ASSESSING EXTERNAL REINFORCEMENT ON REINFORCED CONCRETE BEAMS USING NEURAL NETWORKS

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
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This thesis aims to develop a neural network model of the performance of externally reinforced concrete beams that is sufficiently accurate to be of use to practicing engineers, and to overcome the speed problem of existing models of analysis, thus facilitating the search for an optimal design solution.

The use of carbon fiber reinforced plastic (CFRP) sheets as externally bonded reinforcement is now generally recognized as an efficient and valid procedure for strengthening and upgrading structural concrete members. In this thesis, data collected from a Wright Laboratory Airbase CFRP laminate project are used for a feasibility study by applying neural networks to predict the deflection of tested beams.

Finite element methods (FEM) of solution to this problem have a number of drawbacks; in particular they are computationally slow thereby severely limiting the number of alternative design decisions that can be tested. Earlier work involving the application of neural networks to similar structural engineering problems have proven

successful, demonstrating the feasibility of the neural network approach in terms of performance estimates and the speed with which results can be generated.

The performances of alternative types of neural networks are studied, and their performances are compared with previous analyses using the FEM method, in terms of accuracy and processing time. This thesis demonstrates that using an artificial neural network to analyze external reinforcement is feasible, and a well-trained artificial neural network reveals an extremely fast convergence and a high degree of accuracy.

CHAPTER 1
INTRODUCTION

1.1 Background to the Problem and Literature Review

1.1.1 The Need for External Reinforcement

Several modern cities are being faced with a rapidly deteriorating infrastructure. The cost of replacing entire deteriorated structures is prohibitive. Research methods have therefore focused on methods of strengthening existing structures. The rehabilitation of concrete structures is a challenging problem faced by engineers today. An acceptable method of repairing weak or damaged concrete structural members in bridges or buildings (due to damage, increased load and average daily traffic, marginal design, poor construction, inferior materials, etc.) is the use of external reinforcement. The advantages of this method over others such as post-tensioning or additional supports are lower cost, ease of application and maintenance, elimination of special anchorages and the ability to strengthen the structure while it remains in use (Krasto and Kim,1996). Reinforcement may be in the form of bonded steel plates or fiber-reinforced plastics (FRPs). The bonded steel plate effectively acts as a second layer of reinforcement, increasing flexural strength by up to 40%. Epoxy bonded steel plates have been extensively used to strengthen buildings in Switzerland, bridges in England, the former USSR, Poland and Japan. (Dussek,1990, Klaiber, 1987 and Maeda, 1980). However, the potential for corrosion at the epoxy/steel interface is a significant drawback of using bonded steel plates. Experiments to determine steel/adhesive interface residual strength after 15 years of exposure to weathering, at the

Swiss Federal Laboratories, confirmed this fact (MacDonald and Calder, 1982). Fiber-reinforced composites are now generally recognized to offer superior features. Carbon fiber-reinforced plastics (CFRPs) possess high specific stiffness, strength, and durability in saline/marine environments, are resistant to corrosion by chemicals, and are more cost-effective compared to bonded steel reinforcement. Lab tests in Switzerland and Germany have also shown that replacement of steel plates with CFRP, can reduce the total cost of a reinforcing project by about 20% (Mufti,1991). The weight of a structure reinforced with CFRP will also be significantly lower than one reinforced with steel plates.

1.1.2 Methods of Design/Analysis and their Limitations

Finite element analysis (FEM) has been used to calculate the behavior of externally reinforced structural concrete beams. However, the FEM approach is computationally expensive, often involving CPU times of several hours just for two-dimensional analysis (Saadmanesh and Malek, 1998) and is awkward to use when modeling geometrically complicated forms. More often the FEM approach requires a three-dimensional model thus increasing processing time by an order of magnitude. Both the lengthy CPU time and the inconvenience of building FEM models for this type of problem, reduce the number of alternative external reinforcement configurations that can be evaluated in a study and hinders the search for an optimal solution (Flood et al., 2000). This thesis evaluates an alternative approach to the problem, using neural networks developed from observations of the actual performance of beams tested in the laboratory. The objective of the research is to determine the viability of using neural networks to obtain accurate predictions of the performance of externally reinforced concrete beams, and to assess the speed at which the method can generate solutions.

Considerable research has been done involving the study of strengthening concrete structures through the application of external reinforcement. Hussain et al., (1995) have analyzed the *Flexural Behavior of Precracked Reinforced Concrete Beams Strengthened Externally by Steel Plates*. Their paper presents comprehensive data and interpretation on the plate bonding repair technique in terms of effects of plate thickness and end anchorage on ductility, ultimate load and mode of failure. Reinforced concrete beams were preloaded to 85% of their ultimate capacity and subsequently repaired by bonding steel plates of different thicknesses with and without end anchorages. Anchor bolts were used for end anchorages. The repaired beams showed higher strength than the original beams, provided the plates did not exceed a certain limiting thickness. Increasing the plate thickness changed the mode of failure of the repaired beams from flexural to premature failure, developed due to shear and/or tearing of the plate, causing a reduction in ductility. End anchorages to the bonded plates could not prevent the premature failure of the beams but improved ductility with decreasing significance as the plate thickness increased, and yielded a marginal improvement in ultimate strength. A procedure for designing the bonded plate is suggested, whereby the maximum shear and peeling stresses at the interface do not exceed the corresponding limiting values at which tearing of concrete takes place.

Chajes et al. (1994) have researched the *Flexural Strengthening Of Concrete Beams Using Externally Bonded Composite Materials*. A series of reinforced concrete beams were tested in four-point bending to determine the ability of externally-bonded composite fabrics to improve the beams' flexural capacity. The fabrics used were made of aramid, E-glass and graphite fibers, and were bonded to the beams using a two-part epoxy adhesive. The different fabrics were chosen to allow a variety of fabric stiffnesses and strengths to be studied. The external composite fabric reinforcement led to a 36 to 57% increase in flexural capacity and a 45 to 53% increase in flexural stiffness. For the beams reinforced with E-glass and graphite fiber fabrics, tensile failures occurred in the maximum moment region. The beams reinforced with aramid fabric failed due to the crushing of the concrete in the compression zone. In addition to the test results, an analytical model based on the stress-strain relationships of the concrete, steel and composite fabrics is presented. Using the model, beam response is computed and compared with the experimental results. The comparisons indicate that the flexural behavior of composite-fabric-reinforced concrete beams can be accurately predicted using the described method.

Chajes et al. (1995) have demonstrated *Shear Strengthening Of Reinforced Concrete Beams Using Externally Applied Composite Fabrics.* A series of twelve under-reinforced concrete beams was tested to study the effectiveness of using externally applied composite fabrics as a method of increasing a beam's shear capacity. Woven composite fabrics made of aramid, E-glass, and graphite fibers were bonded to the web of the T-beams using a two-component epoxy adhesive. The three different fabrics were chosen to allow various fabric stiffnesses and strengths to be studied. The beams were tested in flexure, and the performance of eight beams with external shear reinforcement was compared with the results of four control beams with no external reinforcement. All the beams failed in shear and those with composite reinforcement displayed excellent bond characteristics. For the beams with external reinforcement, increases in ultimate strength of 60 to 150 percent were achieved.

Sharif et al. (1994) studied the *Strengthening Of Initially Loaded Reinforced Concrete Beams Using FRP Plates*. The repair of initially loaded reinforced concrete beams with epoxy-bonded fiberglass reinforced plastic (FRP) plates is experimentally investigated. The RC beams are initially loaded to 85% of the ultimate flexural capacity and subsequently repaired with FRP plates, bonded to the soffit of the beam. The plate thickness is varied to assess the premature failure initiated at the plate curtailment zone due to the high concentration of shear and peeling stresses. Different repair and anchoring schemes are conducted in an effort to eliminate such failures and insure ductile behavior. The behavior of the repaired beams is represented by load-deflection curves and the different modes of failure are discussed. The results generally indicate that the flexural strength of the repaired beams is increased. The ductile behavior of the repaired beams increases as the plate thickness decreases. The use of an I-jacket plate provided a proper anchorage system and improved the ductility of beams repaired with plates of large thickness.

Shahawy et al. (1995) have investigated *Flexural Behavior Of Reinforced Concrete Rectangular Beams Strengthened With CFRP Laminates.* The reinforcement used was epoxy-bonded carbon fiber reinforced plastic (CFRP) laminate. Comprehensive test data are presented on the effect of CFRP laminates, bonded to the soffit of a beam, on the first crack load, cracking behavior, deflections, serviceability loads, ultimate strength and failure modes. Varying the number of laminates assesses the increase in strength and stiffness provided by the bonded laminates. The results generally indicate that the flexural strength of strengthened beams is significantly increased. Theoretical analysis using specially developed computer software is presented to predict the ultimate strength and moment-deflection behavior of the beams. The comparison of the experimental results with theoretical values is presented, along with an investigation of failure nodes.

Ritchie et al. (1991) have investigated the *External Reinforcement Of Concrete Beams Using Fiber Reinforced Plastics.* A series of 16 under-reinforced beams was tested to study the effectiveness of external strengthening using fiber-reinforced plastic (FRP) plates. Plates of glass, carbon and aramid fibers were bonded to the tension side of the beams using a two-part epoxy. FRP is attractive for this application due to its good tensile strength, low weight and resistance to corrosion. An iterative analytical method was developed to predict the stiffness and maximum strength in bending of the plated beam. Increases in stiffness (over the working load range) from 17 to 99 percent and increases in strength (ultimate) from 40 to 97 percent were achieved for the beams with FRP plates. Predicted and actual load-deflection curves showed fairly good agreement, although generally the theoretical curves were stiffer. Experimental failure did not occur in the maximum moment region on many of the beams, despite attempts at end anchorage to postpone local shear failure. The ultimate loads of the beams that did fail in the maximum region were within about 5 percent of predicted values.

Bohner and Burleigh (1998) studied *Thermal Non-Destructive Testing (TNDT) Of Composite Reinforcement Adhesively Bonded To Concrete Civil Structures That Were Reinforced With Composite Materials.* The first was an 8 foot tall column with a rectangular cross-section. This column was reinforced with adhesively bonded fiberglass shells to simulate a seismic retrofit. The second structure was a marine pier that was upgraded in deck loading capacity by the application of 4 types of composite reinforcement. TNDT was successful in detecting both simulated and actual disbands in several types of composite reinforcements. Information on the types of defects, which occur in these structures and their locations, has led to process improvements in the application of adhesively bonded laminated composites to steel reinforced concrete structures.

Jones and Hanna (1997) investigated *Composite Wraps For Aging Infrastructure*. The paper evaluated the ability of externally bonded composite wraps to increase the load-carrying capacity of concrete columns and beams. Failure loads were found to occur when the composite wraps reached a critical strain level.

Kaempen (1996) analyzed *Composite-Reinforced Concrete Building And Bridge Structures*. By eliminating the need to use steel as a concrete reinforcing material, and using composite laminate structures, the composite-reinforced structure will not suffer degradation caused by corrosion. The use of composite laminate structures enables an economical method for reducing the inertial mass of concrete load bearing structures used in multi-story buildings and highway overpasses, thereby making them safer when they experience seismic shocks and displacements caused by bombs or earthquakes.

Crasto et al. (1998) studied the *Rehabilitation Of Concrete Bridge Beams With Externally-Bonded Composite Plates*. The Air-Force Materials Directorate worked closely with Butler County in Ohio to demonstrate the feasibility of strengthening concrete beams in bridge decks with externally-bonded composite plates. As a result of these studies a graphite epoxy, AS4C/1919, was selected for the composite reinforcement, which was bonded to the concrete with an epoxy adhesive under ambient conditions. Tests were scaled up to 8.51-m concrete beams identical to those employed on a bridge. The bonding materials and processes employed in the lab trials were adapted for larger-sized beams.

Control beams and beams with composite plates were tested in flexure to provide baseline data for future comparisons, and the data compared with analytical predictions. An optimized bonding process was then employed to bond composite plates onto beams in the bridge. The integrity of the composite and adhesive bond was periodically monitored. After a predetermined outdoor exposure in the actual service environment, the beams were removed from the bridge and their residual flexural properties determined.

1.1.3 Discussion of ANN Applications and How they may be Applicable to this Problem

Artificial Neural Networks (ANNs) have been successfully utilized to solve problems in civil engineering and structures.

Cao et al. (1998) have studied the *Application Of Artificial Neural Networks To Load Identification*. Their study describes the application of an artificial neural network to identify the loads distributed across a cantilevered beam. The distributed loads are approximated by a set of concentrated loads. The paper demonstrates that using an artificial neural network to identify loads is feasible and a well-trained artificial neural network reveals an extremely fast convergence and a high degree of accuracy in the process of load identification for a cantilevered beam model.

Hegazy et al. (1998) analyzed the *Neural Network Approach For Predicting The Structural Behavior Of Concrete Slabs*. Neural networks have been used as a means to develop efficient predictive models of the structural behavior of concrete slabs. Four neural networks have been developed to model the load deflection behavior of concrete slabs, the final crack-pattern formation, and both the reinforcing-steel and concrete strain distributions at failure. The four neural networks were trained and tested using the experimental results of 38 full-scale slabs. The results of this study indicated the applicability of neural networks in predicting deflection, stress and strain failures of concrete slabs.

Highsmith, Alton, and Keshav (1997) have analyzed the *Use Of Measured Damage Parameters To Predict The Residual Strength Of Impacted Composites Through A Neural Network Approach.* The poor performance of composite materials under transverse quasi-static and impact loading is of major concern in their application as primary load carrying components in advanced structural applications. Their paper reports the result of a modeling exercise that used neural networks as a tool to predict the loss in residual strength resulting from localized damage in impacted laminates. Several measured fabric fracture parameters, as well as matrix damage areas, obtained from damaged laminates, were used as inputs. Neural networks were used to identify those damage parameters that were essential for effective residual strength prediction. The predicted strength values were found to be in very good agreement with those obtained from experiments indicating the suitability of neural networks in this application.

Mukherjee et al. (1996) analyzed the *Prediction Of Buckling Load Of Columns Using Artificial Neural Networks*. They developed a tool for the prediction of buckling load of columns, which required minimal assumptions using neural computing techniques. This concept can be extended to include a variety of column types in a single model for the buckling load of columns. This concept can also be further extended for reliability analysis for the network can also predict the standard deviation in the column strength.

Peetathawatchai and Connor (1996) studied the *Applicability Of Neural Network Systems For Structural Damage Diagnosis*. A general architecture of neural network systems for structural damage diagnosis and a methodology for designing the components of the architecture were developed and evaluated. Importance was placed on system design issues like choice of variables, the methodology for choosing the excitation and and type of vibrational signature for the monitored structure, the configuration of the neural networks, and their training algorithm. These design issues were first examined in detail for the case of single-point damage of a multispan beam, and the evaluation was then extended to the case of multi-point damage.

Alexander et al. (1996) investigated the *Application Of Artificial Neural Networks To Concrete Pavement Joint Evaluation*. Using a falling weight deflectometer, pertinent inputs required to evaluate deflection and stress load transfer efficiencies of concrete pavement joints, were experimentally determined. A database was generated using numerical integration of Westergaard-type integrals and was used to train a backpropagation neural network algorithm for joint evaluation. The resulting computer program is simple, efficient and precise, and can be used on site for immediate results. Its predictions were verified by comparisons with closed-form and finite-element solutions pertaining to data collected at three major civilian airports. It was demonstrated that significant savings could be achieved through the reduction of the dimensionality of the problem, which could be reinvested in broadening the range of applicability of the neural network.

Mikami et al. (1998) studied a *Neural Network System For Reasoning Residual Axial Forces Of High-Strength Bolts In Steel Bridges*. High-strength bolts of steel bridges gradually loosen in service, and have to be periodically inspected by experts with hammers. Mitsui Engineering & Shipbuilding Company Ltd., developed an automatic looseness detector of high-strength bolts. A system to reason the residual axial forces of high-strength bolts of steel bridges was built based on a neural network with the faculty of pattern recognition, and its reasoning accuracy was verified.

1.2 Aim, Research Objectives and Methodology

The aim of this research was to develop a neural network model of the performance of externally reinforced beams, that was sufficiently accurate to be of use to practicing engineers, and overcome the speed problem of existing methods of analysis, thus facilitating the search for an optimal design solution.

Research Objectives:

1. To select the most accurate neural network architecture for the problem.
2. To select the training procedure to be adopted for the network based on effectiveness of results generated.
3. To determine the independent variables to be used within the model which are significant to developing an accurate model.
4. To compare relative performance of ANNs and FEM in terms of accuracy and speed, to determine which is most appropriate for the problem at hand.

Methodology:

1. Collate data from tested beams to provide the training and testing patterns for the ANN models.
2. Train and test various neural paradigms and determine how far to train them.
3. Evaluate and compare the accuracy of predictions and speed of solution of different paradigms, by finding error in predictions and correlation coefficients.
4. Qualitatively evaluate and compare the best network with FEM in terms of accuracy, by observing the error in predicted values from the actual ones in either case.

5. Evaluate the processing time required for ANNs and FEM by observing the time required to emerge with an accurate solution in each case, by comparing with published results from FEM analysis.

CHAPTER 2
AN OVERVIEW ON THE USE OF NEURAL NETWORKS IN CIVIL ENGINEERING

2.1 Application Areas

The analysis of the performance of carbon fiber reinforced plastics applied to concrete beams is a typical civil engineering problem that involves prediction of a system's behavior based on a small set of laboratory observations. This requires the development of a mathematical model that will predict the performance of the system by scientifically extrapolating the results of the laboratory tests onto an undefined system. Finite Element Methods and Neural Networks are two such mathematical tools that can be applied for the solution of this problem. The inherent nature of Neural Networks in being able to detect patterns in a set of data, and extracting this pattern from a set of unknown data, makes them suitable for this analysis.

Artificial Neural Networks (ANNs) are applicable in Civil Engineering because they can address the problem areas described below: (Flood and Kartam, 1994)
Using ANNs, incomplete and uncertain data about a system can be mapped into a description of the state of the system. Civil engineering requires the interpretation of incomplete, unorganized data to recognize and formulate problems. An example is the problem of detecting damage in a building with thousands of structural members, by collecting data at various locations on the structure. This is an inverse problem that involves determination of a state from the observed behavior of a system.

Engineers have to analyze potential problem solutions and recognize solutions that deliver desired system behavior and eliminate those that will not. The potentially feasible solution space must then be refined. ANNs can help in the mapping from a space of desired system behaviors to a space of system form attributes that deliver that behavior.

Engineers must be able to predict complex behavior of systems from known system configuration and environmental loads to which the system is subjected. This is a problem of determining a mapping from cause to effect, which can be achieved by utilizing an ANN.

Another aspect of engineering analysis is the prediction of unmeasured attributes based on measured attributes, for example predicting how a model will behave beyond the bounds of its observed behavior. Evaluation of potential solutions to problems and selection of a solution from available alternatives, by estimating values of evaluation criteria (i.e. effects) using a set of known form and behavior attributes (i.e. causes) is an area where ANNs can be effectively used.

Engineering involves planning, scheduling and allocating resources for the activities required to construct a selected alternative. Mapping a selected alternative onto the activities required to build it, is an inverse mapping from the completed product (i.e. effect) to the activities that cause it to exist (i.e. causes). Once the needed activities are identified, the types and amounts of resources required for each activity must be determined, which involves two inverse mappings.

Monitoring the state of resource usage and prediction of resources required to complete a project, requires continuous monitoring. The prediction of final costs is a direct mapping from the existing state of the project and the resource usage to the total cost of the project.

The control and operation of dynamic systems as solutions to formulated problems, for example the control of a HVAC system within a large multi-function building, requires the determination of a control strategy. In determining the control strategy, the engineer must determine the mapping between the space of system states and the space of applied control forces. This is an inverse mapping problem. All of these problems can be classified into two categories: mapping from cause to effect for estimation and prediction, and inverse mapping from effects to possible causes. The nature of a neural network is to map from a set of input patterns to a set of output patterns.

ANNs are currently being applied in civil engineering in classification / interpretation tasks (i.e. inverse mapping from observations to known classes), diagnosis (i.e. inverse mapping from observed effect to cause), modeling (mapping from cause to effect), and control (inverse mapping from observed state to control forces).

One of the most straightforward and common methods of applying neural networks involves direct mapping from a vector of inputs to a vector of outputs. Examples of the use of ANNs as direct-mapping devices in civil engineering are:

- A system for selecting vertical formwork (Kamarthi et al., 1992). In this case, the network maps a set of inputs representing the situation in which a formwork system is implemented, onto a set of outputs representing recommendation levels for different formwork systems.

- Seismic hazard prediction (Wong et al., 1992). A network was trained to map a vector of inputs describing an earthquake, local geology and location data onto an output providing a forecast of its intensity at the location.

- Predicting tower-guy pre-tension (Issa et al., 1992). A vector describing key aspects of a guyed tower, is mapped onto an output that estimates the optimal pre-tension for the cables.

ANNs are applied to solve inverse mapping problems, such as:

- Damage detection in a structural frame (Wu et al., 1992). A modeled structural frame was artificially damaged and subjected to base excitation from several recorded earthquakes. The results from these analyses were then used as training cases to train a network to train a network to take to displacement observations and predict the location and severity of individual member damage.

- Detecting damage in structural systems (Szewczyk and Hajela, 1994). The ANN they developed is quickly able to acquire and compute the mapping from patterns of displacement observations and predict the location and severity of individual member damage.

The use of a modular approach in neural network development includes:

- Simulation of construction activity (Flood, 1990). A network was used to simulate a construction process. A number of modules representing sub-processes can be used to model a wide range of different processes by linking modules as required. Users can extend the construct by developing new modules suited to their particular needs.
- Estimating truck attributes from the strain response of the structure over which they are traveling (Gagarine et al., 1992). The network receives as input a vector of values representing the strain measured at a fixed point on a bridge girder during the passage of a truck. Each element in this vector represents strain at a different point in time. The network outputs a prediction of the velocity of the truck, the spacings of axles and the load on each axle. The network comprises of two modules, the first layer represents the basic class of the truck and the second layer estimates the axle loads, axle spacings or velocity of a truck. Modularization enabled the facilitation of the system to an acceptable level of accuracy and speed.

- Estimating earthmoving equipment production (Karshenas and Feng, 1992). The network comprises of a number of modules arranged in parallel, each dedicated to the prediction of speed of earthmoving equipment under certain environmental factors. The modular approach facilitates the inclusion and removal of new and obsolete equipment considered by the network.

Another area where ANNs are being applied in engineering is for creating models for making predictions and estimations. Some examples are:

- Estimating the strain behavior of a geomaterial in response to changes in its stress state.

- Prediction of flow of a river (Karunanithi et al., 1994). The ANN is trained to take a period of historical river flow data and to predict the flow immediately beyond that period.

- Use of an ANN as an estimator (Chao and Skibniewski, 1994). The use of an ANN to estimate the productivity of various construction activities, is described. Data needed for training the network was obtained from observations of bench-scale operations and construction simulations.

Many problems in Civil engineering require the output of a series of results over time. An example is the simulation of construction processes where a prediction is required of the likely behavior and performance of a system at successive points in time. The simulation system makes predictions about the next state of a system based on its current state. Using two or more previous states as inputs to the network can make an accurate prediction of the following step.

Applications of this approach include:

- Simulating dynamic loading on structures caused by environmental factors, such as winds.
- Extrapolating the time series of ground accelerations during a seismic event.
- Modeling the thermodynamic behavior of a building or its components.
- Predicting the dynamic response of a structure to sudden loading
- Projecting over a period of time the flow response of a drainage system to a storm.

Optimization problems are characterized by the need to select a viable solution from a large number of alternatives, which is optimal according to some measure of performance. Typically, finding an overall optimum solution is very difficult. Neural networks can often overcome this limitation, providing quick solutions that are near optimal. Examples of such problems are:

- Determining the optimal numbers and spacings for access shafts to a tunnel so that construction time is minimized.
- Arranging the cutting of material (such as rebars) so that wastage is minimized.

- Scheduling activities so that the demand for equipment and labor resources are as constant as possible.

2.2 Rationale for Use in Analysis of External Reinforcement Performance

Neural Networks can be effectively used in engineering problems involving the prediction of unmeasured attributes based on measured attributes, such as in the prediction of how a model will behave beyond the bounds of its observed behavior.

In the analysis of external reinforcement on RC beams, the deflection of the beam based on other known criteria, often needs to be found to determine stability of the beam. The measured attributes in this case are the load on the beam, the configuration of external reinforcement (whether placed on shear or tension face or both or none), while deflection needs to be known when measured bounds are exceeded.

Neural networks achieve the ability to predict by ‘learning’ the data patterns in the training set. Depending on the paradigm or architecture selected for training, neural networks use either hidden neurons with weights corresponding to the learning rate, or smoothing factors for genetic adaptive training, to hone in on a solution. The effectiveness of training is verified by evaluation of the learnt pattern on a test set. Training continues until the network reaches the criteria set by the user for termination of training. Termination of training may be set after a pre-determined number of epochs (passes through the training patterns) or after a specified number of events is reached after minimum error is attained. The accuracy of prediction is however limited to the nature of the data the network is trained upon. The determination of when to stop training is also an important criteria since excessive training could cause the network to memorize the training set and not generalize well on new data.

CHAPTER 3
EXPERIMENTAL SETUP OF TESTED BEAMS

A concerted research effort was carried out between 1994 and 1999, by the Wright Laboratory Airbase Survivability Section (WL/FIVCS) to explore the strengthening effect of CFRP laminates applied to reinforced concrete beams, both in the tensile and shear areas of the beam (Ross et al. (1994)). The data from the WL/FIVCS project was used for a feasibility study using neural networks to predict the deflection of externally reinforced concrete beams.

Figure 1 shows the cross-section of the beams used in the WL/FIVCS study while Figure 2 shows the beam length and positioning of the loads. In all beam samples, the cross-section was kept to 200mm by 200mm square, and the diameter of the compression steel was kept constant at 9.5 mm. However, the diameter of the tensile steel bars varied from 9.5 mm to 22 mm between sample beams. Three-ply CFRP laminates oriented at 0°/90°/0° were bonded to either the tension face of the beam only or both the tension face and the sides (shear faces) of the beam. A total of 10 beams were tested, with the various configurations shown in Table 1.

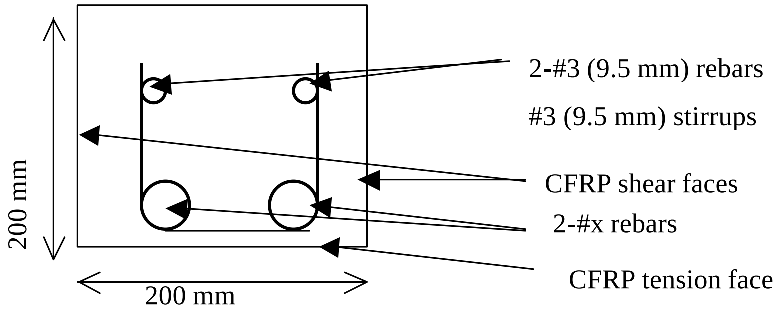


Figure 1: X-Section of Sample Beams

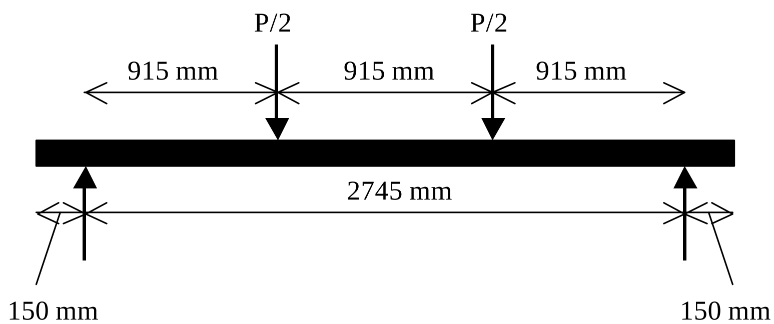


Figure 2: Beam Loading Configuration.

Table 1: X-Section Areas Of Tensile Steel And External Reinforcement Configurations

		External Reinforcement		
Beam Test	***X-Section Area of Tensile Steel (2 bars)***	***None***	***Tensile Face***	***Shear Face***
1	568 mm^2 (19 mm bar dia)	Y		
2	142 mm^2 (9.5mm bar dia)	Y		
3	568 mm^2 (19 mm bar dia)		Y	
4	142 mm^2 (9.5mm bar dia)		Y	
5	568 mm^2 (19 mm bar dia)		Y	Y
6	142 mm^2 (9.5mm bar dia)		Y	Y
7	774 mm^2 (22 mm bar dia)	Y		
8	774 mm^2 (22 mm bar dia)		Y	
9	258 mm^2 (13 mm bar dia)	Y		
10	258 mm^2 (13 mm bar dia)		Y	

Loads were applied to each beam, starting at 0 KN and gradually increasing until the beam failed. The loads were noted at approximately every 5mm increase in deflection. A total of 254 observations resulted from these experiments.

The data generated from loading the beams can be found in the Appendix B. The 254 observations made in the beam deflection experiments were divided into two sets: one for training the neural network; and the second for validating its performance after training. For each beam, 10% of the observations were selected at random for the validation test, providing a training set of 229 beam deflection observations, and a test set of 25 beam deflection observations. A conventional feedforward backpropagation neural network (Neuroshell2 by Ward Systems Group, 1995) was used to train and test the data.

CHAPTER 4
DEVELOPMENT OF THE ANN MODEL

4.1 Establishing Training and Testing Patterns

This chapter presents the setup of neural paradigms used in analysis of the data, and training performance of the different models.

Neural networks mimic the human brain's ability to classify patterns or make predictions or decisions based on past experience. The Neuroshell software (Ward Systems) is able to 'learn' patterns from training data and make its own classifications, predictions, or decisions when presented with new data. However the results obtained from Neuroshell are not always absolutely accurate, especially if patterns fed are in some way conflicting or incomplete.

A total of 10 beams were tested, with configurations as shown in Table 1. Using a total of 254 sets of observations for each beam, one set of data was used to train the network, while 10% of the observations were selected at random for testing the validity of the network.

For this problem, using the Neuroshell2 software, the neural network paradigms adopted were the Backpropagation method (3 layer simple, 3 layer advanced, 4 layer advanced), 3 and 4 layer Backpropagation networks with Jump Connections, a GRNN network, and Ward nets (Networks involving multiple hidden slabs with different activation functions, developed by Ward systems).

The inputs for the networks used were load values of beams, area of tensile steel and CFRP (external reinforcement represented by 0 for no external reinforcement, 1 for external reinforcement on tension face only and 2 for external reinforcement on both tension face and shear face). The output was predicted deflection values for the beams. It is assumed that load, area of steel and type of external reinforcement influence the deflection of the beam. Each type of input is considered a continuous variable that represents the strength of the input neuron, by the network.

The objective of training the network was to enable it to generalize future data and produce the most accurate answers. A feature of Neuroshell that was utilized in analysis is "*Net-Perfect*". Net-Perfect creates an entirely separate set of data patterns from the entire set of patterns, called a test set. The test set is used to evaluate how well the network is predicting or classifying. The test set used was 10% of the size of the training set. Data patterns for the test set were either selected at random by the computer, or were selected in a rotational manner from the entire set of data. Net-Perfect functions by minimizing the mean of the error factors on the test set. The Net-Perfect interval was normally set to 200, and it was set to 225 when Turboprop was being used.   Another feature of Neuroshell that was utilized is "*Turboprop*". Turboprop operates faster than other Backpropagation methods, and is not sensitive to learning rate and momentum. Training proceeds through an entire epoch before weights on neurons are updated. All the weight changes are added and are updated at the end of the epoch. The Net-Perfect interval has therefore got to be set to the number of training patterns.

Training was stopped when either the average error value fell below a pre-defined threshold or the number of training epochs (1 epoch is one run through the entire set of patterns) exceeded a specified number, or the number of events since the last minimum error exceeded a specified number. This depended on the neural paradigm adopted. For the Backpropagation and Ward networks, training was stopped when the number of events since minimum error for the test set reached 40,000 events. For the GRNN network, an initial smoothing factor was used and termination of training was set to no improvement exceeding 1% in 20 generations of genetic breeding.

Definitions of some terminology used in the description of neural paradigms, is given below:

Learning Rate: Each time a pattern is presented to the network, the weights leading to an output node are modified slightly during learning in the direction required to produce a smaller error the next time the same pattern is presented. The amount of weight modification is the learning rate times the error. The larger the learning rate, the larger the weight changes, and the faster the learning will proceed.

Momentum: Large learning rates often lead to oscillation of weight changes and learning never completes, or the model converges to a solution that is not optimum. One way to allow faster learning without oscillation is to make the weight change a function of the previous weight change to provide a smoothing effect. The momentum factor determines the proportion of the last weight change that is added into the new weight change.

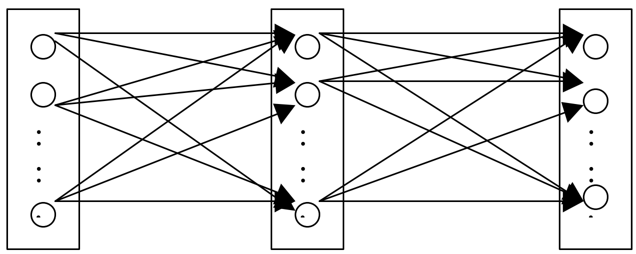
Neuron: A neuron is a basic building block of simulated neural networks which processes a number of input values to produce an output value. Usually the neuron sums the input values and then applies a non-linear function to the sum to arrive at the output value.

Pattern: A pattern is a single record (or row) of variables that influence a network's predictions or classifications.

Weights: As neurons pass values from one layer of the network to the next layer, the values are modified by a weight value in the link that represents connection strengths between the neurons.

Training Paradigms

1) 3-Layer Backpropagation Network



Input Slab	Hidden Slab	Output Slab
Neurons: 3	Neurons: 17	Neurons: 1
Scale Function: Linear(0,1)	Scale Function: Logistic	Scale Function: Logistic
Learning rate 0.6	Learning rate 0.6	Learning rate 0.6
Momentum 0.9	Momentum 0.9	Momentum 0.9
Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3

Figure 3: 3-Layer Simple Backpropagation Network.

Backpropagation networks are known for their ability to generalize well on a wide variety of problems. They are used for a vast majority of working neural network applications. Fig.3 shows the standard type of backpropagation network in which every layer is connected or linked to the immediately previous layer. The number of input and output neurons was set equal to the number of inputs and outputs respectively. The number of hidden neurons was calculated as

# of hidden neurons= ½(Inputs + Outputs) + sq. root of number of patterns in training file.

To calculate the number of neurons, the following formula was found to be better: # of hidden neurons = 2 * square root (number of inputs or defining characterisitics + the number of outputs or classifying characteristics) rounded down to the nearest integer. The complexity was set to very simple, Net-Perfect interval to 200, pattern selection as random, and save training on best test set.

2) <u>3-Layer Backpropagation Network Using Turboprop</u>

Figure 4 shows a backpropagation network in which every layer is connected or linked to the immediately previous layer. "*Turboprop*" is a training method that operates much faster in the batch mode than other Neuroshell2 backpropagation methods, and has the additional advantage that it is not sensitive to learning rate and momentum. Training proceeds through an entire epoch (a complete set of training patterns) before the weights are updated by adding all the weight changes.

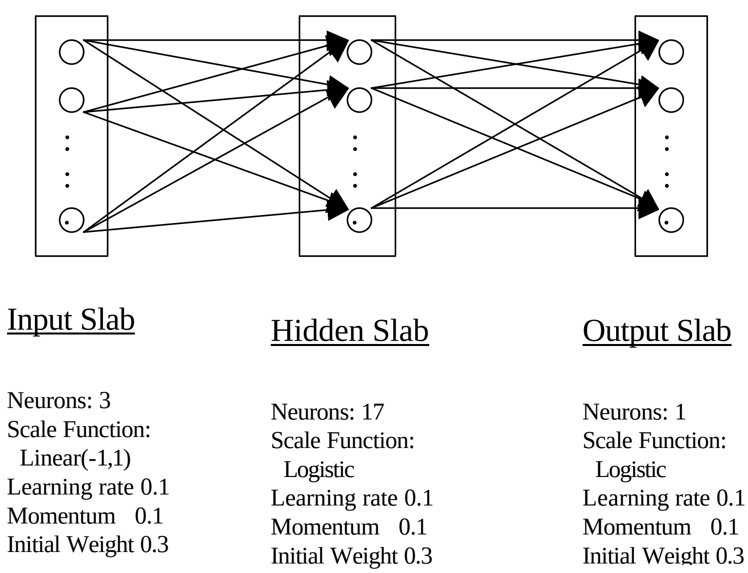
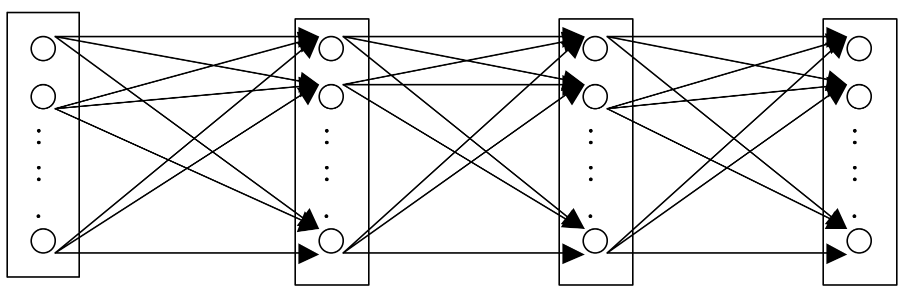


Figure 4: 3-Layer Backpropagation Network using Turboprop.

The number of input and output neurons was again set equal to the number of inputs and outputs respectively. The number of hidden neurons was calculated as # of hidden neurons= ½(Inputs + Outputs) + sq. root of no. of patterns in training file.

Pattern selection was rotational, save training was set to best test set, Net-perfect interval to 200, and stop training was set to events since minimum average error > 40000. Missing values were considered error conditions. Training was done with training and test set in memory. Learning rate, momentum and initial weights were selected by the network, which is the function of Turboprop.

3) <u>4- Layer Backpropagation using Turboprop</u>

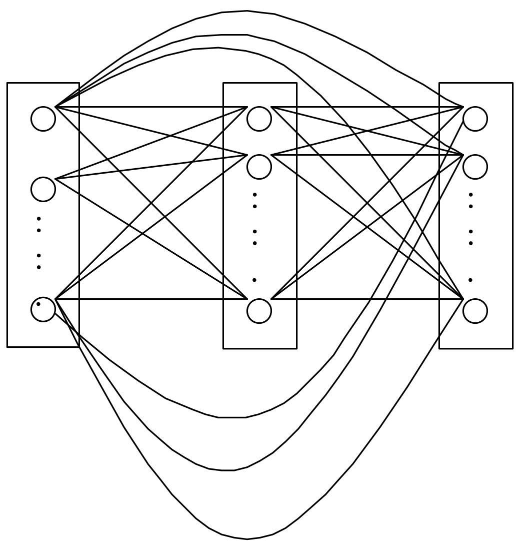


<u>Input Slab</u>	<u>Hidden Slab</u>	<u>Hidden Slab</u>	<u>Output Slab</u>
Neurons: 3	Neurons: 8	Neurons: 8	Neurons: 1
Scale Function: Linear(-1,1)	Scale Function: Logistic	Scale Function: Logistic	Scale Function: Logistic
Learning rate 0.1	Learning rate 0.1	Learning rate 0.1	Learning rate 0.1
Momentum 0.1	Momentum 0.1	Momentum 0.1	Momentum 0.1
Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3

Figure 5: 4-Layer Backpropagation using Turboprop

Figure 5 shows a backpropagation network using Turboprop, in which every layer is connected or linked to the immediately previous layer. Use of two hidden layers facilitates further training on the data. Pattern selection was rotational, save training was set to best test set, Net-perfect interval to 200, and stop training was set to events since minimum average error > 40000. Missing values were considered error conditions. Training was done with training and test set in memory. Learning rate, momentum and initial weights were selected by the network, which is the function of Turboprop.

4) <u>3-Layer Backpropagation, with Jump Connections.</u>

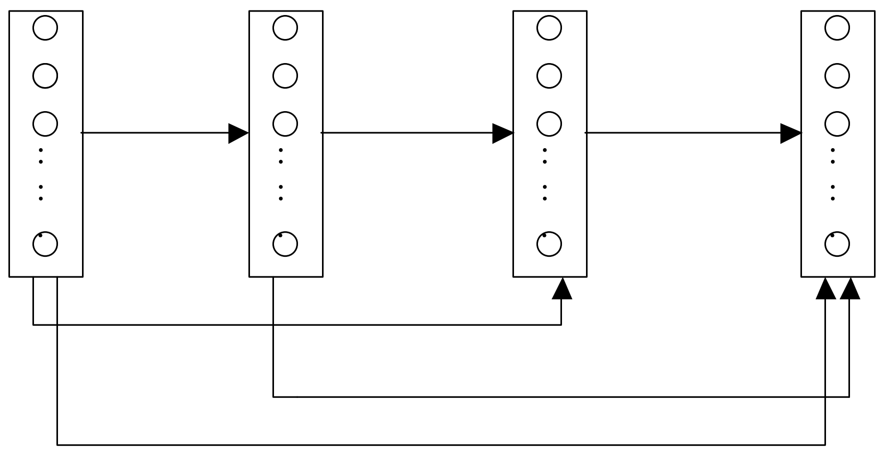


Input Slab	Hidden Slab	Output Slab
Neurons: 3	Neurons: 17	Neurons: 1
Scale Function: Linear(-1,1)	Scale Function: Logistic	Scale Function: Logistic
Learning rate 0.1	Learning rate 0.1	Learning rate 0.1
Momentum 0.1	Momentum 0.1	Momentum 0.1
Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3

Figure 6: 3-Layer Backpropagation with Jump Connections

"*Jump Connections*" imply that every layer is connected or linked to every previous layer, in the backpropagation model. Pattern selection was set to rotational, save training was set to best test set, Net-perfect interval to 225(equal to one epoch), and stop training was set to events since minimum average error > 40000. Missing values were considered error conditions. Training was done with training and test set in memory. Learning rate, momentum and initial weights were selected by the network, which is the function of Turboprop.

5) <u>4-Layer Backpropagation with Jump Connections</u>

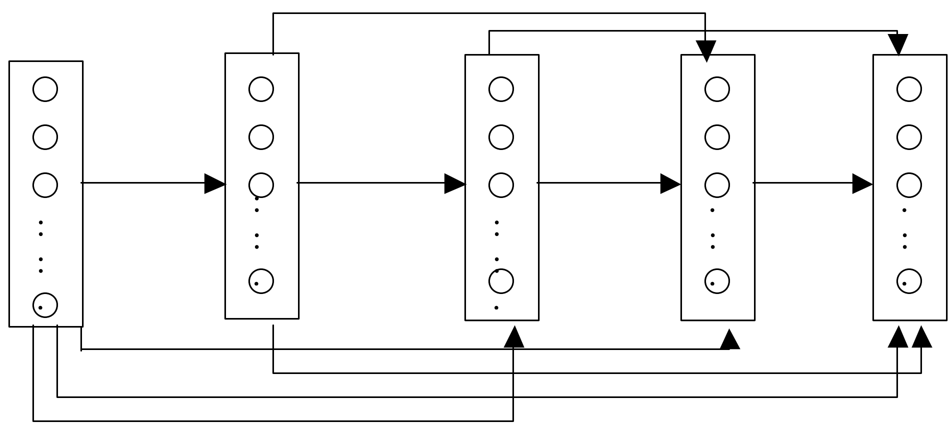


<u>Input Slab</u>	<u>Hidden Slab</u>	<u>Hidden Slab</u>	<u>Output Slab</u>
Neurons: 3	Neurons: 8	Neurons: 8	Neurons: 1
Scale Function:	Scale Function:	Scale Function:	Scale Function:
Linear(-1,1)	Logistic	Logistic	Logistic
Learning rate 0.1	Learning rate 0.1	Learning rate 0.1	Learning rate 0.1
Momentum 0.1	Momentum 0.1	Momentum 0.1	Momentum 0.1
Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3

Figure 7: 4-Layer Backpropagation with Jump connections

A 4-layer Backpropagation Network shown in Fig. 7 uses 2 hidden layers with the same activation function. This and the subsequent 5-layer paradigm were used to test whether they provided improvements on the 3-Layer backpropagation model. Pattern selection was set to rotational, save training was set to best test set, Net-perfect interval to 225(equal to one epoch), and stop training was set to events since minimum average error > 40000. Missing values were considered error conditions. Training was done with training and test set in memory. Learning rate, momentum and initial weights were selected by the network, which is the function of Turboprop.

6) <u>5-Layer Backpropagation, with Jump Connections</u>



Input Slab	Hidden Slab	Hidden Slab	Hidden Slab	Output Slab
Neurons: 3	Neurons: 6	Neurons: 6	Neurons: 6	Neurons: 1
Scale Function: Linear(-1,1)	Scale Function: Logistic	Scale Function: Logistic	Scale Function: Logistic	Scale Function: Logistic
Learning rate 0.1	Learning rate 0.1	Learning rate 0.1	Learning rate 0.1	Learning rate 0.1
Momentum 0.1	Momentum 0.1	Momentum 0.1	Momentum 0.1	Momentum 0.1
Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3

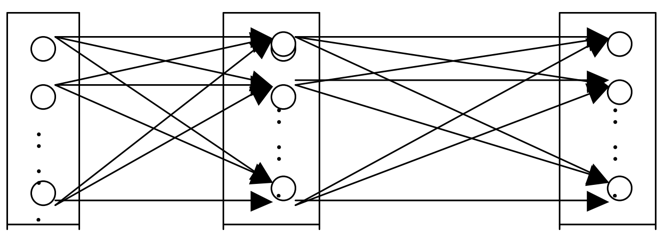
Figure 8: 5-Layer Backpropagation, with Jump connections

As shown in Figure 8, the use of 3 hidden slabs with every layer connected to every previous layer, enables the network to run through a greater number of training sequences, which may result in a superior trained network.

Pattern selection was set to rotational, save training was set to best test set, Net-perfect interval to 225(equal to one epoch), and stop training was set to epochs> 1000, for the training set. Missing values were considered error conditions. Training was done with training and test set in memory. Learning rate, momentum and initial weights were selected by the network, which is the function of Turboprop.

7) <u>GRNN Network</u>

GRNN networks train quickly on sparse data sets. GRNN is a 3-layer network, where there must be one hidden neuron for each training pattern.



<u>Input Slab</u>	<u>Hidden Slab</u>	<u>Output Slab</u>
Neurons: 3 Scale Function: Linear (0,1) Smoothing factor = 3.329E-02	Neurons: 255 Smoothing factor = 3.329E-02	Neurons: 1 Smoothing factor = 3.329E-02

Figure 9: GRNN network

The number of hidden neurons is the number of patterns in the training set for a GRNN network. (Fig.9) There are no training parameters such as learning rate and momentum as there are in Backpropagation networks, but there is a smoothing factor that is used when the network is applied to new data. The smoothing factor determines how tightly the network matches its predictions to the data in the training patterns. While using Neuroshell2, the smoothing factor is automatically computed by Net-Perfect. The number of neurons in the input layer corresponds to the number of inputs, and the number of neurons in the output layer is the number of outputs. GRNN networks work by comparing patterns based upon the ‘distance’ between them. The distance metric selected for this problem was the Vanilla (Euclidean) and a Genetic Adaptive method was adopted to facilitate selection of appropriate smoothing factors. Missing values were considered to be error conditions. Genetic breeding was applied with a pool size of 20, with automatic termination for 20 generations with no improvement of 1%.

8) Ward Networks (implementing multiple hidden slabs with different activation functions).

“*Ward Networks*” are special neural network paradigms developed by Ward Systems Group Inc. This network uses a backpropagation method with 2 hidden slabs, usually each with a different activation function. Pattern selection was set to rotational, save training was set to best test set, Net-perfect interval to 225(equal to one epoch), and stop training was set to events since minimum average error > 40000.

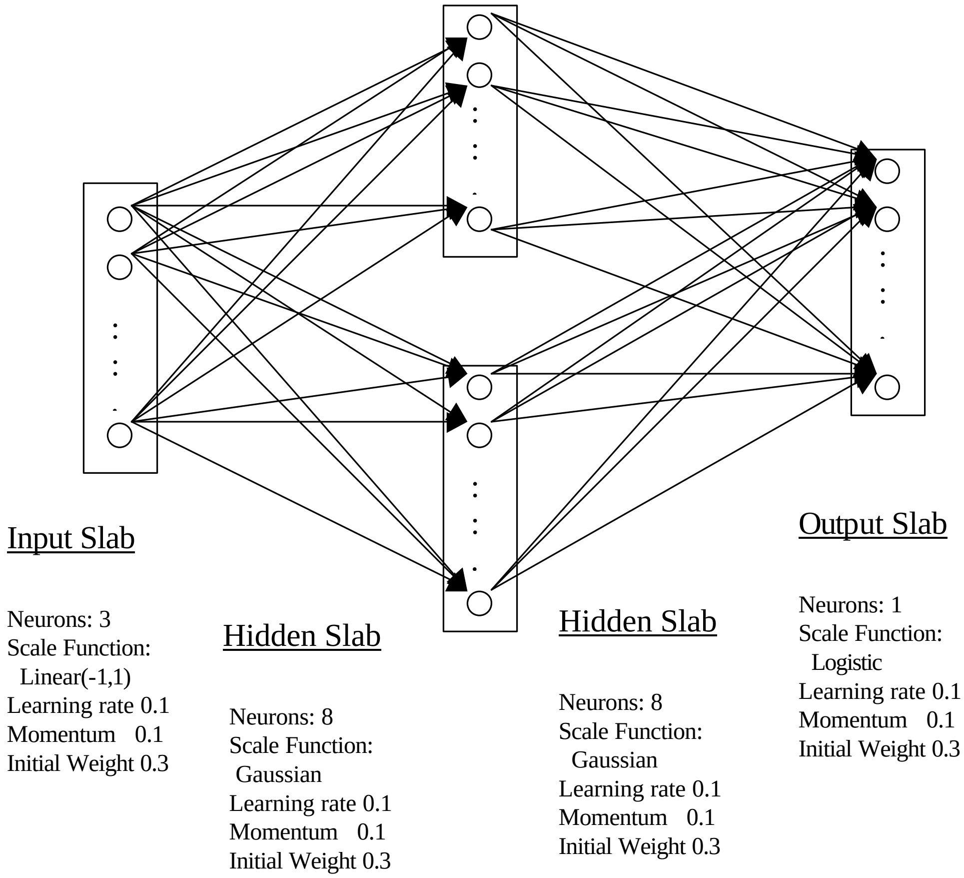
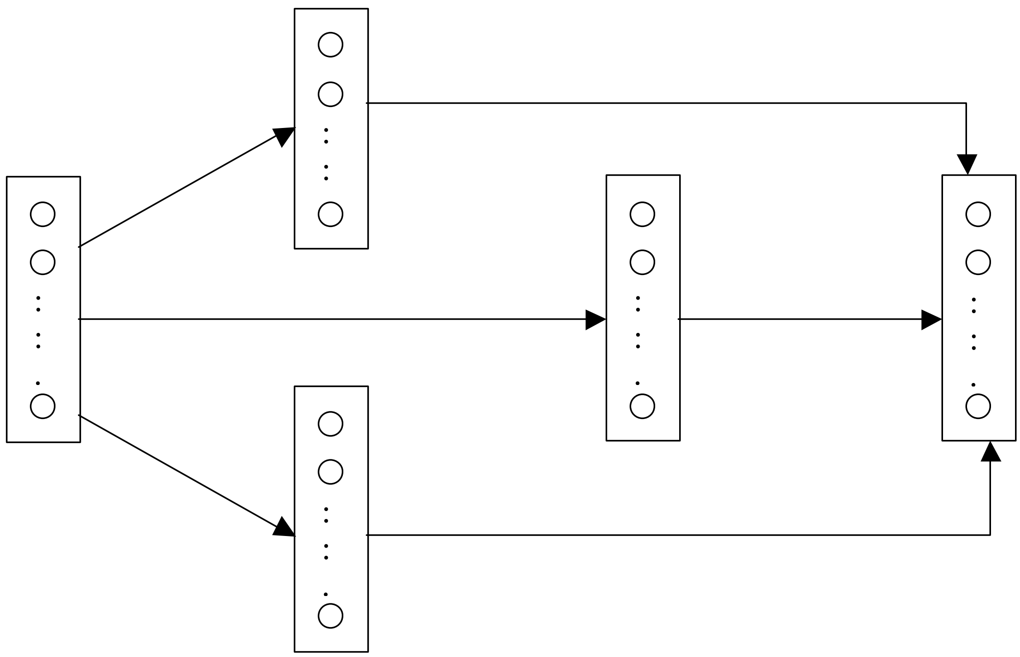


Figure 10: Ward Networks with 2 Hidden Layers

Missing values were considered error conditions. Training was done with training and test set in memory. By applying different activation functions to hidden slabs, different features in a pattern processed through a network can be detected. Combining the different feature sets in the output layer may lead to a better prediction, since different 'views' of the data are obtained.

9) Ward Networks with 3 hidden layers



Input Slab	Hidden Slab	Hidden Slab	Hidden Slab	Output Slab
Neurons: 3	Neurons: 6	Neurons: 6	Neurons: 6	Neurons: 1
Scale Function: Linear(-1,1)	Scale Function: Gaussian	Scale Function: Tanh	Scale Function: Gaussian Comp	Scale Function: Logistic
Learning rate 0.1	Learning rate 0.1	Learning rate 0.1	Learning rate 0.1	Learning rate 0.1
Momentum 0.1	Momentum 0.1	Momentum 0.1	Momentum 0.1	Momentum 0.1
Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3	Initial Weight 0.3

Figure 11: Ward Networks with 3 Hidden Layers

This network uses a backpropagation method with 3 hidden slabs. Different activation functions applied to hidden layer slabs detect different features in a pattern processed through the network. Combining the two feature sets in the output layer may lead to a better prediction. Pattern selection was set to rotational, save training was set to best test set, Net-perfect interval to 225(equal to one epoch), and stop training was set to events since minimum average error > 40000. Missing values were considered error conditions. Training was done with training and test set in memory.

10) Ward Networks with 2 hidden layers (with input connected to output layer)

This network uses a 2- layer backpropagation method with a connection between input and output layers. Each hidden layer has a different activation function. Pattern selection was set to rotational, save training was set to best test set, Net-perfect interval to 225(equal to one epoch), and stop training was set to events since minimum average error > 40000. Missing values were considered error conditions. Training was done with training and test set in memory.

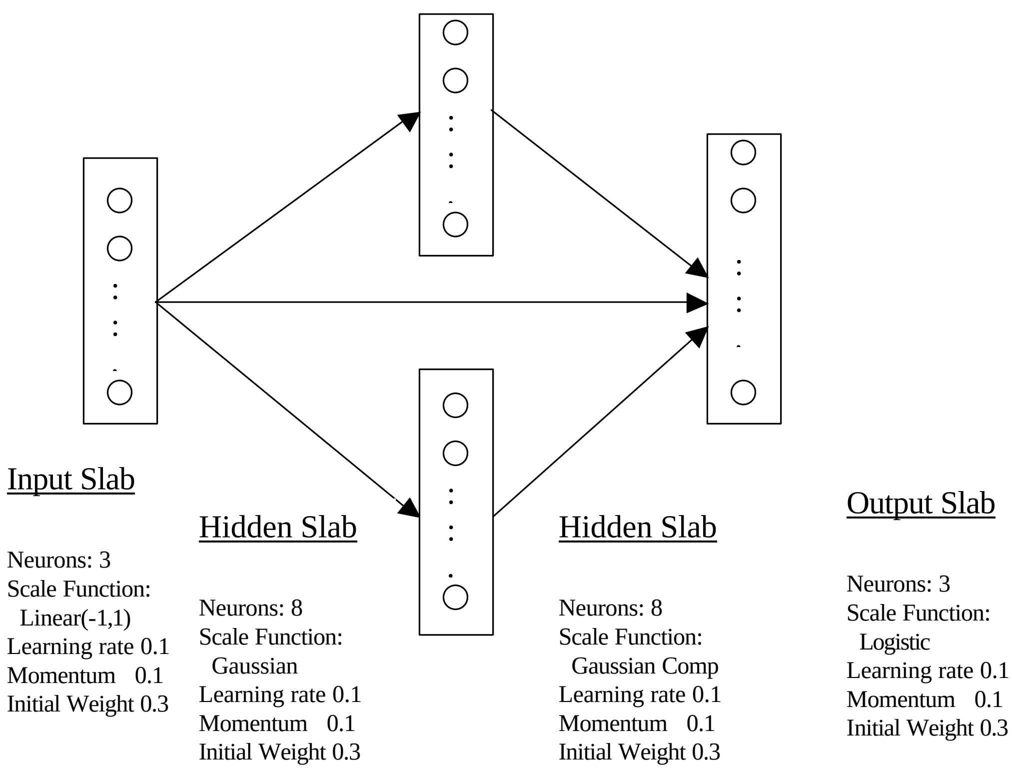


Figure 12: Ward Network with 2 Hidden Layers (with Input-Output Layers Connected)

4.2 Training Results

The results of training were analyzed in terms of the '*Perfect model*', which was assumed to have a correlation coefficient of 1.0, Mean Absolute Error of 0, and training time in the order of a few seconds.

Error was measured for each observation as the absolute difference between the neural network predicted deflection and the actual beam deflection. The most accurate network was found to be the 5-layer Backpropagation network with jump connections. The mean absolute error in the network was found to be 0.909 mm with a correlation factor to the perfect model of 0.973. Training time was approximately 20 seconds. Training was stopped when epochs since minimum average error exceeded 1000 on the training set. Using the GRNN network, with a smoothing factor of 0.03329, the mean absolute error was obtained as 1.86 mm, with a correlation factor to the perfect model of 0.9326. Training time was approximately 30 seconds, training being terminated when genetic breeding failed to produce an improvement greater than 1% over 20 generations. A 3-layer simple backpropagation network gave good results too, using a learning rate of 0.6 and a momentum of 0.9. Learning rate, as defined earlier, is the factor by which weights leading to an output node are modified, resulting in a smaller error the next time the same pattern is presented. Momentum is a factor that determines the proportion of the last weight change that is added to the new weight change, in order to allow for faster learning without oscillation of weight changes (which would result in a non-optimal solution). Different numbers of hidden neurons were applied and the network performance was analyzed. The optimal network configuration was determined to be a single hidden layer comprising 17 hidden neurons. Training lasted for 22.5 hours before there was no further significant improvement in network performance. At this stage, the mean absolute error in the backpropagation network was found to be 1.68 mm. The correlation between the backpropagation model and the perfect model was found to be 0.94. The 4-layer backpropagation method with jump connections, resulted in a mean absolute error of 2.399mm, and a correlation factor to the perfect model of 0.9058. Training time for this model was of the order of 30 seconds. Training was stopped when events since minimum average error exceeded 40,000.

The correlation factors were validated from the set of patterns (the 10% randomly selected test patterns) not used for training. The performance of each neural paradigm was tested on the test set of data, to determine the correlation coefficients and mean absolute errors generated on the Test data set. A correlation factor very close to 1.0 would indicate satisfactory performance, while a Correlation coefficient close to 0 would indicate poor performance. A low Mean Absolute error value would also represent good performance. On the Test set, the 5-Layer Backpropagation network with Jump connections had the best performance, with Correlation coefficient =0.9, and Mean Absolute error = 2.2mm. The results are summarized in the below table.

However, the Backpropagation networks with jump connections gave higher maximum absolute errors. The worst performance was of the Ward networks Backpropagation model with 2 hidden layers. It resulted in a mean absolute error of 6.687mm with a correlation factor to the perfect model of 0.5064 on the training set. Actual training performance data for all the networks are included in Appendix ‘A’. Test set performance data are in Appendix C.

Table 2: Ranking Of Neural Paradigms In Order Of Performance.

Rank	Network type	Mean Abs Error (mm)	Training time	Correlation coefficient
1	5-Layer Backprop with Jump connections	2.2	20 seconds	0.9
2	Simple 3-Layer backpropagation	1.98	22.5 hours	0.94
3	GRNN network	2.64	30 seconds	0.95
4	Ward Network: 3 hidden layers	2.7	40 seconds	0.92
5	4-Layer Backprop with Jump connections	2.8	35 seconds	0.91
6	Ward Network 2 hidden layers, input-output layers connected	3.34	30 seconds	0.91
7	3-Layer Backprop with Jump connections	3.8	35 seconds	0.9
8	3-Layer Backprop using Turboprop	3.64	35 seconds	0.87
9	4-Layer Backprop using Turboprop	6.52	30 seconds	0.79
10	Ward Network: 2 hidden layers	6	65 seconds	0.718

CHAPTER 5
PERFORMANCE AND ANALYSIS OF THE ANN MODELS

5.1 Relative Performance of the ANNs

This chapter looks at the performance of ANN models relative to each other. This is achieved by comparing performance parameters such as correlation coefficient among the training sets and test sets.

The performance of the ANNs was measured in terms of r-sqaured, Mean squared error, Mean Absolute error, Min absolute error, Max absolute error, and Correlation coefficient r. A definition of these terms is given below:

R-squared: This is the square of the correlation coefficient. A perfect fit would result in an R squared value of 1, a very good fit near 1, and a very poor fit near 0.

Mean Squared Error: This is the mean over all patterns in the file of the square of the actual value minus the predicted value, i.e., the mean of |actual-predicted|.

Mean Absolute Error: This is the mean over all patterns of the absolute value of the actual minus predicted, i.e., the mean of |actual – predicted|.

Min absolute Error: This is the minimum of |actual-predicted| of all patterns.

Max absolute error: This is the maximum of |actual-predicted| of all patterns.

Correlation Coefficient: This is a statistical measure of the strength of the relationship between the actual and predicted outputs. This can range from +1 to –1, indicating a positive or negative linear relationship.

Table 3 below summarizes the training performances of the neural paradigms used for data analysis:

Table 3: Training Performance Of Neural Paradigms.

	R-squared	Mean Squared Error	Mean Abs Error	Min Abs Error	Max Abs Error	Correlation Coefficient
Simple 3 -layer backpropagation	0.9584	7.132	1.678	0.000	18.55	0.983
3-layer Backprop using Turboprop	0.8088	32.8	3.52	0.00	23.72	0.899
4-layer Backprop using Turboprop	0.577	72.437	6.555	0.046	29.98	0.783
3 layer Backprop with Jump Connections	0.8511	25.53	3.583	0.000	20.74	0.925
4 layer Backprop with Jump Connections	0.9058	16.154	2.399	0.000	23.01	0.952
5 layer Backprop with Jump Connections	0.9730	4.629	0.909	0.000	28.020	0.987
GRNN network	0.9326	11.568	1.861	0.000	15.228	0.967
Ward Network: 2 hidden layers	0.5064	84.668	6.687	0.000	31.935	0.748
Ward Network: 3 hidden layers	0.8686	22.537	2.97	0.00	21.943	0.933
Ward Network 2 hidden layers, In-Out connected	0.8547	24.93	3.59	0.000	22.614	0.925

Table 4: Test Set Performance Of Neural Paradigms

	R-squared	Mean Squared Error	Mean Abs Error	Min Abs Error	Max Abs Error	Correlation Coefficient
Simple 3 -layer backpropagation	0.8827	16.844	1.980	0.003	18.55	0.940
3-layer Backprop using Turboprop	0.7576	34.814	3.636	0.00	22.512	0.874
4-layer Backprop using Turboprop	0.5556	63.84	6.516	0.325	24.249	0.789
3 layer Backprop with Jump Connections	0.8015	28.516	3.797	0.00	20.75	0.902
4 layer Backprop with Jump Connections	0.8254	25.082	2.805	0.220	23.01	0.909
5 layer Backprop with Jump Connections	0.7900	30.17	2.2	0.00	28.02	0.896
GRNN network	0.8851	16.503	2.641	0.092	15.228	0.949
Ward Network: 2 hidden layers	0.4985	72.034	6.008	0.00	26.26	0.718
Ward Network: 3 hidden layers	0.8363	23.513	2.696	0.000	21.94	0.92
Ward Network 2 hidden layers, input-output layers connected	0.8183	26.097	3.340	0.000	20.855	0.905

Performance Graphs of the Neural Paradigms

The below graphs are scatter plots of predicted versus actual deflection. Points lying along the 45° line on the plot indicates an accurate result. The test set data only was used in plotting the graphs. The accuracy of the network is demonstrated by its ability to predict well on the test data. The 45° line is shown in white on the graphs. The Mean Absolute Error value is the average distance on the plot that points are distant from the 45° line.

<u>Simple 3-layer Backpropagation network</u>

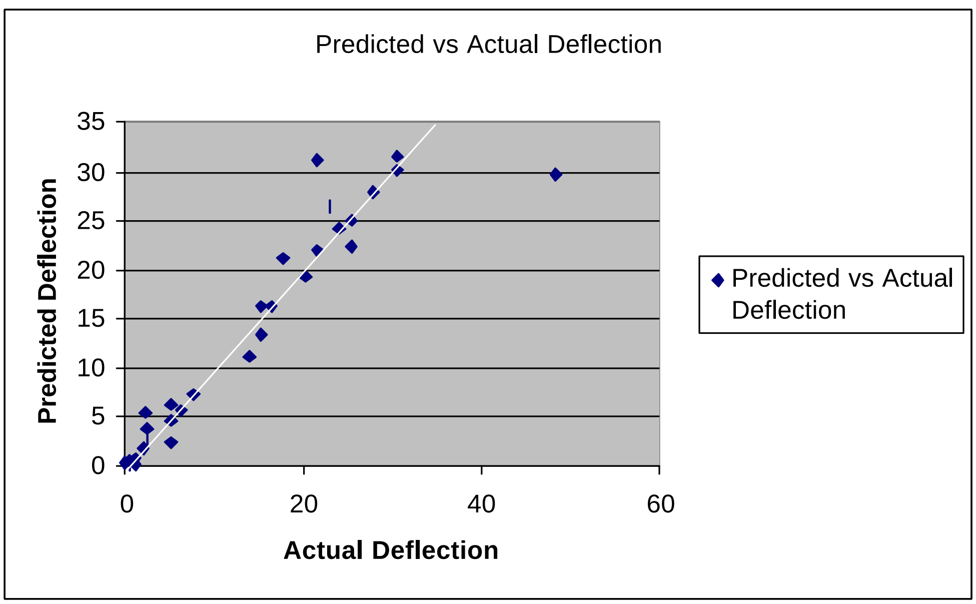


Figure 13: Scatter Plot of 3-Layer Backpropagation Model

Figure 13 shows fairly good accuracy of predicted deflections to actual deflections on the test set. The mean Absolute error was 1.98 mm and the correlation coefficient was

0.940 for this model. The 3-Layer simple backpropagation model was a good predictor for this problem, as is observed in the plot above.

<u>3-layer Backpropagation using Turboprop</u>

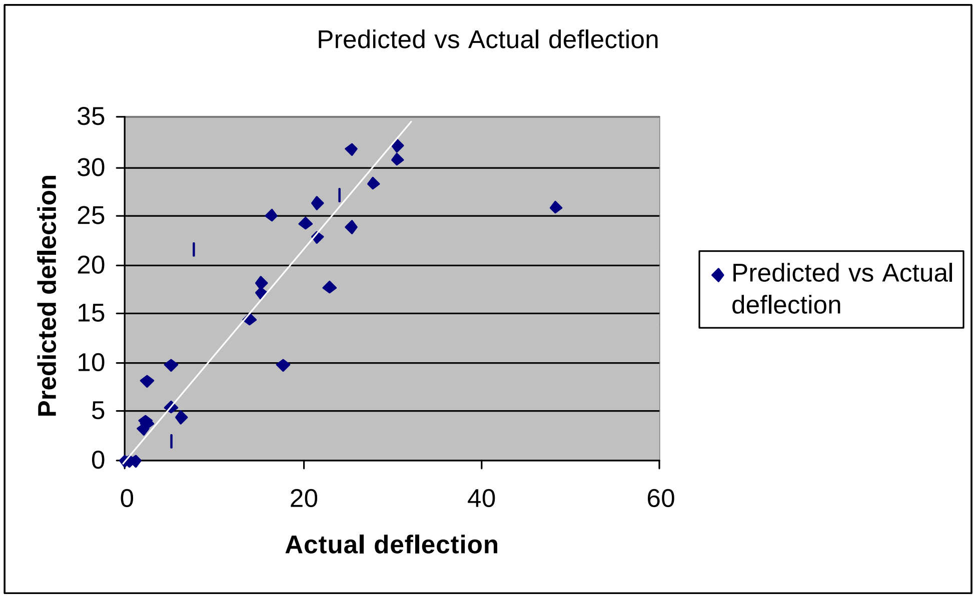


Figure 14: Scatter Plot of 3-Layer Backpropagation using Turboprop

Figure 14 shows a scattered plot of predicted deflections to actual deflections. The mean Absolute error was 3.64 mm and the correlation coefficient was 0.874. The 3-layer backprop using Turboprop was not a very good predictor, as can be inferred from the above plot.

4-layer Backpropagation using Turboprop

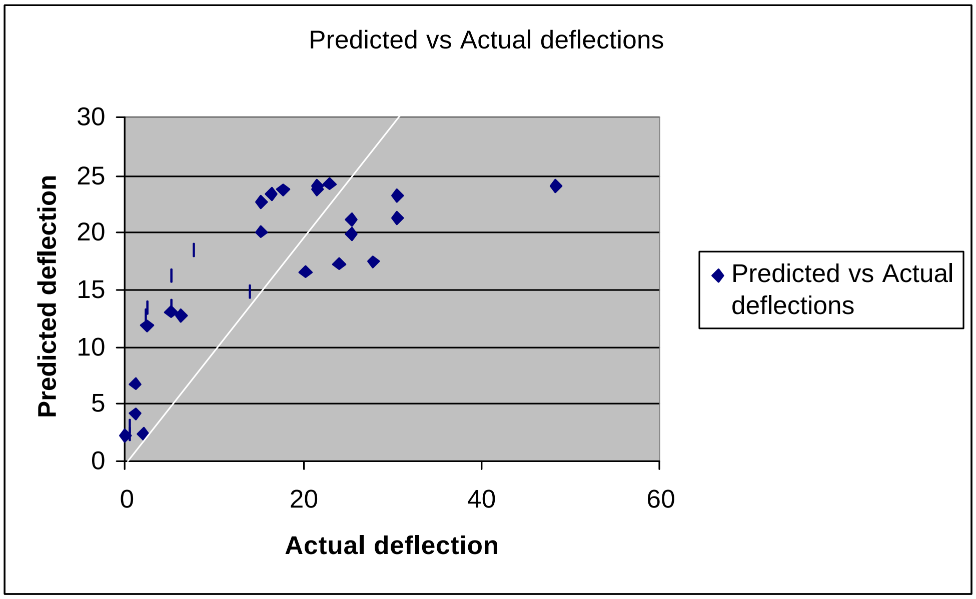


Figure 15: Scatter Plot of 4-Layer Backpropagation using Turboprop

Figure 15 shows a widely scattered plot of predicted deflections to actual deflections. This is because the mean Absolute error was 6.52 mm and the correlation coefficient was 0.789 for this model. The 4-layer backprop using Turboprop did not perform well for this problem.

<u>3-layer Backpropagation with Jump connections</u>

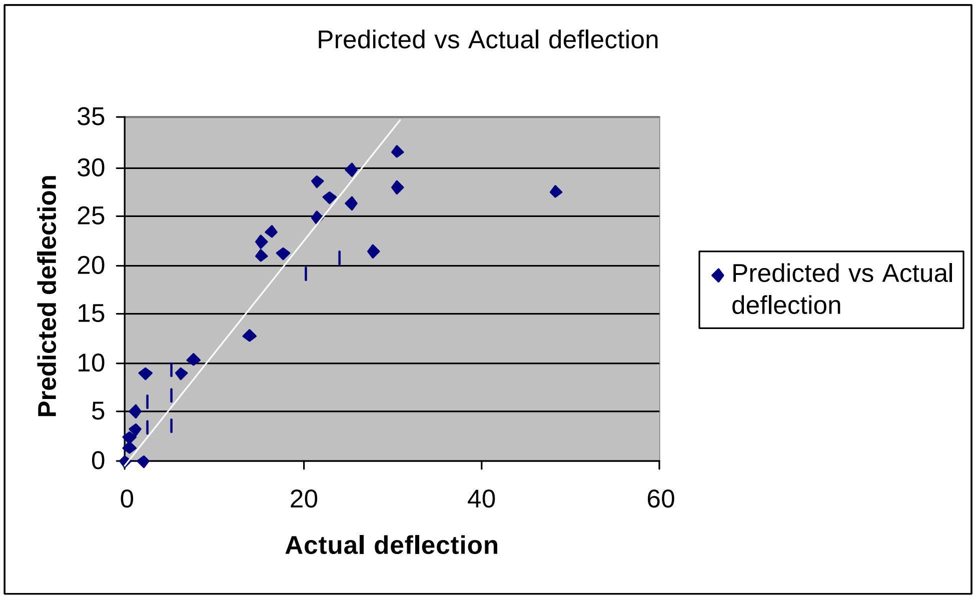


Figure 16: Scatter Plot of 3-Layer Backpropagation with Jump Connections

Figure 16 shows the plot of predicted deflections to actual deflections grouped about the 45° line. The mean Absolute error was 3.8 mm and the correlation coefficient was 0.9. This indicates a moderate accuracy of predictions.

<u>4-layer Backpropagation with Jump Connections</u>

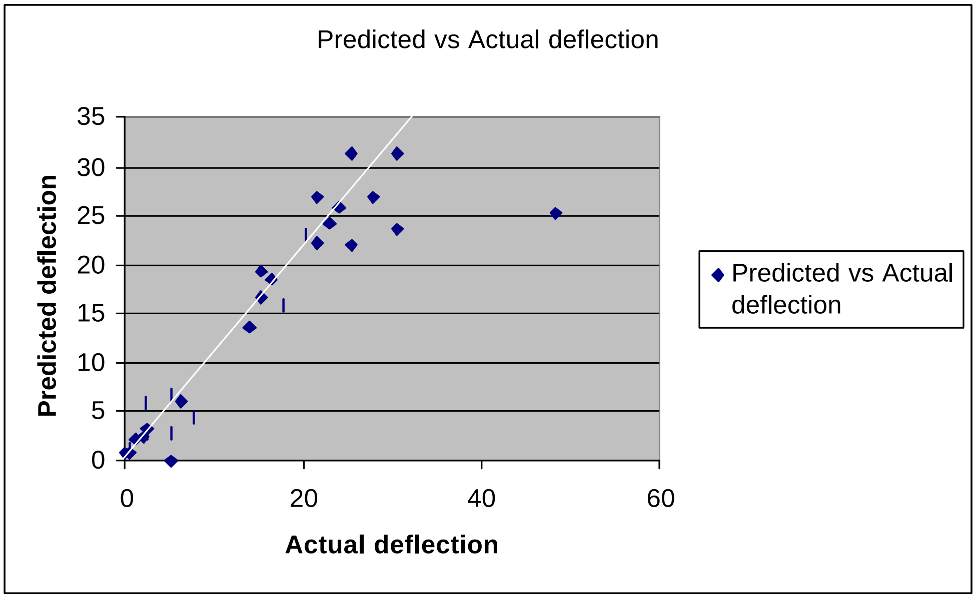


Figure 17: Scatter Plot of 4-Layer Backpropagation with Jump Connections

Figure 17 shows better correlation between predicted deflections and actual deflections. The mean Absolute error was 2.8 mm and the correlation coefficient was 0.91. The graph demonstrates a fairly good accuracy of predictions.

5-layer Backpropagation with Jump Connections

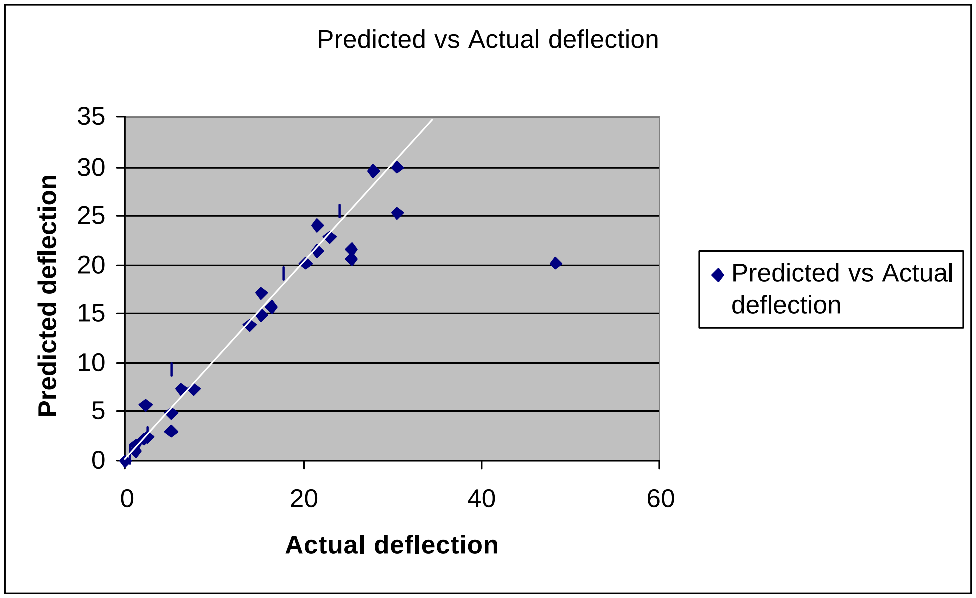


Figure 18: Scatter Plot of 5-Layer Backpropagation with Jump Connections

Figure 18 shows the plot of predicted deflections to actual deflections closely located about the 45° line. The mean Absolute error was 2.2 mm and the correlation coefficient was 0.9 for this paradigm. From the graph, it can be deduced that the 5-Layer Backprop model with Jump connections was a good predictor.

GRNN network

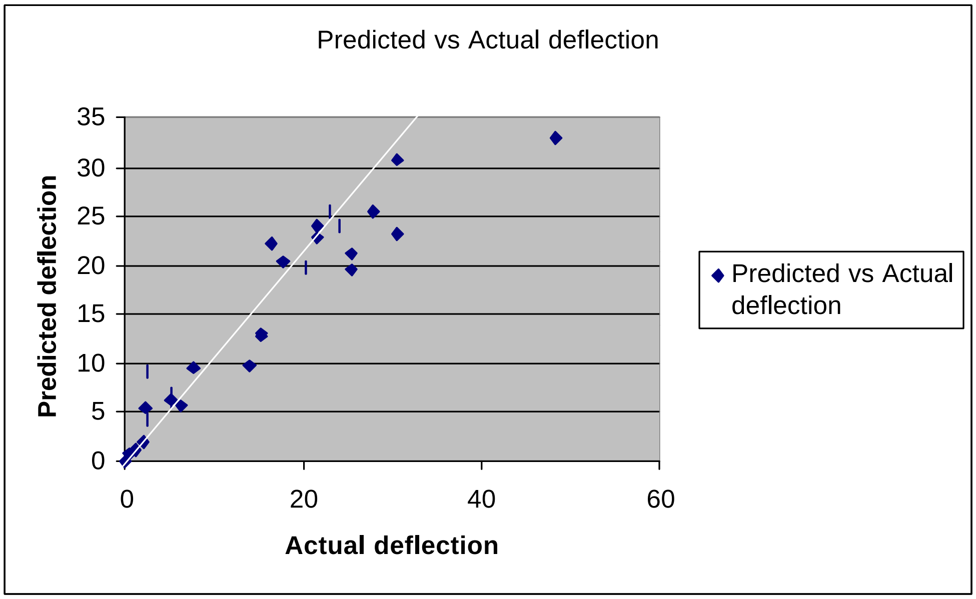


Figure 19: Scatter Plot of GRNN Network

Figure 19 shows the plot of predicted deflection to actual deflection values closely scattered about the 45° line. The mean Absolute error was 2.6 mm and the correlation coefficient was 0.95 for this model. This model provided moderately good accuracy of predictions.

<u>Ward Network Backpropagation 2 hidden slabs</u>

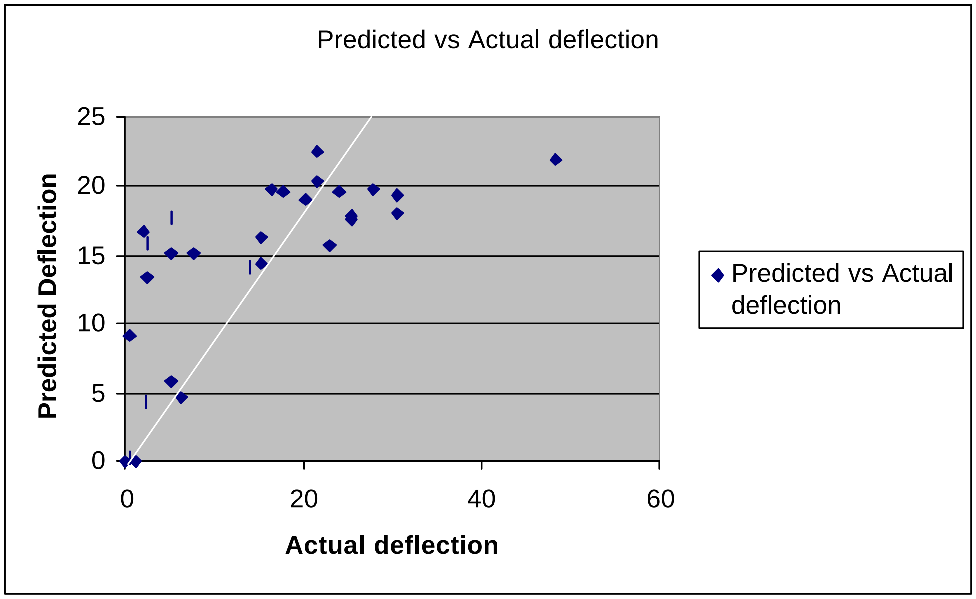


Figure 20: Scatter Plot of Ward Network with 2 Hidden Layers

Figure 20 shows very low correlation between predicted deflections to actual deflections. The mean Absolute error was 6 mm and the correlation coefficient was 0.718, for the 4-Layer Ward network. This model provided very low accuracy of predictions on the test set data, as can be observed from the above graph.

<u>Ward Network 3 hidden layer Backpropagation model</u>

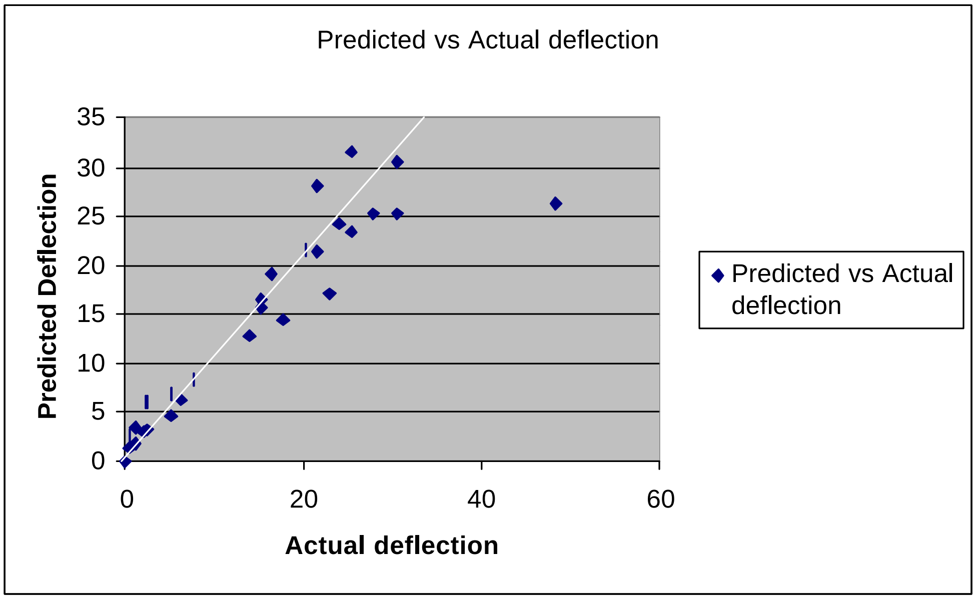


Figure 21: Scatter Plot of Ward Network with 3 Hidden Layers

Figure 21 shows the plot of predicted deflections to actual deflections grouped fairly closely about the 45° line. The mean Absolute error was 2.7 mm and the correlation coefficient was 0.92 for the 5-layer Ward network. Accuracy of predictions was fairly good for data in the lower range, but decreased as deflection values increased.

Ward Network 2 hidden layer Backpropagation with input-output slab connection

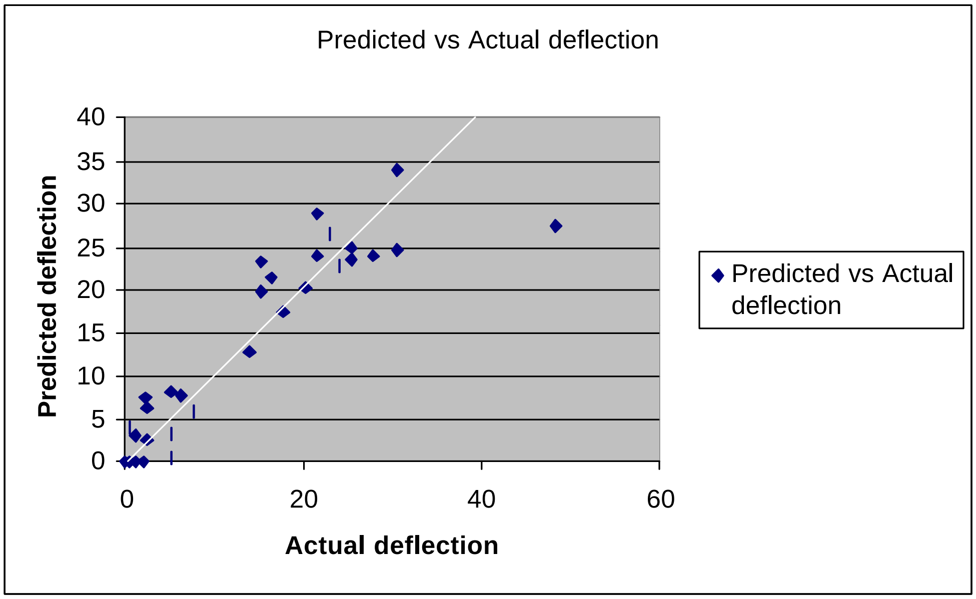


Figure 22: Scatter Plot of Ward Network- 2 Hidden Layers with Input-Output Connected

Figure 22 shows the plot of predicted deflections to actual deflections for test set data. The points are scattered about the 45° line. The mean Absolute error was 3.34mm and the correlation coefficient was 0.91 for the 4-layer Ward network (with input-output slabs connected.) From the above graph, it can be inferred that accuracy of predictions is moderate by this paradigm.

From the above analysis, it is determined that the best training neural network paradigm for this problem is the 5-Layer Backpropagation model with jump connections. It had an R-squared value of 0.9730 and a mean absolute error of 0.909mm on the pattern set (including both training and test set data). Its time to converge to a solution was approximately 20 seconds.

The 3-layer simple backpropagation network also yielded good results, with an R-squared value of 0.9584 and a mean absolute error of 1.678mm on the pattern set. However the time taken by this network to reach this level of accuracy was 22.5 hours, which was considerably longer than the other paradigms.

The 4-layer backpropagation network with jump connections resulted in an R-squared value of 0.9058 and a mean absolute value of 2.399mm on the pattern set. The time taken to converge was approximately 30 seconds.

The GRNN method had an R-squared value of 0.9326 and a mean absolute error of 1.86mm on the pattern set, and converged to a solution within 1 minute.

The Ward network (designed by Ward Systems) with a two-hidden layer and connection from input to output layers, also arrived at good results. It had an R-squared value of 0.8547 and a mean absolute error of 3.59 mm on the pattern set. Time to complete training was about 1 minute.

A comparison of the performances of the network paradigms based on type of external reinforcement is presented below. For each network paradigm, the mean absolute error was found from the test set data for external reinforcement configurations of 0 (no external reinforcement), 1 (external reinforcement on tension face only), and 2 (external reinforcement on both tension and shear faces).

Table 5. Performance Of Neural Paradigms Based On External Reinforcement Configuration

	Mean Absolute Test Set Error (mm) for External Reinforcement = 0	Mean Absolute Test Set Error (mm) for External Reinforcement = 1	Mean Absolute Test Set Error (mm) for External Reinforcement = 2
3-Layer Backpropagation	0.183	0.518	0.441
3-Layer Backpropagation with Jump Connections	1.853	0.598	0.757
3-Layer Backpropagation using Turboprop	0.557	0.506	1.355
4-Layer Backpropagation using Jump Connections	1.616	2.689	0.676
4-Layer Backpropagation using Turboprop	1.542	2.719	1.595
5-Layer Backpropagation using Jump Connections	0.659	3.048	0.711
GRNN network	0.615	0.388	0.522
Ward 2 hidden layer network	1.566	1.151	0.789
Ward 2 hidden layer with Input-output connected	1.28	1.258	1.28
Ward 3-hidden layer	0.813	1.262	0.229

5.2 Analysis of ANN results to compare with FEM

The advantage of the neural network approach compared to FEM in analysis of external reinforcement on RC beams, is that it does not require a new model to be developed for each new problem, and is capable of producing an answer to the problem within seconds. The FEM method is computationally expensive, often requiring CPU times of several hours for just two-dimensional analysis. It would be difficult to use in modeling geometrically complicated forms. For analysis of this problem, a three dimensional model would be required to consider all the external reinforcement configurations on beams, and three-dimensional analysis using FEM would increase processing time over a 2-dimensional analysis.

A finite-element-method study was carried out (Ross et al., 1994) in the study of hardening and rehabilitation of concrete structures using carbon fiber reinforced plastics (CFRP) in 1994. The data used for this study was the same as that used in this thesis. The ADINA finite element computer code was used to calculate the beam response of concrete beams, both with and without CFRP. The FEM analysis required considerable man-hours as well as CPU time. The inelastic-tensile response of the concrete cracking caused the load step to be reduced almost down to 1.0 lb increments during the FEM calculation. This led to increased CPU time on the higher loadings of the beam reinforced with No. 7 steel bars. However, the FEM analysis was worthwhile in that it provided a verification of the section analysis of beams and appeared to agree very well with the experimental data. The lengthy CPU time and the inconvenience of building FEM models for this problem, reduce the number of alternative external reinforcement configurations that can be evaluated in a study.

In comparison, the ANN analysis on the same data yielded results with a correlation to the perfect model in the range of 95% to 72%. Mean absolute errors on deflection prediction were in the range of 1.9 mm to 6.5 mm. Average training time for the network paradigms were in the range of 20seconds to 45 seconds. In one instance (for the 3-Layer simple backpropagation model), training time was 22.5 hours before significant improvement in reduction of error values was noticed.

Garcia, Gabe studied the Relative performance of clustering based neural network and statistical pattern recognition models for non-destructive damage detection (Garcia, 1997). The average localization error for the statistical pattern recognition model (0.25% of the span) was less than the average localization error for the clustering-based neural network method (0.75% of the span). The conclusion of the study was that the statistical pattern recognition model was more efficient in locating damage in terms of the probability of detection and localization accuracy. However, the author acceded that when appropriately trained, the generalization capabilities of the clustering-based neural network should perform as well as statistical pattern recognition techniques. Theoretically, the neural network model should work equally well as the statistical model.

The search for an optimal solution to this problem is easily accomplished using different neural paradigms and experimenting with their number of neurons, weights, learning rates and momentum. The accuracy of a neural network analysis is reliable, and is comparable to an FEM analysis of the problem. ANN is computationally expensive to train, in terms of the computing power required, but results are capable of being obtained in seconds. This is a significant advantage over FEM analysis, which would require re-building a model for every new analysis that had to be performed and would require CPU time of the order of several hours to arrive at a solution. The difficulty involved in formulating an FEM model would also make it inaccessible to the lay person. In comparison, implementing a Neural Network analysis requires only a working knowledge of the software that would be used to analyze the model.

Some advantages of using ANNs are summarized below:

1. They are weighted connection and massively parallel processing with fault tolerance, so that they can automatically learn from experience (internal representation). (Kireetoh, 1995).

2. They have the generalization capability to learn complex patterns of inputs and provide meaningful solutions to problems even when input data contain errors, or are incomplete, or are not presented during training. In other words, they have the ability to integrate information from multiple sources and incorporate new features without degrading prior learning (Karunasekera, 1992; Hawley et al., 1993; Medsker et al., 1993; Chao and Skibniewski, 1994; Flood and Kartam ,1994a and 1994b).

3. They are distribution free because no prior knowledge is needed about the statistical distribution of the classes in the data sources in order to apply the method for classification. This is an advantage over most statistical methods that require modelling of data (Karunasekera, 1992; Hawley et al., 1993; Wu and Lim, 1993; Khoshgoftaar and Lanning, 1995). Neural networks could avoid some of the shortcomings of the currently used statistically or empirically based techniques.

4. They take care of determining how much weight each data source should have in the classification, which remains a problem for statistical methods (Karunasekera, 1992; Wu and Lim, 1993). The non-linear learning and smooth interpolation capabilities give the neural network an edge over standard computers and rule-based systems for solving certain problems (Kimoto et al.,1993; Wu and Lim, 1993).

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

This thesis demonstrates the viability of using neural networks to predict deflection in externally reinforced concrete beams. The neural network approach is determined to be able to provide accurate estimates of beam deflection from three parameters (the cross-sectional area of tensile steel, the position of external reinforcement, and the load) for a beam of fixed size and load orientation. All networks applied generated accurate predictions for deflection, the least accurate being within 15% of the actual beam deflection.

A synopsis of performance data for the network paradigms implemented in this study is below:

- For the 3-layer backpropagation model, mean absolute error was obtained as 1.98 mm with a correlation coefficient of 0.94 on the test set data.
- The 5-layer backpropagation model with jump connections arrived at a mean absolute error of 2.2 mm, with a correlation coefficient of 0.9 on the test set data.
- For the GRNN network, mean absolute error was obtained as 2.6 mm with a correlation coefficient of 0.95 on the test set data.
- The worst performance for the scope of this study was the Ward Network with 2 hidden layers, resulting in a mean absolute error of 6 mm and a correlation coefficient of 0.72.

The most accurate neural network architecture for this problem was the 3-Layer backpropagation model, although its training time was significantly longer than the other paradigms. Based on effectiveness of results generated, the 5-Layer backpropagation model with jump connections would probably be the best training procedure to be adopted for this problem. The independent variables used within the neural network models that were found to be significant in training were the load applied on the beam, the area of tensile steel, the presence or absence of CFRP and its application configuration, and the deflection generated under the loading condition.

A comparison of the relative performance of ANNs and FEM suggested that comparable accuracies in deflection prediction were obtained for the best Neural paradigm for this problem and the FEM analysis method. The ANN method generally had a training time in the order of 20-45 seconds and the trained network could predict values on a new set of data within seconds. The FEM method required processing time in the order of several hours, and involved reconstructing the model for every new beam loading configuration and beam reinforcement.

It was qualitatively determined that an Artificial Neural Network model is advantageous to the FEM model in the analysis of this problem, since an ANN does not require the creation of a new model for each new problem, and is capable of producing an answer to a problem within seconds. For the use of FEM, a three-dimensional model would be required, which would be difficult to construct, as well as being computationally expensive by requiring lengthy CPU time.

A limitation of this work is the inability to compare quantitatively the performance (in terms of speed and accuracy) of the FEM method on the same set of training data.

This thesis arrived at a neural network model for the performance of externally reinforced beams, that is sufficiently accurate to be applicable in actual engineering problems, and overcomes the speed problem of existing methods of analysis such as FEM and Statistical pattern recognition. However, the accuracy of paradigms that did not predict well within the scope of this study, may be improved by having a larger set of training data. Another area that is open for experimentation is the adjustment of number of neurons, the learning rate and momentum, and activation functions at the neurons. Varying these parameters with a larger set of training data may provide better predictions with the network models that failed to provide very accurate predictions in this analysis.

Future work could analyze the same problem using Probabilistic neural networks, and the Kohonen unsupervised network, if a larger and more variable set of data is available. For this thesis, the data available was inadequate to generate meaningful results using these two paradigms. The fitness of all individuals in the population was found to be the same and the Genetic algorithm could not proceed. An adequate solution was not reached since a larger breeding pool was not available.

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APPENDIX A

TRAINING DATA

Appendix A incorporates the data used in training the Neural Network models. Load is represented in KiloNewtons, Area of tensile steel in square millimeters, CFRP external reinforcement as a value (0= no CFRP, 1= CFRP on tension face, 2= CFRP on tension and shear face), Actual deflection and the Network predicted deflection in millimeters, and the Error is calculated as the difference of the Actual and Predicted deflections.

5-Layer Backpropagation Network with Jump Connections

			Actual deflection (in mm)	Predicted Deflection (in mm)	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)
0	567.7408	0	0	0	0
3.6920226	567.7408	0	0.254000008	0.04293159	0.21106842
7.5174918	567.7408	0	0.508000016	1.062196732	-0.5541967
10.898139	567.7408	0	0.762000024	1.443637967	-0.6816379
13.4113833	567.7408	0	1.016000032	1.672314644	-0.6563146
14.9460192	567.7408	0	1.269999981	1.843201756	-0.5732018
15.5465289	567.7408	0	1.524000049	1.917415023	-0.393415
17.0144415	567.7408	0	1.777999997	2.114818096	-0.3368181
18.460113	567.7408	0	2.032000065	2.328862429	-0.2968624
19.2830337	567.7408	0	2.286000013	2.458258629	-0.1722586
20.5952586	567.7408	0	2.539999962	2.674554825	-0.1345549
25.6217472	567.7408	0	3.809999943	3.595994234	0.21400571
31.0040934	567.7408	0	5.079999924	4.715117455	0.36488247
36.8757438	567.7408	0	6.349999905	6.071269035	0.27873087
42.035679	567.7408	0	7.619999886	7.371602058	0.24839783
46.9732032	567.7408	0	8.890000343	8.703854561	0.18614578
51.9774507	567.7408	0	10.15999985	10.13076687	0.02923298
57.4265202	567.7408	0	11.43000031	11.7524786	-0.3224783
63.6317871	567.7408	0	12.69999981	13.6554203	-0.9554205
69.2143032	567.7408	0	13.97000027	15.4078455	-1.4378452
74.3519973	567.7408	0	15.23999977	17.07495117	-1.8349514
79.2895215	567.7408	0	16.51000023	18.75535965	-2.2453594
84.6273855	567.7408	0	17.78000069	18.18295097	-0.4029503
88.2526848	567.7408	0	19.04999924	19.09909821	-0.049099
90.298866	567.7408	0	20.31999969	20.75270844	-0.4327087

91.3219566	567.7408	0	21.59000015	21.9244976	-0.3344975
91.9002252	567.7408	0	22.86000061	22.71040916	0.14959145
92.7231459	567.7408	0	24.12999916	23.98640823	0.14359093
93.6127899	567.7408	0	25.39999962	25.5587616	-0.158762
94.9250148	567.7408	0	27.94000053	28.15386772	-0.2138672
96.081552	567.7408	0	30.47999954	30.57716179	-0.0971622
97.7718756	567.7408	0	33.02000046	34.07014084	-1.0501404
99.3954759	567.7408	0	35.56000137	37.13212585	-1.5721245
100.707701	567.7408	0	38.09999847	39.29722214	-1.1972237
102.264578	567.7408	0	40.63999939	41.47063828	-0.8306389
103.354392	567.7408	0	43.18000031	42.74575043	0.43424988
104.310759	567.7408	0	45.72000122	43.7137413	2.00625992
105.311609	567.7408	0	48.25999832	44.59341812	3.6665802
0	141.9352	0	0	0	0
2.891343	141.9352	0	0.254000008	0.4506419	-0.1966419
8.3181714	141.9352	0	0.508000016	0.337584734	0.17041528
9.9862539	141.9352	0	0.762000024	0.589119852	0.17288017
13.1444901	141.9352	0	1.016000032	0.943647206	0.07235283
14.3010273	141.9352	0	1.269999981	1.355989695	-0.0859897
15.9691098	141.9352	0	1.524000049	1.44854176	0.07545829
17.9040855	141.9352	0	1.777999997	2.184108257	-0.4061083
17.8596033	141.9352	0	2.032000065	2.114660025	-0.08266
18.2821842	141.9352	0	2.286000013	5.693309784	-3.4073098
18.1264965	141.9352	0	2.539999962	3.278800964	-0.738801
18.1932198	141.9352	0	3.809999943	4.135506153	-0.3255062
18.6380418	141.9352	0	5.079999924	9.446576118	-4.3665762
18.3711486	141.9352	0	6.349999905	7.256037712	-0.9060378
18.3489075	141.9352	0	7.619999886	6.897034645	0.72296524
18.4156308	141.9352	0	8.890000343	7.880403519	1.00959682
18.7492473	141.9352	0	10.15999985	9.776610374	0.38338947
19.6611324	141.9352	0	11.43000031	11.9268589	-0.4968586
20.0614722	141.9352	0	12.69999981	12.84028435	-0.1402845
20.6397408	141.9352	0	13.97000027	13.93496132	0.03503895
21.3292149	141.9352	0	15.23999977	15.10927963	0.13072014
21.9519657	141.9352	0	16.51000023	16.38286781	0.12713242
22.5302343	141.9352	0	17.78000069	17.84153938	-0.0615387
23.0862618	141.9352	0	19.04999924	19.2322464	-0.1822472
23.4643605	141.9352	0	20.31999969	20.22411537	0.09588432
23.8869414	141.9352	0	21.59000015	21.68719482	-0.0971947
24.3095223	141.9352	0	22.86000061	23.70238304	-0.8423824
24.5986566	141.9352	0	24.12999916	25.42682838	-1.2968292
24.7543443	141.9352	0	25.39999962	26.47483444	-1.0748348
25.1546841	141.9352	0	27.94000053	29.52471161	-1.5847111
25.5105417	141.9352	0	30.47999954	32.52240753	-2.042408
25.6662294	141.9352	0	33.02000046	33.84803772	-0.8280373

25.8441582	141.9352	0	35.56000137	35.32495499	0.23504639
25.9331226	141.9352	0	38.09999847	36.03686905	2.06312943
26.1555336	141.9352	0	40.63999939	37.7077713	2.93222809
0	567.7408	1	0	0	0
2.53993362	567.7408	1	0.254000008	0.153437749	0.10056226
4.28363586	567.7408	1	0.508000016	0.442647249	0.06535277
6.48995298	567.7408	1	0.762000024	0.765775084	-0.0037751
8.7629934	567.7408	1	1.016000032	1.073728323	-0.0577283
11.7744383	567.7408	1	1.269999981	1.30730319	-0.0373032
14.6880224	567.7408	1	1.524000049	0.376362383	1.14763767
17.0144415	567.7408	1	1.777999997	0.704520822	1.07347918
19.0116923	567.7408	1	2.032000065	1.001803517	1.03019655
24.5853119	567.7408	1	2.286000013	1.88305676	0.40294325
29.7496954	567.7408	1	2.539999962	2.773976564	-0.2339766
34.5938069	567.7408	1	3.809999943	3.680078506	0.12992144
40.03398	567.7408	1	5.079999924	4.783222198	0.29677773
45.5186353	567.7408	1	6.349999905	5.989840984	0.36015892
51.1990122	567.7408	1	7.619999886	7.340175152	0.27982473
56.9238713	567.7408	1	8.890000343	8.801509857	0.08849049
62.6442823	567.7408	1	10.15999985	10.35294628	-0.1929464
68.7161026	567.7408	1	11.43000031	12.05708885	-0.6270885
74.810164	567.7408	1	12.69999981	10.94734859	1.75265121
80.2547852	567.7408	1	13.97000027	12.42880726	1.54119301
86.0419195	567.7408	1	15.23999977	14.04766178	1.19233799
91.8690877	567.7408	1	16.51000023	15.76563549	0.74436474
97.1179873	567.7408	1	17.78000069	17.42340279	0.3565979
102.460299	567.7408	1	19.04999924	19.22584534	-0.1758461
106.205701	567.7408	1	20.31999969	20.56944847	-0.2494488
108.425363	567.7408	1	21.59000015	21.42269516	0.16730499
110.235788	567.7408	1	22.86000061	22.17486954	0.68513107
113.852191	567.7408	1	24.12999916	23.92639923	0.20359993
117.366285	567.7408	1	25.39999962	26.08973312	-0.6897335
120.90262	567.7408	1	27.94000053	28.80529022	-0.8652897
124.038615	567.7408	1	30.47999954	31.5897274	-1.1097279
127.041163	567.7408	1	33.02000046	34.41215897	-1.3921585
129.665613	567.7408	1	35.56000137	36.84076309	-1.2807617
132.178857	567.7408	1	38.09999847	39.01304245	-0.913044
134.491932	567.7408	1	40.63999939	40.81595993	-0.1759605
135.990982	567.7408	1	43.18000031	41.87023926	1.30976105
137.378826	567.7408	1	45.72000122	42.76473999	2.95526123
105.311609	567.7408	1	48.25999832	20.24028206	28.0197163
0	141.9352	1	0	0	0
2.66448378	141.9352	1	0.254000008	0.326959103	-0.0729591
4.35035916	141.9352	1	0.508000016	0.550672412	-0.0426724
7.44187206	141.9352	1	0.762000024	1.159987569	-0.3979875

10.5778672	141.9352	1	1.016000032	1.485563278	-0.4695632
14.5323347	141.9352	1	1.269999981	1.458437324	-0.1884373
16.6274464	141.9352	1	1.524000049	1.61352396	-0.0895239
17.6416405	141.9352	1	1.777999997	1.735392809	0.04260719
19.976956	141.9352	1	2.032000065	2.078426361	-0.0464263
21.1512861	141.9352	1	2.286000013	2.278162956	0.00783706
21.5115919	141.9352	1	2.539999962	2.344336033	0.19566393
21.978655	141.9352	1	3.809999943	2.434988976	1.37501097
25.4705077	141.9352	1	5.079999924	3.667862654	1.41213727
28.1928184	141.9352	1	6.349999905	6.02493906	0.32506084
30.0699672	141.9352	1	7.619999886	7.317203522	0.30279636
32.0004947	141.9352	1	8.890000343	8.20187664	0.6881237
33.1303426	141.9352	1	10.15999985	8.669887543	1.4901123
38.0500739	141.9352	1	11.43000031	11.18537712	0.24462318
39.2911273	141.9352	1	12.69999981	12.05879593	0.64120388
41.3995835	141.9352	1	13.97000027	13.86200333	0.10799694
42.3737437	141.9352	1	15.23999977	14.83884335	0.40115643
44.219755	141.9352	1	16.51000023	16.88510132	-0.3751011
45.5230835	141.9352	1	17.78000069	17.71737862	0.06262207
47.0221336	141.9352	1	19.04999924	19.01166916	0.03833008
47.9696045	141.9352	1	20.31999969	20.23558044	0.08441925
49.6287905	141.9352	1	21.59000015	22.68108368	-1.0910835
48.7035608	141.9352	1	22.86000061	21.24388885	1.61611176
48.748043	141.9352	1	24.12999916	21.30796432	2.82203484
48.9170753	141.9352	1	25.39999962	21.5553112	3.84468842
50.2159556	141.9352	1	27.94000053	23.7544651	4.18553543
50.8965332	141.9352	1	30.47999954	25.24596596	5.23403358
52.4623067	141.9352	1	33.02000046	30.23975372	2.78024673
53.6099474	141.9352	1	35.56000137	35.52633286	0.03366852
0	567.7408	2	0	0.258493662	-0.2584937
1.21881228	567.7408	2	0.254000008	0.319325924	-0.0653259
6.52998696	567.7408	2	0.508000016	0	0.50800002
9.31457268	567.7408	2	0.762000024	0.228649765	0.53335026
12.8509076	567.7408	2	1.016000032	0.728937685	0.28706235
15.8401114	567.7408	2	1.269999981	1.191228986	0.078771
18.1087036	567.7408	2	1.524000049	1.559157729	-0.0351577
20.3595029	567.7408	2	1.777999997	1.938352108	-0.1603521
21.8007262	567.7408	2	2.032000065	2.188704014	-0.1567039
23.5043945	567.7408	2	2.286000013	2.49243331	-0.2064333
24.6920692	567.7408	2	2.539999962	2.709263325	-0.1692634
30.3235157	567.7408	2	3.809999943	3.796237946	0.013762
36.333061	567.7408	2	5.079999924	5.067764759	0.01223516
42.6940156	567.7408	2	6.349999905	6.544143677	-0.1941438
48.3565996	567.7408	2	7.619999886	7.973833561	-0.3538337
54.5885558	567.7408	2	8.890000343	9.673434258	-0.7834339

60.5847564	567.7408	2	10.15999985	9.869497299	0.29050255
66.4475104	567.7408	2	11.43000031	10.65399075	0.77600956
72.1723695	567.7408	2	12.69999981	12.32174397	0.37825584
78.328706	567.7408	2	13.97000027	14.19344139	-0.2234411
84.1825635	567.7408	2	15.23999977	16.01932907	-0.7793293
90.1476265	567.7408	2	16.51000023	17.88908958	-1.3790894
96.0237251	567.7408	2	17.78000069	19.71518135	-1.9351807
101.637379	567.7408	2	19.04999924	21.45820618	-2.4082069
106.294665	567.7408	2	20.31999969	22.93422508	-2.6142254
109.90662	567.7408	2	21.59000015	24.11208725	-2.5220871
111.85494	567.7408	2	22.86000061	24.76057434	-1.9005737
113.901121	567.7408	2	24.12999916	25.4509716	-1.3209724
115.5781	567.7408	2	25.39999962	26.02355003	-0.6235504
119.835047	567.7408	2	27.94000053	27.51267242	0.42732811
123.847341	567.7408	2	30.47999954	29.04049492	1.43950462
127.477089	567.7408	2	33.02000046	30.70206642	2.31793404
131.854137	567.7408	2	35.56000137	33.2913475	2.26865387
135.163613	567.7408	2	38.09999847	35.66852951	2.43146896
138.366331	567.7408	2	40.63999939	38.14926147	2.49073792
0	141.9352	2	0	0.215275362	-0.2152754
0.05782686	141.9352	2	0.254000008	0.220672145	0.03332786
4.92862776	141.9352	2	0.508000016	0.945739269	-0.4377393
9.68377494	141.9352	2	0.762000024	0.842015207	-0.0800152
12.8953898	141.9352	2	1.016000032	0.420753062	0.59524697
16.5918606	141.9352	2	1.269999981	0.844469666	0.42553031
20.2883314	141.9352	2	1.524000049	1.32541728	0.19858277
22.281134	141.9352	2	1.777999997	1.611992955	0.16600704
24.3629009	141.9352	2	2.032000065	1.977523923	0.05447614
25.4883006	141.9352	2	2.286000013	2.265819311	0.0201807
25.6217472	141.9352	2	2.539999962	2.308584929	0.23141503
29.8920384	141.9352	2	3.809999943	5.169563293	-1.3595634
33.6952665	141.9352	2	5.079999924	6.741468906	-1.661469
36.3775432	141.9352	2	6.349999905	7.412313461	-1.0623136
39.589158	141.9352	2	7.619999886	8.21795845	-0.5979586
43.0765625	141.9352	2	8.890000343	9.147535324	-0.257535
46.6974136	141.9352	2	10.15999985	10.19715214	-0.0371523
49.7133067	141.9352	2	11.43000031	11.16771412	0.26228619
52.1108973	141.9352	2	12.69999981	12.71244335	-0.0124435
54.855449	141.9352	2	13.97000027	14.58885479	-0.6188545
57.2663843	141.9352	2	15.23999977	15.59836769	-0.3583679
59.5883551	141.9352	2	16.51000023	16.5992012	-0.089201
61.7146043	141.9352	2	17.78000069	17.52415848	0.25584221
63.8675428	141.9352	2	19.04999924	18.46446419	0.58553505
66.5676123	141.9352	2	20.31999969	19.6777935	0.64220619
68.8717903	141.9352	2	21.59000015	20.83288002	0.75712013

71.2738291	141.9352	2	22.86000061	22.24450493	0.61549568
73.4045264	141.9352	2	24.12999916	23.65086746	0.4791317
75.9933905	141.9352	2	25.39999962	25.45420456	-0.0542049
80.0813047	141.9352	2	27.94000053	28.35725975	-0.4172592
82.2698289	141.9352	2	30.47999954	29.9337368	0.54626274
84.1736671	141.9352	2	33.02000046	31.3278389	1.69216156
0	774.192	0	0	0	0
17.79288	774.192	0	2.539999962	1.754709005	0.78529096
31.13754	774.192	0	5.079999924	4.157893181	0.92210674
44.4822	774.192	0	7.619999886	7.092042923	0.52795696
57.82686	774.192	0	10.15999985	10.58166313	-0.4216633
68.94741	774.192	0	12.69999981	13.88581562	-1.1858158
80.06796	774.192	0	15.23999977	15.29004574	-0.050046
91.18851	774.192	0	17.78000069	16.01569748	1.76430321
102.30906	774.192	0	20.31999969	19.47645378	0.84354591
111.2055	774.192	0	22.86000061	22.75304985	0.10695076
115.65372	774.192	0	25.39999962	25.04311371	0.35688591
0	774.192	1	0	0	0
26.68932	774.192	1	2.539999962	1.945963502	0.59403646
37.80987	774.192	1	5.079999924	2.99820137	2.08179855
55.60275	774.192	1	7.619999886	8.355574608	-0.7355747
66.7233	774.192	1	10.15999985	9.60956955	0.5504303
80.06796	774.192	1	12.69999981	10.81829071	1.8817091
95.63673	774.192	1	15.23999977	15.5503273	-0.3103275
106.75728	774.192	1	17.78000069	19.18312263	-1.4031219
122.32605	774.192	1	20.31999969	20.71483994	-0.3948402
133.4466	774.192	1	22.86000061	24.24181557	-1.381815
142.34304	774.192	1	25.39999962	27.29301643	-1.8930168
0	258.064	0	0	0.002316356	-0.0023164
20.01699	258.064	0	5.079999924	4.763210297	0.31678963
28.91343	258.064	0	10.15999985	13.58454227	-3.4245424
35.58576	258.064	0	15.23999977	17.60326195	-2.3632622
36.475404	258.064	0	20.31999969	18.53609085	1.78390884
37.80987	258.064	0	25.39999962	20.50885582	4.8911438
40.03398	258.064	0	30.47999954	28.78214455	1.697855
40.923624	258.064	0	35.56000137	35.28065872	0.27934265
41.813268	258.064	0	40.63999939	42.00836182	-1.3683624
42.702912	258.064	0	45.72000122	47.07924652	-1.3592453
43.370145	258.064	0	50.79999924	49.58152008	1.21847916
0	258.064	1	0	0.052454859	-0.0524549
24.46521	258.064	1	5.079999924	4.9526577	0.12734222
37.80987	258.064	1	10.15999985	9.757398605	0.40260124
51.15453	258.064	1	15.23999977	13.6613884	1.57861137
55.60275	258.064	1	20.31999969	15.68225384	4.63774586
66.7233	258.064	1	25.39999962	25.40167618	-0.0016766

72.283575	258.064	1	30.47999954	31.00452995	-0.5245304
80.06796	258.064	1	35.56000137	37.40085983	-1.8408585
86.74029	258.064	1	40.63999939	42.2421608	-1.6021614
91.18851	258.064	1	45.72000122	45.43424225	0.28575897
97.86084	258.064	1	50.79999924	48.98107529	1.81892395

Mean absolute error=0.909mm Max error=28 mm

4-Layer Backpropagation with Jump Connections

			Actual Deflection	Predicted Deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)
0	567.7408	0	0	0	0
3.692023	567.7408	0	0.254000008	0.399079323	-0.14507931
7.517492	567.7408	0	0.508000016	0.877570987	-0.36957097
10.89814	567.7408	0	0.762000024	1.666728139	-0.90472811
13.41138	567.7408	0	1.016000032	2.190505505	-1.17450547
14.94602	567.7408	0	1.269999981	2.484836102	-1.21483612
15.54653	567.7408	0	1.524000049	2.597754717	-1.07375467
17.01444	567.7408	0	1.777999997	2.872861624	-1.09486163
18.46011	567.7408	0	2.032000065	3.146835089	-1.11483502
19.28303	567.7408	0	2.286000013	3.305569649	-1.01956964
20.59526	567.7408	0	2.539999962	3.564107418	-1.02410746
25.62175	567.7408	0	3.809999943	4.624937057	-0.81493711
31.00409	567.7408	0	5.079999924	5.878867626	-0.7988677
36.87574	567.7408	0	6.349999905	7.365961552	-1.01596165
42.03568	567.7408	0	7.619999886	8.764969826	-1.14496994
46.9732	567.7408	0	8.890000343	10.1795845	-1.28958416
51.97745	567.7408	0	10.15999985	11.68638706	-1.52638721
57.42652	567.7408	0	11.43000031	13.40984249	-1.97984219
63.63179	567.7408	0	12.69999981	15.48184776	-2.78184795
69.2143	567.7408	0	13.97000027	17.45951462	-3.48951435
74.352	567.7408	0	15.23999977	19.39911842	-4.15911865
79.28952	567.7408	0	16.51000023	21.40340042	-4.89340019
84.62739	567.7408	0	17.78000069	23.76263809	-5.98263741
88.25268	567.7408	0	19.04999924	25.48676109	-6.43676186
90.29887	567.7408	0	20.31999969	26.49821091	-6.17821121
91.32196	567.7408	0	21.59000015	27.01211548	-5.42211533
91.90023	567.7408	0	22.86000061	27.30451393	-4.44451332
92.72315	567.7408	0	24.12999916	27.72253609	-3.59253693
93.61279	567.7408	0	25.39999962	28.17635345	-2.77635384
94.92501	567.7408	0	27.94000053	28.84760857	-0.90760803

96.08155	567.7408	0	30.47999954	29.43906975	1.040929794
97.77188	567.7408	0	33.02000046	30.2989521	2.721048355
99.39548	567.7408	0	35.56000137	31.11468887	4.4453125
100.7077	567.7408	0	38.09999847	31.76311302	6.336885452
102.2646	567.7408	0	40.63999939	32.5163269	8.123672485
103.3544	567.7408	0	43.18000031	33.0315094	10.14849091
104.3108	567.7408	0	45.72000122	33.47459412	12.2454071
105.3116	567.7408	0	48.25999832	33.92873001	14.33126831
0	141.9352	0	0	0.043521088	-0.04352109
2.891343	141.9352	0	0.254000008	0.443133146	-0.18913314
8.318171	141.9352	0	0.508000016	1.215917826	-0.70791781
9.986254	141.9352	0	0.762000024	1.48878181	-0.72678179
13.14449	141.9352	0	1.016000032	2.137047768	-1.12104774
14.30103	141.9352	0	1.269999981	2.457399368	-1.18739939
15.96911	141.9352	0	1.524000049	3.146503925	-1.62250388
17.90409	141.9352	0	1.777999997	5.179655552	-3.40165555
17.8596	141.9352	0	2.032000065	5.101323605	-3.06932354
18.28218	141.9352	0	2.286000013	5.930646896	-3.64464688
18.1265	141.9352	0	2.539999962	5.602532864	-3.0625329
18.19322	141.9352	0	3.809999943	5.739846706	-1.92984676
18.63804	141.9352	0	5.079999924	6.783280849	-1.70328093
18.37115	141.9352	0	6.349999905	6.130347729	0.219652176
18.34891	141.9352	0	7.619999886	6.07957983	1.540420055
18.41563	141.9352	0	8.890000343	6.233567238	2.656433105
18.74925	141.9352	0	10.15999985	7.078927517	3.08107233
19.66113	141.9352	0	11.43000031	9.954587936	1.475412369
20.06147	141.9352	0	12.69999981	11.39373302	1.306266785
20.63974	141.9352	0	13.97000027	13.53980255	0.430197716
21.32921	141.9352	0	15.23999977	16.07967567	-0.8396759
21.95197	141.9352	0	16.51000023	18.27796745	-1.76796722
22.53023	141.9352	0	17.78000069	20.19708443	-2.41708374
23.08626	141.9352	0	19.04999924	21.90499687	-2.85499763
23.46436	141.9352	0	20.31999969	22.97935104	-2.65935135
23.88694	141.9352	0	21.59000015	24.09128952	-2.50128937
24.30952	141.9352	0	22.86000061	25.10789299	-2.24789238
24.59866	141.9352	0	24.12999916	25.74933434	-1.61933517
24.75434	141.9352	0	25.39999962	26.07702637	-0.67702675
25.15468	141.9352	0	27.94000053	26.86517143	1.074829102
25.51054	141.9352	0	30.47999954	27.50366402	2.976335526
25.66623	141.9352	0	33.02000046	27.76586723	5.254133224
25.84416	141.9352	0	35.56000137	28.05349541	7.506505966
25.93312	141.9352	0	38.09999847	28.19268417	9.907314301
26.15553	141.9352	0	40.63999939	28.52775002	12.11224937
0	567.7408	1	0	0.722970307	-0.72297031
2.539934	567.7408	1	0.254000008	1.220793724	-0.96679372

4.283636	567.7408	1	0.508000016	1.008885026	-0.50088501
6.489953	567.7408	1	0.762000024	0.716770172	0.045229852
8.762993	567.7408	1	1.016000032	0.884994566	0.131005466
11.77444	567.7408	1	1.269999981	1.151002645	0.118997335
14.68802	567.7408	1	1.524000049	1.544953465	-0.02095342
17.01444	567.7408	1	1.777999997	1.949771166	-0.17177117
19.01169	567.7408	1	2.032000065	2.238199949	-0.20619988
24.58531	567.7408	1	2.286000013	2.686860561	-0.40086055
29.7497	567.7408	1	2.539999962	3.301107407	-0.76110744
34.59381	567.7408	1	3.809999943	3.352626324	0.457373619
40.03398	567.7408	1	5.079999924	2.810445786	2.269554138
45.51864	567.7408	1	6.349999905	3.318955898	3.031044006
51.19901	567.7408	1	7.619999886	4.564107895	3.055891991
56.92387	567.7408	1	8.890000343	6.07463789	2.815362453
62.64428	567.7408	1	10.15999985	7.730021	2.429978848
68.7161	567.7408	1	11.43000031	9.626077652	1.803922653
74.81016	567.7408	1	12.69999981	11.6756649	1.024334908
80.25479	567.7408	1	13.97000027	13.64685631	0.323143959
86.04192	567.7408	1	15.23999977	15.92088604	-0.68088627
91.86909	567.7408	1	16.51000023	18.44743729	-1.93743706
97.11799	567.7408	1	17.78000069	20.96040344	-3.18040276
102.4603	567.7408	1	19.04999924	23.72528267	-4.67528343
106.2057	567.7408	1	20.31999969	25.72960091	-5.40960121
108.4254	567.7408	1	21.59000015	26.91476822	-5.32476807
110.2358	567.7408	1	22.86000061	27.86836052	-5.00835991
113.8522	567.7408	1	24.12999916	29.7115593	-5.58156013
117.3663	567.7408	1	25.39999962	31.39616013	-5.99616051
120.9026	567.7408	1	27.94000053	32.96994019	-5.02993965
124.0386	567.7408	1	30.47999954	34.26395416	-3.78395462
127.0412	567.7408	1	33.02000046	35.41999817	-2.39999771
129.6656	567.7408	1	35.56000137	36.37069321	-0.81069183
132.1789	567.7408	1	38.09999847	37.23442841	0.865570068
134.4919	567.7408	1	40.63999939	37.99312592	2.646873474
135.991	567.7408	1	43.18000031	38.46786499	4.712135315
137.3788	567.7408	1	45.72000122	38.89631271	6.823688507
105.3116	567.7408	1	48.25999832	25.24999809	23.01000023
0	141.9352	1	0	0	0
2.664484	141.9352	1	0.254000008	0	0.254000008
4.350359	141.9352	1	0.508000016	0	0.508000016
7.441872	141.9352	1	0.762000024	0.139960214	0.62203981
10.57787	141.9352	1	1.016000032	0.648094654	0.367905378
14.53233	141.9352	1	1.269999981	1.25167799	0.018321991
16.62745	141.9352	1	1.524000049	1.513029337	0.010970712
17.64164	141.9352	1	1.777999997	1.675421119	0.102578878
19.97696	141.9352	1	2.032000065	2.294844866	-0.2628448

21.15129	141.9352	1	2.286000013	2.733283281	-0.44728327
21.51159	141.9352	1	2.539999962	2.867594004	-0.32759404
21.97866	141.9352	1	3.809999943	3.03421545	0.775784492
25.47051	141.9352	1	5.079999924	4.460278034	0.619721889
28.19282	141.9352	1	6.349999905	6.101997852	0.248002052
30.06997	141.9352	1	7.619999886	7.366098881	0.253901005
32.00049	141.9352	1	8.890000343	8.720038414	0.169961929
33.13034	141.9352	1	10.15999985	9.530387878	0.629611969
38.05007	141.9352	1	11.43000031	13.22031403	-1.79031372
39.29113	141.9352	1	12.69999981	14.19918251	-1.4991827
41.39958	141.9352	1	13.97000027	15.90360451	-1.93360424
42.37374	141.9352	1	15.23999977	16.70453644	-1.46453667
44.21976	141.9352	1	16.51000023	18.23343086	-1.72343063
45.52308	141.9352	1	17.78000069	19.31227303	-1.53227234
47.02213	141.9352	1	19.04999924	20.5416584	-1.49165916
47.9696	141.9352	1	20.31999969	21.3080101	-0.98801041
49.62879	141.9352	1	21.59000015	22.62288857	-1.03288841
48.70356	141.9352	1	22.86000061	21.8943119	0.965688705
48.74804	141.9352	1	24.12999916	21.92961693	2.200382233
48.91708	141.9352	1	25.39999962	22.06352997	3.33646965
50.21596	141.9352	1	27.94000053	23.07860756	4.861392975
50.89653	141.9352	1	30.47999954	23.59996986	6.880029678
52.46231	141.9352	1	33.02000046	24.76996994	8.250030518
53.60995	141.9352	1	35.56000137	25.60054588	9.95945549
0	567.7408	2	0	0	0
1.218812	567.7408	2	0.254000008	0	0.254000008
6.529987	567.7408	2	0.508000016	0	0.508000016
9.314573	567.7408	2	0.762000024	0	0.762000024
12.85091	567.7408	2	1.016000032	0.511236191	0.504763842
15.84011	567.7408	2	1.269999981	1.107247353	0.162752628
18.1087	567.7408	2	1.524000049	1.605949402	-0.08194935
20.3595	567.7408	2	1.777999997	2.141289711	-0.36328971
21.80073	567.7408	2	2.032000065	2.504390717	-0.47239065
23.50439	567.7408	2	2.286000013	2.950294018	-0.664294
24.69207	567.7408	2	2.539999962	3.266360044	-0.72636008
30.32352	567.7408	2	3.809999943	4.16734314	-0.3573432
36.33306	567.7408	2	5.079999924	2.447544575	2.632455349
42.69402	567.7408	2	6.349999905	3.678874969	2.671124935
48.3566	567.7408	2	7.619999886	5.388741016	2.231258869
54.58856	567.7408	2	8.890000343	7.4789114	1.411088943
60.58476	567.7408	2	10.15999985	9.634044647	0.5259552
66.44751	567.7408	2	11.43000031	11.48759651	-0.05759621
72.17237	567.7408	2	12.69999981	12.48121548	0.218784332
78.32871	567.7408	2	13.97000027	14.37507439	-0.40507412
84.18256	567.7408	2	15.23999977	16.69459915	-1.45459938

90.14763	567.7408	2	16.51000023	17.8630085	-1.35300827
96.02373	567.7408	2	17.78000069	16.78026009	0.999740601
101.6374	567.7408	2	19.04999924	17.88138008	1.168619156
106.2947	567.7408	2	20.31999969	20.14638901	0.173610687
109.9066	567.7408	2	21.59000015	22.23096085	-0.64096069
111.8549	567.7408	2	22.86000061	23.43406677	-0.57406616
113.9011	567.7408	2	24.12999916	24.74685478	-0.61685562
115.5781	567.7408	2	25.39999962	25.85406303	-0.45406342
119.835	567.7408	2	27.94000053	28.73684692	-0.79684639
123.8473	567.7408	2	30.47999954	31.42387199	-0.94387245
127.4771	567.7408	2	33.02000046	33.69792557	-0.67792511
131.8541	567.7408	2	35.56000137	36.13762283	-0.57762146
135.1636	567.7408	2	38.09999847	37.75111771	0.348880768
138.3663	567.7408	2	40.63999939	39.1436348	1.496364594
0	141.9352	2	0	0	0
0.057827	141.9352	2	0.254000008	0	0.254000008
4.928628	141.9352	2	0.508000016	0.515699506	-0.00769949
9.683775	141.9352	2	0.762000024	1.403264523	-0.6412645
12.89539	141.9352	2	1.016000032	2.23127079	-1.21527076
16.59186	141.9352	2	1.269999981	1.491104364	-0.22110438
20.28833	141.9352	2	1.524000049	0.846811116	0.677188933
22.28113	141.9352	2	1.777999997	1.122720957	0.65527904
24.3629	141.9352	2	2.032000065	1.624895692	0.407104373
25.4883	141.9352	2	2.286000013	1.957117677	0.328882337
25.62175	141.9352	2	2.539999962	1.99891901	0.541080952
29.89204	141.9352	2	3.809999943	3.553475618	0.256524324
33.69527	141.9352	2	5.079999924	5.126929283	-0.04692936
36.37754	141.9352	2	6.349999905	6.2175951	0.132404804
39.58916	141.9352	2	7.619999886	7.455691814	0.164308071
43.07656	141.9352	2	8.890000343	8.753899574	0.136100769
46.69741	141.9352	2	10.15999985	10.13169765	0.028302193
49.71331	141.9352	2	11.43000031	11.35969543	0.070304871
52.1109	141.9352	2	12.69999981	12.41509247	0.284907341
54.85545	141.9352	2	13.97000027	13.73057079	0.239429474
57.26638	141.9352	2	15.23999977	14.9934864	0.246513367
59.58836	141.9352	2	16.51000023	16.3104744	0.199525833
61.7146	141.9352	2	17.78000069	17.60169411	0.17830658
63.86754	141.9352	2	19.04999924	18.98430634	0.065692902
66.56761	141.9352	2	20.31999969	20.80295563	-0.48295593
68.87179	141.9352	2	21.59000015	22.40211105	-0.8121109
71.27383	141.9352	2	22.86000061	24.08474159	-1.22474098
73.40453	141.9352	2	24.12999916	25.56837845	-1.43837929
75.99339	141.9352	2	25.39999962	27.33743095	-1.93743134
80.0813	141.9352	2	27.94000053	30.02065659	-2.08065605
82.26983	141.9352	2	30.47999954	31.39419556	-0.91419601

84.17367	141.9352	2	33.02000046	32.55231094	0.467689514
0	774.192	0	0	0	0
17.79288	774.192	0	2.539999962	0	2.539999962
31.13754	774.192	0	5.079999924	1.820885062	3.259114861
44.4822	774.192	0	7.619999886	4.374661446	3.24533844
57.82686	774.192	0	10.15999985	7.444105625	2.715894222
68.94741	774.192	0	12.69999981	10.39051056	2.30948925
80.06796	774.192	0	15.23999977	13.66336632	1.576633453
91.18851	774.192	0	17.78000069	17.21779251	0.562208176
102.3091	774.192	0	20.31999969	21.00687218	-0.68687248
111.2055	774.192	0	22.86000061	24.20622253	-1.34622192
115.6537	774.192	0	25.39999962	25.8806591	-0.48065948
0	774.192	1	0	0	0
26.68932	774.192	1	2.539999962	0	2.539999962
37.80987	774.192	1	5.079999924	0	5.079999924
55.60275	774.192	1	7.619999886	2.101116896	5.51888299
66.7233	774.192	1	10.15999985	4.451178074	5.708821774
80.06796	774.192	1	12.69999981	7.777737141	4.922262669
95.63673	774.192	1	15.23999977	12.30719471	2.932805061
106.7573	774.192	1	17.78000069	15.91643143	1.86356926
122.3261	774.192	1	20.31999969	21.47688866	-1.15688896
133.4466	774.192	1	22.86000061	25.99133682	-3.13133621
142.343	774.192	1	25.39999962	30.08508301	-4.68508339
0	258.064	0	0	0	0
20.01699	258.064	0	5.079999924	18.042799	-12.9627991
28.91343	258.064	0	10.15999985	25.79247475	-15.6324749
35.58576	258.064	0	15.23999977	29.96155167	-14.7215519
36.4754	258.064	0	20.31999969	30.48217583	-10.1621761
37.80987	258.064	0	25.39999962	31.24627876	-5.84627914
40.03398	258.064	0	30.47999954	32.47169876	-1.99169922
40.92362	258.064	0	35.56000137	32.94410324	2.615898132
41.81327	258.064	0	40.63999939	33.40602875	7.233970642
42.70291	258.064	0	45.72000122	33.85734558	11.86265564
43.37015	258.064	0	50.79999924	34.18883514	16.61116409
0	258.064	1	0	0	0
24.46521	258.064	1	5.079999924	4.749726772	0.330273151
37.80987	258.064	1	10.15999985	11.44941711	-1.28941727
51.15453	258.064	1	15.23999977	19.67797279	-4.43797302
55.60275	258.064	1	20.31999969	22.82769966	-2.50769997
66.7233	258.064	1	25.39999962	30.41502762	-5.015028
72.28358	258.064	1	30.47999954	33.65052414	-3.1705246
80.06796	258.064	1	35.56000137	37.49334717	-1.93334579
86.74029	258.064	1	40.63999939	40.25579834	0.38420105
91.18851	258.064	1	45.72000122	41.86654282	3.853458405
97.86084	258.064	1	50.79999924	43.97071838	6.829280853

Mean absolute error= 2.399 mm, Max error= 23.01 mm

GRNN Network

			Actual Deflection	Predicted Deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)
0	567.7408	0	0	0.068654977	-0.068654977
3.692023	567.7408	0	0.254000008	0.345111012	-0.091111004
7.517492	567.7408	0	0.508000016	0.78768158	-0.279681563
10.89814	567.7408	0	0.762000024	0.96657896	-0.204578936
13.41138	567.7408	0	1.016000032	1.307263136	-0.291263103
14.94602	567.7408	0	1.269999981	1.487757564	-0.217757583
15.54653	567.7408	0	1.524000049	1.551990509	-0.02799046
17.01444	567.7408	0	1.777999997	1.76014626	0.017853737
18.46011	567.7408	0	2.032000065	1.988907576	0.043092489
19.28303	567.7408	0	2.286000013	2.095602512	0.190397501
20.59526	567.7408	0	2.539999962	2.230579853	0.309420109
25.62175	567.7408	0	3.809999943	3.154846907	0.655153036
31.00409	567.7408	0	5.079999924	4.830469608	0.249530315
36.87574	567.7408	0	6.349999905	5.759119034	0.590880871
42.03568	567.7408	0	7.619999886	7.368995667	0.251004219
46.9732	567.7408	0	8.890000343	8.066763878	0.823236465
51.97745	567.7408	0	10.15999985	10.05042458	0.109575272
57.42652	567.7408	0	11.43000031	10.3930378	1.036962509
63.63179	567.7408	0	12.69999981	11.75105667	0.948943138
69.2143	567.7408	0	13.97000027	12.92796993	1.042030334
74.352	567.7408	0	15.23999977	12.76074314	2.47925663
79.28952	567.7408	0	16.51000023	15.41827679	1.091723442
84.62739	567.7408	0	17.78000069	16.84755516	0.932445526
88.25268	567.7408	0	19.04999924	19.03291893	0.017080307
90.29887	567.7408	0	20.31999969	21.1650219	-0.845022202
91.32196	567.7408	0	21.59000015	22.20096016	-0.610960007
91.90023	567.7408	0	22.86000061	22.81951904	0.040481567
92.72315	567.7408	0	24.12999916	23.77983093	0.350168228

93.61279	567.7408	0	25.39999962	24.9139061	0.486093521
94.92501	567.7408	0	27.94000053	26.37422943	1.565771103
96.08155	567.7408	0	30.47999954	27.20980644	3.2701931
97.77188	567.7408	0	33.02000046	29.53329849	3.486701965
99.39548	567.7408	0	35.56000137	33.43157196	2.128429413
100.7077	567.7408	0	38.09999847	34.98027039	3.119728088
102.2646	567.7408	0	40.63999939	36.54109955	4.098899841
103.3544	567.7408	0	43.18000031	38.52260208	4.657398224
104.3108	567.7408	0	45.72000122	39.66244507	6.057556152
105.3116	567.7408	0	48.25999832	38.97538376	9.284614563
0	141.9352	0	0	0.061245669	-0.061245669
2.891343	141.9352	0	0.254000008	0.273599833	-0.019599825
8.318171	141.9352	0	0.508000016	0.792349279	-0.284349263
9.986254	141.9352	0	0.762000024	0.851477981	-0.089477956
13.14449	141.9352	0	1.016000032	1.274574041	-0.258574009
14.30103	141.9352	0	1.269999981	1.641238451	-0.37123847
15.96911	141.9352	0	1.524000049	2.95342803	-1.429427981
17.90409	141.9352	0	1.777999997	5.108992577	-3.330992579
17.8596	141.9352	0	2.032000065	5.056828022	-3.024827957
18.28218	141.9352	0	2.286000013	5.565524101	-3.279524088
18.1265	141.9352	0	2.539999962	5.374355793	-2.834355831
18.19322	141.9352	0	3.809999943	5.455670357	-1.645670414
18.63804	141.9352	0	5.079999924	6.024611473	-0.944611549
18.37115	141.9352	0	6.349999905	5.677164078	0.672835827
18.34891	141.9352	0	7.619999886	5.649073601	1.970926285
18.41563	141.9352	0	8.890000343	5.733707905	3.156292439
18.74925	141.9352	0	10.15999985	6.175785542	3.984214306
19.66113	141.9352	0	11.43000031	7.61255312	3.817447186
20.06147	141.9352	0	12.69999981	8.386609077	4.313390732
20.63974	141.9352	0	13.97000027	9.694396973	4.275603294
21.32921	141.9352	0	15.23999977	11.57620525	3.663794518
21.95197	141.9352	0	16.51000023	13.61049557	2.899504662
22.53023	141.9352	0	17.78000069	15.79814053	1.981860161
23.08626	141.9352	0	19.04999924	18.10823822	0.941761017
23.46436	141.9352	0	20.31999969	19.71082497	0.609174728
23.88694	141.9352	0	21.59000015	21.43466568	0.155334473
24.30952	141.9352	0	22.86000061	23.00414848	-0.144147873
24.59866	141.9352	0	24.12999916	23.95874214	0.171257019
24.75434	141.9352	0	25.39999962	24.42818451	0.971815109
25.15468	141.9352	0	27.94000053	25.48514748	2.454853058
25.51054	141.9352	0	30.47999954	26.23686409	4.243135452
25.66623	141.9352	0	33.02000046	26.50755692	6.512443542
25.84416	141.9352	0	35.56000137	26.77099228	8.789009094
25.93312	141.9352	0	38.09999847	26.88341141	11.21658707
26.15553	141.9352	0	40.63999939	27.10398865	13.53601074

0	567.7408	1	0	0.100738443	-0.100738443
2.539934	567.7408	1	0.254000008	0.278613478	-0.02461347
4.283636	567.7408	1	0.508000016	0.428214788	0.079785228
6.489953	567.7408	1	0.762000024	0.66350466	0.098495364
8.762993	567.7408	1	1.016000032	0.862418592	0.15358144
11.77444	567.7408	1	1.269999981	1.086756349	0.183243632
14.68802	567.7408	1	1.524000049	1.432662249	0.0913378
17.01444	567.7408	1	1.777999997	1.705374241	0.072625756
19.01169	567.7408	1	2.032000065	1.957491279	0.074508786
24.58531	567.7408	1	2.286000013	2.642647505	-0.356647491
29.7497	567.7408	1	2.539999962	4.336151123	-1.796151161
34.59381	567.7408	1	3.809999943	4.48984623	-0.679846287
40.03398	567.7408	1	5.079999924	6.881983757	-1.801983833
45.51864	567.7408	1	6.349999905	7.12364006	-0.773640156
51.19901	567.7408	1	7.619999886	9.603768349	-1.983768463
56.92387	567.7408	1	8.890000343	9.77480793	-0.884807587
62.64428	567.7408	1	10.15999985	10.93559837	-0.775598526
68.7161	567.7408	1	11.43000031	12.31064129	-0.880640984
74.81016	567.7408	1	12.69999981	12.79867458	-0.098674774
80.25479	567.7408	1	13.97000027	14.75630856	-0.786308289
86.04192	567.7408	1	15.23999977	16.32108116	-1.08108139
91.86909	567.7408	1	16.51000023	22.18501663	-5.675016403
97.11799	567.7408	1	17.78000069	25.2514782	-7.471477509
102.4603	567.7408	1	19.04999924	31.9801445	-12.93014526
106.2057	567.7408	1	20.31999969	30.18181419	-9.861814499
108.4254	567.7408	1	21.59000015	23.91671562	-2.326715469
110.2358	567.7408	1	22.86000061	22.94147301	-0.081472397
113.8522	567.7408	1	24.12999916	24.17117119	-0.041172028
117.3663	567.7408	1	25.39999962	25.69538498	-0.295385361
120.9026	567.7408	1	27.94000053	28.17720795	-0.237207413
124.0386	567.7408	1	30.47999954	30.56855202	-0.088552475
127.0412	567.7408	1	33.02000046	33.03781891	-0.017818451
129.6656	567.7408	1	35.56000137	35.29885864	0.261142731
132.1789	567.7408	1	38.09999847	37.57992172	0.520076752
134.4919	567.7408	1	40.63999939	40.38449097	0.255508423
135.991	567.7408	1	43.18000031	41.96487427	1.215126038
137.3788	567.7408	1	45.72000122	42.9292717	2.790729523
105.3116	567.7408	1	48.25999832	33.03176498	15.22823334
0	141.9352	1	0	0.081549957	-0.081549957
2.664484	141.9352	1	0.254000008	0.27455768	-0.020557672
4.350359	141.9352	1	0.508000016	0.421100914	0.086899102
7.441872	141.9352	1	0.762000024	0.730577767	0.031422257
10.57787	141.9352	1	1.016000032	0.896230161	0.119769871
14.53233	141.9352	1	1.269999981	1.577337503	-0.307337523
16.62745	141.9352	1	1.524000049	3.082778215	-1.558778167

17.64164	141.9352	1	1.777999997	4.102640152	-2.324640155
19.97696	141.9352	1	2.032000065	6.653576374	-4.621576309
21.15129	141.9352	1	2.286000013	8.434126854	-6.148126841
21.51159	141.9352	1	2.539999962	9.177409172	-6.63740921
21.97866	141.9352	1	3.809999943	10.32806778	-6.518067837
25.47051	141.9352	1	5.079999924	19.99451447	-14.91451454
28.19282	141.9352	1	6.349999905	15.21820545	-8.868205547
30.06997	141.9352	1	7.619999886	7.755726337	-0.135726452
32.00049	141.9352	1	8.890000343	8.015823364	0.874176979
33.13034	141.9352	1	10.15999985	8.172818184	1.987181664
38.05007	141.9352	1	11.43000031	10.50219727	0.92780304
39.29113	141.9352	1	12.69999981	11.12367535	1.576324463
41.39958	141.9352	1	13.97000027	12.22212219	1.747878075
42.37374	141.9352	1	15.23999977	12.96298027	2.277019501
44.21976	141.9352	1	16.51000023	15.17603588	1.333964348
45.52308	141.9352	1	17.78000069	16.81250381	0.967496872
47.02213	141.9352	1	19.04999924	18.86930275	0.180696487
47.9696	141.9352	1	20.31999969	20.12705421	0.19294548
49.62879	141.9352	1	21.59000015	21.67520523	-0.085205078
48.70356	141.9352	1	22.86000061	20.89399719	1.966003418
48.74804	141.9352	1	24.12999916	20.93459511	3.195404053
48.91708	141.9352	1	25.39999962	21.08416176	4.31583786
50.21596	141.9352	1	27.94000053	22.22624969	5.713750839
50.89653	141.9352	1	30.47999954	23.12311935	7.356880188
52.46231	141.9352	1	33.02000046	26.04013062	6.979869843
53.60995	141.9352	1	35.56000137	26.7578373	8.802164078
0	567.7408	2	0	0.114406541	-0.114406541
1.218812	567.7408	2	0.254000008	0.175531358	0.078468651
6.529987	567.7408	2	0.508000016	0.644696653	-0.136696637
9.314573	567.7408	2	0.762000024	0.858443141	-0.096443117
12.85091	567.7408	2	1.016000032	1.172438741	-0.156438708
15.84011	567.7408	2	1.269999981	1.485689759	-0.215689778
18.1087	567.7408	2	1.524000049	1.734228611	-0.210228562
20.3595	567.7408	2	1.777999997	1.926045418	-0.148045421
21.80073	567.7408	2	2.032000065	2.123580456	-0.091580391
23.50439	567.7408	2	2.286000013	2.385480881	-0.099480867
24.69207	567.7408	2	2.539999962	2.481292725	0.058707237
30.32352	567.7408	2	3.809999943	4.007786751	-0.197786808
36.33306	567.7408	2	5.079999924	4.941522121	0.138477802
42.69402	567.7408	2	6.349999905	6.544304848	-0.194304943
48.3566	567.7408	2	7.619999886	7.656723499	-0.036723614
54.58856	567.7408	2	8.890000343	9.021968842	-0.131968498
60.58476	567.7408	2	10.15999985	10.2035284	-0.043528557
66.44751	567.7408	2	11.43000031	11.51954174	-0.089541435
72.17237	567.7408	2	12.69999981	12.6736393	0.026360512

78.32871	567.7408	2	13.97000027	14.20945644	-0.239456177
84.18256	567.7408	2	15.23999977	15.55913067	-0.319130898
90.14763	567.7408	2	16.51000023	18.39377975	-1.883779526
96.02373	567.7408	2	17.78000069	21.13720894	-3.357208252
101.6374	567.7408	2	19.04999924	25.02436829	-5.974369049
106.2947	567.7408	2	20.31999969	24.3280201	-4.008020401
109.9066	567.7408	2	21.59000015	22.77288246	-1.182882309
111.8549	567.7408	2	22.86000061	23.35476303	-0.494762421
113.9011	567.7408	2	24.12999916	24.20061111	-0.070611954
115.5781	567.7408	2	25.39999962	24.86204147	0.537958145
119.835	567.7408	2	27.94000053	27.70519066	0.234809875
123.8473	567.7408	2	30.47999954	30.48184395	-0.001844406
127.4771	567.7408	2	33.02000046	33.21837997	-0.198379517
131.8541	567.7408	2	35.56000137	36.86117935	-1.301177979
135.1636	567.7408	2	38.09999847	40.42089462	-2.320896149
138.3663	567.7408	2	40.63999939	42.21762466	-1.577625275
0	141.9352	2	0	0.101856261	-0.101856261
0.057827	141.9352	2	0.254000008	0.102890939	0.15110907
4.928628	141.9352	2	0.508000016	0.488759369	0.019240648
9.683775	141.9352	2	0.762000024	0.8446154	-0.082615376
12.89539	141.9352	2	1.016000032	1.09699297	-0.080992937
16.59186	141.9352	2	1.269999981	2.320744514	-1.050744534
20.28833	141.9352	2	1.524000049	4.7382617	-3.214261651
22.28113	141.9352	2	1.777999997	6.704191685	-4.926191688
24.3629	141.9352	2	2.032000065	10.0276022	-7.995602131
25.4883	141.9352	2	2.286000013	11.16633892	-8.880338907
25.62175	141.9352	2	2.539999962	11.26454353	-8.724543571
29.89204	141.9352	2	3.809999943	6.469919205	-2.659919262
33.69527	141.9352	2	5.079999924	7.244553566	-2.164553642
36.37754	141.9352	2	6.349999905	7.864371777	-1.514371872
39.58916	141.9352	2	7.619999886	10.34260845	-2.722608566
43.07656	141.9352	2	8.890000343	12.41287327	-3.522872925
46.69741	141.9352	2	10.15999985	16.99487877	-6.834878922
49.71331	141.9352	2	11.43000031	19.98731613	-8.557315826
52.1109	141.9352	2	12.69999981	22.20508003	-9.505080223
54.85545	141.9352	2	13.97000027	20.60906029	-6.63906002
57.26638	141.9352	2	15.23999977	15.89608288	-0.656083107
59.58836	141.9352	2	16.51000023	16.5824337	-0.072433472
61.7146	141.9352	2	17.78000069	17.75958633	0.020414352
63.86754	141.9352	2	19.04999924	18.89602089	0.153978348
66.56761	141.9352	2	20.31999969	20.41453552	-0.094535828
68.87179	141.9352	2	21.59000015	21.58165741	0.008342743
71.27383	141.9352	2	22.86000061	22.92370033	-0.063699722
73.40453	141.9352	2	24.12999916	23.99844933	0.131549835
75.99339	141.9352	2	25.39999962	25.19221306	0.20778656

80.0813	141.9352	2	27.94000053	28.02173805	-0.081737518
82.26983	141.9352	2	30.47999954	30.77278519	-0.292785645
84.17367	141.9352	2	33.02000046	32.84871292	0.171287537
0	774.192	0	0	0	0
17.79288	774.192	0	2.539999962	2.539999962	0
31.13754	774.192	0	5.079999924	5.047780991	0.032218933
44.4822	774.192	0	7.619999886	7.620000362	-4.76837E-07
57.82686	774.192	0	10.15999985	9.649963379	0.510036469
68.94741	774.192	0	12.69999981	12.18996525	0.510034561
80.06796	774.192	0	15.23999977	14.214674	1.025325775
91.18851	774.192	0	17.78000069	17.74778175	0.032218933
102.3091	774.192	0	20.31999969	20.31954002	0.000459671
111.2055	774.192	0	22.86000061	25.39996529	-2.539964676
115.6537	774.192	0	25.39999962	25.39953995	0.000459671
0	774.192	1	0	0	0
26.68932	774.192	1	2.539999962	2.572219133	-0.032219172
37.80987	774.192	1	5.079999924	6.350004673	-1.270004749
55.60275	774.192	1	7.619999886	8.130036354	-0.510036469
66.7233	774.192	1	10.15999985	10.67003345	-0.510033607
80.06796	774.192	1	12.69999981	13.72532463	-1.025324821
95.63673	774.192	1	15.23999977	15.2726717	-0.032671928
106.7573	774.192	1	17.78000069	20.32003403	-2.54003334
122.3261	774.192	1	20.31999969	20.32045937	-0.000459671
133.4466	774.192	1	22.86000061	22.86000061	0
142.343	774.192	1	25.39999962	25.39999962	0
0	258.064	0	0	0	0
20.01699	258.064	0	5.079999924	5.080000401	-4.76837E-07
28.91343	258.064	0	10.15999985	10.09634686	0.063652992
35.58576	258.064	0	15.23999977	16.85069275	-1.610692978
36.4754	258.064	0	20.31999969	17.03648567	3.283514023
37.80987	258.064	0	25.39999962	19.57788277	5.822116852
40.03398	258.064	0	30.47999954	33.52078247	-3.040782928
40.92362	258.064	0	35.56000137	37.51759338	-1.95759201
41.81327	258.064	0	40.63999939	40.62810516	0.011894226
42.70291	258.064	0	45.72000122	43.19643021	2.523571014
43.37015	258.064	0	50.79999924	44.76833344	6.031665802
0	258.064	1	0	0	0
24.46521	258.064	1	5.079999924	5.143631458	-0.063631535
37.80987	258.064	1	10.15999985	17.1569519	-6.996952057
51.15453	258.064	1	15.23999977	15.3347578	-0.094758034
55.60275	258.064	1	20.31999969	20.22537994	0.094619751
66.7233	258.064	1	25.39999962	25.41034508	-0.010345459
72.28358	258.064	1	30.47999954	30.46968079	0.010318756
80.06796	258.064	1	35.56000137	35.5606575	-0.000656128
86.74029	258.064	1	40.63999939	40.73394012	-0.093940735

91.18851	258.064	1	45.72000122	45.6260643	0.09393692
97.86084	258.064	1	50.79999924	50.79931641	0.000682831

Mean absolute error= 1.86 mm, Max error = 15.23 mm

Simple Backpropagation Network

			ACTUAL DATA	TRAINED DATA	ERROR	
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)	Absolute error
0	567.7408	0	0	0	0	0
3.692023	567.7408	0	0.254000008	0	0.254000008	0.254000008
7.517492	567.7408	0	0.508000016	0.136708513	0.371291503	0.371291503
10.89814	567.7408	0	0.762000024	0.554100096	0.207899928	0.207899928
13.41138	567.7408	0	1.016000032	0.885760069	0.130239964	0.130239964
14.94602	567.7408	0	1.269999981	1.099540353	0.170459628	0.170459628
15.54653	567.7408	0	1.524000049	1.185815215	0.338184834	0.338184834
17.01444	567.7408	0	1.777999997	1.403404474	0.374595523	0.374595523
18.46011	567.7408	0	2.032000065	1.627652049	0.404348016	0.404348016
19.28303	567.7408	0	2.286000013	1.759989858	0.526010156	0.526010156
20.59526	567.7408	0	2.539999962	1.978402972	0.56159699	0.56159699
25.62175	567.7408	0	3.809999943	2.904310226	0.905689716	0.905689716
31.00409	567.7408	0	5.079999924	4.052268028	1.027731895	1.027731895
36.87574	567.7408	0	6.349999905	5.44604826	0.903951645	0.903951645
42.03568	567.7408	0	7.619999886	6.715855598	0.904144287	0.904144287
46.9732	567.7408	0	8.890000343	7.894256115	0.995744228	0.995744228
51.97745	567.7408	0	10.15999985	8.999910355	1.160089493	1.160089493
57.42652	567.7408	0	11.43000031	10.08813	1.341870308	1.341870308
63.63179	567.7408	0	12.69999981	11.23656178	1.463438034	1.463438034
69.2143	567.7408	0	13.97000027	12.3045435	1.665456772	1.665456772
74.352	567.7408	0	15.23999977	13.45160866	1.788391113	1.788391113
79.28952	567.7408	0	16.51000023	14.82118511	1.688815117	1.688815117
84.62739	567.7408	0	17.78000069	16.68751335	1.092487335	1.092487335
88.25268	567.7408	0	19.04999924	18.31244278	0.737556458	0.737556458
90.29887	567.7408	0	20.31999969	19.81343842	0.506561279	0.506561279
91.32196	567.7408	0	21.59000015	21.20120811	0.388792038	0.388792038
91.90023	567.7408	0	22.86000061	22.39188766	0.468112946	0.468112946
92.72315	567.7408	0	24.12999916	24.78429604	-0.654296875	0.654296875
93.61279	567.7408	0	25.39999962	28.07761002	-2.677610397	2.677610397
94.92501	567.7408	0	27.94000053	32.34885025	-4.408849716	4.408849716
96.08155	567.7408	0	30.47999954	34.62709045	-4.147090912	4.147090912

97.77188	567.7408	0	33.02000046	36.75547409	-3.735473633	3.735473633
99.39548	567.7408	0	35.56000137	38.69404984	-3.134048462	3.134048462
100.7077	567.7408	0	38.09999847	40.56068802	-2.460689545	2.460689545
102.2646	567.7408	0	40.63999939	43.20806503	-2.568065643	2.568065643
103.3544	567.7408	0	43.18000031	45.30474472	-2.124744415	2.124744415
104.3108	567.7408	0	45.72000122	47.35056305	-1.630561829	1.630561829
105.3116	567.7408	0	48.25999832	49.90964508	-1.649646759	1.649646759
0	141.9352	0	0	0.193302155	-0.193302155	0.193302155
2.891343	141.9352	0	0.254000008	1.629522681	-1.375522673	1.375522673
8.318171	141.9352	0	0.508000016	0.660596192	-0.152596176	0.152596176
9.986254	141.9352	0	0.762000024	0.184476256	0.577523768	0.577523768
13.14449	141.9352	0	1.016000032	0.211023986	0.804976046	0.804976046
14.30103	141.9352	0	1.269999981	0.641276181	0.6287238	0.6287238
15.96911	141.9352	0	1.524000049	1.892618299	-0.36861825	0.36861825
17.90409	141.9352	0	1.777999997	4.732728004	-2.954728007	2.954728007
17.8596	141.9352	0	2.032000065	4.648146629	-2.616146564	2.616146564
18.28218	141.9352	0	2.286000013	5.486230373	-3.20023036	3.20023036
18.1265	141.9352	0	2.539999962	5.168624878	-2.628624916	2.628624916
18.19322	141.9352	0	3.809999943	5.303521156	-1.493521214	1.493521214
18.63804	141.9352	0	5.079999924	6.248215675	-1.168215752	1.168215752
18.37115	141.9352	0	6.349999905	5.672150135	0.67784977	0.67784977
18.34891	141.9352	0	7.619999886	5.625362396	1.994637489	1.994637489
18.41563	141.9352	0	8.890000343	5.766269207	3.123731136	3.123731136
18.74925	141.9352	0	10.15999985	6.495925903	3.664073944	3.664073944
19.66113	141.9352	0	11.43000031	8.669061661	2.760938644	2.760938644
20.06147	141.9352	0	12.69999981	9.685228348	3.014771461	3.014771461
20.63974	141.9352	0	13.97000027	11.19730091	2.772699356	2.772699356
21.32921	141.9352	0	15.23999977	13.04705906	2.192940712	2.192940712
21.95197	141.9352	0	16.51000023	14.7531271	1.756873131	1.756873131
22.53023	141.9352	0	17.78000069	16.38246346	1.397537231	1.397537231
23.08626	141.9352	0	19.04999924	18.03722	1.012779236	1.012779236
23.46436	141.9352	0	20.31999969	19.2599659	1.060033798	1.060033798
23.88694	141.9352	0	21.59000015	20.79418564	0.795814514	0.795814514
24.30952	141.9352	0	22.86000061	22.62019539	0.239805222	0.239805222
24.59866	141.9352	0	24.12999916	24.12665367	0.00334549	0.00334549
24.75434	141.9352	0	25.39999962	25.05439949	0.345600128	0.345600128
25.15468	141.9352	0	27.94000053	27.92940712	0.010593414	0.010593414
25.51054	141.9352	0	30.47999954	31.23256874	-0.752569199	0.752569199
25.66623	141.9352	0	33.02000046	32.93581009	0.084190369	0.084190369
25.84416	141.9352	0	35.56000137	35.07962799	0.480373383	0.480373383
25.93312	141.9352	0	38.09999847	36.22628021	1.873718262	1.873718262
26.15553	141.9352	0	40.63999939	39.27550507	1.364494324	1.364494324
0	567.7408	1	0	0.492317379	-0.492317379	0.492317379
2.539934	567.7408	1	0.254000008	0.64180845	-0.387808442	0.387808442
4.283636	567.7408	1	0.508000016	0.739326239	-0.231326222	0.231326222

6.489953	567.7408	1	0.762000024	0.859926701	-0.097926676	0.097926676
8.762993	567.7408	1	1.016000032	0.984877467	0.031122565	0.031122565
11.77444	567.7408	1	1.269999981	1.159057856	0.110942125	0.110942125
14.68802	567.7408	1	1.524000049	1.345639944	0.178360105	0.178360105
17.01444	567.7408	1	1.777999997	1.513237	0.264762998	0.264762998
19.01169	567.7408	1	2.032000065	1.673750162	0.358249903	0.358249903
24.58531	567.7408	1	2.286000013	2.223892212	0.062107801	0.062107801
29.7497	567.7408	1	2.539999962	2.897157907	-0.357157946	0.357157946
34.59381	567.7408	1	3.809999943	3.689193487	0.120806456	0.120806456
40.03398	567.7408	1	5.079999924	4.753669739	0.326330185	0.326330185
45.51864	567.7408	1	6.349999905	5.960764408	0.389235497	0.389235497
51.19901	567.7408	1	7.619999886	7.255840302	0.364159584	0.364159584
56.92387	567.7408	1	8.890000343	8.50428772	0.385712624	0.385712624
62.64428	567.7408	1	10.15999985	9.635409355	0.524590492	0.524590492
68.7161	567.7408	1	11.43000031	10.72402096	0.705979347	0.705979347
74.81016	567.7408	1	12.69999981	11.80426788	0.895731926	0.895731926
80.25479	567.7408	1	13.97000027	12.90162563	1.068374634	1.068374634
86.04192	567.7408	1	15.23999977	14.37173748	0.868262291	0.868262291
91.86909	567.7408	1	16.51000023	16.27722168	0.232778549	0.232778549
97.11799	567.7408	1	17.78000069	18.31809807	-0.538097382	0.538097382
102.4603	567.7408	1	19.04999924	24.35286903	-5.302869797	5.302869797
106.2057	567.7408	1	20.31999969	30.27274323	-9.95274353	9.95274353
108.4254	567.7408	1	21.59000015	31.13757133	-9.547571182	9.547571182
110.2358	567.7408	1	22.86000061	31.68259621	-8.822595596	8.822595596
113.8522	567.7408	1	24.12999916	32.60660553	-8.476606369	8.476606369
117.3663	567.7408	1	25.39999962	33.36376572	-7.963766098	7.963766098
120.9026	567.7408	1	27.94000053	34.25434875	-6.314348221	6.314348221
124.0386	567.7408	1	30.47999954	36.16093445	-5.680934906	5.680934906
127.0412	567.7408	1	33.02000046	38.69126511	-5.671264648	5.671264648
129.6656	567.7408	1	35.56000137	40.08866882	-4.52866745	4.52866745
132.1789	567.7408	1	38.09999847	41.64070129	-3.54070282	3.54070282
134.4919	567.7408	1	40.63999939	43.83740616	-3.197406769	3.197406769
135.991	567.7408	1	43.18000031	45.52642822	-2.346427917	2.346427917
137.3788	567.7408	1	45.72000122	47.01876831	-1.29876709	1.29876709
105.3116	567.7408	1	48.25999832	29.7077713	18.55222702	18.55222702
0	141.9352	1	0	0	0	0
2.664484	141.9352	1	0.254000008	0.066419229	0.187580779	0.187580779
4.350359	141.9352	1	0.508000016	0.252668709	0.255331308	0.255331308
7.441872	141.9352	1	0.762000024	0.652956843	0.109043181	0.109043181
10.57787	141.9352	1	1.016000032	1.149867177	-0.133867145	0.133867145
14.53233	141.9352	1	1.269999981	1.936225057	-0.666225076	0.666225076
16.62745	141.9352	1	1.524000049	2.439715385	-0.915715337	0.915715337
17.64164	141.9352	1	1.777999997	2.708379507	-0.93037951	0.93037951
19.97696	141.9352	1	2.032000065	3.396142244	-1.364142179	1.364142179
21.15129	141.9352	1	2.286000013	3.781824112	-1.495824099	1.495824099

21.51159	141.9352	1	2.539999962	3.905904293	-1.365904331	1.365904331
21.97866	141.9352	1	3.809999943	4.070908546	-0.260908604	0.260908604
25.47051	141.9352	1	5.079999924	5.463754654	-0.38375473	0.38375473
28.19282	141.9352	1	6.349999905	6.759959221	-0.409959316	0.409959316
30.06997	141.9352	1	7.619999886	7.765193462	-0.145193577	0.145193577
32.00049	141.9352	1	8.890000343	8.890574455	-0.000574112	0.000574112
33.13034	141.9352	1	10.15999985	9.589231491	0.570768356	0.570768356
38.05007	141.9352	1	11.43000031	12.9133234	-1.483323097	1.483323097
39.29113	141.9352	1	12.69999981	13.81235123	-1.112351418	1.112351418
41.39958	141.9352	1	13.97000027	15.40355682	-1.433556557	1.433556557
42.37374	141.9352	1	15.23999977	16.18022346	-0.940223694	0.940223694
44.21976	141.9352	1	16.51000023	17.79878998	-1.288789749	1.288789749
45.52308	141.9352	1	17.78000069	19.17110252	-1.391101837	1.391101837
47.02213	141.9352	1	19.04999924	21.22759438	-2.177595139	2.177595139
47.9696	141.9352	1	20.31999969	22.92936516	-2.609365463	2.609365463
49.62879	141.9352	1	21.59000015	26.71951675	-5.129516602	5.129516602
48.70356	141.9352	1	22.86000061	24.49193954	-1.631938934	1.631938934
48.74804	141.9352	1	24.12999916	24.59306908	-0.463069916	0.463069916
48.91708	141.9352	1	25.39999962	24.98345375	0.416545868	0.416545868
50.21596	141.9352	1	27.94000053	28.23765373	-0.297653198	0.297653198
50.89653	141.9352	1	30.47999954	30.06507683	0.414922714	0.414922714
52.46231	141.9352	1	33.02000046	34.55067444	-1.530673981	1.530673981
53.60995	141.9352	1	35.56000137	38.19617844	-2.636177063	2.636177063
0	567.7408	2	0	0.400904119	-0.400904119	0.400904119
1.218812	567.7408	2	0.254000008	0.4150199	-0.161019892	0.161019892
6.529987	567.7408	2	0.508000016	0.549874723	-0.041874707	0.041874707
9.314573	567.7408	2	0.762000024	0.680652797	0.081347227	0.081347227
12.85091	567.7408	2	1.016000032	0.918638468	0.097361565	0.097361565
15.84011	567.7408	2	1.269999981	1.183959126	0.086040854	0.086040854
18.1087	567.7408	2	1.524000049	1.420191526	0.103808522	0.103808522
20.3595	567.7408	2	1.777999997	1.677958012	0.100041986	0.100041986
21.80073	567.7408	2	2.032000065	1.852141738	0.179858327	0.179858327
23.50439	567.7408	2	2.286000013	2.064659834	0.221340179	0.221340179
24.69207	567.7408	2	2.539999962	2.2160604	0.323939562	0.323939562
30.32352	567.7408	2	3.809999943	2.96302247	0.846977472	0.846977472
36.33306	567.7408	2	5.079999924	3.843336105	1.236663818	1.236663818
42.69402	567.7408	2	6.349999905	4.946492195	1.40350771	1.40350771
48.3566	567.7408	2	7.619999886	6.100585938	1.519413948	1.519413948
54.58856	567.7408	2	8.890000343	7.495708942	1.394291401	1.394291401
60.58476	567.7408	2	10.15999985	8.841981888	1.31801796	1.31801796
66.44751	567.7408	2	11.43000031	10.0554285	1.3745718	1.3745718
72.17237	567.7408	2	12.69999981	11.10530949	1.594690323	1.594690323
78.32871	567.7408	2	13.97000027	12.13686752	1.833132744	1.833132744
84.18256	567.7408	2	15.23999977	13.15285397	2.087145805	2.087145805
90.14763	567.7408	2	16.51000023	14.40681267	2.103187561	2.103187561

96.02373	567.7408	2	17.78000069	16.02496147	1.755039215	1.755039215
101.6374	567.7408	2	19.04999924	17.96095657	1.089042664	1.089042664
106.2947	567.7408	2	20.31999969	19.76120186	0.558797836	0.558797836
109.9066	567.7408	2	21.59000015	22.07649994	-0.486499786	0.486499786
111.8549	567.7408	2	22.86000061	26.3451004	-3.485099792	3.485099792
113.9011	567.7408	2	24.12999916	30.46710014	-6.337100983	6.337100983
115.5781	567.7408	2	25.39999962	31.66956902	-6.269569397	6.269569397
119.835	567.7408	2	27.94000053	33.36264038	-5.422639847	5.422639847
123.8473	567.7408	2	30.47999954	35.31147385	-4.831474304	4.831474304
127.4771	567.7408	2	33.02000046	37.72388458	-4.703884125	4.703884125
131.8541	567.7408	2	35.56000137	40.73505402	-5.175052643	5.175052643
135.1636	567.7408	2	38.09999847	42.30021286	-4.200214386	4.200214386
138.3663	567.7408	2	40.63999939	43.1695137	-2.529514313	2.529514313
0	141.9352	2	0	0.137486309	-0.137486309	0.137486309
0.057827	141.9352	2	0.254000008	0.139902964	0.114097044	0.114097044
4.928628	141.9352	2	0.508000016	0.394391268	0.113608748	0.113608748
9.683775	141.9352	2	0.762000024	0.758991599	0.003008425	0.003008425
12.89539	141.9352	2	1.016000032	1.085956812	-0.069956779	0.069956779
16.59186	141.9352	2	1.269999981	1.558459401	-0.28845942	0.28845942
20.28833	141.9352	2	1.524000049	2.149601221	-0.625601172	0.625601172
22.28113	141.9352	2	1.777999997	2.523323774	-0.745323777	0.745323777
24.3629	141.9352	2	2.032000065	2.95853281	-0.926532745	0.926532745
25.4883	141.9352	2	2.286000013	3.213919401	-0.927919388	0.927919388
25.62175	141.9352	2	2.539999962	3.245172262	-0.7051723	0.7051723
29.89204	141.9352	2	3.809999943	4.359958172	-0.549958229	0.549958229
33.69527	141.9352	2	5.079999924	5.55638361	-0.476383686	0.476383686
36.37754	141.9352	2	6.349999905	6.528000832	-0.178000927	0.178000927
39.58916	141.9352	2	7.619999886	7.841059685	-0.221059799	0.221059799
43.07656	141.9352	2	8.890000343	9.456921577	-0.566921234	0.566921234
46.69741	141.9352	2	10.15999985	11.33368397	-1.17368412	1.17368412
49.71331	141.9352	2	11.43000031	13.027071	-1.597070694	1.597070694
52.1109	141.9352	2	12.69999981	14.43449116	-1.734491348	1.734491348
54.85545	141.9352	2	13.97000027	16.08234978	-2.11234951	2.11234951
57.26638	141.9352	2	15.23999977	17.53337288	-2.293373108	2.293373108
59.58836	141.9352	2	16.51000023	18.90504265	-2.395042419	2.395042419
61.7146	141.9352	2	17.78000069	20.1142807	-2.334280014	2.334280014
63.86754	141.9352	2	19.04999924	21.27074814	-2.220748901	2.220748901
66.56761	141.9352	2	20.31999969	22.59747505	-2.277475357	2.277475357
68.87179	141.9352	2	21.59000015	23.6075592	-2.017559052	2.017559052
71.27383	141.9352	2	22.86000061	24.54394531	-1.683944702	1.683944702
73.40453	141.9352	2	24.12999916	25.30059624	-1.170597076	1.170597076
75.99339	141.9352	2	25.39999962	26.25604439	-0.856044769	0.856044769
80.0813	141.9352	2	27.94000053	29.2156105	-1.27560997	1.27560997
82.26983	141.9352	2	30.47999954	31.49516106	-1.015161514	1.015161514
84.17367	141.9352	2	33.02000046	32.80700684	0.212993622	0.212993622

0	774.192	0	0	0	0	0
17.79288	774.192	0	2.539999962	1.373519421	1.166480541	1.166480541
31.13754	774.192	0	5.079999924	3.093397141	1.986602783	1.986602783
44.4822	774.192	0	7.619999886	5.819315434	1.800684452	1.800684452
57.82686	774.192	0	10.15999985	9.013239861	1.146759987	1.146759987
68.94741	774.192	0	12.69999981	11.09754086	1.602458954	1.602458954
80.06796	774.192	0	15.23999977	12.47515583	2.764843941	2.764843941
91.18851	774.192	0	17.78000069	15.0552597	2.724740982	2.724740982
102.3091	774.192	0	20.31999969	23.69821548	-3.37821579	3.37821579
111.2055	774.192	0	22.86000061	26.39966965	-3.539669037	3.539669037
115.6537	774.192	0	25.39999962	28.10910416	-2.709104538	2.709104538
0	774.192	1	0	0.64108932	-0.64108932	0.64108932
26.68932	774.192	1	2.539999962	1.457342625	1.082657337	1.082657337
37.80987	774.192	1	5.079999924	2.501196384	2.578803539	2.578803539
55.60275	774.192	1	7.619999886	5.716783524	1.903216362	1.903216362
66.7233	774.192	1	10.15999985	8.103355408	2.05664444	2.05664444
80.06796	774.192	1	12.69999981	10.23294353	2.467056274	2.467056274
95.63673	774.192	1	15.23999977	11.80722141	3.432778358	3.432778358
106.7573	774.192	1	17.78000069	21.22229385	-3.442293167	3.442293167
122.3261	774.192	1	20.31999969	25.94849205	-5.628492355	5.628492355
133.4466	774.192	1	22.86000061	30.1002121	-7.240211487	7.240211487
142.343	774.192	1	25.39999962	32.46292496	-7.062925339	7.062925339
0	258.064	0	0	0	0	0
20.01699	258.064	0	5.079999924	5.539708138	-0.459708214	0.459708214
28.91343	258.064	0	10.15999985	9.292630196	0.867369652	0.867369652
35.58576	258.064	0	15.23999977	15.98624706	-0.746247292	0.746247292
36.4754	258.064	0	20.31999969	18.06868744	2.251312256	2.251312256
37.80987	258.064	0	25.39999962	22.40293694	2.997062683	2.997062683
40.03398	258.064	0	30.47999954	32.91650391	-2.436504364	2.436504364
40.92362	258.064	0	35.56000137	37.7833252	-2.223323822	2.223323822
41.81327	258.064	0	40.63999939	42.58349991	-1.943500519	1.943500519
42.70291	258.064	0	45.72000122	46.93615341	-1.216152191	1.216152191
43.37015	258.064	0	50.79999924	49.69796753	1.102031708	1.102031708
0	258.064	1	0	0	0	0
24.46521	258.064	1	5.079999924	4.389547825	0.690452099	0.690452099
37.80987	258.064	1	10.15999985	9.37134552	0.788654327	0.788654327
51.15453	258.064	1	15.23999977	15.42032433	-0.180324554	0.180324554
55.60275	258.064	1	20.31999969	17.75981522	2.560184479	2.560184479
66.7233	258.064	1	25.39999962	23.87393951	1.526060104	1.526060104
72.28358	258.064	1	30.47999954	29.78920364	0.690795898	0.690795898
80.06796	258.064	1	35.56000137	33.51081848	2.049182892	2.049182892
86.74029	258.064	1	40.63999939	40.13523102	0.504768372	0.504768372
91.18851	258.064	1	45.72000122	45.23723602	0.482765198	0.482765198
97.86084	258.064	1	50.79999924	50.79999924	0	0

						1.67802654
						average error
						18.55
						worst error

3-Layer Backpropagation using Turboprop

Actual Deflection	Predicted Deflection	Error
Actual(1)	Network(1)	Act-Net(1)
0	6.15631485	-6.15631485
0.254000008	1.138810515	-0.88481051
0.508000016	0	0.508000016
0.762000024	0	0.762000024
1.016000032	0	1.016000032
1.269999981	0	1.269999981
1.524000049	0.078504875	1.445495173
1.777999997	0.336136997	1.441863
2.032000065	0.664544761	1.367455304
2.286000013	0.885246754	1.40075326
2.539999962	1.287467003	1.252532959
3.809999943	3.329458952	0.480540991
5.079999924	5.934710979	-0.85471106
6.349999905	8.179730415	-1.82973051
7.619999886	9.228502274	-1.60850239
8.890000343	9.697112083	-0.80711174
10.15999985	9.912654877	0.247344971
11.43000031	10.02551651	1.404483795
12.69999981	10.24702358	2.452976227
13.97000027	11.88910389	2.080896378
15.23999977	17.156353	-1.91635323
16.51000023	20.20324898	-3.69324875
17.78000069	20.74677086	-2.96677017
19.04999924	20.79724503	-1.74724579
20.31999969	21.00123024	-0.68123055
21.59000015	23.15250587	-1.56250572
22.86000061	24.42451286	-1.56451225
24.12999916	24.79109573	-0.66109657

25.39999962	24.82056808	0.579431534
27.94000053	24.82291412	3.117086411
30.47999954	24.82328224	5.6567173
33.02000046	24.8235817	8.196418762
35.56000137	24.82374573	10.73625565
38.09999847	24.82383347	13.27616501
40.63999939	24.82391357	15.81608582
43.18000031	24.82395554	18.35604477
45.72000122	24.82399559	20.89600563
48.25999832	24.82403374	23.43596458
0	0	0
0.254000008	0	0.254000008
0.508000016	0	0.508000016
0.762000024	0	0.762000024
1.016000032	0	1.016000032
1.269999981	0	1.269999981
1.524000049	0	1.524000049
1.777999997	2.890006304	-1.11200631
2.032000065	2.763377905	-0.73137784
2.286000013	4.090994358	-1.80499434
2.539999962	3.569220781	-1.02922082
3.809999943	3.788141966	0.021857977
5.079999924	5.424072742	-0.34407282
6.349999905	4.406261921	1.943737984
7.619999886	4.326285839	3.293714046
8.890000343	4.568499088	4.321501255
10.15999985	5.877993584	4.282006264
11.43000031	10.02998829	1.400012016
12.69999981	11.91524601	0.784753799
13.97000027	14.50101089	-0.53101063
15.23999977	17.27939606	-2.03939629
16.51000023	19.52147102	-3.01147079
17.78000069	21.41847229	-3.6384716
19.04999924	23.09936333	-4.04936409
20.31999969	24.16726685	-3.84726715
21.59000015	25.2894249	-3.69942474
22.86000061	26.3352108	-3.47521019
24.12999916	27.00612831	-2.87612915
25.39999962	27.35225677	-1.95225716
27.94000053	28.19364738	-0.25364685
30.47999954	28.88322067	1.59677887
33.02000046	29.16791534	3.852085114
35.56000137	29.48086357	6.079137802
38.09999847	29.63244057	8.467557907
40.63999939	29.9973526	10.64264679

0	0	0
0.254000008	0.075299069	0.178700939
0.508000016	0.845724881	-0.33772486
0.762000024	1.829347134	-1.06734711
1.016000032	1.447966456	-0.43196642
1.269999981	0.22117649	1.048823491
1.524000049	1.993330598	-0.46933055
1.777999997	3.042953968	-1.26495397
2.032000065	3.590646982	-1.55864692
2.286000013	5.763460636	-3.47746062
2.539999962	8.10219574	-5.56219578
3.809999943	8.808190346	-4.9981904
5.079999924	9.797991753	-4.71799183
6.349999905	21.17933655	-14.8293366
7.619999886	21.61666489	-13.996665
8.890000343	21.98265266	-13.0926523
10.15999985	22.7983799	-12.6383801
11.43000031	23.94981575	-12.5198154
12.69999981	24.58876419	-11.8887644
13.97000027	24.78120232	-10.811202
15.23999977	24.86640167	-9.6264019
16.51000023	24.95792007	-8.44791985
17.78000069	25.11673546	-7.33673477
19.04999924	25.44863701	-6.39863777
20.31999969	25.8666172	-5.54661751
21.59000015	26.22137642	-4.63137627
22.86000061	26.58433914	-3.72433853
24.12999916	27.53830719	-3.40830803
25.39999962	28.76669502	-3.3666954
27.94000053	30.23113441	-2.29113388
30.47999954	31.58755875	-1.1075592
33.02000046	32.80170441	0.218296051
35.56000137	33.71876907	1.8412323
38.09999847	34.44133759	3.658660889
40.63999939	34.97133636	5.668663025
43.18000031	35.25140762	7.928592682
45.72000122	35.47114563	10.24885559
48.25999832	25.74827576	22.51172256
0	0	0
0.254000008	0	0.254000008
0.508000016	0.368255615	0.139744401
0.762000024	1.529534221	-0.7675342
1.016000032	3.074371338	-2.05837131
1.269999981	5.052273273	-3.78227329
1.524000049	2.004262209	-0.48026216

1.777999997	1.94941628	-0.17141628
2.032000065	3.036234617	-1.00423455
2.286000013	3.635456562	-1.34945655
2.539999962	3.818439007	-1.27843904
3.809999943	4.05442524	-0.2444253
5.079999924	5.760643005	-0.68064308
6.349999905	7.090192318	-0.74019241
7.619999886	8.164099693	-0.54409981
8.890000343	9.616269112	-0.72626877
10.15999985	10.69600868	-0.53600883
11.43000031	15.97401619	-4.54401588
12.69999981	16.87057304	-4.17057323
13.97000027	17.86073303	-3.89073277
15.23999977	18.15473747	-2.9147377
16.51000023	18.57078743	-2.0607872
17.78000069	18.9006443	-1.12064362
19.04999924	19.7933712	-0.74337196
20.31999969	21.21567726	-0.89567757
21.59000015	26.49410057	-4.90410042
22.86000061	23.14398766	-0.28398705
24.12999916	23.28608322	0.843915939
25.39999962	23.84941101	1.550588608
27.94000053	28.6625843	-0.72258377
30.47999954	30.69244957	-0.21245003
33.02000046	33.05683136	-0.0368309
35.56000137	33.77766037	1.782341003
0	0	0
0.254000008	0	0.254000008
0.508000016	0	0.508000016
0.762000024	0	0.762000024
1.016000032	2.056507111	-1.04050708
1.269999981	3.721345186	-2.45134521
1.524000049	2.526202202	-1.00220215
1.777999997	2.921381235	-1.14338124
2.032000065	3.174379587	-1.14237952
2.286000013	3.43252182	-1.14652181
2.539999962	3.588263512	-1.04826355
3.809999943	4.115826607	-0.30582666
5.079999924	4.577964306	0.502035618
6.349999905	6.297617435	0.052382469
7.619999886	7.04801321	0.571986675
8.890000343	8.014572144	0.8754282
10.15999985	9.621442795	0.538557053
11.43000031	11.57218933	-0.14218903
12.69999981	12.80493164	-0.10493183

13.97000027	14.12081814	-0.15081787
15.23999977	15.1783123	0.061687469
16.51000023	16.46164513	0.048355103
17.78000069	18.4262352	-0.64623451
19.04999924	20.73108482	-1.68108559
20.31999969	22.18718147	-1.86718178
21.59000015	22.87138367	-1.28138351
22.86000061	23.1154213	-0.25542068
24.12999916	23.30383873	0.826160431
25.39999962	23.41917992	1.980819702
27.94000053	23.69911385	4.240886688
30.47999954	31.45495033	-0.97495079
33.02000046	36.44560623	-3.42560577
35.56000137	36.53718948	-0.97718811
38.09999847	36.54766083	1.552337646
40.63999939	36.55362701	4.086372375
0	0	0
0.254000008	0	0.254000008
0.508000016	0	0.508000016
0.762000024	0	0.762000024
1.016000032	0	1.016000032
1.269999981	0.768325627	0.501674354
1.524000049	2.074966908	-0.55096686
1.777999997	3.013986111	-1.23598611
2.032000065	4.009438992	-1.97743893
2.286000013	3.526703119	-1.24070311
2.539999962	3.321345091	-0.78134513
3.809999943	1.953117013	1.85688293
5.079999924	3.857823849	1.222176075
6.349999905	5.139929295	1.21007061
7.619999886	6.508131981	1.111867905
8.890000343	7.871527195	1.018473148
10.15999985	9.755456924	0.404542923
11.43000031	12.48681831	-1.05681801
12.69999981	15.09075069	-2.39075089
13.97000027	17.26562881	-3.29562855
15.23999977	18.24079323	-3.00079346
16.51000023	18.68717766	-2.17717743
17.78000069	18.89236259	-1.11236191
19.04999924	19.00725937	0.042739868
20.31999969	19.08900642	1.230993271
21.59000015	19.13137054	2.458629608
22.86000061	19.16206741	3.697933197
24.12999916	19.19117165	4.938827515
25.39999962	19.36368179	6.036317825

27.94000053	25.60169792	2.338302612
30.47999954	32.12195587	-1.64195633
33.02000046	33.585289	-0.56528854
0	0	0
2.539999962	0	2.539999962
5.079999924	0	5.079999924
7.619999886	6.862148762	0.757851124
10.15999985	7.637528896	2.522470951
12.69999981	7.731140614	4.968859196
15.23999977	7.754249096	7.485750675
17.78000069	8.493272781	9.286727905
20.31999969	16.85922623	3.460773468
22.86000061	17.71259499	5.147405624
25.39999962	17.73006821	7.669931412
0	1.051152349	-1.05115235
2.539999962	1.833548427	0.706451535
5.079999924	1.951066494	3.12893343
7.619999886	3.531681299	4.088318586
10.15999985	4.034440041	6.125559807
12.69999981	8.323775291	4.376224518
15.23999977	9.621408463	5.618591309
17.78000069	9.786799431	7.993201256
20.31999969	17.53046227	2.78953743
22.86000061	21.64033318	1.219667435
25.39999962	21.64102745	3.758972168
0	0	0
5.079999924	12.69960499	-7.61960506
10.15999985	22.42892265	-12.2689228
15.23999977	28.66085434	-13.4208546
20.31999969	29.93221092	-9.61221123
25.39999962	31.76288986	-6.36289024
30.47999954	34.08847046	-3.60847092
35.56000137	34.7100029	0.849998474
40.63999939	35.18061066	5.459388733
45.72000122	35.52976608	10.19023514
50.79999924	35.72911835	15.07088089
0	0.36741063	-0.36741063
5.079999924	13.44244194	-8.36244202
10.15999985	33.88693237	-23.7269325
15.23999977	36.07854462	-20.8385448
20.31999969	36.51799774	-16.197998
25.39999962	36.55331421	-11.1533146
30.47999954	36.55846024	-6.07846069
35.56000137	36.56138611	-1.00138474
40.63999939	36.56229782	4.077701569

45.72000122	36.56257629	9.157424927
50.79999924	36.56276703	14.23723221

Mean absolute error= 3.52mm Max error= 23.72 mm

4-Layer Backpropagation Network Using Turboprop

			Actual Deflection	Predicted Deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)
0	567.7408	0	0	2.330347061	-2.330347061
3.6920226	567.7408	0	0.254000008	2.345957994	-2.091957986
7.5174918	567.7408	0	0.508000016	2.484365702	-1.976365685
10.898139	567.7408	0	0.762000024	3.109577417	-2.347577393
13.4113833	567.7408	0	1.016000032	4.272653103	-3.25665307
14.9460192	567.7408	0	1.269999981	5.327436924	-4.057436943
15.5465289	567.7408	0	1.524000049	5.798352718	-4.27435267
17.0144415	567.7408	0	1.777999997	7.038479328	-5.260479331
18.460113	567.7408	0	2.032000065	8.308512688	-6.276512623
19.2830337	567.7408	0	2.286000013	9.020759583	-6.734759569
20.5952586	567.7408	0	2.539999962	10.10574722	-7.565747261
25.6217472	567.7408	0	3.809999943	13.39176464	-9.581764698
31.0040934	567.7408	0	5.079999924	15.60856819	-10.52856827
36.8757438	567.7408	0	6.349999905	17.25232887	-10.90232897
42.035679	567.7408	0	7.619999886	18.38961792	-10.76961803
46.9732032	567.7408	0	8.890000343	19.32296944	-10.43296909
51.9774507	567.7408	0	10.15999985	20.15179062	-9.991790771
57.4265202	567.7408	0	11.43000031	20.93833923	-9.508338928
63.6317871	567.7408	0	12.69999981	21.70214462	-9.002144814
69.2143032	567.7408	0	13.97000027	22.28209686	-8.312096596
74.3519973	567.7408	0	15.23999977	22.73665047	-7.496650696
79.2895215	567.7408	0	16.51000023	23.11062431	-6.600624084
84.6273855	567.7408	0	17.78000069	23.45452309	-5.6745224
88.2526848	567.7408	0	19.04999924	23.65672493	-4.606725693
90.298866	567.7408	0	20.31999969	23.76080704	-3.440807343
91.3219566	567.7408	0	21.59000015	23.81030655	-2.220306396
91.9002252	567.7408	0	22.86000061	23.83756256	-0.977561951
92.7231459	567.7408	0	24.12999916	23.87547874	0.254520416
93.6127899	567.7408	0	25.39999962	23.91533279	1.484666824
94.9250148	567.7408	0	27.94000053	23.97203827	3.967962265
96.081552	567.7408	0	30.47999954	24.02002907	6.459970474

97.7718756	567.7408	0	33.02000046	24.08696556	8.933034897
99.3954759	567.7408	0	35.56000137	24.14784622	11.41215515
100.7077008	567.7408	0	38.09999847	24.1947155	13.90528297
102.2645778	567.7408	0	40.63999939	24.24774742	16.39225197
103.3543917	567.7408	0	43.18000031	24.2832737	18.89672661
104.310759	567.7408	0	45.72000122	24.31341171	21.40658951
105.3116085	567.7408	0	48.25999832	24.34394073	23.91605759
0	141.9352	0	0	2.330976248	-2.330976248
2.891343	141.9352	0	0.254000008	2.352267265	-2.098267257
8.3181714	141.9352	0	0.508000016	3.071550608	-2.563550591
9.9862539	141.9352	0	0.762000024	3.920146704	-3.158146679
13.1444901	141.9352	0	1.016000032	6.817551136	-5.801551104
14.3010273	141.9352	0	1.269999981	8.173521996	-6.903522015
15.9691098	141.9352	0	1.524000049	10.1743803	-8.650380254
17.9040855	141.9352	0	1.777999997	12.32683659	-10.54883659
17.8596033	141.9352	0	2.032000065	12.2807951	-10.24879503
18.2821842	141.9352	0	2.286000013	12.71078396	-10.42478395
18.1264965	141.9352	0	2.539999962	12.55432415	-10.01432419
18.1932198	141.9352	0	3.809999943	12.62165737	-8.811657429
18.6380418	141.9352	0	5.079999924	13.05965328	-7.979653358
18.3711486	141.9352	0	6.349999905	12.79914665	-6.449146748
18.3489075	141.9352	0	7.619999886	12.77712917	-5.157129288
18.4156308	141.9352	0	8.890000343	12.84304905	-3.953048706
18.7492473	141.9352	0	10.15999985	13.16614819	-3.006148338
19.6611324	141.9352	0	11.43000031	13.99352074	-2.563520432
20.0614722	141.9352	0	12.69999981	14.33101273	-1.631012917
20.6397408	141.9352	0	13.97000027	14.79139233	-0.821392059
21.3292149	141.9352	0	15.23999977	15.29995155	-0.059951782
21.9519657	141.9352	0	16.51000023	15.72356796	0.786432266
22.5302343	141.9352	0	17.78000069	16.08851624	1.691484451
23.0862618	141.9352	0	19.04999924	16.4153595	2.63463974
23.4643605	141.9352	0	20.31999969	16.62499046	3.695009232
23.8869414	141.9352	0	21.59000015	16.84792137	4.742078781
24.3095223	141.9352	0	22.86000061	17.05953789	5.800462723
24.5986566	141.9352	0	24.12999916	17.19816017	6.931838989
24.7543443	141.9352	0	25.39999962	17.2708168	8.129182816
25.1546841	141.9352	0	27.94000053	17.45153618	10.48846436
25.5105417	141.9352	0	30.47999954	17.60512733	12.87487221
25.6662294	141.9352	0	33.02000046	17.67033386	15.3496666
25.8441582	141.9352	0	35.56000137	17.74342537	17.816576
25.9331226	141.9352	0	38.09999847	17.77941322	20.32058525
26.1555336	141.9352	0	40.63999939	17.86779594	22.77220345
0	567.7408	1	0	2.328192472	-2.328192472
2.53993362	567.7408	1	0.254000008	2.328242779	-2.074242771
4.28363586	567.7408	1	0.508000016	2.329314709	-1.821314692

6.48995298	567.7408	1	0.762000024	2.350742817	-1.588742793
8.7629934	567.7408	1	1.016000032	2.522001028	-1.506000996
11.77443834	567.7408	1	1.269999981	3.471181631	-2.20118165
14.68802244	567.7408	1	1.524000049	5.35698843	-3.832988381
17.0144415	567.7408	1	1.777999997	7.149478912	-5.371478915
19.01169228	567.7408	1	2.032000065	8.600594521	-6.568594456
24.58531194	567.7408	1	2.286000013	11.63850975	-9.352509737
29.74969536	567.7408	1	2.539999962	13.47835159	-10.93835163
34.59380694	567.7408	1	3.809999943	14.82828522	-11.01828527
40.03398	567.7408	1	5.079999924	16.15245056	-11.07245064
45.51863526	567.7408	1	6.349999905	17.36140442	-11.01140451
51.1990122	567.7408	1	7.619999886	18.49621391	-10.87621403
56.92387134	567.7408	1	8.890000343	19.51726151	-10.62726116
62.64428226	567.7408	1	10.15999985	20.41337013	-10.25337029
68.71610256	567.7408	1	11.43000031	21.23329163	-9.803291321
74.81016396	567.7408	1	12.69999981	21.93040276	-9.230402946
80.25478524	567.7408	1	13.97000027	22.45755577	-8.487555504
86.04191946	567.7408	1	15.23999977	22.93098259	-7.690982819
91.86908766	567.7408	1	16.51000023	23.32940483	-6.819404602
97.11798726	567.7408	1	17.78000069	23.63070869	-5.850708008
102.4602995	567.7408	1	19.04999924	23.88958549	-4.839586258
106.2057007	567.7408	1	20.31999969	24.04620361	-3.726203918
108.4253625	567.7408	1	21.59000015	24.13041306	-2.540412903
110.235788	567.7408	1	22.86000061	24.19471931	-1.334718704
113.8521909	567.7408	1	24.12999916	24.31232643	-0.182327271
117.3662847	567.7408	1	25.39999962	24.41398621	0.986013412
120.9026196	567.7408	1	27.94000053	24.50508881	3.434911728
124.0386147	567.7408	1	30.47999954	24.5774498	5.902549744
127.0411632	567.7408	1	33.02000046	24.6400528	8.379947662
129.665613	567.7408	1	35.56000137	24.68990517	10.87009621
132.1788573	567.7408	1	38.09999847	24.7337513	13.36624718
134.4919317	567.7408	1	40.63999939	24.77100182	15.86899757
135.9909818	567.7408	1	43.18000031	24.79366112	18.38633919
137.3788265	567.7408	1	45.72000122	24.81366158	20.90633965
105.3116085	567.7408	1	48.25999832	24.01052666	24.24947166
0	141.9352	1	0	2.328192472	-2.328192472
2.66448378	141.9352	1	0.254000008	2.328192472	-2.074192464
4.35035916	141.9352	1	0.508000016	2.328193426	-1.82019341
7.44187206	141.9352	1	0.762000024	2.328714848	-1.566714823
10.57786716	141.9352	1	1.016000032	2.383848429	-1.367848396
14.53233474	141.9352	1	1.269999981	3.750891924	-2.480891943
16.62744636	141.9352	1	1.524000049	5.852584362	-4.328584313
17.64164052	141.9352	1	1.777999997	7.127477169	-5.349477172
19.97695602	141.9352	1	2.032000065	10.14495277	-8.112952709
21.1512861	141.9352	1	2.286000013	11.51684093	-9.230840921

21.51159192	141.9352	1	2.539999962	11.90618896	-9.366189003
21.97865502	141.9352	1	3.809999943	12.38729095	-8.577291012
25.47050772	141.9352	1	5.079999924	15.17862988	-10.09862995
28.19281836	141.9352	1	6.349999905	16.58758354	-10.23758364
30.0699672	141.9352	1	7.619999886	17.3118782	-9.691878319
32.00049468	141.9352	1	8.890000343	17.91922379	-9.029223442
33.13034256	141.9352	1	10.15999985	18.22794151	-8.067941666
38.05007388	141.9352	1	11.43000031	19.32079315	-7.890792847
39.29112726	141.9352	1	12.69999981	19.55319023	-6.853190422
41.39958354	141.9352	1	13.97000027	19.92113304	-5.951132774
42.37374372	141.9352	1	15.23999977	20.08137512	-4.841375351
44.21975502	141.9352	1	16.51000023	20.37046814	-3.860467911
45.52308348	141.9352	1	17.78000069	20.56422043	-2.784219742
47.02213362	141.9352	1	19.04999924	20.77745628	-1.727457047
47.96960448	141.9352	1	20.31999969	20.90726852	-0.587268829
49.62879054	141.9352	1	21.59000015	21.12587547	0.46412468
48.70356078	141.9352	1	22.86000061	21.00530434	1.854696274
48.74804298	141.9352	1	24.12999916	21.01117706	3.118822098
48.91707534	141.9352	1	25.39999962	21.03342628	4.366573334
50.21595558	141.9352	1	27.94000053	21.2006855	6.739315033
50.89653324	141.9352	1	30.47999954	21.28579521	9.19420433
52.46230668	141.9352	1	33.02000046	21.47524452	11.54475594
53.60994744	141.9352	1	35.56000137	21.60868263	13.95131874
0	567.7408	2	0	2.328192472	-2.328192472
1.21881228	567.7408	2	0.254000008	2.328192472	-2.074192464
6.52998696	567.7408	2	0.508000016	2.328192472	-1.820192456
9.31457268	567.7408	2	0.762000024	2.328192472	-1.566192448
12.85090758	567.7408	2	1.016000032	2.328192472	-1.31219244
15.84011142	567.7408	2	1.269999981	2.328193426	-1.058193445
18.10870362	567.7408	2	1.524000049	2.328312635	-0.804312587
20.35950294	567.7408	2	1.777999997	2.332537651	-0.554537654
21.80072622	567.7408	2	2.032000065	2.356807232	-0.324807167
23.50439448	567.7408	2	2.286000013	2.494989157	-0.208989143
24.69206922	567.7408	2	2.539999962	2.759911776	-0.219911814
30.32351574	567.7408	2	3.809999943	6.94379425	-3.133794308
36.33306096	567.7408	2	5.079999924	11.7473278	-6.667327881
42.69401556	567.7408	2	6.349999905	14.36271858	-8.012718678
48.35659962	567.7408	2	7.619999886	15.87730694	-8.257307053
54.58855584	567.7408	2	8.890000343	17.26691628	-8.376915932
60.5847564	567.7408	2	10.15999985	18.45237923	-8.292379379
66.44751036	567.7408	2	11.43000031	19.48359108	-8.053590775
72.1723695	567.7408	2	12.69999981	20.36939812	-7.669398308
78.32870598	567.7408	2	13.97000027	21.19263077	-7.222630501
84.1825635	567.7408	2	15.23999977	21.85972214	-6.619722366
90.14762652	567.7408	2	16.51000023	22.43512344	-5.925123215

96.02372514	567.7408	2	17.78000069	22.91136742	-5.13136673
101.6373788	567.7408	2	19.04999924	23.29365349	-4.243654251
106.2946651	567.7408	2	20.31999969	23.56417274	-3.24417305
109.9066198	567.7408	2	21.59000015	23.74843025	-2.158430099
111.8549401	567.7408	2	22.86000061	23.8394413	-0.979440689
113.9011213	567.7408	2	24.12999916	23.92915535	0.200843811
115.5781003	567.7408	2	25.39999962	23.99844742	1.4015522
119.8350468	567.7408	2	27.94000053	24.15854645	3.781454086
123.8473412	567.7408	2	30.47999954	24.29068375	6.189315796
127.4770888	567.7408	2	33.02000046	24.3963604	8.62364006
131.8541372	567.7408	2	35.56000137	24.50834656	11.05165482
135.1636129	567.7408	2	38.09999847	24.58307457	13.5169239
138.3663313	567.7408	2	40.63999939	24.6481266	15.99187279
0	141.9352	2	0	2.328192472	-2.328192472
0.05782686	141.9352	2	0.254000008	2.328192472	-2.074192464
4.92862776	141.9352	2	0.508000016	2.328192472	-1.820192456
9.68377494	141.9352	2	0.762000024	2.328192472	-1.566192448
12.89538978	141.9352	2	1.016000032	2.328192472	-1.31219244
16.5918606	141.9352	2	1.269999981	2.328192472	-1.058192492
20.28833142	141.9352	2	1.524000049	2.328193426	-0.804193377
22.28113398	141.9352	2	1.777999997	2.3282125	-0.550212502
24.36290094	141.9352	2	2.032000065	2.328930616	-0.296930552
25.4883006	141.9352	2	2.286000013	2.332467556	-0.046467543
25.6217472	141.9352	2	2.539999962	2.333398581	0.206601381
29.8920384	141.9352	2	3.809999943	2.921063185	0.888936758
33.6952665	141.9352	2	5.079999924	6.700643063	-1.620643139
36.37754316	141.9352	2	6.349999905	10.75441933	-4.404419422
39.589158	141.9352	2	7.619999886	14.64425182	-7.024251938
43.07656248	141.9352	2	8.890000343	17.17764664	-8.287646294
46.69741356	141.9352	2	10.15999985	18.66381264	-8.50381279
49.71330672	141.9352	2	11.43000031	19.46332741	-8.033327103
52.1108973	141.9352	2	12.69999981	19.95352364	-7.253523827
54.85544904	141.9352	2	13.97000027	20.42353249	-6.453532219
57.26638428	141.9352	2	15.23999977	20.7843895	-5.544389725
59.58835512	141.9352	2	16.51000023	21.0993309	-4.589330673
61.71460428	141.9352	2	17.78000069	21.36556625	-3.585565567
63.86754276	141.9352	2	19.04999924	21.61688614	-2.566886902
66.5676123	141.9352	2	20.31999969	21.90925598	-1.589256287
68.87179026	141.9352	2	21.59000015	22.1406002	-0.550600052
71.27382906	141.9352	2	22.86000061	22.36543655	0.494564056
73.40452644	141.9352	2	24.12999916	22.55183983	1.578159332
75.99339048	141.9352	2	25.39999962	22.76289749	2.637102127
80.08130466	141.9352	2	27.94000053	23.06432533	4.875675201
82.2698289	141.9352	2	30.47999954	23.21090698	7.26909256
84.17366706	141.9352	2	33.02000046	23.33065224	9.689348221

0	774.192	0	0	2.330145597	-2.330145597
17.79288	774.192	0	2.539999962	5.697451115	-3.157451153
31.13754	774.192	0	5.079999924	13.46170712	-8.381707191
44.4822	774.192	0	7.619999886	17.09101868	-9.471018791
57.82686	774.192	0	10.15999985	19.66213608	-9.50213623
68.94741	774.192	0	12.69999981	21.27229118	-8.572291374
80.06796	774.192	0	15.23999977	22.45962524	-7.219625473
91.18851	774.192	0	17.78000069	23.30879402	-5.528793335
102.30906	774.192	0	20.31999969	23.90517807	-3.585178375
111.2055	774.192	0	22.86000061	24.24853706	-1.388536453
115.65372	774.192	0	25.39999962	24.38581276	1.014186859
0	774.192	1	0	2.328199148	-2.328199148
26.68932	774.192	1	2.539999962	10.57474995	-8.034749985
37.80987	774.192	1	5.079999924	13.57338238	-8.493382454
55.60275	774.192	1	7.619999886	17.61723137	-9.997231483
66.7233	774.192	1	10.15999985	19.66898537	-9.508985519
80.06796	774.192	1	12.69999981	21.53104591	-8.831046104
95.63673	774.192	1	15.23999977	22.9853878	-7.745388031
106.75728	774.192	1	17.78000069	23.67201042	-5.892009735
122.32605	774.192	1	20.31999969	24.3014164	-3.981416702
133.4466	774.192	1	22.86000061	24.59031296	-1.730312347
142.34304	774.192	1	25.39999962	24.75599098	0.644008636
0	258.064	0	0	2.330855131	-2.330855131
20.01699	258.064	0	5.079999924	13.14497185	-8.064971924
28.91343	258.064	0	10.15999985	17.86347771	-7.703477859
35.58576	258.064	0	15.23999977	19.52066231	-4.280662537
36.475404	258.064	0	20.31999969	19.69310188	0.626897812
37.80987	258.064	0	25.39999962	19.9378624	5.462137222
40.03398	258.064	0	30.47999954	20.31447029	10.16552925
40.923624	258.064	0	35.56000137	20.45569229	15.10430908
41.813268	258.064	0	40.63999939	20.59215546	20.04784393
42.702912	258.064	0	45.72000122	20.72419548	24.99580574
43.370145	258.064	0	50.79999924	20.82049751	29.97950172
0	258.064	1	0	2.328192472	-2.328192472
24.46521	258.064	1	5.079999924	13.94334793	-8.863348007
37.80987	258.064	1	10.15999985	18.39772797	-8.237728119
51.15453	258.064	1	15.23999977	20.66867638	-5.428676605
55.60275	258.064	1	20.31999969	21.25537491	-0.935375214
66.7233	258.064	1	25.39999962	22.4355526	2.964447021
72.283575	258.064	1	30.47999954	22.8947525	7.58524704
80.06796	258.064	1	35.56000137	23.4185009	12.14150047
86.74029	258.064	1	40.63999939	23.77553368	16.86446571
91.18851	258.064	1	45.72000122	23.97445107	21.74555016
97.86084	258.064	1	50.79999924	24.22389221	26.57610703

Mean absolute error= 6.55mm Max error= 29.98 mm

3 Layer Backpropagation with Jump Connections

			Actual Deflection	Predicted Deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)
0	567.7408	0	0	0	0
3.6920226	567.7408	0	0.25400001	0.294135541	-0.0401355
7.5174918	567.7408	0	0.50800002	1.361023664	-0.8530236
10.898139	567.7408	0	0.76200002	2.381085396	-1.6190854
13.411383	567.7408	0	1.01600003	3.18699646	-2.1709964
14.946019	567.7408	0	1.26999998	3.693586826	-2.4235868
15.546529	567.7408	0	1.52400005	3.894104958	-2.3701049
17.014442	567.7408	0	1.778	4.388440609	-2.6104406
18.460113	567.7408	0	2.03200006	4.879514694	-2.8475146
19.283034	567.7408	0	2.28600001	5.160215855	-2.8742158
20.595259	567.7408	0	2.53999996	5.608622551	-3.0686226
25.621747	567.7408	0	3.80999994	7.316511154	-3.5065112
31.004093	567.7408	0	5.07999992	9.087758064	-4.0077581
36.875744	567.7408	0	6.3499999	10.92449188	-4.574492
42.035679	567.7408	0	7.61999989	12.47358799	-4.8535881
46.973203	567.7408	0	8.89000034	13.93441963	-5.0444193
51.977451	567.7408	0	10.1599998	15.42450428	-5.2645044
57.42652	567.7408	0	11.4300003	17.07583046	-5.6458302
63.631787	567.7408	0	12.6999998	18.9926548	-6.292655
69.214303	567.7408	0	13.9700003	20.73769379	-6.7676935
74.351997	567.7408	0	15.2399998	22.34850121	-7.1085014
79.289522	567.7408	0	16.5100002	23.8917408	-7.3817406
84.627386	567.7408	0	17.7800007	25.5467453	-7.7667446
88.252685	567.7408	0	19.0499992	26.65932274	-7.6093235
90.298866	567.7408	0	20.3199997	27.28232765	-6.962328
91.321957	567.7408	0	21.5900002	27.59235954	-6.0023594
91.900225	567.7408	0	22.8600006	27.76714134	-4.9071407
92.723146	567.7408	0	24.1299992	28.01529121	-3.8852921
93.61279	567.7408	0	25.3999996	28.28277779	-2.8827782
94.925015	567.7408	0	27.9400005	28.67577744	-0.7357769
96.081552	567.7408	0	30.4799995	29.02057457	1.45942497
97.771876	567.7408	0	33.0200005	29.52175522	3.49824524
99.395476	567.7408	0	35.5600014	29.99994278	5.56005859
100.7077	567.7408	0	38.0999985	30.38403702	7.71596146
102.26458	567.7408	0	40.6399994	30.83688164	9.80311775
103.35439	567.7408	0	43.1800003	31.15196228	12.028038
104.31076	567.7408	0	45.7200012	31.4271431	14.2928581
105.31161	567.7408	0	48.2599983	31.71376228	16.546236
0	141.9352	0	0	0	0

2.891343	141.9352	0	0.25400001	0.112309188	0.14169082
8.3181714	141.9352	0	0.50800002	2.362000227	-1.8540002
9.9862539	141.9352	0	0.76200002	3.202188253	-2.4401882
13.14449	141.9352	0	1.01600003	5.002894402	-3.9868944
14.301027	141.9352	0	1.26999998	5.737093449	-4.4670935
15.96911	141.9352	0	1.52400005	6.891694546	-5.3676945
17.904086	141.9352	0	1.778	8.532309532	-6.7543095
17.859603	141.9352	0	2.03200006	8.487420082	-6.45542
18.282184	141.9352	0	2.28600001	8.935955048	-6.649955
18.126497	141.9352	0	2.53999996	8.764677048	-6.2246771
18.19322	141.9352	0	3.80999994	8.837156296	-5.0271564
18.638042	141.9352	0	5.07999992	9.358553886	-4.278554
18.371149	141.9352	0	6.3499999	9.037332535	-2.6873326
18.348908	141.9352	0	7.61999989	9.011733055	-1.3917332
18.415631	141.9352	0	8.89000034	9.089046478	-0.1990461
18.749247	141.9352	0	10.1599998	9.500657082	0.65934277
19.661132	141.9352	0	11.4300003	10.89314461	0.5368557
20.061472	141.9352	0	12.6999998	11.65313721	1.0468626
20.639741	141.9352	0	13.9700003	12.91179943	1.05820084
21.329215	141.9352	0	15.2399998	14.58169746	0.65830231
21.951966	141.9352	0	16.5100002	16.10218239	0.40781784
22.530234	141.9352	0	17.7800007	17.40291023	0.37709045
23.086262	141.9352	0	19.0499992	18.49938965	0.55060959
23.464361	141.9352	0	20.3199997	19.15657997	1.16341972
23.886941	141.9352	0	21.5900002	19.8164444	1.77355576
24.309522	141.9352	0	22.8600006	20.41116142	2.44883919
24.598657	141.9352	0	24.1299992	20.78791618	3.34208298
24.754344	141.9352	0	25.3999996	20.9823761	4.41762352
25.154684	141.9352	0	27.9400005	21.46009445	6.47990608
25.510542	141.9352	0	30.4799995	21.86292076	8.61707878
25.666229	141.9352	0	33.0200005	22.03399277	10.9860077
25.844158	141.9352	0	35.5600014	22.22624779	13.3337536
25.933123	141.9352	0	38.0999985	22.32120323	15.7787952
26.155534	141.9352	0	40.6399994	22.5555172	18.0844822
0	567.7408	1	0	0	0
2.5399336	567.7408	1	0.25400001	0	0.25400001
4.2836359	567.7408	1	0.50800002	0	0.50800002
6.489953	567.7408	1	0.76200002	0	0.76200002
8.7629934	567.7408	1	1.01600003	0	1.01600003
11.774438	567.7408	1	1.26999998	0	1.26999998
14.688022	567.7408	1	1.52400005	0	1.52400005
17.014442	567.7408	1	1.778	0	1.778
19.011692	567.7408	1	2.03200006	0.294904351	1.73709571
24.585312	567.7408	1	2.28600001	1.875764132	0.41023588
29.749695	567.7408	1	2.53999996	3.441440821	-0.9014409

34.593807	567.7408	1	3.80999994	4.968307972	-1.158308
40.03398	567.7408	1	5.07999992	6.722664833	-1.6426649
45.518635	567.7408	1	6.3499999	8.51186657	-2.1618667
51.199012	567.7408	1	7.61999989	10.37067795	-2.7506781
56.923871	567.7408	1	8.89000034	12.24034786	-3.3503475
62.644282	567.7408	1	10.1599998	14.09983253	-3.9398327
68.716103	567.7408	1	11.4300003	16.06143761	-4.6314373
74.810164	567.7408	1	12.6999998	18.01627731	-5.3162775
80.254785	567.7408	1	13.9700003	19.74986076	-5.7798605
86.041919	567.7408	1	15.2399998	21.5774231	-6.3374233
91.869088	567.7408	1	16.5100002	23.39935112	-6.8893509
97.117987	567.7408	1	17.7800007	25.02185249	-7.2418518
102.4603	567.7408	1	19.0499992	26.65172958	-7.6017303
106.2057	567.7408	1	20.3199997	27.77945709	-7.4594574
108.42536	567.7408	1	21.5900002	28.4413147	-6.8513145
110.23579	567.7408	1	22.8600006	28.97731209	-6.1173115
113.85219	567.7408	1	24.1299992	30.03700829	-5.9070091
117.36628	567.7408	1	25.3999996	31.05163574	-5.6516361
120.90262	567.7408	1	27.9400005	32.05643845	-4.1164379
124.03861	567.7408	1	30.4799995	32.93288803	-2.4528885
127.04116	567.7408	1	33.0200005	33.75838852	-0.7383881
129.66561	567.7408	1	35.5600014	34.46846008	1.09154129
132.17886	567.7408	1	38.0999985	35.1379776	2.96202087
134.49193	567.7408	1	40.6399994	35.74481201	4.89518738
135.99098	567.7408	1	43.1800003	36.13316727	7.04683304
137.37883	567.7408	1	45.7200012	36.48918533	9.23081589
105.31161	567.7408	1	48.2599983	27.51146126	20.7485371
0	141.9352	1	0	0	0
2.6644838	141.9352	1	0.25400001	0	0.25400001
4.3503592	141.9352	1	0.50800002	0	0.50800002
7.4418721	141.9352	1	0.76200002	0	0.76200002
10.577867	141.9352	1	1.01600003	0	1.01600003
14.532335	141.9352	1	1.26999998	0.033994507	1.23600547
16.627446	141.9352	1	1.52400005	2.078525782	-0.5545257
17.641641	141.9352	1	1.778	3.252276421	-1.4742764
19.976956	141.9352	1	2.03200006	5.212502956	-3.1805029
21.151286	141.9352	1	2.28600001	5.935997963	-3.6499979
21.511592	141.9352	1	2.53999996	6.14712429	-3.6071243
21.978655	141.9352	1	3.80999994	6.418040276	-2.6080403
25.470508	141.9352	1	5.07999992	8.490344048	-3.4103441
28.192818	141.9352	1	6.3499999	10.24527168	-3.8952718
30.069967	141.9352	1	7.61999989	11.5323925	-3.9123926
32.000495	141.9352	1	8.89000034	12.91658783	-4.0265875
33.130343	141.9352	1	10.1599998	13.75248528	-3.5924854
38.050074	141.9352	1	11.4300003	17.56707382	-6.1370735

39.291127	141.9352	1	12.6999998	18.56143188	-5.8614321
41.399584	141.9352	1	13.9700003	20.26573181	-6.2957315
42.373744	141.9352	1	15.2399998	21.05610085	-5.8161011
44.219755	141.9352	1	16.5100002	22.55207062	-6.0420704
45.523083	141.9352	1	17.7800007	23.60235214	-5.8223515
47.022134	141.9352	1	19.0499992	24.79907227	-5.749073
47.969604	141.9352	1	20.3199997	25.54689598	-5.2268963
49.628791	141.9352	1	21.5900002	26.83564949	-5.2456493
48.703561	141.9352	1	22.8600006	26.12056541	-3.2605648
48.748043	141.9352	1	24.1299992	26.15516281	-2.0251637
48.917075	141.9352	1	25.3999996	26.28642273	-0.8864231
50.215956	141.9352	1	27.9400005	27.28420067	0.65579987
50.896533	141.9352	1	30.4799995	27.79849243	2.68150711
52.462307	141.9352	1	33.0200005	28.95578384	4.06421661
53.609947	141.9352	1	35.5600014	29.77781868	5.78218269
0	567.7408	2	0	0	0
1.2188123	567.7408	2	0.25400001	0	0.25400001
6.529987	567.7408	2	0.50800002	0	0.50800002
9.3145727	567.7408	2	0.76200002	0	0.76200002
12.850908	567.7408	2	1.01600003	0	1.01600003
15.840111	567.7408	2	1.26999998	0	1.26999998
18.108704	567.7408	2	1.52400005	0	1.52400005
20.359503	567.7408	2	1.778	0	1.778
21.800726	567.7408	2	2.03200006	0	2.03200006
23.504394	567.7408	2	2.28600001	0	2.28600001
24.692069	567.7408	2	2.53999996	0	2.53999996
30.323516	567.7408	2	3.80999994	0	3.80999994
36.333061	567.7408	2	5.07999992	1.399472475	3.68052745
42.694016	567.7408	2	6.3499999	3.276098728	3.07390118
48.3566	567.7408	2	7.61999989	5.039872169	2.58012772
54.588556	567.7408	2	8.89000034	7.043174267	1.84682608
60.584756	567.7408	2	10.1599998	9.002742767	1.15725708
66.44751	567.7408	2	11.4300003	10.92892551	0.50107479
72.17237	567.7408	2	12.6999998	12.80722904	-0.1072292
78.328706	567.7408	2	13.9700003	14.81576633	-0.8457661
84.182564	567.7408	2	15.2399998	16.70983696	-1.4698372
90.147627	567.7408	2	16.5100002	18.62097359	-2.1109734
96.023725	567.7408	2	17.7800007	20.48267937	-2.7026787
101.63738	567.7408	2	19.0499992	22.23981667	-3.1898174
106.29467	567.7408	2	20.3199997	23.68012238	-3.3601227
109.90662	567.7408	2	21.5900002	24.78522301	-3.1952229
111.85494	567.7408	2	22.8600006	25.37669945	-2.5166988
113.90112	567.7408	2	24.1299992	25.99419785	-1.8641987
115.5781	567.7408	2	25.3999996	26.49735832	-1.0973587
119.83505	567.7408	2	27.9400005	27.76211548	0.17788506

123.84734	567.7408	2	30.4799995	28.93663216	1.54336739
127.47709	567.7408	2	33.0200005	29.98328781	3.03671265
131.85414	567.7408	2	35.5600014	31.2238102	4.33619118
135.16361	567.7408	2	38.0999985	32.1449852	5.95501328
138.36633	567.7408	2	40.6399994	33.02185059	7.6181488
0	141.9352	2	0	0	0
0.0578269	141.9352	2	0.25400001	0	0.25400001
4.9286278	141.9352	2	0.50800002	0	0.50800002
9.6837749	141.9352	2	0.76200002	0	0.76200002
12.89539	141.9352	2	1.01600003	0	1.01600003
16.591861	141.9352	2	1.26999998	0	1.26999998
20.288331	141.9352	2	1.52400005	0.337589443	1.18641061
22.281134	141.9352	2	1.778	0.938797295	0.8392027
24.362901	141.9352	2	2.03200006	1.617453575	0.41454649
25.488301	141.9352	2	2.28600001	2.006500006	0.27950001
25.621747	141.9352	2	2.53999996	2.053673983	0.48632598
29.892038	141.9352	2	3.80999994	3.679225922	0.13077402
33.695267	141.9352	2	5.07999992	5.308623314	-0.2286234
36.377543	141.9352	2	6.3499999	6.546187401	-0.1961875
39.589158	141.9352	2	7.61999989	8.093073845	-0.473074
43.076562	141.9352	2	8.89000034	9.789458275	-0.8994579
46.697414	141.9352	2	10.1599998	11.47558689	-1.315587
49.713307	141.9352	2	11.4300003	12.79268932	-1.362689
52.110897	141.9352	2	12.6999998	13.82541847	-1.1254187
54.855449	141.9352	2	13.9700003	15.07219505	-1.1021948
57.266384	141.9352	2	15.2399998	16.27307701	-1.0330772
59.588355	141.9352	2	16.5100002	17.53325653	-1.0232563
61.714604	141.9352	2	17.7800007	18.76520348	-0.9852028
63.867543	141.9352	2	19.0499992	20.07126427	-1.021265
66.567612	141.9352	2	20.3199997	21.76623917	-1.4462395
68.87179	141.9352	2	21.5900002	23.24206924	-1.6520691
71.273829	141.9352	2	22.8600006	24.79151726	-1.9315166
73.404526	141.9352	2	24.1299992	26.16281891	-2.0328197
75.99339	141.9352	2	25.3999996	27.80929756	-2.4092979
80.081305	141.9352	2	27.9400005	30.31833076	-2.3783302
82.269829	141.9352	2	30.4799995	31.58812141	-1.1081219
84.173667	141.9352	2	33.0200005	32.63356018	0.38644028
0	774.192	0	0	0	0
17.79288	774.192	0	2.53999996	2.725667953	-0.185668
31.13754	774.192	0	5.07999992	5.532458305	-0.4524584
44.4822	774.192	0	7.61999989	8.5131464	-0.8931465
57.82686	774.192	0	10.1599998	11.82849503	-1.6684952
68.94741	774.192	0	12.6999998	14.7917347	-2.0917349
80.06796	774.192	0	15.2399998	17.8824482	-2.6424484
91.18851	774.192	0	17.7800007	21.0592804	-3.2792797

102.30906	774.192	0	20.3199997	24.27922821	-3.9592285
111.2055	774.192	0	22.8600006	26.85360146	-3.9936008
115.65372	774.192	0	25.3999996	28.1310482	-2.7310486
0	774.192	1	0	0	0
26.68932	774.192	1	2.53999996	1.3250705	1.21492946
37.80987	774.192	1	5.07999992	3.631772757	1.44822717
55.60275	774.192	1	7.61999989	7.61213398	0.00786591
66.7233	774.192	1	10.1599998	10.28674412	-0.1267443
80.06796	774.192	1	12.6999998	13.69747925	-0.9974794
95.63673	774.192	1	15.2399998	17.93509483	-2.6950951
106.75728	774.192	1	17.7800007	21.09342194	-3.3134212
122.32605	774.192	1	20.3199997	25.60414314	-5.2841434
133.4466	774.192	1	22.8600006	28.81406212	-5.9540615
142.34304	774.192	1	25.3999996	31.32956505	-5.9295654
0	258.064	0	0	0.304560572	-0.3045606
20.01699	258.064	0	5.07999992	17.37655067	-12.296551
28.91343	258.064	0	10.1599998	23.62124825	-13.461248
35.58576	258.064	0	15.2399998	28.34686279	-13.106863
36.475404	258.064	0	20.3199997	28.94033432	-8.6203346
37.80987	258.064	0	25.3999996	29.80656052	-4.4065609
40.03398	258.064	0	30.4799995	31.17899323	-0.6989937
40.923624	258.064	0	35.5600014	31.70069313	3.85930824
41.813268	258.064	0	40.6399994	32.20560837	8.43439102
42.702912	258.064	0	45.7200012	32.69285202	13.0271492
43.370145	258.064	0	50.7999992	33.04607391	17.7539253
0	258.064	1	0	0	0
24.46521	258.064	1	5.07999992	10.2927618	-5.2127619
37.80987	258.064	1	10.1599998	19.59712029	-9.4371204
51.15453	258.064	1	15.2399998	24.49261856	-9.2526188
55.60275	258.064	1	20.3199997	26.48552322	-6.1655235
66.7233	258.064	1	25.3999996	32.30200958	-6.90201
72.283575	258.064	1	30.4799995	34.94929123	-4.4692917
80.06796	258.064	1	35.5600014	38.14265823	-2.5826569
86.74029	258.064	1	40.6399994	40.43574905	0.20425034
91.18851	258.064	1	45.7200012	41.75814819	3.96185303
97.86084	258.064	1	50.7999992	43.38919449	7.41080475

Mean absolute error = 3.58mm Max error= 20.74 mm

Ward Nets Backpropagation with 2 hidden slabs

			Actual Deflection	Predicted Deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)
0	567.7408	0	0	0	0
3.6920226	567.7408	0	0.254000008	10.39552021	-10.1415202
7.5174918	567.7408	0	0.508000016	9.191227913	-8.6832279
10.898139	567.7408	0	0.762000024	1.981320143	-1.21932012
13.4113833	567.7408	0	1.016000032	0	1.016000032
14.9460192	567.7408	0	1.269999981	0	1.269999981
15.5465289	567.7408	0	1.524000049	0.700370193	0.823629856
17.0144415	567.7408	0	1.777999997	4.792417526	-3.01441753
18.460113	567.7408	0	2.032000065	7.958411217	-5.92641115
19.2830337	567.7408	0	2.286000013	8.990468979	-6.70446897
20.5952586	567.7408	0	2.539999962	9.996071815	-7.45607185
25.6217472	567.7408	0	3.809999943	11.13956261	-7.32956266
31.0040934	567.7408	0	5.079999924	10.88715363	-5.8071537
36.8757438	567.7408	0	6.349999905	10.78146744	-4.43146753
42.035679	567.7408	0	7.619999886	10.85443878	-3.2344389
46.9732032	567.7408	0	8.890000343	11.066329	-2.17632866
51.9774507	567.7408	0	10.15999985	11.41759682	-1.25759697
57.4265202	567.7408	0	11.43000031	11.94758987	-0.51758957
63.6317871	567.7408	0	12.69999981	12.72219563	-0.02219582
69.2143032	567.7408	0	13.97000027	13.55548763	0.414512634
74.3519973	567.7408	0	15.23999977	14.4177227	0.822277069
79.2895215	567.7408	0	16.51000023	15.31480885	1.195191383
84.6273855	567.7408	0	17.78000069	16.33981514	1.440185547
88.2526848	567.7408	0	19.04999924	17.05778503	1.992214203
90.298866	567.7408	0	20.31999969	17.46782875	2.852170944
91.3219566	567.7408	0	21.59000015	17.67368317	3.916316986
91.9002252	567.7408	0	22.86000061	17.79021072	5.069789886
92.7231459	567.7408	0	24.12999916	17.95619774	6.173801422
93.6127899	567.7408	0	25.39999962	18.13578033	7.264219284
94.9250148	567.7408	0	27.94000053	18.40075302	9.539247513
96.081552	567.7408	0	30.47999954	18.63418579	11.84581375
97.7718756	567.7408	0	33.02000046	18.97483826	14.0451622
99.3954759	567.7408	0	35.56000137	19.30103874	16.25896263
100.7077008	567.7408	0	38.09999847	19.56367111	18.53632736
102.2645778	567.7408	0	40.63999939	19.87378502	20.76621437
103.3543917	567.7408	0	43.18000031	20.08972359	23.09027672
104.310759	567.7408	0	45.72000122	20.27830315	25.44169807
105.3116085	567.7408	0	48.25999832	20.4745369	27.78546143

0	141.9352	0	0	2.224230051	-2.22423005
2.891343	141.9352	0	0.254000008	3.542120934	-3.28812093
8.3181714	141.9352	0	0.508000016	0.258154929	0.249845088
9.9862539	141.9352	0	0.762000024	2.418313742	-1.65631372
13.1444901	141.9352	0	1.016000032	0	1.016000032
14.3010273	141.9352	0	1.269999981	0	1.269999981
15.9691098	141.9352	0	1.524000049	0	1.524000049
17.9040855	141.9352	0	1.777999997	2.745468616	-0.96746862
17.8596033	141.9352	0	2.032000065	2.571759939	-0.53975987
18.2821842	141.9352	0	2.286000013	4.307855606	-2.02185559
18.1264965	141.9352	0	2.539999962	3.647465944	-1.10746598
18.1932198	141.9352	0	3.809999943	3.927860498	-0.11786056
18.6380418	141.9352	0	5.079999924	5.881875038	-0.80187511
18.3711486	141.9352	0	6.349999905	4.694102764	1.655897141
18.3489075	141.9352	0	7.619999886	4.596989155	3.023010731
18.4156308	141.9352	0	8.890000343	4.889308929	4.000691414
18.7492473	141.9352	0	10.15999985	6.385486603	3.774513245
19.6611324	141.9352	0	11.43000031	10.45755291	0.972447395
20.0614722	141.9352	0	12.69999981	12.08015251	0.619847298
20.6397408	141.9352	0	13.97000027	14.12190628	-0.15190601
21.3292149	141.9352	0	15.23999977	16.03894806	-0.79894829
21.9519657	141.9352	0	16.51000023	17.31123734	-0.80123711
22.5302343	141.9352	0	17.78000069	18.16226578	-0.38226509
23.0862618	141.9352	0	19.04999924	18.74266052	0.307338715
23.4643605	141.9352	0	20.31999969	19.03378296	1.286216736
23.8869414	141.9352	0	21.59000015	19.28316689	2.306833267
24.3095223	141.9352	0	22.86000061	19.47147179	3.388528824
24.5986566	141.9352	0	24.12999916	19.57382774	4.556171417
24.7543443	141.9352	0	25.39999962	19.62194443	5.778055191
25.1546841	141.9352	0	27.94000053	19.72807121	8.211929321
25.5105417	141.9352	0	30.47999954	19.80646133	10.67353821
25.6662294	141.9352	0	33.02000046	19.83732414	13.18267632
25.8441582	141.9352	0	35.56000137	19.87062645	15.68937492
25.9331226	141.9352	0	38.09999847	19.88661003	18.21338844
26.1555336	141.9352	0	40.63999939	19.92497063	20.71502876
0	567.7408	1	0	0	0
2.53993362	567.7408	1	0.254000008	0	0.254000008
4.28363586	567.7408	1	0.508000016	0.681209207	-0.17320919
6.48995298	567.7408	1	0.762000024	9.945008278	-9.18300825
8.7629934	567.7408	1	1.016000032	13.0384407	-12.0224407
11.77443834	567.7408	1	1.269999981	16.83844376	-15.5684438
14.68802244	567.7408	1	1.524000049	18.07340622	-16.5494062
17.0144415	567.7408	1	1.777999997	17.74889946	-15.9708995
19.01169228	567.7408	1	2.032000065	17.41013527	-15.3781352
24.58531194	567.7408	1	2.286000013	16.54592705	-14.259927

29.74969536	567.7408	1	2.539999962	15.91010284	-13.3701029
34.59380694	567.7408	1	3.809999943	15.46789837	-11.6578984
40.03398	567.7408	1	5.079999924	15.1525526	-10.0725527
45.51863526	567.7408	1	6.349999905	15.02737999	-8.67738008
51.1990122	567.7408	1	7.619999886	15.0950861	-7.47508621
56.92387134	567.7408	1	8.890000343	15.35440826	-6.46440792
62.64428226	567.7408	1	10.15999985	15.78804398	-5.62804413
68.71610256	567.7408	1	11.43000031	16.41504288	-4.98504257
74.81016396	567.7408	1	12.69999981	17.18690109	-4.48690128
80.25478524	567.7408	1	13.97000027	17.96949577	-3.99949551
86.04191946	567.7408	1	15.23999977	18.86796951	-3.62796974
91.86908766	567.7408	1	16.51000023	19.81229782	-3.30229759
97.11798726	567.7408	1	17.78000069	20.67361641	-2.89361572
102.4602995	567.7408	1	19.04999924	21.54161072	-2.49161148
106.2057007	567.7408	1	20.31999969	22.13676643	-1.81676674
108.4253625	567.7408	1	21.59000015	22.48228264	-0.89228249
110.235788	567.7408	1	22.86000061	22.75952721	0.100473404
113.8521909	567.7408	1	24.12999916	23.29984093	0.830158234
117.3662847	567.7408	1	25.39999962	23.80631447	1.59368515
120.9026196	567.7408	1	27.94000053	24.29659462	3.643405914
124.0386147	567.7408	1	30.47999954	24.71483421	5.765165329
127.0411632	567.7408	1	33.02000046	25.10085106	7.919149399
129.665613	567.7408	1	35.56000137	25.42699432	10.13300705
132.1788573	567.7408	1	38.09999847	25.72984695	12.37015152
134.4919317	567.7408	1	40.63999939	26.00074196	14.63925743
135.9909818	567.7408	1	43.18000031	26.17247772	17.00752258
137.3788265	567.7408	1	45.72000122	26.32890511	19.39109612
105.3116085	567.7408	1	48.25999832	21.99598885	26.26400948
0	141.9352	1	0	0	0
2.66448378	141.9352	1	0.254000008	0	0.254000008
4.35035916	141.9352	1	0.508000016	2.423853874	-1.91585386
7.44187206	141.9352	1	0.762000024	8.549684525	-7.7876845
10.57786716	141.9352	1	1.016000032	0	1.016000032
14.53233474	141.9352	1	1.269999981	0	1.269999981
16.62744636	141.9352	1	1.524000049	2.79812789	-1.27412784
17.64164052	141.9352	1	1.777999997	6.723510742	-4.94551075
19.97695602	141.9352	1	2.032000065	12.36524963	-10.3332496
21.1512861	141.9352	1	2.286000013	13.24941444	-10.9634144
21.51159192	141.9352	1	2.539999962	13.38956928	-10.8495693
21.97865502	141.9352	1	3.809999943	13.51953888	-9.70953894
25.47050772	141.9352	1	5.079999924	13.92591095	-8.84591103
28.19281836	141.9352	1	6.349999905	14.19342804	-7.84342813
30.0699672	141.9352	1	7.619999886	14.4037981	-6.78379822
32.00049468	141.9352	1	8.890000343	14.64241505	-5.7524147
33.13034256	141.9352	1	10.15999985	14.79242706	-4.63242722

38.05007388	141.9352	1	11.43000031	15.53259754	-4.10259724
39.29112726	141.9352	1	12.69999981	15.74098015	-3.04098034
41.39958354	141.9352	1	13.97000027	16.11416054	-2.14416027
42.37374372	141.9352	1	15.23999977	16.29449844	-1.05449867
44.21975502	141.9352	1	16.51000023	16.64946556	-0.13946533
45.52308348	141.9352	1	17.78000069	16.91015816	0.869842529
47.02213362	141.9352	1	19.04999924	17.21986008	1.83013916
47.96960448	141.9352	1	20.31999969	17.42084503	2.899154663
49.62879054	141.9352	1	21.59000015	17.78211403	3.807886124
48.70356078	141.9352	1	22.86000061	17.57921982	5.280780792
48.74804298	141.9352	1	24.12999916	17.58889771	6.541101456
48.91707534	141.9352	1	25.39999962	17.62573051	7.774269104
50.21595558	141.9352	1	27.94000053	17.9126873	10.02731323
50.89653324	141.9352	1	30.47999954	18.06574821	12.41425133
52.46230668	141.9352	1	33.02000046	18.42458153	14.59541893
53.60994744	141.9352	1	35.56000137	18.69320679	16.86679459
0	567.7408	2	0	4.512843609	-4.51284361
1.21881228	567.7408	2	0.254000008	7.774940491	-7.52094048
6.52998696	567.7408	2	0.508000016	18.86530685	-18.3573068
9.31457268	567.7408	2	0.762000024	19.56062889	-18.7986289
12.85090758	567.7408	2	1.016000032	17.04941559	-16.0334156
15.84011142	567.7408	2	1.269999981	19.38687325	-18.1168733
18.10870362	567.7408	2	1.524000049	18.96998024	-17.4459802
20.35950294	567.7408	2	1.777999997	17.63306236	-15.8550624
21.80072622	567.7408	2	2.032000065	16.78359985	-14.7515998
23.50439448	567.7408	2	2.286000013	16.6103344	-14.3243344
24.69206922	567.7408	2	2.539999962	16.91747665	-14.3774767
30.32351574	567.7408	2	3.809999943	16.86104393	-13.051044
36.33306096	567.7408	2	5.079999924	16.03903961	-10.9590397
42.69401556	567.7408	2	6.349999905	15.42138195	-9.07138205
48.35659962	567.7408	2	7.619999886	15.09250641	-7.47250652
54.58855584	567.7408	2	8.890000343	14.96405506	-6.07405472
60.5847564	567.7408	2	10.15999985	15.05734921	-4.89734936
66.44751036	567.7408	2	11.43000031	15.33476257	-3.90476227
72.1723695	567.7408	2	12.69999981	15.76033592	-3.06033611
78.32870598	567.7408	2	13.97000027	16.35837936	-2.3883791
84.1825635	567.7408	2	15.23999977	17.02981186	-1.78981209
90.14762652	567.7408	2	16.51000023	17.78273582	-1.2727356
96.02372514	567.7408	2	17.78000069	18.55937386	-0.77937317
101.6373788	567.7408	2	19.04999924	19.30591774	-0.2559185
106.2946651	567.7408	2	20.31999969	19.91217804	0.407821655
109.9066198	567.7408	2	21.59000015	20.3669281	1.223072052
111.8549401	567.7408	2	22.86000061	20.60508156	2.254919052
113.9011213	567.7408	2	24.12999916	20.84910202	3.280897141
115.5781003	567.7408	2	25.39999962	21.04412842	4.355871201

119.8350468	567.7408	2	27.94000053	21.51772499	6.422275543
123.8473412	567.7408	2	30.47999954	21.93456841	8.545431137
127.4770888	567.7408	2	33.02000046	22.28654289	10.73345757
131.8541372	567.7408	2	35.56000137	22.67996216	12.88003922
135.1636129	567.7408	2	38.09999847	22.9560833	15.14391518
138.3663313	567.7408	2	40.63999939	23.20715332	17.43284607
0	141.9352	2	0	0.774290621	-0.77429062
0.05782686	141.9352	2	0.254000008	0.668153167	-0.41415316
4.92862776	141.9352	2	0.508000016	0	0.508000016
9.68377494	141.9352	2	0.762000024	0	0.762000024
12.89538978	141.9352	2	1.016000032	0	1.016000032
16.5918606	141.9352	2	1.269999981	5.524067879	-4.2540679
20.28833142	141.9352	2	1.524000049	8.641509056	-7.11750901
22.28113398	141.9352	2	1.777999997	8.146165848	-6.36816585
24.36290094	141.9352	2	2.032000065	7.812746525	-5.78074646
25.4883006	141.9352	2	2.286000013	8.078313828	-5.79231381
25.6217472	141.9352	2	2.539999962	8.126652718	-5.58665276
29.8920384	141.9352	2	3.809999943	9.356348038	-5.54634809
33.6952665	141.9352	2	5.079999924	9.694317818	-4.61431789
36.37754316	141.9352	2	6.349999905	9.957971573	-3.60797167
39.589158	141.9352	2	7.619999886	10.32584572	-2.70584583
43.07656248	141.9352	2	8.890000343	10.78874588	-1.89874554
46.69741356	141.9352	2	10.15999985	11.33726501	-1.17726517
49.71330672	141.9352	2	11.43000031	11.84479046	-0.41479015
52.1108973	141.9352	2	12.69999981	12.27949333	0.420506477
54.85544904	141.9352	2	13.97000027	12.80914402	1.160856247
57.26638428	141.9352	2	15.23999977	13.30079842	1.939201355
59.58835512	141.9352	2	16.51000023	13.79584694	2.71415329
61.71460428	141.9352	2	17.78000069	14.26613331	3.513867378
63.86754276	141.9352	2	19.04999924	14.75728798	4.292711258
66.5676123	141.9352	2	20.31999969	15.39200592	4.927993774
68.87179026	141.9352	2	21.59000015	15.94776058	5.642239571
71.27382906	141.9352	2	22.86000061	16.53845024	6.321550369
73.40452644	141.9352	2	24.12999916	17.07005501	7.059944153
75.99339048	141.9352	2	25.39999962	17.72297478	7.677024841
80.08130466	141.9352	2	27.94000053	18.76224518	9.177755356
82.2698289	141.9352	2	30.47999954	19.31920433	11.16079521
84.17366706	141.9352	2	33.02000046	19.80224228	13.21775818
0	774.192	0	0	10.39592552	-10.3959255
17.79288	774.192	0	2.539999962	0	2.539999962
31.13754	774.192	0	5.079999924	12.44906616	-7.36906624
44.4822	774.192	0	7.619999886	11.1323843	-3.51238441
57.82686	774.192	0	10.15999985	10.81046009	-0.65046024
68.94741	774.192	0	12.69999981	11.20788574	1.492114067
80.06796	774.192	0	15.23999977	12.07574844	3.164251328

91.18851	774.192	0	17.78000069	13.25615501	4.523845673
102.30906	774.192	0	20.31999969	14.58506393	5.73493576
111.2055	774.192	0	22.86000061	15.64636517	7.213635445
115.65372	774.192	0	25.39999962	15.85432625	9.54567337
0	774.192	1	0	4.563327312	-4.56332731
26.68932	774.192	1	2.539999962	15.82243919	-13.2824392
37.80987	774.192	1	5.079999924	17.66333771	-12.5833378
55.60275	774.192	1	7.619999886	16.14911461	-8.52911472
66.7233	774.192	1	10.15999985	16.13142204	-5.9714222
80.06796	774.192	1	12.69999981	16.86759186	-4.16759205
95.63673	774.192	1	15.23999977	18.37403297	-3.1340332
106.75728	774.192	1	17.78000069	19.596632	-1.81663132
122.32605	774.192	1	20.31999969	21.19524384	-0.87524414
133.4466	774.192	1	22.86000061	22.16109276	0.698907852
142.34304	774.192	1	25.39999962	22.82684326	2.573156357
0	258.064	0	0	0	0
20.01699	258.064	0	5.079999924	14.00211811	-8.92211819
28.91343	258.064	0	10.15999985	16.56517601	-6.40517616
35.58576	258.064	0	15.23999977	17.47597313	-2.23597336
36.475404	258.064	0	20.31999969	17.61767769	2.702322006
37.80987	258.064	0	25.39999962	17.83881378	7.561185837
40.03398	258.064	0	30.47999954	18.22959137	12.25040817
40.923624	258.064	0	35.56000137	18.39344215	17.16655922
41.813268	258.064	0	40.63999939	18.56146622	22.07853317
42.702912	258.064	0	45.72000122	18.73356438	26.98643684
43.370145	258.064	0	50.79999924	18.86525536	31.93474388
0	258.064	1	0	0	0
24.46521	258.064	1	5.079999924	13.71039581	-8.63039589
37.80987	258.064	1	10.15999985	14.7147646	-4.55476475
51.15453	258.064	1	15.23999977	16.78722954	-1.54722977
55.60275	258.064	1	20.31999969	17.67651176	2.64348793
66.7233	258.064	1	25.39999962	20.19724274	5.202756882
72.283575	258.064	1	30.47999954	21.5504055	8.92959404
80.06796	258.064	1	35.56000137	23.45921898	12.10078239
86.74029	258.064	1	40.63999939	25.04705429	15.5929451
91.18851	258.064	1	45.72000122	26.05635071	19.66365051
97.86084	258.064	1	50.79999924	27.47190857	23.32809067

Mean absolute error= 6.687mm Max error = 31.94mm

Ward Networks 3-hidden layer backpropagation model

			Actual Deflection	Predicted Deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)
0	567.7408	0	0	0	0
3.6920226	567.7408	0	0.254000008	0	0.254000008
7.5174918	567.7408	0	0.508000016	1.385382295	-0.877382278
10.898139	567.7408	0	0.762000024	3.151672125	-2.389672101
13.4113833	567.7408	0	1.016000032	3.555244207	-2.539244175
14.9460192	567.7408	0	1.269999981	3.708393335	-2.438393354
15.5465289	567.7408	0	1.524000049	3.765076876	-2.241076827
17.0144415	567.7408	0	1.777999997	3.905978918	-2.127978921
18.460113	567.7408	0	2.032000065	4.053783894	-2.021783829
19.2830337	567.7408	0	2.286000013	4.143251419	-1.857251406
20.5952586	567.7408	0	2.539999962	4.294528008	-1.754528046
25.6217472	567.7408	0	3.809999943	4.962857723	-1.15285778
31.0040934	567.7408	0	5.079999924	5.778254986	-0.698255062
36.8757438	567.7408	0	6.349999905	6.733062744	-0.38306284
42.035679	567.7408	0	7.619999886	7.641671181	-0.021671295
46.9732032	567.7408	0	8.890000343	8.595013618	0.294986725
51.9774507	567.7408	0	10.15999985	9.662987709	0.497012138
57.4265202	567.7408	0	11.43000031	10.96554089	0.464459419
63.6317871	567.7408	0	12.69999981	12.67645359	0.023546219
69.2143032	567.7408	0	13.97000027	14.49904823	-0.529047966
74.3519973	567.7408	0	15.23999977	16.49858856	-1.258588791
79.2895215	567.7408	0	16.51000023	18.77937317	-2.26937294
84.6273855	567.7408	0	17.78000069	21.65869522	-3.878694534
88.2526848	567.7408	0	19.04999924	23.81007004	-4.760070801
90.298866	567.7408	0	20.31999969	25.06265259	-4.742652893
91.3219566	567.7408	0	21.59000015	25.69215584	-4.102155685
91.9002252	567.7408	0	22.86000061	26.04763794	-3.187637329
92.7231459	567.7408	0	24.12999916	26.55202484	-2.422025681
93.6127899	567.7408	0	25.39999962	27.09399033	-1.693990707
94.9250148	567.7408	0	27.94000053	27.88374329	0.056257248
96.081552	567.7408	0	30.47999954	28.56671143	1.913288116
97.7718756	567.7408	0	33.02000046	29.53595161	3.484048843
99.3954759	567.7408	0	35.56000137	30.42726517	5.132736206
100.7077008	567.7408	0	38.09999847	31.1146965	6.985301971
102.2645778	567.7408	0	40.63999939	31.88816261	8.751836777
103.3543917	567.7408	0	43.18000031	32.40076447	10.77923584
104.310759	567.7408	0	45.72000122	32.83037949	12.88962173
105.3116085	567.7408	0	48.25999832	33.25943375	15.00056458

0	141.9352	0	0	0	0
2.891343	141.9352	0	0.254000008	0.045270655	0.208729353
8.3181714	141.9352	0	0.508000016	2.690789223	-2.182789207
9.9862539	141.9352	0	0.762000024	2.626554012	-1.864553988
13.1444901	141.9352	0	1.016000032	1.928099751	-0.912099719
14.3010273	141.9352	0	1.269999981	1.897634268	-0.627634287
15.9691098	141.9352	0	1.524000049	2.60120368	-1.077203631
17.9040855	141.9352	0	1.777999997	5.242405415	-3.464405417
17.8596033	141.9352	0	2.032000065	5.154252529	-3.122252464
18.2821842	141.9352	0	2.286000013	6.046763897	-3.760763884
18.1264965	141.9352	0	2.539999962	5.703674316	-3.163674355
18.1932198	141.9352	0	3.809999943	5.848677635	-2.038677692
18.6380418	141.9352	0	5.079999924	6.892446518	-1.812446594
18.3711486	141.9352	0	6.349999905	6.250223637	0.099776268
18.3489075	141.9352	0	7.619999886	6.19885397	1.421145916
18.4156308	141.9352	0	8.890000343	6.353965759	2.536034584
18.7492473	141.9352	0	10.15999985	7.173822403	2.986177444
19.6611324	141.9352	0	11.43000031	9.756323814	1.673676491
20.0614722	141.9352	0	12.69999981	11.01683712	1.683162689
20.6397408	141.9352	0	13.97000027	12.920681	1.049319267
21.3292149	141.9352	0	15.23999977	15.23309708	0.006902695
21.9519657	141.9352	0	16.51000023	17.27206802	-0.762067795
22.5302343	141.9352	0	17.78000069	19.05938339	-1.279382706
23.0862618	141.9352	0	19.04999924	20.64398575	-1.593986511
23.4643605	141.9352	0	20.31999969	21.63583183	-1.315832138
23.8869414	141.9352	0	21.59000015	22.65850449	-1.068504333
24.3095223	141.9352	0	22.86000061	23.59086037	-0.730859756
24.5986566	141.9352	0	24.12999916	24.17830658	-0.048307419
24.7543443	141.9352	0	25.39999962	24.4782486	0.921751022
25.1546841	141.9352	0	27.94000053	25.19939613	2.740604401
25.5105417	141.9352	0	30.47999954	25.78339958	4.69659996
25.6662294	141.9352	0	33.02000046	26.02316093	6.996839523
25.8441582	141.9352	0	35.56000137	26.28609657	9.2739048
25.9331226	141.9352	0	38.09999847	26.41329956	11.68669891
26.1555336	141.9352	0	40.63999939	26.71938133	13.92061806
0	567.7408	1	0	0	0
2.53993362	567.7408	1	0.254000008	0	0.254000008
4.28363586	567.7408	1	0.508000016	1.691370726	-1.183370709
6.48995298	567.7408	1	0.762000024	4.490244865	-3.728244841
8.7629934	567.7408	1	1.016000032	5.552168846	-4.536168814
11.77443834	567.7408	1	1.269999981	5.90363884	-4.633638859
14.68802244	567.7408	1	1.524000049	5.957182884	-4.433182836
17.0144415	567.7408	1	1.777999997	5.954565525	-4.176565528
19.01169228	567.7408	1	2.032000065	5.952275753	-3.920275688
24.58531194	567.7408	1	2.286000013	6.011897564	-3.725897551

29.74969536	567.7408	1	2.539999962	6.188559055	-3.648559093
34.59380694	567.7408	1	3.809999943	6.472407341	-2.662407398
40.03398	567.7408	1	5.079999924	6.930254936	-1.850255013
45.51863526	567.7408	1	6.349999905	7.538978577	-1.188978672
51.1990122	567.7408	1	7.619999886	8.320323944	-0.700324059
56.92387134	567.7408	1	8.890000343	9.2570858	-0.367085457
62.64428226	567.7408	1	10.15999985	10.33885479	-0.178854942
68.71610256	567.7408	1	11.43000031	11.65073299	-0.220732689
74.81016396	567.7408	1	12.69999981	13.16110706	-0.461107254
80.25478524	567.7408	1	13.97000027	14.72111225	-0.751111984
86.04191946	567.7408	1	15.23999977	16.67758179	-1.437582016
91.86908766	567.7408	1	16.51000023	19.06252289	-2.552522659
97.11798726	567.7408	1	17.78000069	21.63207626	-3.852075577
102.4602995	567.7408	1	19.04999924	24.6233902	-5.573390961
106.2057007	567.7408	1	20.31999969	26.85233307	-6.532333374
108.4253625	567.7408	1	21.59000015	28.17667198	-6.586671829
110.235788	567.7408	1	22.86000061	29.23760414	-6.377603531
113.8521909	567.7408	1	24.12999916	31.25192451	-7.121925354
117.3662847	567.7408	1	25.39999962	33.01120758	-7.611207962
120.9026196	567.7408	1	27.94000053	34.53743744	-6.597436905
124.0386147	567.7408	1	30.47999954	35.67461014	-5.194610596
127.0411632	567.7408	1	33.02000046	36.58029938	-3.56029892
129.665613	567.7408	1	35.56000137	37.23796082	-1.677959442
132.1788573	567.7408	1	38.09999847	37.76369476	0.336303711
134.4919317	567.7408	1	40.63999939	38.1685524	2.471446991
135.9909818	567.7408	1	43.18000031	38.39517212	4.784828186
137.3788265	567.7408	1	45.72000122	38.58246994	7.137531281
105.3116085	567.7408	1	48.25999832	26.31669426	21.94330406
0	141.9352	1	0	0	0
2.66448378	141.9352	1	0.254000008	0.296006233	-0.042006224
4.35035916	141.9352	1	0.508000016	0.443420798	0.064579219
7.44187206	141.9352	1	0.762000024	0	0.762000024
10.57786716	141.9352	1	1.016000032	0	1.016000032
14.53233474	141.9352	1	1.269999981	0	1.269999981
16.62744636	141.9352	1	1.524000049	0	1.524000049
17.64164052	141.9352	1	1.777999997	0.361320734	1.416679263
19.97695602	141.9352	1	2.032000065	2.162692308	-0.130692244
21.1512861	141.9352	1	2.286000013	2.956760406	-0.670760393
21.51159192	141.9352	1	2.539999962	3.185625553	-0.645625591
21.97865502	141.9352	1	3.809999943	3.475645065	0.334354877
25.47050772	141.9352	1	5.079999924	5.619188786	-0.539188862
28.19281836	141.9352	1	6.349999905	7.172361374	-0.822361469
30.0699672	141.9352	1	7.619999886	8.007522583	-0.387522697
32.00049468	141.9352	1	8.890000343	8.69699955	0.193000793
33.13034256	141.9352	1	10.15999985	9.076863289	1.083136559

38.05007388	141.9352	1	11.43000031	11.45449448	-0.024494171
39.29112726	141.9352	1	12.69999981	12.42552567	0.274474144
41.39958354	141.9352	1	13.97000027	14.50315857	-0.533158302
42.37374372	141.9352	1	15.23999977	15.62127781	-0.381278038
44.21975502	141.9352	1	16.51000023	17.90552521	-1.395524979
45.52308348	141.9352	1	17.78000069	19.55297089	-1.7729702
47.02213362	141.9352	1	19.04999924	21.3751812	-2.325181961
47.96960448	141.9352	1	20.31999969	22.44855881	-2.128559113
49.62879054	141.9352	1	21.59000015	24.133255	-2.543254852
48.70356078	141.9352	1	22.86000061	23.22638893	-0.366388321
48.74804298	141.9352	1	24.12999916	23.27190781	0.858091354
48.91707534	141.9352	1	25.39999962	23.44312477	1.956874847
50.21595558	141.9352	1	27.94000053	24.66458702	3.275413513
50.89653324	141.9352	1	30.47999954	25.23748207	5.242517471
52.46230668	141.9352	1	33.02000046	26.38779831	6.632202148
53.60994744	141.9352	1	35.56000137	27.09642029	8.463581085
0	567.7408	2	0	0	0
1.21881228	567.7408	2	0.254000008	0	0.254000008
6.52998696	567.7408	2	0.508000016	1.754942775	-1.246942759
9.31457268	567.7408	2	0.762000024	1.661234379	-0.899234354
12.85090758	567.7408	2	1.016000032	3.234061718	-2.218061686
15.84011142	567.7408	2	1.269999981	3.103974819	-1.833974838
18.10870362	567.7408	2	1.524000049	2.18181181	-0.657811761
20.35950294	567.7408	2	1.777999997	2.356764793	-0.578764796
21.80072622	567.7408	2	2.032000065	2.976573467	-0.944573402
23.50439448	567.7408	2	2.286000013	3.644815683	-1.35881567
24.69206922	567.7408	2	2.539999962	3.875162363	-1.335162401
30.32351574	567.7408	2	3.809999943	3.89461875	-0.084618807
36.33306096	567.7408	2	5.079999924	4.468161583	0.611838341
42.69401556	567.7408	2	6.349999905	5.555670738	0.794329166
48.35659962	567.7408	2	7.619999886	6.306169987	1.313829899
54.58855584	567.7408	2	8.890000343	6.930922985	1.959077358
60.5847564	567.7408	2	10.15999985	7.649342537	2.51065731
66.44751036	567.7408	2	11.43000031	8.52184391	2.908156395
72.1723695	567.7408	2	12.69999981	9.533881187	3.166118622
78.32870598	567.7408	2	13.97000027	10.79459381	3.175406456
84.1825635	567.7408	2	15.23999977	12.16336346	3.076636314
90.14762652	567.7408	2	16.51000023	13.75132751	2.758672714
96.02372514	567.7408	2	17.78000069	15.55785751	2.222143173
101.6373788	567.7408	2	19.04999924	17.5878315	1.46216774
106.2946651	567.7408	2	20.31999969	19.56579018	0.754209518
109.9066198	567.7408	2	21.59000015	21.31337357	0.276626587
111.8549401	567.7408	2	22.86000061	22.33561707	0.524383545
113.9011213	567.7408	2	24.12999916	23.4657402	0.664258957
115.5781003	567.7408	2	25.39999962	24.43048859	0.969511032

119.8350468	567.7408	2	27.94000053	26.99117851	0.948822021
123.8473412	567.7408	2	30.47999954	29.44892502	1.031074524
127.4770888	567.7408	2	33.02000046	31.58926201	1.430738449
131.8541372	567.7408	2	35.56000137	33.92552948	1.634471893
135.1636129	567.7408	2	38.09999847	35.45117569	2.648822784
138.3663313	567.7408	2	40.63999939	36.71061325	3.929386139
0	141.9352	2	0	0.774673879	-0.774673879
0.05782686	141.9352	2	0.254000008	0.782996833	-0.528996825
4.92862776	141.9352	2	0.508000016	0	0.508000016
9.68377494	141.9352	2	0.762000024	0	0.762000024
12.89538978	141.9352	2	1.016000032	0	1.016000032
16.5918606	141.9352	2	1.269999981	0.639035046	0.630964935
20.28833142	141.9352	2	1.524000049	2.788028955	-1.264028907
22.28113398	141.9352	2	1.777999997	3.359473228	-1.581473231
24.36290094	141.9352	2	2.032000065	3.074987411	-1.042987347
25.4883006	141.9352	2	2.286000013	2.605902672	-0.319902658
25.6217472	141.9352	2	2.539999962	2.546171188	-0.006171227
29.8920384	141.9352	2	3.809999943	2.641383171	1.168616772
33.6952665	141.9352	2	5.079999924	5.869728088	-0.789728165
36.37754316	141.9352	2	6.349999905	7.060940742	-0.710940838
39.589158	141.9352	2	7.619999886	7.626421928	-0.006422043
43.07656248	141.9352	2	8.890000343	8.095502853	0.79449749
46.69741356	141.9352	2	10.15999985	8.683319092	1.476680756
49.71330672	141.9352	2	11.43000031	9.331616402	2.098383904
52.1108973	141.9352	2	12.69999981	10.02363014	2.676369667
54.85544904	141.9352	2	13.97000027	11.13803005	2.831970215
57.26638428	141.9352	2	15.23999977	12.55670643	2.683293343
59.58835512	141.9352	2	16.51000023	14.45388508	2.05611515
61.71460428	141.9352	2	17.78000069	16.68169785	1.098302841
63.86754276	141.9352	2	19.04999924	19.28100014	-0.2310009
66.5676123	141.9352	2	20.31999969	22.57542229	-2.255422592
68.87179026	141.9352	2	21.59000015	25.01050186	-3.420501709
71.27382906	141.9352	2	22.86000061	26.99418259	-4.134181976
73.40452644	141.9352	2	24.12999916	28.30206108	-4.17206192
75.99339048	141.9352	2	25.39999962	29.42149734	-4.021497726
80.08130466	141.9352	2	27.94000053	30.34582138	-2.405820847
82.2698289	141.9352	2	30.47999954	30.50059319	-0.020593643
84.17366706	141.9352	2	33.02000046	30.52597427	2.494026184
0	774.192	0	0	0.03844649	-0.03844649
17.79288	774.192	0	2.539999962	3.718547106	-1.178547144
31.13754	774.192	0	5.079999924	4.996032715	0.083967209
44.4822	774.192	0	7.619999886	6.857054234	0.762945652
57.82686	774.192	0	10.15999985	9.069900513	1.090099335
68.94741	774.192	0	12.69999981	11.11407089	1.585928917
80.06796	774.192	0	15.23999977	13.12614632	2.113853455

91.18851	774.192	0	17.78000069	14.9078722	2.872128487
102.30906	774.192	0	20.31999969	16.33317184	3.98682785
111.2055	774.192	0	22.86000061	17.18873024	5.67127037
115.65372	774.192	0	25.39999962	17.52494812	7.875051498
0	774.192	1	0	0	0
26.68932	774.192	1	2.539999962	4.441661835	-1.901661873
37.80987	774.192	1	5.079999924	4.691626549	0.388373375
55.60275	774.192	1	7.619999886	6.212284088	1.407715797
66.7233	774.192	1	10.15999985	7.782926559	2.377073288
80.06796	774.192	1	12.69999981	10.0649929	2.635006905
95.63673	774.192	1	15.23999977	12.8147459	2.425253868
106.75728	774.192	1	17.78000069	14.54024124	3.239759445
122.32605	774.192	1	20.31999969	16.35922813	3.960771561
133.4466	774.192	1	22.86000061	17.20178795	5.658212662
142.34304	774.192	1	25.39999962	17.6350441	7.764955521
0	258.064	0	0	1.668237448	-1.668237448
20.01699	258.064	0	5.079999924	25.53627968	-20.45627975
28.91343	258.064	0	10.15999985	29.39807129	-19.23807144
35.58576	258.064	0	15.23999977	31.0925045	-15.85250473
36.475404	258.064	0	20.31999969	31.31135941	-10.99135971
37.80987	258.064	0	25.39999962	31.63773346	-6.237733841
40.03398	258.064	0	30.47999954	32.17672729	-1.696727753
40.923624	258.064	0	35.56000137	32.39051437	3.169487
41.813268	258.064	0	40.63999939	32.60319901	8.036800385
42.702912	258.064	0	45.72000122	32.81471252	12.9052887
43.370145	258.064	0	50.79999924	32.97252655	17.82747269
0	258.064	1	0	0	0
24.46521	258.064	1	5.079999924	11.82510948	-6.745109558
37.80987	258.064	1	10.15999985	23.65019226	-13.49019241
51.15453	258.064	1	15.23999977	27.9424324	-12.70243263
55.60275	258.064	1	20.31999969	29.11040878	-8.790409088
66.7233	258.064	1	25.39999962	31.94565392	-6.545654297
72.283575	258.064	1	30.47999954	33.26267624	-2.782676697
80.06796	258.064	1	35.56000137	34.93296051	0.627040863
86.74029	258.064	1	40.63999939	36.17824173	4.46175766
91.18851	258.064	1	45.72000122	36.9083519	8.811649323
97.86084	258.064	1	50.79999924	37.85614777	12.94385147

Mean absolute error = 2.97 mm Max error= 21.94mm

Ward Network 2 hidden layer Backpropagation model with connection between Input and Output slabs

			Actual Deflection	Predicted Deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)
0	567.7408	0	0	0	0
3.6920226	567.7408	0	0.254000008	0	0.254000008
7.5174918	567.7408	0	0.508000016	0	0.508000016
10.898139	567.7408	0	0.762000024	0	0.762000024
13.4113833	567.7408	0	1.016000032	0	1.016000032
14.9460192	567.7408	0	1.269999981	0.053700089	1.216299891
15.5465289	567.7408	0	1.524000049	0.114071056	1.409928992
17.0144415	567.7408	0	1.777999997	0.236722946	1.541277051
18.460113	567.7408	0	2.032000065	0.351121873	1.680878192
19.2830337	567.7408	0	2.286000013	0.42482087	1.861179143
20.5952586	567.7408	0	2.539999962	0.567099333	1.972900629
25.6217472	567.7408	0	3.809999943	1.494706631	2.315293312
31.0040934	567.7408	0	5.079999924	3.143274307	1.936725616
36.8757438	567.7408	0	6.349999905	5.807476044	0.542523861
42.035679	567.7408	0	7.619999886	9.179785728	-1.559785843
46.9732032	567.7408	0	8.890000343	13.30049706	-4.410496712
51.9774507	567.7408	0	10.15999985	17.70487404	-7.544874191
57.4265202	567.7408	0	11.43000031	21.4646225	-10.03462219
63.6317871	567.7408	0	12.69999981	23.40427589	-10.70427608
69.2143032	567.7408	0	13.97000027	23.51589394	-9.545893669
74.3519973	567.7408	0	15.23999977	23.33167839	-8.091678619
79.2895215	567.7408	0	16.51000023	23.63385773	-7.123857498
84.6273855	567.7408	0	17.78000069	24.75261307	-6.972612381
88.2526848	567.7408	0	19.04999924	25.91086578	-6.860866547
90.298866	567.7408	0	20.31999969	26.66368675	-6.343687057
91.3219566	567.7408	0	21.59000015	27.05941582	-5.469415665
91.9002252	567.7408	0	22.86000061	27.28767586	-4.427675247
92.7231459	567.7408	0	24.12999916	27.61736298	-3.487363815
93.6127899	567.7408	0	25.39999962	27.97919464	-2.579195023
94.9250148	567.7408	0	27.94000053	28.52088928	-0.580888748
96.081552	567.7408	0	30.47999954	29.00398064	1.476018906
97.7718756	567.7408	0	33.02000046	29.71554184	3.304458618
99.3954759	567.7408	0	35.56000137	30.40118599	5.158815384
100.707701	567.7408	0	38.09999847	30.95448494	7.145513535

102.264578	567.7408	0	40.63999939	31.60783005	9.032169342
103.354392	567.7408	0	43.18000031	32.06220245	11.11779785
104.310759	567.7408	0	45.72000122	32.45843887	13.26156235
105.311609	567.7408	0	48.25999832	32.87029266	15.38970566
0	141.9352	0	0	2.96344924	-2.96344924
2.891343	141.9352	0	0.254000008	3.745766401	-3.491766393
8.3181714	141.9352	0	0.508000016	3.8969841	-3.388984084
9.9862539	141.9352	0	0.762000024	3.450636148	-2.688636124
13.1444901	141.9352	0	1.016000032	2.913208723	-1.897208691
14.3010273	141.9352	0	1.269999981	3.14835	-1.878350019
15.9691098	141.9352	0	1.524000049	4.1945858	-2.670585752
17.9040855	141.9352	0	1.777999997	6.733463287	-4.95546329
17.8596033	141.9352	0	2.032000065	6.657588959	-4.625588894
18.2821842	141.9352	0	2.286000013	7.411699295	-5.125699282
18.1264965	141.9352	0	2.539999962	7.125259399	-4.585259438
18.1932198	141.9352	0	3.809999943	7.246795177	-3.436795235
18.6380418	141.9352	0	5.079999924	8.103339195	-3.023339272
18.3711486	141.9352	0	6.349999905	7.579830647	-1.229830742
18.3489075	141.9352	0	7.619999886	7.537491322	0.082508564
18.4156308	141.9352	0	8.890000343	7.665101528	1.224898815
18.7492473	141.9352	0	10.15999985	8.329762459	1.830237389
19.6611324	141.9352	0	11.43000031	10.35662079	1.073379517
20.0614722	141.9352	0	12.69999981	11.33067322	1.369326591
20.6397408	141.9352	0	13.97000027	12.80704498	1.162955284
21.3292149	141.9352	0	15.23999977	14.63893795	0.601061821
21.9519657	141.9352	0	16.51000023	16.31939507	0.190605164
22.5302343	141.9352	0	17.78000069	17.86639977	-0.086399078
23.0862618	141.9352	0	19.04999924	19.31381989	-0.263820648
23.4643605	141.9352	0	20.31999969	20.26374435	0.056255341
23.8869414	141.9352	0	21.59000015	21.28393555	0.306064606
24.3095223	141.9352	0	22.86000061	22.25369835	0.606302261
24.5986566	141.9352	0	24.12999916	22.88536072	1.244638443
24.7543443	141.9352	0	25.39999962	23.21419525	2.185804367
25.1546841	141.9352	0	27.94000053	24.02218437	3.917816162
25.5105417	141.9352	0	30.47999954	24.69379425	5.786205292
25.6662294	141.9352	0	33.02000046	24.97361755	8.046382904
25.8441582	141.9352	0	35.56000137	25.28293419	10.27706718
25.9331226	141.9352	0	38.09999847	25.43340111	12.66659737
26.1555336	141.9352	0	40.63999939	25.79734993	14.84264946
0	567.7408	1	0	0	0
2.53993362	567.7408	1	0.254000008	0	0.254000008
4.28363586	567.7408	1	0.508000016	0.605606377	-0.097606361
6.48995298	567.7408	1	0.762000024	1.325223207	-0.563223183
8.7629934	567.7408	1	1.016000032	1.864719868	-0.848719835
11.7744383	567.7408	1	1.269999981	2.424481153	-1.154481173

14.6880224	567.7408	1	1.524000049	2.811427116	-1.287427068
17.0144415	567.7408	1	1.777999997	2.976559162	-1.198559165
19.0116923	567.7408	1	2.032000065	3.014510393	-0.982510328
24.5853119	567.7408	1	2.286000013	2.802985907	-0.516985893
29.7496954	567.7408	1	2.539999962	2.608007908	-0.068007946
34.5938069	567.7408	1	3.809999943	2.732489347	1.077510595
40.03398	567.7408	1	5.079999924	3.325904131	1.754095793
45.5186353	567.7408	1	6.349999905	4.359653473	1.990346432
51.1990122	567.7408	1	7.619999886	5.784116745	1.835883141
56.9238713	567.7408	1	8.890000343	7.491949558	1.398050785
62.6442823	567.7408	1	10.15999985	9.416025162	0.743974686
68.7161026	567.7408	1	11.43000031	11.66002369	-0.230023384
74.810164	567.7408	1	12.69999981	14.08828735	-1.388287544
80.2547852	567.7408	1	13.97000027	16.37573624	-2.40573597
86.0419195	567.7408	1	15.23999977	18.89260101	-3.652601242
91.8690877	567.7408	1	16.51000023	21.47588539	-4.965885162
97.1179873	567.7408	1	17.78000069	23.81115341	-6.031152725
102.460299	567.7408	1	19.04999924	26.16625214	-7.116252899
106.205701	567.7408	1	20.31999969	27.79030609	-7.470306396
108.425363	567.7408	1	21.59000015	28.73847389	-7.14847374
110.235788	567.7408	1	22.86000061	29.50268555	-6.642684937
113.852191	567.7408	1	24.12999916	31.0016861	-6.871686935
117.366285	567.7408	1	25.39999962	32.41927338	-7.019273758
120.90262	567.7408	1	27.94000053	33.80319214	-5.863191605
124.038615	567.7408	1	30.47999954	34.99222565	-4.512226105
127.041163	567.7408	1	33.02000046	36.09539795	-3.075397491
129.665613	567.7408	1	35.56000137	37.03052521	-1.470523834
132.178857	567.7408	1	38.09999847	37.90003204	0.199966431
134.491932	567.7408	1	40.63999939	38.67750931	1.962490082
135.990982	567.7408	1	43.18000031	39.16964722	4.010353088
137.378826	567.7408	1	45.72000122	39.61701584	6.102985382
105.311609	567.7408	1	48.25999832	27.40517998	20.85481834
0	141.9352	1	0	1.251562119	-1.251562119
2.66448378	141.9352	1	0.254000008	0.979709685	-0.725709677
4.35035916	141.9352	1	0.508000016	0.598611414	-0.090611398
7.44187206	141.9352	1	0.762000024	0	0.762000024
10.5778672	141.9352	1	1.016000032	0	1.016000032
14.5323347	141.9352	1	1.269999981	0.886325896	0.383674085
16.6274464	141.9352	1	1.524000049	2.48910737	-0.965107322
17.6416405	141.9352	1	1.777999997	3.344543695	-1.566543698
19.976956	141.9352	1	2.032000065	5.22877121	-3.196771145
21.1512861	141.9352	1	2.286000013	6.07482338	-3.788823366
21.5115919	141.9352	1	2.539999962	6.321701527	-3.781701565
21.978655	141.9352	1	3.809999943	6.635019779	-2.825019836
25.4705077	141.9352	1	5.079999924	8.951335907	-3.871335983

28.1928184	141.9352	1	6.349999905	10.99183464	-4.641834736
30.0699672	141.9352	1	7.619999886	12.50892258	-4.888922691
32.0004947	141.9352	1	8.890000343	14.04485512	-5.154854774
33.1303426	141.9352	1	10.15999985	14.88521004	-4.72521019
38.0500739	141.9352	1	11.43000031	17.79149437	-6.361494064
39.2911273	141.9352	1	12.69999981	18.38434601	-5.684346199
41.3995835	141.9352	1	13.97000027	19.37800217	-5.4080019
42.3737437	141.9352	1	15.23999977	19.85334396	-4.613344193
44.219755	141.9352	1	16.51000023	20.80555916	-4.295558929
45.5230835	141.9352	1	17.78000069	21.52026939	-3.740268707
47.0221336	141.9352	1	19.04999924	22.37764168	-3.327642441
47.9696045	141.9352	1	20.31999969	22.93291283	-2.612913132
49.6287905	141.9352	1	21.59000015	23.91664314	-2.32664299
48.7035608	141.9352	1	22.86000061	23.36713791	-0.507137299
48.748043	141.9352	1	24.12999916	23.39352226	0.736476898
48.9170753	141.9352	1	25.39999962	23.49383545	1.906164169
50.2159556	141.9352	1	27.94000053	24.2652607	3.674739838
50.8965332	141.9352	1	30.47999954	24.66813087	5.811868668
52.4623067	141.9352	1	33.02000046	25.58526421	7.434736252
53.6099474	141.9352	1	35.56000137	26.24505043	9.314950943
0	567.7408	2	0	0	0
1.21881228	567.7408	2	0.254000008	0	0.254000008
6.52998696	567.7408	2	0.508000016	0	0.508000016
9.31457268	567.7408	2	0.762000024	0	0.762000024
12.8509076	567.7408	2	1.016000032	0	1.016000032
15.8401114	567.7408	2	1.269999981	0	1.269999981
18.1087036	567.7408	2	1.524000049	0	1.524000049
20.3595029	567.7408	2	1.777999997	0	1.777999997
21.8007262	567.7408	2	2.032000065	0	2.032000065
23.5043945	567.7408	2	2.286000013	0	2.286000013
24.6920692	567.7408	2	2.539999962	0.067899123	2.472100839
30.3235157	567.7408	2	3.809999943	0.647016943	3.162983
36.333061	567.7408	2	5.079999924	1.352710605	3.727289319
42.6940156	567.7408	2	6.349999905	2.233114004	4.1168859
48.3565996	567.7408	2	7.619999886	3.161058664	4.458941221
54.5885558	567.7408	2	8.890000343	4.367125034	4.522875309
60.5847564	567.7408	2	10.15999985	5.731695175	4.428304672
66.4475104	567.7408	2	11.43000031	7.272658348	4.157341957
72.1723695	567.7408	2	12.69999981	8.978417397	3.721582413
78.328706	567.7408	2	13.97000027	11.02764702	2.942353249
84.1825635	567.7408	2	15.23999977	13.16523266	2.074767113
90.1476265	567.7408	2	16.51000023	15.5045681	1.005432129
96.0237251	567.7408	2	17.78000069	17.93204498	-0.152044296
101.637379	567.7408	2	19.04999924	20.32736397	-1.277364731
106.294665	567.7408	2	20.31999969	22.34403229	-2.024032593

109.90662	567.7408	2	21.59000015	23.9121151	-2.322114944
111.85494	567.7408	2	22.86000061	24.75580025	-1.895799637
113.901121	567.7408	2	24.12999916	25.63830566	-1.508306503
115.5781	567.7408	2	25.39999962	26.3578434	-0.957843781
119.835047	567.7408	2	27.94000053	28.16378021	-0.223779678
123.847341	567.7408	2	30.47999954	29.83091164	0.649087906
127.477089	567.7408	2	33.02000046	31.30285072	1.717149734
131.854137	567.7408	2	35.56000137	33.02477646	2.535224915
135.163613	567.7408	2	38.09999847	34.28422165	3.815776825
138.366331	567.7408	2	40.63999939	35.46573257	5.174266815
0	141.9352	2	0	0	0
0.05782686	141.9352	2	0.254000008	0	0.254000008
4.92862776	141.9352	2	0.508000016	0	0.508000016
9.68377494	141.9352	2	0.762000024	0	0.762000024
12.8953898	141.9352	2	1.016000032	0	1.016000032
16.5918606	141.9352	2	1.269999981	0	1.269999981
20.2883314	141.9352	2	1.524000049	0	1.524000049
22.281134	141.9352	2	1.777999997	0.677624404	1.100375593
24.3629009	141.9352	2	2.032000065	1.415606141	0.616393924
25.4883006	141.9352	2	2.286000013	1.837941647	0.448058367
25.6217472	141.9352	2	2.539999962	1.889591336	0.650408626
29.8920384	141.9352	2	3.809999943	3.794010401	0.015989542
33.6952665	141.9352	2	5.079999924	6.026660442	-0.946660519
36.3775432	141.9352	2	6.349999905	7.855436325	-1.50543642
39.589158	141.9352	2	7.619999886	10.00972748	-2.389727592
43.0765625	141.9352	2	8.890000343	11.93783474	-3.047834396
46.6974136	141.9352	2	10.15999985	13.57455349	-3.414553642
49.7133067	141.9352	2	11.43000031	14.99838257	-3.568382263
52.1108973	141.9352	2	12.69999981	16.29623222	-3.596232414
54.855449	141.9352	2	13.97000027	17.95105553	-3.98105526
57.2663843	141.9352	2	15.23999977	19.49518776	-4.255187988
59.5883551	141.9352	2	16.51000023	21.01231003	-4.502309799
61.7146043	141.9352	2	17.78000069	22.40024757	-4.620246887
63.8675428	141.9352	2	19.04999924	23.78868103	-4.738681793
66.5676123	141.9352	2	20.31999969	25.4910717	-5.171072006
68.8717903	141.9352	2	21.59000015	26.90019608	-5.310195923
71.2738291	141.9352	2	22.86000061	28.31904793	-5.459047318
73.4045264	141.9352	2	24.12999916	29.5303154	-5.400316238
75.9933905	141.9352	2	25.39999962	30.93776321	-5.537763596
80.0813047	141.9352	2	27.94000053	33.00904083	-5.069040298
82.2698289	141.9352	2	30.47999954	34.04016876	-3.56016922
84.1736671	141.9352	2	33.02000046	34.89317322	-1.87317276
0	774.192	0	0	0	0
17.79288	774.192	0	2.539999962	0	2.539999962
31.13754	774.192	0	5.079999924	0	5.079999924

44.4822	774.192	0	7.619999886	2.490009069	5.129990816
57.82686	774.192	0	10.15999985	10.00422859	0.155771255
68.94741	774.192	0	12.69999981	17.42028809	-4.720288277
80.06796	774.192	0	15.23999977	18.83028603	-3.590286255
91.18851	774.192	0	17.78000069	19.17340088	-1.393400192
102.30906	774.192	0	20.31999969	22.59323692	-2.273237228
111.2055	774.192	0	22.86000061	26.45541382	-3.595413208
115.65372	774.192	0	25.39999962	28.4415493	-3.041549683
0	774.192	1	0	0	0
26.68932	774.192	1	2.539999962	1.015695453	1.524304509
37.80987	774.192	1	5.079999924	0.572819233	4.507180691
55.60275	774.192	1	7.619999886	1.483323574	6.136676311
66.7233	774.192	1	10.15999985	3.660952568	6.499047279
80.06796	774.192	1	12.69999981	7.317734241	5.382265568
95.63673	774.192	1	15.23999977	12.86960602	2.370393753
106.75728	774.192	1	17.78000069	17.51288795	0.267112732
122.32605	774.192	1	20.31999969	24.46156311	-4.141563416
133.4466	774.192	1	22.86000061	29.37301636	-6.513015747
142.34304	774.192	1	25.39999962	33.09237671	-7.69237709
0	258.064	0	0	1.482764363	-1.482764363
20.01699	258.064	0	5.079999924	11.59696102	-6.516961098
28.91343	258.064	0	10.15999985	18.15947151	-7.999471664
35.58576	258.064	0	15.23999977	23.12317276	-7.883172989
36.475404	258.064	0	20.31999969	23.84964561	-3.52964592
37.80987	258.064	0	25.39999962	24.89798164	0.502017975
40.03398	258.064	0	30.47999954	26.45670509	4.023294449
40.923624	258.064	0	35.56000137	26.99461365	8.565387726
41.813268	258.064	0	40.63999939	27.47756767	13.16243172
42.702912	258.064	0	45.72000122	27.90377235	17.81622887
43.370145	258.064	0	50.79999924	28.18589592	22.61410332
0	258.064	1	0	2.560465813	-2.560465813
24.46521	258.064	1	5.079999924	10.95373154	-5.873731613
37.80987	258.064	1	10.15999985	15.41487408	-5.254874229
51.15453	258.064	1	15.23999977	21.57455444	-6.334554672
55.60275	258.064	1	20.31999969	23.47131729	-3.151317596
66.7233	258.064	1	25.39999962	27.87040901	-2.470409393
72.283575	258.064	1	30.47999954	29.94061852	0.539381027
80.06796	258.064	1	35.56000137	32.74632645	2.813674927
86.74029	258.064	1	40.63999939	35.07886124	5.561138153
91.18851	258.064	1	45.72000122	36.59391785	9.126083374
97.86084	258.064	1	50.79999924	38.79267502	12.00732422

Mean absolute error = 3.59 mm Max error= 22.62mm.

APPENDIX B

BEAM DATA

Appendix B contains beam data from experiments conducted on them. Deflection is measured in millimeters, load in KiloNewtons, Diameter of tensile steel in millimeter, Area of steel in square millimeters (for 2 bars), and CFRP external reinforcement represented by a value (0= no CFRP, 1= CFRP on tensile face only, and 2= CFRP on both tensile and shear faces).

BEAM 1 DATA

Deflection (mm)	Load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2-bars)	CFRP
0.00	0.00	19.05	567.74	0.00
0.25	3.69	19.05	567.74	0.00
0.51	7.52	19.05	567.74	0.00
0.76	10.90	19.05	567.74	0.00
1.02	13.41	19.05	567.74	0.00
1.27	14.95	19.05	567.74	0.00
1.52	15.55	19.05	567.74	0.00
1.78	17.01	19.05	567.74	0.00
2.03	18.46	19.05	567.74	0.00
2.29	19.28	19.05	567.74	0.00
2.54	20.60	19.05	567.74	0.00
3.81	25.62	19.05	567.74	0.00
5.08	31.00	19.05	567.74	0.00
6.35	36.88	19.05	567.74	0.00
7.62	42.04	19.05	567.74	0.00
8.89	46.97	19.05	567.74	0.00
10.16	51.98	19.05	567.74	0.00
11.43	57.43	19.05	567.74	0.00
12.70	63.63	19.05	567.74	0.00
13.97	69.21	19.05	567.74	0.00
15.24	74.35	19.05	567.74	0.00
16.51	79.29	19.05	567.74	0.00
17.78	84.63	19.05	567.74	0.00
19.05	88.25	19.05	567.74	0.00
20.32	90.30	19.05	567.74	0.00

21.59	91.32	19.05	567.74	0.00
22.86	91.90	19.05	567.74	0.00
24.13	92.72	19.05	567.74	0.00
25.40	93.61	19.05	567.74	0.00
27.94	94.93	19.05	567.74	0.00
30.48	96.08	19.05	567.74	0.00
33.02	97.77	19.05	567.74	0.00
35.56	99.40	19.05	567.74	0.00
38.10	100.71	19.05	567.74	0.00
40.64	102.26	19.05	567.74	0.00
43.18	103.35	19.05	567.74	0.00
45.72	104.31	19.05	567.74	0.00
48.26	105.31	19.05	567.74	0.00

BEAM 2 DATA

Deflection(mm)	Load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2-bars)	CFRP
0.00	0.00	9.53	141.94	0.00
0.25	2.89	9.53	141.94	0.00
0.51	8.32	9.53	141.94	0.00
0.76	9.99	9.53	141.94	0.00
1.02	13.14	9.53	141.94	0.00
1.27	14.30	9.53	141.94	0.00
1.52	15.97	9.53	141.94	0.00
1.78	17.90	9.53	141.94	0.00
2.03	17.86	9.53	141.94	0.00
2.29	18.28	9.53	141.94	0.00
2.54	18.13	9.53	141.94	0.00
3.81	18.19	9.53	141.94	0.00
5.08	18.64	9.53	141.94	0.00
6.35	18.37	9.53	141.94	0.00
7.62	18.35	9.53	141.94	0.00
8.89	18.42	9.53	141.94	0.00
10.16	18.75	9.53	141.94	0.00
11.43	19.66	9.53	141.94	0.00
12.70	20.06	9.53	141.94	0.00
13.97	20.64	9.53	141.94	0.00
15.24	21.33	9.53	141.94	0.00
16.51	21.95	9.53	141.94	0.00
17.78	22.53	9.53	141.94	0.00

19.05	23.09	9.53	141.94	0.00
20.32	23.46	9.53	141.94	0.00
21.59	23.89	9.53	141.94	0.00
22.86	24.31	9.53	141.94	0.00
24.13	24.60	9.53	141.94	0.00
25.40	24.75	9.53	141.94	0.00
27.94	25.15	9.53	141.94	0.00
30.48	25.51	9.53	141.94	0.00
33.02	25.67	9.53	141.94	0.00
35.56	25.84	9.53	141.94	0.00
38.10	25.93	9.53	141.94	0.00
40.64	26.16	9.53	141.94	0.00
43.18		9.53	141.94	0.00
45.72		9.53	141.94	0.00
48.26		9.53	141.94	0.00

BEAM 3 DATA

Deflection(mm)	Load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2-bars)	CFRP
0.00	0.00	19.05	567.74	1.00
0.25	2.54	19.05	567.74	1.00
0.51	4.28	19.05	567.74	1.00
0.76	6.49	19.05	567.74	1.00
1.02	8.76	19.05	567.74	1.00
1.27	11.77	19.05	567.74	1.00
1.52	14.69	19.05	567.74	1.00
1.78	17.01	19.05	567.74	1.00
2.03	19.01	19.05	567.74	1.00
2.29	24.59	19.05	567.74	1.00
2.54	29.75	19.05	567.74	1.00
3.81	34.59	19.05	567.74	1.00
5.08	40.03	19.05	567.74	1.00
6.35	45.52	19.05	567.74	1.00
7.62	51.20	19.05	567.74	1.00
8.89	56.92	19.05	567.74	1.00
10.16	62.64	19.05	567.74	1.00

11.43	68.72	19.05	567.74	1.00
12.70	74.81	19.05	567.74	1.00
13.97	80.25	19.05	567.74	1.00
15.24	86.04	19.05	567.74	1.00
16.51	91.87	19.05	567.74	1.00
17.78	97.12	19.05	567.74	1.00
19.05	102.46	19.05	567.74	1.00
20.32	106.21	19.05	567.74	1.00
21.59	108.43	19.05	567.74	1.00
22.86	110.24	19.05	567.74	1.00
24.13	113.85	19.05	567.74	1.00
25.40	117.37	19.05	567.74	1.00
27.94	120.90	19.05	567.74	1.00
30.48	124.04	19.05	567.74	1.00
33.02	127.04	19.05	567.74	1.00
35.56	129.67	19.05	567.74	1.00
38.10	132.18	19.05	567.74	1.00
40.64	134.49	19.05	567.74	1.00
43.18	135.99	19.05	567.74	1.00
45.72	137.38	19.05	567.74	1.00
48.26	105.31	19.05	567.74	1.00

BEAM 4 DATA

Deflection(mm)	Load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2-bars)	CFRP
0.00	0.00	9.53	141.94	1.00
0.25	2.66	9.53	141.94	1.00
0.51	4.35	9.53	141.94	1.00
0.76	7.44	9.53	141.94	1.00
1.02	10.58	9.53	141.94	1.00
1.27	14.53	9.53	141.94	1.00
1.52	16.63	9.53	141.94	1.00
1.78	17.64	9.53	141.94	1.00
2.03	19.98	9.53	141.94	1.00
2.29	21.15	9.53	141.94	1.00
2.54	21.51	9.53	141.94	1.00
3.81	21.98	9.53	141.94	1.00
5.08	25.47	9.53	141.94	1.00
6.35	28.19	9.53	141.94	1.00

7.62	30.07	9.53	141.94	1.00
8.89	32.00	9.53	141.94	1.00
10.16	33.13	9.53	141.94	1.00
11.43	38.05	9.53	141.94	1.00
12.70	39.29	9.53	141.94	1.00
13.97	41.40	9.53	141.94	1.00
15.24	42.37	9.53	141.94	1.00
16.51	44.22	9.53	141.94	1.00
17.78	45.52	9.53	141.94	1.00
19.05	47.02	9.53	141.94	1.00
20.32	47.97	9.53	141.94	1.00
21.59	49.63	9.53	141.94	1.00
22.86	48.70	9.53	141.94	1.00
24.13	48.75	9.53	141.94	1.00
25.40	48.92	9.53	141.94	1.00
27.94	50.22	9.53	141.94	1.00
30.48	50.90	9.53	141.94	1.00
33.02	52.46	9.53	141.94	1.00
35.56	53.61	9.53	141.94	1.00
38.10		9.53	141.94	1.00
40.64		9.53	141.94	1.00
43.18		9.53	141.94	1.00
45.72		9.53	141.94	1.00
48.26		9.53	141.94	1.00

BEAM 5 DATA

Deflection(mm)	Load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2-bars)	CFRP
0.00	0.00	19.05	567.74	2.00
0.25	1.22	19.05	567.74	2.00
0.51	6.53	19.05	567.74	2.00
0.76	9.31	19.05	567.74	2.00
1.02	12.85	19.05	567.74	2.00
1.27	15.84	19.05	567.74	2.00
1.52	18.11	19.05	567.74	2.00
1.78	20.36	19.05	567.74	2.00
2.03	21.80	19.05	567.74	2.00
2.29	23.50	19.05	567.74	2.00
2.54	24.69	19.05	567.74	2.00
3.81	30.32	19.05	567.74	2.00
5.08	36.33	19.05	567.74	2.00
6.35	42.69	19.05	567.74	2.00

7.62	48.36	19.05	567.74	2.00
8.89	54.59	19.05	567.74	2.00
10.16	60.58	19.05	567.74	2.00
11.43	66.45	19.05	567.74	2.00
12.70	72.17	19.05	567.74	2.00
13.97	78.33	19.05	567.74	2.00
15.24	84.18	19.05	567.74	2.00
16.51	90.15	19.05	567.74	2.00
17.78	96.02	19.05	567.74	2.00
19.05	101.64	19.05	567.74	2.00
20.32	106.29	19.05	567.74	2.00
21.59	109.91	19.05	567.74	2.00
22.86	111.85	19.05	567.74	2.00
24.13	113.90	19.05	567.74	2.00
25.40	115.58	19.05	567.74	2.00
27.94	119.84	19.05	567.74	2.00
30.48	123.85	19.05	567.74	2.00
33.02	127.48	19.05	567.74	2.00
35.56	131.85	19.05	567.74	2.00
38.10	135.16	19.05	567.74	2.00
40.64	138.37	19.05	567.74	2.00
43.18		19.05	567.74	2.00
45.72		19.05	567.74	2.00
48.26		19.05	567.74	2.00

BEAM 6 DATA

Deflection(mm)	Load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2-bars)	CFRP
0.00	0.00	9.53	141.94	2.00
0.25	0.06	9.53	141.94	2.00
0.51	4.93	9.53	141.94	2.00
0.76	9.68	9.53	141.94	2.00
1.02	12.90	9.53	141.94	2.00
1.27	16.59	9.53	141.94	2.00
1.52	20.29	9.53	141.94	2.00
1.78	22.28	9.53	141.94	2.00
2.03	24.36	9.53	141.94	2.00
2.29	25.49	9.53	141.94	2.00

2.54	25.62	9.53	141.94	2.00
3.81	29.89	9.53	141.94	2.00
5.08	33.70	9.53	141.94	2.00
6.35	36.38	9.53	141.94	2.00
7.62	39.59	9.53	141.94	2.00
8.89	43.08	9.53	141.94	2.00
10.16	46.70	9.53	141.94	2.00
11.43	49.71	9.53	141.94	2.00
12.70	52.11	9.53	141.94	2.00
13.97	54.86	9.53	141.94	2.00
15.24	57.27	9.53	141.94	2.00
16.51	59.59	9.53	141.94	2.00
17.78	61.71	9.53	141.94	2.00
19.05	63.87	9.53	141.94	2.00
20.32	66.57	9.53	141.94	2.00
21.59	68.87	9.53	141.94	2.00
22.86	71.27	9.53	141.94	2.00
24.13	73.40	9.53	141.94	2.00
25.40	75.99	9.53	141.94	2.00
27.94	80.08	9.53	141.94	2.00
30.48	82.27	9.53	141.94	2.00
33.02	84.17	9.53	141.94	2.00
35.56		9.53	141.94	2.00
38.10		9.53	141.94	2.00
40.64		9.53	141.94	2.00
43.18		9.53	141.94	2.00
45.72		9.53	141.94	2.00
48.26		9.53	141.94	2.00

BEAM 7 DATA

Deflection (mm)	load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2 bars)	CFRP
0	0	31.3963804	774.192	0

2.54	17.79288	31.3963804	774.192	0
5.08	31.13754	31.3963804	774.192	0
7.62	44.4822	31.3963804	774.192	0
10.16	57.82686	31.3963804	774.192	0
12.7	68.94741	31.3963804	774.192	0
15.24	80.06796	31.3963804	774.192	0
17.78	91.18851	31.3963804	774.192	0
20.32	102.3091	31.3963804	774.192	0
22.86	111.2055	31.3963804	774.192	0
25.4	115.6537	31.3963804	774.192	0

BEAM 8 DATA

Deflection (mm)	load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2 bars)	CFRP
0	0	31.3963804	774.192	1
2.54	26.68932	31.3963804	774.192	1
5.08	37.80987	31.3963804	774.192	1
7.62	55.60275	31.3963804	774.192	1
10.16	66.7233	31.3963804	774.192	1
12.7	80.06796	31.3963804	774.192	1
15.24	95.63673	31.3963804	774.192	1
17.78	106.7573	31.3963804	774.192	1
20.32	122.3261	31.3963804	774.192	1
22.86	133.4466	31.3963804	774.192	1
25.4	142.343	31.3963804	774.192	1

BEAM 9 DATA

Deflection (mm)	load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2 bars)	CFRP
0	0	18.12670868	258.064	0

5.08	20.01699	18.12670868	258.064	0
10.16	28.91343	18.12670868	258.064	0
15.24	35.58576	18.12670868	258.064	0
20.32	36.4754	18.12670868	258.064	0
25.4	37.80987	18.12670868	258.064	0
30.48	40.03398	18.12670868	258.064	0
35.56	40.92362	18.12670868	258.064	0
40.64	41.81327	18.12670868	258.064	0
45.72	42.70291	18.12670868	258.064	0
50.8	43.37015	18.12670868	258.064	0

BEAM 10 DATA

Deflection (mm)	load(KN)	Dia of tensile steel(mm)	Area of steel,mm2 (2 bars)	CFRP
0	0	18.12670868	258.064	1
5.08	24.46521	18.12670868	258.064	1
10.16	37.80987	18.12670868	258.064	1
15.24	51.15453	18.12670868	258.064	1
20.32	55.60275	18.12670868	258.064	1
25.4	66.7233	18.12670868	258.064	1
30.48	72.28358	18.12670868	258.064	1
35.56	80.06796	18.12670868	258.064	1
40.64	86.74029	18.12670868	258.064	1
45.72	91.18851	18.12670868	258.064	1
50.8	97.86084	18.12670868	258.064	1

APPENDIX C

TEST SET DATA

Appendix C contains the performance data of the Neural Paradigms on the Test set in each case. The test set was a randomly selected 10% of the entire pattern set. Deflection is measured in millimeters, Load in KiloNewtons, Area of tensile steel in square millimeters, External CFRP reinforcement as a value (0= no CFRP, 1= CFRP on tensile face only, 2= CFRP on both tensile and shear face), Actual and Predicted deflection measured in millimeters, and Error measured in millimeters as the difference between Actual and Predicted deflection.

3 Layer Simple Backpropagation model

				Actual deflection	Predicted deflection	Error
Deflection(mm)	Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Network(1)	Act-Net(1)
0.508	7.517492	567.7408	0	0.508	0.136709	0.371292
1.016	13.41138	567.7408	0	1.016	0.88576	0.13024
15.24	74.352	567.7408	0	15.24	13.45161	1.788391
0.508	8.318171	141.9352	0	0.508	0.660596	-0.1526
1.016	13.14449	141.9352	0	1.016	0.211024	0.804976
2.286	18.28218	141.9352	0	2.286	5.48623	-3.20023
5.08	18.63804	141.9352	0	5.08	6.248216	-1.16822
6.35	18.37115	141.9352	0	6.35	5.67215	0.67785
13.97	20.63974	141.9352	0	13.97	11.1973	2.772699
20.32	23.46436	141.9352	0	20.32	19.25997	1.060034

24.13	24.59866	141.9352	0	24.13	24.12665	0.003345
27.94	25.15468	141.9352	0	27.94	27.92941	0.010593
0	0	567.7408	1	0	0.492317	-0.49232
2.54	29.7497	567.7408	1	2.54	2.897158	-0.35716
5.08	40.03398	567.7408	1	5.08	4.75367	0.32633
7.62	51.19901	567.7408	1	7.62	7.25584	0.36416
16.51	91.86909	567.7408	1	16.51	16.27722	0.232779
21.59	108.4254	567.7408	1	21.59	31.13757	-9.54757
48.26	105.3116	567.7408	1	48.26	29.70777	18.55223
2.54	21.51159	141.9352	1	2.54	3.905904	-1.3659
15.24	42.37374	141.9352	1	15.24	16.18022	-0.94022
25.4	48.91708	141.9352	1	25.4	24.98345	0.416546
30.48	50.89653	141.9352	1	30.48	30.06508	0.414923
2.032	21.80073	567.7408	2	2.032	1.852142	0.179858
21.59	109.9066	567.7408	2	21.59	22.0765	-0.4865
30.48	82.26983	141.9352	2	30.48	31.49516	-1.01516
22.86	111.2055	774.192	0	22.86	26.39967	-3.53967
5.08	37.80987	774.192	1	5.08	2.501196	2.578804
17.78	106.7573	774.192	1	17.78	21.22229	-3.44229
25.4	37.80987	258.064	0	25.4	22.40294	2.997063

3-Layer Backpropagation Using Turboprop

				Actual deflection	Predicted deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Actual(1)	Network(1)	Act-Net(1)
7.517492	567.7408	0	0.508	0.508	0	0.508
13.41138	567.7408	0	1.016	1.016	0	1.016
74.352	567.7408	0	15.24	15.24	17.15635	-1.91635
8.318171	141.9352	0	0.508	0.508	0	0.508
13.14449	141.9352	0	1.016	1.016	0	1.016
18.28218	141.9352	0	2.286	2.286	4.090994	-1.80499
18.63804	141.9352	0	5.08	5.08	5.424073	-0.34407
18.37115	141.9352	0	6.35	6.35	4.406262	1.943738
20.63974	141.9352	0	13.97	13.97	14.50101	-0.53101
23.46436	141.9352	0	20.32	20.32	24.16727	-3.84727
24.59866	141.9352	0	24.13	24.13	27.00613	-2.87613
25.15468	141.9352	0	27.94	27.94	28.19365	-0.25365
0	567.7408	1	0	0	0	0
29.7497	567.7408	1	2.54	2.54	8.102196	-5.5622
40.03398	567.7408	1	5.08	5.08	9.797992	-4.71799
51.19901	567.7408	1	7.62	7.62	21.61666	-13.9967

91.86909	567.7408	1	16.51	16.51	24.95792	-8.44792
108.4254	567.7408	1	21.59	21.59	26.22138	-4.63138
105.3116	567.7408	1	48.26	48.26	25.74828	22.51172
21.51159	141.9352	1	2.54	2.54	3.818439	-1.27844
42.37374	141.9352	1	15.24	15.24	18.15474	-2.91474
48.91708	141.9352	1	25.4	25.4	23.84941	1.550589
50.89653	141.9352	1	30.48	30.48	30.69245	-0.21245
21.80073	567.7408	2	2.032	2.032	3.17438	-1.14238
109.9066	567.7408	2	21.59	21.59	22.87138	-1.28138
82.26983	141.9352	2	30.48	30.48	32.12196	-1.64196
111.2055	774.192	0	22.86	22.86	17.71259	5.147406
37.80987	774.192	1	5.08	5.08	1.951066	3.128933
106.7573	774.192	1	17.78	17.78	9.786799	7.993201
37.80987	258.064	0	25.4	25.4	31.76289	-6.36289

4-Layer Backprop Using Turboprop

				Actual deflection	Predicted deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Actual(1)	Network(1)	Act-Net(1)
7.517492	567.7408	0	0.508	0.508	2.484366	-1.97637
13.41138	567.7408	0	1.016	1.016	4.272653	-3.25665
74.352	567.7408	0	15.24	15.24	22.73665	-7.49665
8.318171	141.9352	0	0.508	0.508	3.071551	-2.56355
13.14449	141.9352	0	1.016	1.016	6.817551	-5.80155
18.28218	141.9352	0	2.286	2.286	12.71078	-10.4248
18.63804	141.9352	0	5.08	5.08	13.05965	-7.97965
18.37115	141.9352	0	6.35	6.35	12.79915	-6.44915
20.63974	141.9352	0	13.97	13.97	14.79139	-0.82139
23.46436	141.9352	0	20.32	20.32	16.62499	3.695009
24.59866	141.9352	0	24.13	24.13	17.19816	6.931839
25.15468	141.9352	0	27.94	27.94	17.45154	10.48846
0	567.7408	1	0	0	2.328192	-2.32819
29.7497	567.7408	1	2.54	2.54	13.47835	-10.9384
40.03398	567.7408	1	5.08	5.08	16.15245	-11.0725
51.19901	567.7408	1	7.62	7.62	18.49621	-10.8762
91.86909	567.7408	1	16.51	16.51	23.3294	-6.8194
108.4254	567.7408	1	21.59	21.59	24.13041	-2.54041
105.3116	567.7408	1	48.26	48.26	24.01053	24.24947
21.51159	141.9352	1	2.54	2.54	11.90619	-9.36619
42.37374	141.9352	1	15.24	15.24	20.08138	-4.84138
48.91708	141.9352	1	25.4	25.4	21.03343	4.366573

50.89653	141.9352	1	30.48	30.48	21.2858	9.194204
21.80073	567.7408	2	2.032	2.032	2.356807	-0.32481
109.9066	567.7408	2	21.59	21.59	23.74843	-2.15843
82.26983	141.9352	2	30.48	30.48	23.21091	7.269093
111.2055	774.192	0	22.86	22.86	24.24854	-1.38854
37.80987	774.192	1	5.08	5.08	13.57338	-8.49338
106.7573	774.192	1	17.78	17.78	23.67201	-5.89201
37.80987	258.064	0	25.4	25.4	19.93786	5.462137

3-Layer Backprop with Jump connections

				Actual deflection	Predicted deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Actual(1)	Network(1)	Act-Net(1)
7.517492	567.7408	0	0.508	0.508	1.361024	-0.85302
13.41138	567.7408	0	1.016	1.016	3.186996	-2.171
74.352	567.7408	0	15.24	15.24	22.3485	-7.1085
8.318171	141.9352	0	0.508	0.508	2.362	-1.854
13.14449	141.9352	0	1.016	1.016	5.002894	-3.98689
18.28218	141.9352	0	2.286	2.286	8.935955	-6.64996
18.63804	141.9352	0	5.08	5.08	9.358554	-4.27855
18.37115	141.9352	0	6.35	6.35	9.037333	-2.68733
20.63974	141.9352	0	13.97	13.97	12.9118	1.058201
23.46436	141.9352	0	20.32	20.32	19.15658	1.16342
24.59866	141.9352	0	24.13	24.13	20.78792	3.342083
25.15468	141.9352	0	27.94	27.94	21.46009	6.479906
0	567.7408	1	0	0	0	0
29.7497	567.7408	1	2.54	2.54	3.441441	-0.90144
40.03398	567.7408	1	5.08	5.08	6.722665	-1.64266
51.19901	567.7408	1	7.62	7.62	10.37068	-2.75068
91.86909	567.7408	1	16.51	16.51	23.39935	-6.88935
108.4254	567.7408	1	21.59	21.59	28.44131	-6.85131
105.3116	567.7408	1	48.26	48.26	27.51146	20.74854

21.51159	141.9352	1	2.54	2.54	6.147124	-3.60712
42.37374	141.9352	1	15.24	15.24	21.0561	-5.8161
48.91708	141.9352	1	25.4	25.4	26.28642	-0.88642
50.89653	141.9352	1	30.48	30.48	27.79849	2.681507
21.80073	567.7408	2	2.032	2.032	0	2.032
109.9066	567.7408	2	21.59	21.59	24.78522	-3.19522
82.26983	141.9352	2	30.48	30.48	31.58812	-1.10812
111.2055	774.192	0	22.86	22.86	26.8536	-3.9936
37.80987	774.192	1	5.08	5.08	3.631773	1.448227
106.7573	774.192	1	17.78	17.78	21.09342	-3.31342
37.80987	258.064	0	25.4	25.4	29.80656	-4.40656

4-Layer Backprop Using Jump Connections

				Actual deflection	Predicted deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Actual(1)	Network(1)	Act-Net(1)
7.517492	567.7408	0	0.508	0.508	0.877571	-0.36957
13.41138	567.7408	0	1.016	1.016	2.190506	-1.17451
74.352	567.7408	0	15.24	15.24	19.39912	-4.15912
8.318171	141.9352	0	0.508	0.508	1.215918	-0.70792
13.14449	141.9352	0	1.016	1.016	2.137048	-1.12105
18.28218	141.9352	0	2.286	2.286	5.930647	-3.64465
18.63804	141.9352	0	5.08	5.08	6.783281	-1.70328
18.37115	141.9352	0	6.35	6.35	6.130348	0.219652
20.63974	141.9352	0	13.97	13.97	13.5398	0.430198
23.46436	141.9352	0	20.32	20.32	22.97935	-2.65935
24.59866	141.9352	0	24.13	24.13	25.74933	-1.61934
25.15468	141.9352	0	27.94	27.94	26.86517	1.074829
0	567.7408	1	0	0	0.72297	-0.72297
29.7497	567.7408	1	2.54	2.54	3.301107	-0.76111
40.03398	567.7408	1	5.08	5.08	2.810446	2.269554
51.19901	567.7408	1	7.62	7.62	4.564108	3.055892
91.86909	567.7408	1	16.51	16.51	18.44744	-1.93744
108.4254	567.7408	1	21.59	21.59	26.91477	-5.32477
105.3116	567.7408	1	48.26	48.26	25.25	23.01
21.51159	141.9352	1	2.54	2.54	2.867594	-0.32759
42.37374	141.9352	1	15.24	15.24	16.70454	-1.46454
48.91708	141.9352	1	25.4	25.4	22.06353	3.33647
50.89653	141.9352	1	30.48	30.48	23.59997	6.88003

21.80073	567.7408	2	2.032	2.032	2.504391	-0.47239
109.9066	567.7408	2	21.59	21.59	22.23096	-0.64096
82.26983	141.9352	2	30.48	30.48	31.3942	-0.9142
111.2055	774.192	0	22.86	22.86	24.20622	-1.34622
37.80987	774.192	1	5.08	5.08	0	5.08
106.7573	774.192	1	17.78	17.78	15.91643	1.863569
37.80987	258.064	0	25.4	25.4	31.24628	-5.84628

5-Layer Backprop Using Jump Connections

				Actual deflection	Predicted deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Actual(1)	Network(1)	Act-Net(1)
7.517492	567.7408	0	0.508	0.508	1.062197	-0.5542
13.41138	567.7408	0	1.016	1.016	1.672315	-0.65631
74.352	567.7408	0	15.24	15.24	17.07495	-1.83495
8.318171	141.9352	0	0.508	0.508	0.337585	0.170415
13.14449	141.9352	0	1.016	1.016	0.943647	0.072353
18.28218	141.9352	0	2.286	2.286	5.69331	-3.40731
18.63804	141.9352	0	5.08	5.08	9.446576	-4.36658
18.37115	141.9352	0	6.35	6.35	7.256038	-0.90604
20.63974	141.9352	0	13.97	13.97	13.93496	0.035039
23.46436	141.9352	0	20.32	20.32	20.22412	0.095884
24.59866	141.9352	0	24.13	24.13	25.42683	-1.29683
25.15468	141.9352	0	27.94	27.94	29.52471	-1.58471
0	567.7408	1	0	0	0	0
29.7497	567.7408	1	2.54	2.54	2.773977	-0.23398
40.03398	567.7408	1	5.08	5.08	4.783222	0.296778
51.19901	567.7408	1	7.62	7.62	7.340175	0.279825
91.86909	567.7408	1	16.51	16.51	15.76564	0.744365
108.4254	567.7408	1	21.59	21.59	21.4227	0.167305
105.3116	567.7408	1	48.26	48.26	20.24028	28.01972
21.51159	141.9352	1	2.54	2.54	2.344336	0.195664
42.37374	141.9352	1	15.24	15.24	14.83884	0.401156
48.91708	141.9352	1	25.4	25.4	21.55531	3.844688

50.89653	141.9352	1	30.48	30.48	25.24597	5.234034
21.80073	567.7408	2	2.032	2.032	2.188704	-0.1567
109.9066	567.7408	2	21.59	21.59	24.11209	-2.52209
82.26983	141.9352	2	30.48	30.48	29.93374	0.546263
111.2055	774.192	0	22.86	22.86	22.75305	0.106951
37.80987	774.192	1	5.08	5.08	2.998201	2.081799
106.7573	774.192	1	17.78	17.78	19.18312	-1.40312
37.80987	258.064	0	25.4	25.4	20.50886	4.891144

GRNN Network

				Actual deflection	Predicted deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Actual(1)	Network(1)	Act-Net(1)
7.517492	567.7408	0	0.508	0.508	0.787682	-0.27968
13.41138	567.7408	0	1.016	1.016	1.307263	-0.29126
74.352	567.7408	0	15.24	15.24	12.76074	2.479257
8.318171	141.9352	0	0.508	0.508	0.792349	-0.28435
13.14449	141.9352	0	1.016	1.016	1.274574	-0.25857
18.28218	141.9352	0	2.286	2.286	5.565524	-3.27952
18.63804	141.9352	0	5.08	5.08	6.024611	-0.94461
18.37115	141.9352	0	6.35	6.35	5.677164	0.672836
20.63974	141.9352	0	13.97	13.97	9.694397	4.275603
23.46436	141.9352	0	20.32	20.32	19.71082	0.609175
24.59866	141.9352	0	24.13	24.13	23.95874	0.171257
25.15468	141.9352	0	27.94	27.94	25.48515	2.454853
0	567.7408	1	0	0	0.100738	-0.10074
29.7497	567.7408	1	2.54	2.54	4.336151	-1.79615
40.03398	567.7408	1	5.08	5.08	6.881984	-1.80198
51.19901	567.7408	1	7.62	7.62	9.603768	-1.98377
91.86909	567.7408	1	16.51	16.51	22.18502	-5.67502
108.4254	567.7408	1	21.59	21.59	23.91672	-2.32672
105.3116	567.7408	1	48.26	48.26	33.03176	15.22823
21.51159	141.9352	1	2.54	2.54	9.177409	-6.63741
42.37374	141.9352	1	15.24	15.24	12.96298	2.27702
48.91708	141.9352	1	25.4	25.4	21.08416	4.315838
50.89653	141.9352	1	30.48	30.48	23.12312	7.35688
21.80073	567.7408	2	2.032	2.032	2.12358	-0.09158
109.9066	567.7408	2	21.59	21.59	22.77288	-1.18288
82.26983	141.9352	2	30.48	30.48	30.77279	-0.29279
111.2055	774.192	0	22.86	22.86	25.39997	-2.53996
37.80987	774.192	1	5.08	5.08	6.350005	-1.27
106.7573	774.192	1	17.78	17.78	20.32003	-2.54003
37.80987	258.064	0	25.4	25.4	19.57788	5.822117

Ward Network: 2 hidden layers

Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Actual Deflection Actual(1)	Predicted Deflection Network(1)	Error Act-Net(1)
7.517492	567.7408	0	0.508	0.508	9.191228	-8.68323
13.41138	567.7408	0	1.016	1.016	0	1.016
74.352	567.7408	0	15.24	15.24	14.41772	0.822277
8.318171	141.9352	0	0.508	0.508	0.258155	0.249845
13.14449	141.9352	0	1.016	1.016	0	1.016
18.28218	141.9352	0	2.286	2.286	4.307856	-2.02186
18.63804	141.9352	0	5.08	5.08	5.881875	-0.80188
18.37115	141.9352	0	6.35	6.35	4.694103	1.655897
20.63974	141.9352	0	13.97	13.97	14.12191	-0.15191
23.46436	141.9352	0	20.32	20.32	19.03378	1.286217
24.59866	141.9352	0	24.13	24.13	19.57383	4.556171
25.15468	141.9352	0	27.94	27.94	19.72807	8.211929
0	567.7408	1	0	0	0	0
29.7497	567.7408	1	2.54	2.54	15.9101	-13.3701
40.03398	567.7408	1	5.08	5.08	15.15255	-10.0726
51.19901	567.7408	1	7.62	7.62	15.09509	-7.47509
91.86909	567.7408	1	16.51	16.51	19.8123	-3.3023
108.4254	567.7408	1	21.59	21.59	22.48228	-0.89228
105.3116	567.7408	1	48.26	48.26	21.99599	26.26401
21.51159	141.9352	1	2.54	2.54	13.38957	-10.8496
42.37374	141.9352	1	15.24	15.24	16.2945	-1.0545
48.91708	141.9352	1	25.4	25.4	17.62573	7.774269
50.89653	141.9352	1	30.48	30.48	18.06575	12.41425
21.80073	567.7408	2	2.032	2.032	16.7836	-14.7516
109.9066	567.7408	2	21.59	21.59	20.36693	1.223072
82.26983	141.9352	2	30.48	30.48	19.3192	11.1608
111.2055	774.192	0	22.86	22.86	15.64637	7.213635
37.80987	774.192	1	5.08	5.08	17.66334	-12.5833
106.7573	774.192	1	17.78	17.78	19.59663	-1.81663
37.80987	258.064	0	25.4	25.4	17.83881	7.561186

Ward Network: 3 Hidden layers

				Actual deflection	Predicted Deflection	Error
Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Actual(1)	Network(1)	Act-Net(1)
7.517492	567.7408	0	0.508	0.508	1.385382	-0.87738
13.41138	567.7408	0	1.016	1.016	3.555244	-2.53924
74.352	567.7408	0	15.24	15.24	16.49859	-1.25859
8.318171	141.9352	0	0.508	0.508	2.690789	-2.18279
13.14449	141.9352	0	1.016	1.016	1.9281	-0.9121
18.28218	141.9352	0	2.286	2.286	6.046764	-3.76076
18.63804	141.9352	0	5.08	5.08	6.892447	-1.81245
18.37115	141.9352	0	6.35	6.35	6.250224	0.099776
20.63974	141.9352	0	13.97	13.97	12.92068	1.049319
23.46436	141.9352	0	20.32	20.32	21.63583	-1.31583
24.59866	141.9352	0	24.13	24.13	24.17831	-0.04831
25.15468	141.9352	0	27.94	27.94	25.1994	2.740604
0	567.7408	1	0	0	0	0
29.7497	567.7408	1	2.54	2.54	6.188559	-3.64856
40.03398	567.7408	1	5.08	5.08	6.930255	-1.85026
51.19901	567.7408	1	7.62	7.62	8.320324	-0.70032
91.86909	567.7408	1	16.51	16.51	19.06252	-2.55252
108.4254	567.7408	1	21.59	21.59	28.17667	-6.58667
105.3116	567.7408	1	48.26	48.26	26.31669	21.9433
21.51159	141.9352	1	2.54	2.54	3.185626	-0.64563
42.37374	141.9352	1	15.24	15.24	15.62128	-0.38128
48.91708	141.9352	1	25.4	25.4	23.44312	1.956875
50.89653	141.9352	1	30.48	30.48	25.23748	5.242517
21.80073	567.7408	2	2.032	2.032	2.976573	-0.94457
109.9066	567.7408	2	21.59	21.59	21.31337	0.276627
82.26983	141.9352	2	30.48	30.48	30.50059	-0.02059
111.2055	774.192	0	22.86	22.86	17.18873	5.67127
37.80987	774.192	1	5.08	5.08	4.691627	0.388373
106.7573	774.192	1	17.78	17.78	14.54024	3.239759
37.80987	258.064	0	25.4	25.4	31.63773	-6.23773

Ward Network: 2 hidden layers, input-output layers connected

Load(KN)	Area of steel,mm2 (2-bars)	CFRP	Actual(1)	Actual deflection Actual(1)	Predicted deflection Network(1)	Error Act-Net(1)
7.517492	567.7408	0	0.508	0.508	0	0.508
13.41138	567.7408	0	1.016	1.016	0	1.016
74.352	567.7408	0	15.24	15.24	23.33168	-8.09168
8.318171	141.9352	0	0.508	0.508	3.896984	-3.38898
13.14449	141.9352	0	1.016	1.016	2.913209	-1.89721
18.28218	141.9352	0	2.286	2.286	7.411699	-5.1257
18.63804	141.9352	0	5.08	5.08	8.103339	-3.02334
18.37115	141.9352	0	6.35	6.35	7.579831	-1.22983
20.63974	141.9352	0	13.97	13.97	12.80704	1.162955
23.46436	141.9352	0	20.32	20.32	20.26374	0.056255
24.59866	141.9352	0	24.13	24.13	22.88536	1.244638
25.15468	141.9352	0	27.94	27.94	24.02218	3.917816
0	567.7408	1	0	0	0	0
29.7497	567.7408	1	2.54	2.54	2.608008	-0.06801
40.03398	567.7408	1	5.08	5.08	3.325904	1.754096
51.19901	567.7408	1	7.62	7.62	5.784117	1.835883
91.86909	567.7408	1	16.51	16.51	21.47589	-4.96589
108.4254	567.7408	1	21.59	21.59	28.73847	-7.14847
105.3116	567.7408	1	48.26	48.26	27.40518	20.85482
21.51159	141.9352	1	2.54	2.54	6.321702	-3.7817
42.37374	141.9352	1	15.24	15.24	19.85334	-4.61334
48.91708	141.9352	1	25.4	25.4	23.49384	1.906164
50.89653	141.9352	1	30.48	30.48	24.66813	5.811869
21.80073	567.7408	2	2.032	2.032	0	2.032
109.9066	567.7408	2	21.59	21.59	23.91212	-2.32211
82.26983	141.9352	2	30.48	30.48	34.04017	-3.56017
111.2055	774.192	0	22.86	22.86	26.45541	-3.59541
37.80987	774.192	1	5.08	5.08	0.572819	4.507181
106.7573	774.192	1	17.78	17.78	17.51289	0.267113
37.80987	258.064	0	25.4	25.4	24.89798	0.502018

BIOGRAPHICAL SKETCH

Sujay Nandy was born in Calcutta, India in 1976 and grew up in Shillong in North-east India. After attending high school and pre-university in Shillong, he enrolled in Karnataka Regional Engineering College at Surathkal under Mangalore University, in 1994, for his Bachelor of Engineering in Civil engineering. He graduated with a first class in 1998. He subsequently worked for five months as a programmer in Oracle and SQL in Bangalore, India. He then moved to Gainesville, Florida in 1999 for his Master of Science in Building Construction, at the M.E. Rinker, Sr., School of Building Construction at the University of Florida, and received his degree in 2001.