td>
<td>0.0053</td>
<td>0.0000</td>
</tr>
<tr>
<td>60.0180</td>
<td></td>
<td>-0.0180</td>
<td>0.0180</td>
<td>0.0300</td>
<td>0.0003</td>
</tr>
<tr>
<td>60.0295</td>
<td></td>
<td>-0.0295</td>
<td>0.0295</td>
<td>0.0492</td>
<td>0.0009</td>
</tr>
<tr>
<td>59.9652</td>
<td></td>
<td>0.0348</td>
<td>0.0348</td>
<td>0.0580</td>
<td>0.0012</td>
</tr>
<tr>
<td>60.0047</td>
<td></td>
<td>-0.0048</td>
<td>0.0048</td>
<td>0.0080</td>
<td>0.0000</td>
</tr>
<tr>
<td>59.9933</td>
<td></td>
<td>0.0067</td>
<td>0.0067</td>
<td>0.0112</td>
<td>0.0000</td>
</tr>
<tr>
<td>59.9290</td>
<td></td>
<td>0.0710</td>
<td>0.0710</td>
<td>0.1183</td>
<td>0.0050</td>
</tr>
<tr>
<td>60.0200</td>
<td></td>
<td>-0.0200</td>
<td>0.0200</td>
<td>0.0333</td>
<td>0.0004</td>
</tr>
<tr>
<td>59.9336</td>
<td></td>
<td>0.0664</td>
<td>0.0664</td>
<td>0.1106</td>
<td>0.0044</td>
</tr>
<tr>
<td>59.9266</td>
<td></td>
<td>0.0734</td>
<td>0.0734</td>
<td>0.1223</td>
<td>0.0054</td>
</tr>
<tr>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>-</td>
<td>0.0328</td>
<td>0.0546</td>
<td>0.0018</td>
<td></td>
</tr>
</tbody>
</table>

RMSE                  | - | 0.0424| -              | -      |               |
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In addition, when the obtained results of objective functions are analysed, it is seen that error values are extremely small and there are only 1.614% differences from real optimum results as percentage. As result, the ANN prediction model is effective tool and suitable to approach real observations.

Table 10. $t_w$ predictions of designs within test model by using ANN.

<table>
<thead>
<tr>
<th>Predictions via ANNs</th>
<th>Error</th>
<th>Absolute error</th>
<th>Error %</th>
<th>Squared error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_w$ (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8851</td>
<td>0.0149</td>
<td>0.0149</td>
<td>1.652</td>
<td>0.0002</td>
</tr>
<tr>
<td>1.5850</td>
<td>0.0454</td>
<td>0.0454</td>
<td>2.782</td>
<td>0.0021</td>
</tr>
<tr>
<td>1.7029</td>
<td>-0.0196</td>
<td>0.0196</td>
<td>1.163</td>
<td>0.0004</td>
</tr>
<tr>
<td>0.9401</td>
<td>-0.0401</td>
<td>0.0401</td>
<td>4.457</td>
<td>0.0016</td>
</tr>
<tr>
<td>1.0728</td>
<td>0.0443</td>
<td>0.0443</td>
<td>3.965</td>
<td>0.0020</td>
</tr>
<tr>
<td>0.9265</td>
<td>-0.0265</td>
<td>0.0265</td>
<td>2.948</td>
<td>0.0007</td>
</tr>
<tr>
<td>1.0968</td>
<td>-0.0333</td>
<td>0.0333</td>
<td>3.133</td>
<td>0.0011</td>
</tr>
<tr>
<td>1.7537</td>
<td>-0.0420</td>
<td>0.0420</td>
<td>2.451</td>
<td>0.0018</td>
</tr>
<tr>
<td>1.2371</td>
<td>-0.0295</td>
<td>0.0295</td>
<td>2.447</td>
<td>0.0009</td>
</tr>
<tr>
<td>0.9422</td>
<td>-0.0422</td>
<td>0.0422</td>
<td>4.684</td>
<td>0.0018</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>MAE</td>
<td>MAPE</td>
<td>MSE</td>
</tr>
<tr>
<td>Average</td>
<td>-</td>
<td>0.0338</td>
<td>2.9681</td>
<td>0.0012</td>
</tr>
<tr>
<td><strong>RMSE</strong></td>
<td>-</td>
<td>0.0346</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In addition, when the obtained results of objective functions are analysed, it is seen that error values are extremely small and there are only 1.614% differences from real optimum results as percentage. As result, the ANN prediction model is effective tool and suitable to approach real observations.

Table 11. $t_f$ predictions of designs within test model by using ANN.

<table>
<thead>
<tr>
<th>Predictions via ANNs</th>
<th>Error</th>
<th>Absolute error</th>
<th>Error %</th>
<th>Squared error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_f$ (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.7867</td>
<td>-0.0101</td>
<td>0.0101</td>
<td>0.5669</td>
<td>0.0000</td>
</tr>
<tr>
<td>1.2128</td>
<td>-0.0395</td>
<td>0.0395</td>
<td>3.3666</td>
<td>0.0000</td>
</tr>
<tr>
<td>1.1206</td>
<td>0.0083</td>
<td>0.0083</td>
<td>0.7344</td>
<td>0.0000</td>
</tr>
<tr>
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<td>0.0356</td>
<td>2.0065</td>
<td>0.0000</td>
</tr>
<tr>
<td>1.6336</td>
<td>-0.0347</td>
<td>0.0347</td>
<td>2.1718</td>
<td>0.0000</td>
</tr>
<tr>
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<td>0.0280</td>
<td>1.5764</td>
<td>0.0000</td>
</tr>
<tr>
<td>1.6088</td>
<td>0.0340</td>
<td>0.0340</td>
<td>2.0714</td>
<td>0.0000</td>
</tr>
<tr>
<td>1.0812</td>
<td>0.0238</td>
<td>0.0238</td>
<td>2.1558</td>
<td>0.0000</td>
</tr>
<tr>
<td>1.4951</td>
<td>0.0293</td>
<td>0.0293</td>
<td>1.9223</td>
<td>0.0000</td>
</tr>
<tr>
<td>1.7341</td>
<td>0.0426</td>
<td>0.0426</td>
<td>2.3957</td>
<td>0.0000</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>MAE</td>
<td>MAPE</td>
<td>MSE</td>
</tr>
<tr>
<td>Average</td>
<td>-</td>
<td>0.0286</td>
<td>1.8968</td>
<td>0.0000</td>
</tr>
<tr>
<td><strong>RMSE</strong></td>
<td>-</td>
<td>0.0000</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 12. Calculations of Min f (x) values via ANNs predictions for the test model samples.

<table>
<thead>
<tr>
<th>Objective Function Values Calculated via Predictions</th>
<th>-</th>
<th>Error</th>
<th>Absolute error</th>
<th>Error %</th>
<th>Squared error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min f (x)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0020</td>
<td></td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.277</td>
<td>0.00000000</td>
</tr>
<tr>
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<td>0.0008</td>
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<td>1.613</td>
<td>0.0000006</td>
</tr>
<tr>
<td>0.0388</td>
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<td>0.0000</td>
<td>0.0000</td>
<td>0.070</td>
<td>0.0000000</td>
</tr>
<tr>
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<td>0.0000</td>
<td>0.0000</td>
<td>1.225</td>
<td>0.0000000</td>
</tr>
<tr>
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<td>1.143</td>
<td>0.0000001</td>
</tr>
<tr>
<td>0.0012</td>
<td></td>
<td>0.0000</td>
<td>0.0000</td>
<td>1.006</td>
<td>0.0000000</td>
</tr>
<tr>
<td>0.0131</td>
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<td>-0.0002</td>
<td>0.0002</td>
<td>1.357</td>
<td>0.0000000</td>
</tr>
<tr>
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<td>-0.0003</td>
<td>0.0003</td>
<td>0.653</td>
<td>0.0000001</td>
</tr>
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<td>0.0002</td>
<td>1.191</td>
<td>0.0000000</td>
</tr>
<tr>
<td>0.0069</td>
<td></td>
<td>-0.0001</td>
<td>0.0001</td>
<td>1.614</td>
<td>0.0000000</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>MAE</td>
<td>1.015</td>
<td>0.0000001</td>
</tr>
<tr>
<td>RMSE</td>
<td></td>
<td>0.0003</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

REFERENCES


Artificial Neural Networks (ANNs) and Solution of Civil Engineering Problems


%App. (2.1): Cost Optimization of Tubular Column Under Compressive Load via TLBO Algorithm

clear all

% DESIGN CONSTANTS AND VALUES
% yield: yield strength (kgf/cm^2)
% E: elasticity modulus (kgf/cm^2)
% ro: density (kgf/cm^3)
% P: axial compressive load (kgf)
% l: column length (cm)

yield=500; E=0.85E6; ro=0.0025;

% DESIGN VARIABLES OF PROBLEM
% d: average diameter of column crossection (cm)
% t: thickness of column crosssection (cm)

% LIMITATIONS FOR DESIGN VARIABLES
% mind: lower limit for average diameter
% maksd: upper limit for average diameter
% mint: lower limit for thickness
% makst: upper limit for thickness

mind=2; maksd=14; mint=0.2; makst=0.9;

% PARAMETERS OF TLBO ALGORITHM
% stop_criteria: stopping criteria of algorithm (maximum iteration)
% pn: population size (learner number)

stop_criteria=20000; pn=15;

tic
for ii=1:10000
    P(ii)=round(100+4900*rand());
    l(ii)=round(100+700*rand());
end
Artificial Neural Networks (ANNs) and Solution of Civil Engineering Problems

OPT_P_l_comb(ii,1)=P(ii); %recording of P random values
OPT_P_l_comb(ii,2)=l(ii); %recording of l random values

% GENERATION OF INITIAL MATRIX

for i=1:pn

% Assigning of random values for design variables between determined limits
    d=mind+(maksd-mind)*rand;
    t=mint+(makst-mint)*rand;

% OBJECTIVE FUNCTION OF PROBLEM
    Fd_t=9.8*d*t+2*d;

% CONSTRAINT FUNCTIONS
% g1: axial load capacity (compressive strength should not exceed the yield strength in design.)
    g1=(P(ii)/(pi*d*t*yield))-1;
    g2=8*P(ii)*(l(ii)^2)/((pi^3)*E*d*t*(d^2+t^2))-1;

% OPT: Initial solution matrix
    OPT(1,i)=d;
    OPT(2,i)=t;
    OPT(3,i)=g1;
    OPT(4,i)=g2;
    OPT(5,i)=Fd_t;

    if OPT(3,i)>0
        OPT(5,i)=10^6;
    end
    if OPT(4,i)>0
        OPT(5,i)=10^6;
    end
end

% ITERATION PROCESS
for dongu=1:stop_criteria

% GENERATION OF NEW SOLUTION MATRIX ACCORDING TO TLBO ALGORITHM RULES
% Teacher phase
for i=1:pn

% Obtaining of the best solution (teacher ensuring that objective function is minimum in initial solution matrix, and design variables belonging to this solution

[p,r]=min(OPT(5,:));
best_d=OPT(1,r);
best_t=OPT(2,r);

% Determining again of design variables according to TLBO rules

% TF: teaching factor
TF=round(1+rand);
d=OPT(1,i)+rand*(best_d-TF*mean(OPT(1,:)));
t=OPT(2,i)+rand*(best_t-TF*mean(OPT(2,:)));

% Controlling of lower and upper limits of new generated design variables
if d>maksd
    d=maksd;
end
if d<mind
    d=mind;
end
if t>makst
    t=makst;
end
if t<mint
    t=mint;
end

% Objective function of problem
Fd_t=9.8*d*t+2*d;

% Inequality constraints of problem
g1=(P(ii)/(pi*d*t*yield))-1;
g2=8*P(ii)*(l(ii)^2)/(pi^3*E*d*t*(d^2+t^2))-1;

%OPT_Y: New solution matrix
OPT_Y(1,i)=d;
OPT_Y(2,i)=t;
OPT_Y(3,i)=g1;
OPT\_Y(4,i)=g2;
OPT\_Y(5,i)=F\_d\_t;

% Penalized of solutions not providing required constraints in respect to design, with a big value (10^6)
if OPT\_Y(3,i)>0
OPT\_Y(5,i)=10^6;
end
if OPT\_Y(4,i)>0
OPT\_Y(5,i)=10^6;
end
end

% UPDATING OF MATRIX WITH VALUE OF VARIABLES BELONGING TO BETTER SOLUTION, BY COMPARING OF CURRENT VALUES WITH NEWLY PRODUCED VALUES IN TERMS OF MINIMIZATION OF OBJECTIVE FUNCTION

for i=1:pn
if OPT(5,i)>OPT\_Y(5,i)
OPT(:,i)=OPT\_Y(:,i);
end
end

% Learner phase
for i=1:pn

% Determining again of design variables according to learner phase rules

% Selecting randomly of required two solutions (students) as different from each other

xi=ceil(rand*pn);
xj=ceil(rand*pn);

while xi==xj
xi=ceil(rand*pn);
xj=ceil(rand*pn);
end

if OPT(5,xi)<OPT(5,xj)
d=OPT(1,i)+rand*(OPT(1,xi)-OPT(1,xj));
t=OPT(2,i)+rand*(OPT(2,xi)-OPT(2,xj));
end
else
    d=OPT(1,i)+rand*(OPT(1,xj)-OPT(1,xi));
    t=OPT(2,i)+rand*(OPT(2,xj)-OPT(2,xi));
end

% Controlling of lower and upper limits of new generated design variables
if d>maksd
    d=maksd;
end
if d<mind
    d=mind;
end
if t>makst
    t=makst;
end
if t<mint
    t=mint;
end

% Objective function of problem
Fd_t=9.8*d*t+2*d;

% Inequality constraints of problem
g1=(P(ii)/(pi*d*t*yield))-1;
g2=8*P(ii)*(l(ii)^2)/(pi^3*E*d*t*(d^2+t^2))-1;

%OPT_Y: New solution matrix
OPT_Y(1,i)=d;
OPT_Y(2,i)=t;
OPT_Y(3,i)=g1;
OPT_Y(4,i)=g2;
OPT_Y(5,i)=Fd_t;

% Penalized of solutions not providing required constraints in respect to design, with a big value (10^6)
if OPT_Y(3,i)>0
    OPT_Y(5,i)=10^6;
end
if OPT_Y(4,i)>0
    OPT_Y(5,i)=10^6;
end
end
% UPDATING OF MATRIX WITH VALUE OF VARIABLES BELONGING TO BETTER SOLUTION, BY
COMPARING OF CURRENT VALUES WITH NEWLY PRODUCED VALUES IN TERMS OF MINIMIZATION OF OBJECTIVE FUNCTION

for i=1:pn
    if OPT(5,i)>OPT_Y(5,i)
        OPT(:,i)=OPT_Y(:,i);
    end
end

end  %end of the iteration

OPT_cycle=zeros(5,1);
[min_value,rank]=min(OPT(5,:));
OPT_cycle(1,1)=OPT(1,rank);  %d
OPT_cycle(2,1)=OPT(2,rank);  %t
OPT_cycle(3,1)=OPT(3,rank);  %g1
OPT_cycle(4,1)=OPT(4,rank);  %g2
OPT_cycle(5,1)=OPT(5,rank);  %min Fd_t

% OPT_cycle vector is that recording of result ensuring the minimum conditions
for each compressive load (that in end of iteration)

% OPT_CEV is result storage matrix containing thickness, center diameter with
objective function values of vector that ensuring minimization of objective
function in updated optimization matrix generating for each compressive load

    OPT_CEV(:,ii)=OPT_cycle(:,,:);
end % end of any compressive load cycle
toc