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RESEARCH ARTICLE

Analysis of Multi-Storey Structures using MATLAB

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ABSTRACT

An important aspect in the multi-storey frame analysis is the impact of sequential application of dead load, and because of the sequential nature of structures, it is ignored by many engineers in the past. One of the effective methods to consider this impact is to perform the analysis with step-by-step processes along with sequential application of dead loads. However, these processes require complex computations and more processing time. In this current work, various studies and analysis on multi-storey building is done in consideration with dead loads. For performing the analysis, sequential and simultaneous approaches are followed out. The analysis results with dominant structural probable parameters helps in calculating η (the ratio of moment force by sequential analysis to simultaneous analysis). Using the extracted analysis values, network model is proposed and the validation analysis is performed to determine the values of sequential moment forces of any floor in the building. The strength of the neural network is verified for a number of sample buildings with extensive variations in their structural characteristics within the practical range.

Keywords: Sequential, Simultaneous, Stiffness, Multi-storey, ANN.

1. INTRODUCTION

The structural investigation of multi-storey constructions is attracted by many engineering researchers and designers. However, in the past, one of the areas that are ignored by many researchers in these structural investigations is the influence of construction sequence in multi-storey frame analysis. The exterior beam structure is roughly loaded with one-half of the gravity load to which the interior beam is subjected (for example, exterior cover of buildings, weight of columns, concrete beams, slabs, steel structures and walls). The effects of sequential loading should be considered to assess the worst conditions to which any component may be subjected, and also to determine the true behaviour of the frame. In multi-storey reinforced concrete construction, the usual practice is to store the freshly placed floor on several previously cast floor. The horizontal member at the ground level becomes more dangerous due to the cumulative nature of time dependent inelastic horizontal deflections (shrinkage and creep) in accordance with the increasing building height. The construction loads in the supporting floor due to the weight of wet concrete and formwork may appreciably exceed the loads under service conditions. Such loads depend on the sequence and rate of erection. The commonly used processes for evaluating these deflections are termed as approximate processes which are suggested for those structures having lengthy span joint system or RCC layer or constant column stiffness. The inconsistency experienced with this process is that the shearing behaviour of columns is ignored while determining the deflections. In addition, no difference is made within the applications of sequential nature of dead loads

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and simultaneous nature of live loads. Beam axial deformations are calculated with respect to the dead loads like how they are applied to the completed building structure. Bending moment in the horizontal components results from any differential column shortening because of the cumulative effect over the highest level of the building. However, the effect of such differential movements would be greatly overestimated due to the occurrence of initial axial deformation during the construction sequence. The deformation of that particular floor is caused by the loads that are applied subsequently to its construction. Such sequential effect must be considered if an accurate assessment due to dead loads is to be achieved. Though computers considerably advance the sophistication of multi-storey building for lateral loads, the soundest approach to design slab system for gravity loads is the traditional method of considering each floor slab with its columns attached above and below to it. The method, which is followed in general, is technically valid and easy to handle the design of various slab systems. Besides many of the comprehensive computer programs used for gravity load analysis, there is an inherent susceptibility of receiving misleading results when a load analysis is carried out. The reason behind is that these programs are based on the inputs of the entire structural system with its loading, and then an analysis is performed for the entire structure as one unit. The dead load in a real building, however, it is built up gradually and for example, in a 50 storey building, a dead load of the 10^{th} floor cannot be by a 50 storey frame, since at a time of 10^{th} floor load is applied, there is only a 10-storey frame available to resist this load, and not a 50 storey frame.

Computer program that is developed must treat the construction time as an additional variable, which means that the vertical load is applied gradually to the storey while at the same time the framework is progressively built up. At unit time when such programs are available, the traditional method designs one storey at a time produces much more reliable results. The proposed work includes several analysis of 100 storey structure with dead load using sequential and simultaneous approach. To develop the computer program and to make such analysis easier, Artificial Neural Network (ANN) is adopted. Taking these probable parameters as input to ANN software, network models are proposed. The trained network is validated to determine the values of sequential moment forces of any floor in the building. The neural network developed is particularly useful in planning an optimized way at the starting stage. The research is further extended by considering the extensive variations in the structural characteristics of the sample buildings. The calculated η is correspondingly matched with analyzed values of conventional approaches. The result yields a closer relation between the real values which shows the accuracy of proposed network model. The obtained η values support to determine sequential value in short time without making much effort.

2. ANN IN STRUCTURE

A multi-storey building has been analyzed on the assumption that the full load is placed on the whole structure. In the design field, it is not common to use sequential analysis for the dead load, though the procedure for sequential analysis has been available in the literature [1-7]. Several studies report on the behavioural characteristics under sequential loading. Nowadays neural system gains potential due to its self-learning technique. A computationally efficient method called neural network is simulated to overcome the difficulties in structural engineering field [8]. The purpose of using these methods is that the neural network can build the activities of human brain. From a statistical view, neural networks are attractive because of their effective application in classification and prediction problems. Neural networks are considered as one of the promising techniques for emerging computing since it provides a way to do tasks beyond the scope of conventional processors. Further, it can identify the patterns within large data set and generalize those patterns into suggested courses of action. One of the main advantages of neural networks is that it does not require any complex calculation and expensive programming for solving the problems. A roughly simulated mathematical design of a biological neuron is called as an artificial neuron. It is the fundamental unit of human brain that simultaneously performs multiple tasks at a time with extremely large and parallel neural networks. A human brain works with thousands of such kind of neurons which are interlinked by highly complex networks. ANN is a self-adaptive and non-linear data driven technique unlike the conventional design based techniques. The adaptive nature of ANN is an important attribute which replaces learning strategy into programming on problem solving. This attribute makes the computational designs very attractive especially in the application areas where one has poor knowledge about problem solving although training data sets can be easily available. ANN is comprised of a group of system to convert an input set into a searched output set via a set of simple operating units or nodes and the interface between them. The subsets of the units are input and output nodes and a hidden layer is formed by the interface nodes between the inputs and outputs. They are the dominant pattern identifiers and classifiers which functions like a black-box, design-free and adaptive machine to fetch and learn the important structures in datasets.

The ANNs models adopted for structural engineering may have different architectures [9-11] and possess different patterns of connectivity. The most widely used neural network is the back propagation model [12, 13] which is used for classification and pattern recognition. The key reason behind its popularity is its ease of use [14-22]. Though structural analysis of multi-storey building is crucial, research gap still exists in analyzing the influence of construction sequence in multi-storey frame analysis. Loads independent of construction sequence comprises live load, wind load or seismic load, whereas the load influencing building frame considered during construction are dead load. The literature review shows that the calculation of dead load effect using sequential procedure is quite a tough task and time consuming. So, to make it easier and simplify the analysis under such condition, an ANN model is developed in this work.

3. ANALYSIS PROCEDURE AND NEURAL NETWORK MODEL

Nowadays due to the shortage of land, people prefer high rise buildings or vertical structures rather than horizontal structures. In high rise buildings, the concerned parameters are the forces that present on a building, its own load as well as the soil carrying capacity. The strength of columns, beams and reinforcement must be superior in order to destroy the external forces acting on the building successfully. Manual computation analysis for a highly raised vertical structure takes more time. So, the use of STAAD-PRO solves this problem. Typical difficulties such as seismic analysis, static analysis and natural frequency can be solved by STAAD-PRO. In addition, when compared to the manual methods, STAAD-PRO is more advantageous as it offers highly accurate and precise results. From model formation, testing and visualization design and result analysis, STAAD-PRO is the expert's choice for aluminium, concrete, steel, timber and cold-formed steel model of low and tall buildings, bridges, culverts, tunnels, petrochemical plants, piles etc. The proposed work is confined to the analysis of 100^{th} storey RCC frame under dead load condition using sequential and simultaneous method through STAAD-PRO software. The structural parameters which have been taken into account are bays, span, height, columns, uniformly distributed load on building, elasticity of concrete and Poisson's ratio and density.

3.1. Sequential analysis

In the structural verification of multi-storey buildings, two significant facts have major influence on the accuracy of verification but are rarely approached in practice. They are:

1) The impact of sequential functioning of dead loads because of the sequential nature of construction.
2) The differential column reduction owing to the dissimilar tributary regions.

As the building construction proceeds, the structural members are added in their respective stages. Thus, their dead load is carried by the structural portion completed at the stage of implementation. Hence, it is proved that the displacement and stress distributions in the structural portions completed at any stage due to the dead load of members implemented by that stage could not depend up on properties, sizes or the existence of members completing the rest of the structure. For designing the 100^{th} storey building, the procedure is to be followed step-by-step in RCC frame analysis. Initially, 1st floor is taken into consideration and then its bending moments in beam are calculated considering the above stated structural parameters with UDL on 1st floor. The bending moments are calculated for exterior and last 2nd exterior beam at both the ends of beam and its centre point. In similar way, the 2nd floor analysis has been performed but the UDL is applied only to 2nd floor and removed from 1st floor and then the bending moment in beam with respect to base is calculated. Using this similar procedure, total up to 100th floor bending moments in beam is calculated with respect to base shifting UDL from floor to floor. The similar analysis is also carried out at various heights of the building such as 20th floor, 40th floor, 60th floor and 80th floor.

3.2. Simultaneous analysis

For designing 100th storey building, the procedure is quite similar to sequential procedure with the only difference is that instead of shifting UDL floor wise; it is kept throughout the floor i.e. from 1st floor to 100th floor, the UDL is similar. The bending moments are calculated with respect to base at different heights of building i.e. 20th floor, 40th floor, 60th floor, and 80th floor.

3.2.1. Calculation of parameter

Having the calculated value of bending moments with sequential and simultaneous procedures at different locations of beam at different height of buildings; the value of η is computed using the (1).

$$\eta = (\text{moment force in beam})_{\text{sequential analysis}} / (\text{moment force in beam})_{\text{simultaneous analysis}} \quad (1)$$

Some probable parameter, which affects the main parameters of building are:

i) Stiffness factor (S_f)
ii) Number of storeys (N)
iii) Normalized height of the floor: x/H (height of floor from the ground, x divided by the total height of the frame, H)
iv) Position of beams: exterior or interior

Later, with the help of graph, the variation in the probable parameters and the main parameters for exterior and interior structure at different heights of floor is analysed.

3.3. Numerical study

In simultaneous analysis procedure, the loads at all floor levels are assumed to be applied after the entire structure is completed as shown in figure 1, where only one analysis is required. As stated above, in sequential application, columns of the storey are levelled before the application of loads from this storey, and the axial load in column of this storey does not affect the stresses in upper storey. Therefore, the sequential analysis procedure of an N storey building frame is visualized as the superposition of analysis with n substructures as shown in figure 2. The member forces are obtained by superposing the member forces from the analysis of these sub-structures.

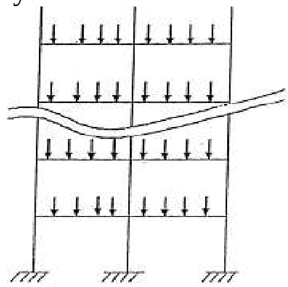

Figure 1.simultaneous analysis procedure for N-multi-storey building frame

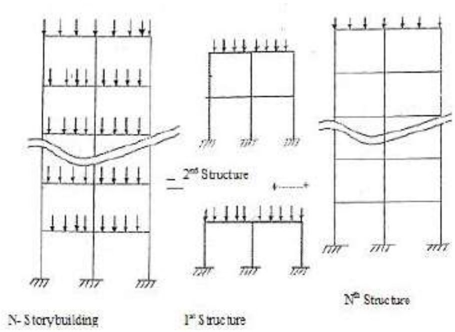

Figure 2.Sequential analysis procedure for N-multi-storey building frame

Probable structural parameters of a frame which influence η are tentatively selected as: S_f (shear stiffness of beams to column axial stiffness designated as stiffness factor), N (No. of storeys), normalized height of the floor: x/H (height of floor from the ground, x divided by the total height of the frame, H), and position of beams: exterior or interior.

The study is done on sequential and simultaneous analysis for a multi-storey building. For this purpose, a 6-bay, 100 storey uniform building frame with each bay having a span of 5 m, storey 3 m high and all column of size 1 m x 1 m is considered. The intensity of uniformly distributed load is assumed as 30 kN/m and the modulus of elasticity of the concrete as 1.5 x 107 kN/m^2, with Poisson's ratio 0.15 and density as 25 kN/m^3. The analysis is carried out using the commercial software package STAAD-PRO. Bending moment in each member has been determined.

3.3.1. Effect of stiffness factor (S_f)

It may be observed that the flow of vertical loads from beams to columns depends on the shear stiffness of the beams (force required to induce unit relative displacement at end $12EI_b/L_b^3$). Stiffer beams results in more equitable of the load distribution among columns. A non-dimensional number, designated as stiffness factor S_f, which is the ratio of shear stiffness of beam to axial stiffness of column ($12\ EI_bh_c/L_b^3AE$) is therefore selected as a parameter. For sensitivity analysis of η to S_f, some numerical studies have to be followed. Practical range of S_f from 0.24 x 10^{-3} to 48 x 10^{-3} is considered presently. S_f is varied by specifying different values of I_b as shown in table 1.

Table 1.Sectional properties of the members of the building frame

Sl. No.	$Ac(m^2)$	$I_b(m^4)$	S_f
1	1	0.1668	0.048
2	1	0.0834	0.024
3	1	0.00834	0.0024
4	1	0.000834	0.00024

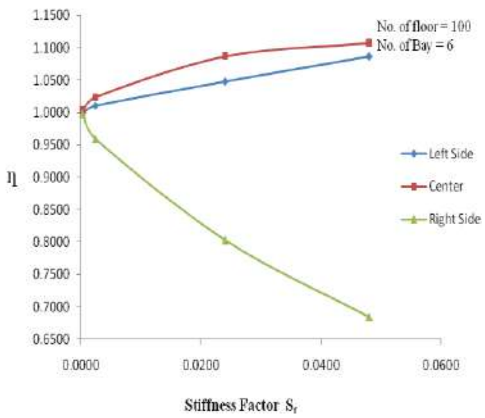

Figure 3.Exterior base beam

Figures 3-5 show variation in the individual values of S_f for exterior beams, also it clearly shows the value of simultaneous analysis to be either overestimated or underestimated with respect to sequential analysis. This result shows that the calculated simultaneous values does not follow the sequential values, and also specifies the extreme variation in bending moment with respect to increase in stiffness.

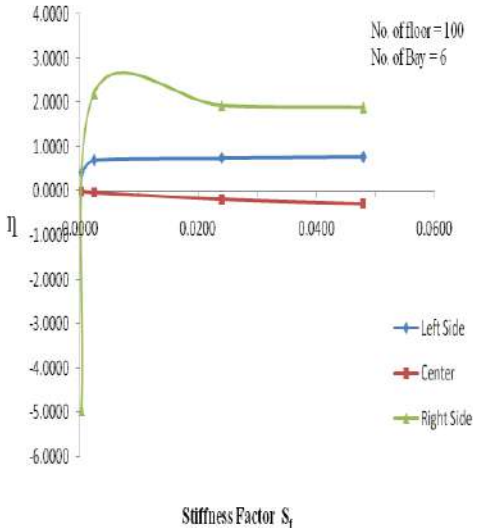

Figure 4.40th floor's exterior beam

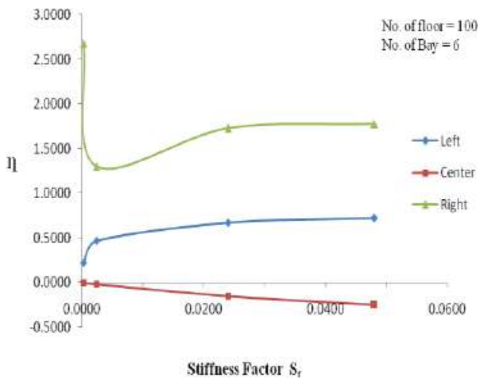

Figure 5.80th floor's exterior beam

3.3.2. Effect of no. of storeys

It may be observed that, more the number of storeys, more equitable the distribution of vertical load among beams will be the segments – bottom, middle and top of building. Hence the number of storeys is selected as a parameter. To study the effect of change in number of storeys, N on η, an example building frames with different number of storeys in the practical range 20, 40………100 stories, are considered. Figures 6-9 show the variation of η with number of storeys or floor.

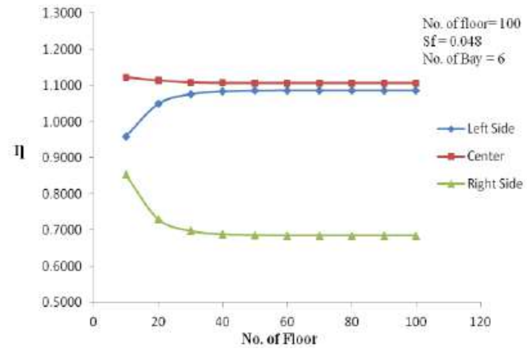

Figure 6.Exterior base beam (S_f-0.048)

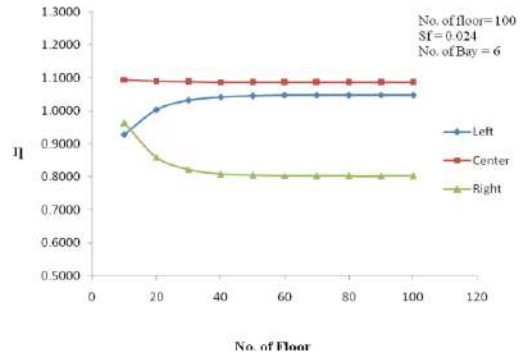

Figure 7.For exterior Base Beam (S_f-0.024)

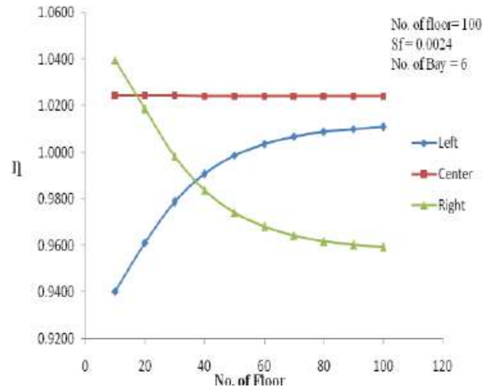

Figure 8.Exterior base beam (S_f-0.0024)

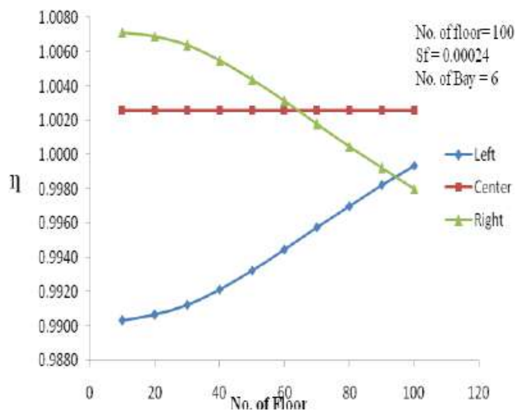

Figure 9.exterior base beam (S_f-0.00024)

For exterior column, it observed that the variation in η increases with the number of floors N increases in the range 24 x 10^{-3} to 48 x 10^{-3} and variation in η decreases with the no. of floor N in the range 0.24 x 10^{-3} to 2.4 x 10^{-3}.

3.3.3. Effect of normalized height of the storey (x/H)

It is seen from all the previous cases that observed η increases with no. of floor N for both exterior and interior beams, and further variation of η with N is gentle and monotonic at all x/h for both exterior and interior beams. Figures 10 to 13 show the variation of η with x/H for exterior and second last exterior beams of 100 storeys.

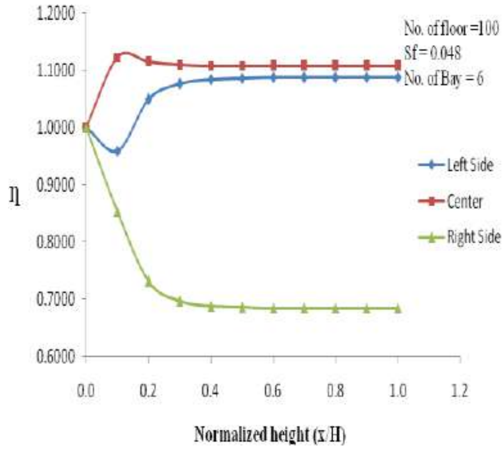

Figure 10.Exterior base beam (S_f-0.048)\

It is observed from figures 10 to 13 that the value of η varies with the normalized height x/H, which forms an important governing parameter in the analysis conducted in the study.

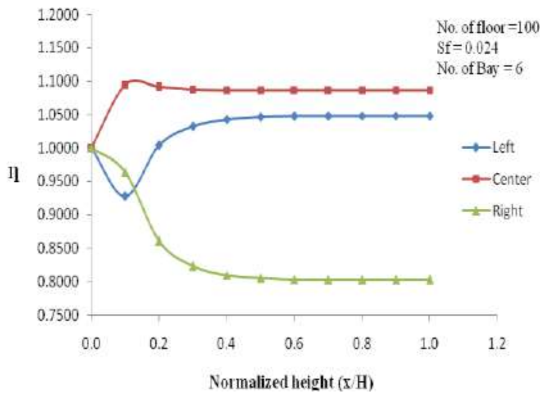

Figure 11.Exterior base beam (S_f-0.024)

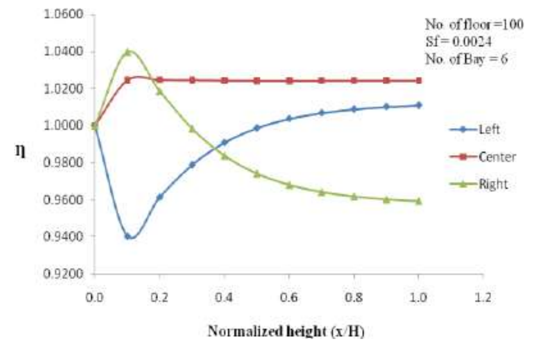

Figure 12.Exterior base beam (S_f-0.0024)

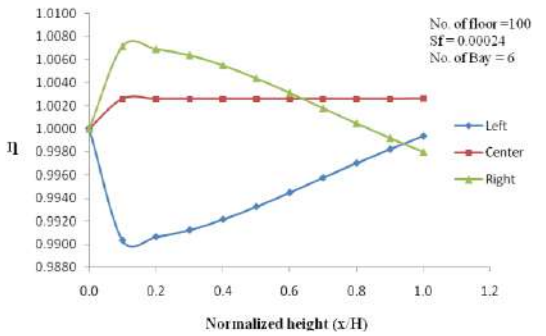

Figure 13.Exterior base beam (S_f-0.00024)

3.3.4. Effect of the position of beam

Figures 14 to 17 show variation in η with the position of beams. It is thus observed that S_f is a relevant parameter and for the generation of training patterns, the chosen values of S_f are 0.024 x 10^{-3}, 0.24 x 10^{-3}, 2.4 x 10^{-3} and 48 x 10^{-3} respectively.

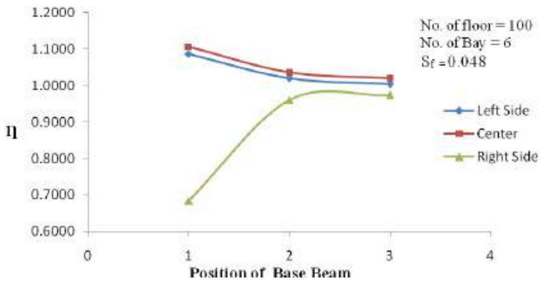

Figure14.Exterior base beam (S_f-0.048)

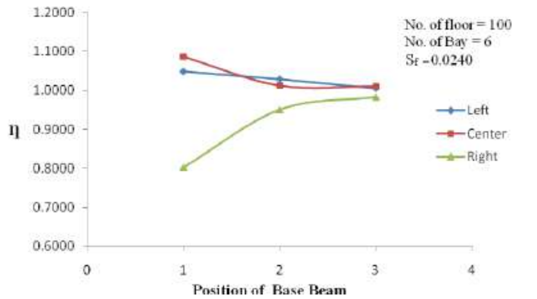

Figure15.Exterior base beam (S_f-0.024)

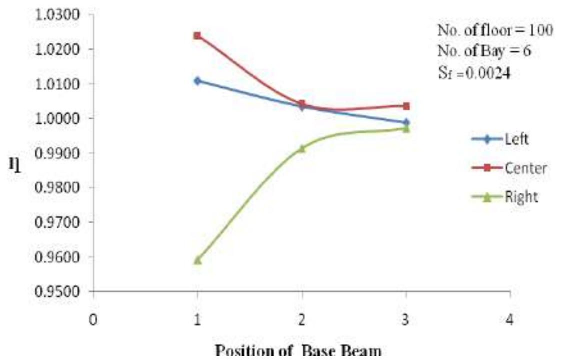

Figure16.Exterior base beam (S_f-0.0024)

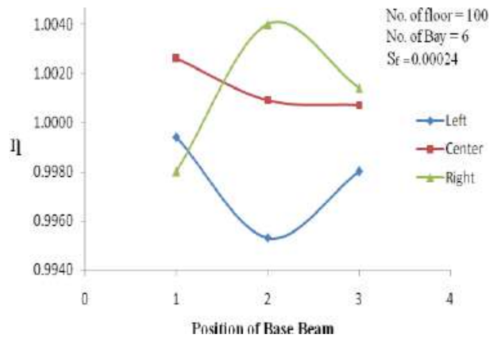

Figure17.Exterior base beam (S_f-0.00024)

3.4. Neural network model

It has been noticed that stiffness ratio, position of floor, total number of floor and position of the column significantly affect the behaviour under vertical loads. In this regard, a neural network is proposed which convert the result of simultaneous analysis into approximate value of sequential analysis. The effect of sequential construction is generally significant for the exterior bays. Here the neural network is proposed for exterior bays and the 1^{st} interior bays for stiffness factor is of 0.024 (i.e. 1 m x 1 m beam). The network is trained for the data values obtained during the analysis of 1^{st} to 60^{th} floors. The trained network is then used for the validation of 65^{th} floor to 100^{th} floors for the above given structural parameters.

3.4.1. ANN configuration

The inputs of the proposed neural network are the following dominant structural parameters.

1) N_i (i^{th} floor)
2) X/H = Normalized height of the storey (height of the storey divided by the total height of the building)

3) Bending moment of simultaneous analysis
4) S_f (Stiffness factors)

The network comprises input, output and the hidden layers. The input layer is given with the value of structural parameters which are processed through the hidden and output layers.

3.4.2. Generation of training data

The performance in terms of generalization and prediction qualities of neural network depends on the training data and the domain. Generation of training patterns is performed for (a) Exterior beam and (b) Second last exterior beam.

3.4.3. Training of ANN

The network is trained with one input and output layer along with two hidden layers with consideration of 6 neurons and 9 neurons for training the analysis data of multi-storey building as shown in figures 18 and 19.

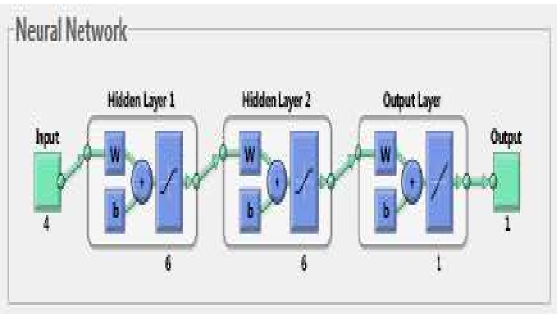

Figure 18.Neural network training with two hidden layer using 6 neurons

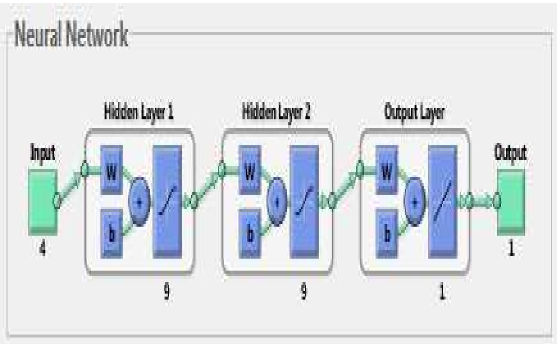

Figure 19.Neural network training with two hidden layer using 9 neurons

3.3.4. Stimulus of neural network

i) Input to the network:

- Bending moments in beam: data obtained by simultaneous method stiffness factor: taken as,

  0.0480 for 1.2 m x 1.2 m beam
  0.0240 for 1 m x 1 m beam
  0.0024 for 0.6 m x 0.6 m beam
  0.00024 for 0.3 m x 0.3 m beam

- Normalized height of storey (i.e. height of storey divided by the total height of the building)
- Total number of floor: taken as 1-100

ii) Output to the network:

- η = moment in beam by sequential analysis divided by moment in beam by simultaneous analysis.

The network is trained for 100th storey building. Figures 20 to 22 show the training graph of neural network of the exterior beam (for left, center & right end beam). Similarly, the network is trained for 2nd last exterior beam (for left, center & right end beam).

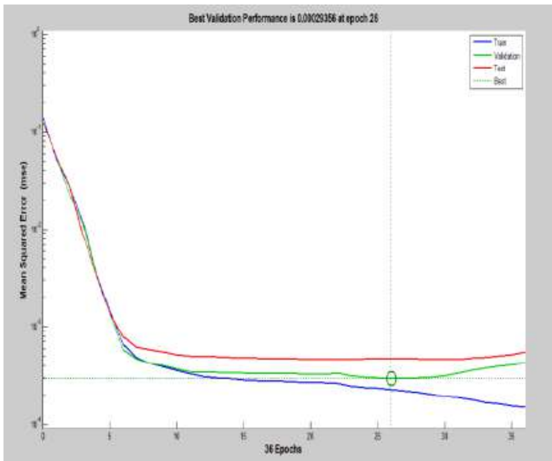

Figure 20.Training graph of exterior beam (left end) with the no. of hidden layer = 2 and no. of neurons = 9

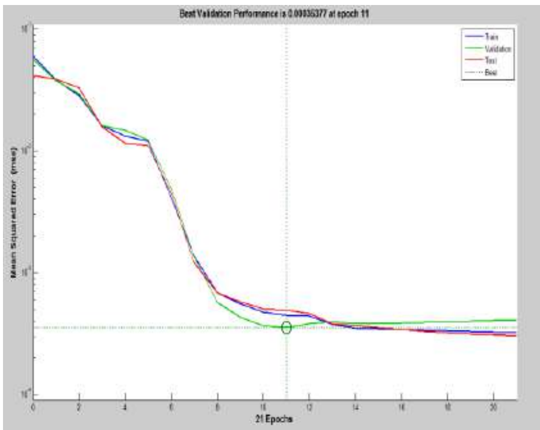

Figure 21.Training graph of exterior beam (center) with the no. of hidden layer = 2 and no. of neurons = 9

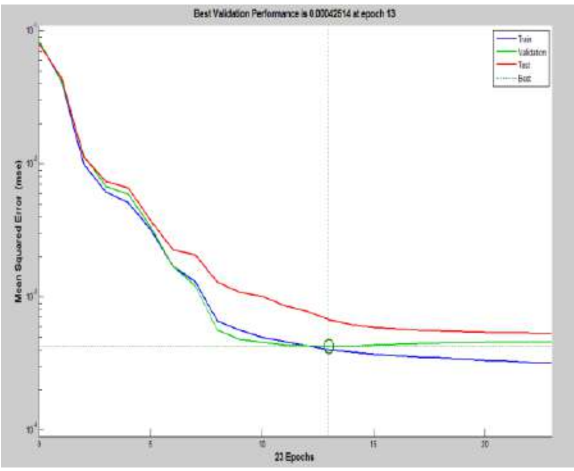

Figure 22.Training graph of exterior beam (right end) with the no. of hidden layer = 2 & no. of neurons = 9

4. RESULTS AND DISSCUSSION

Neural network is tested for the data for which it is not trained and it has been observed that there is close agreement between the values obtained from the analysis and neural network. Figures 23 to 28 show the ANN based validated result for untrained stiffness data values 0.0015 & 0.0125 of 12th storey building. ANN is trained for 6 and 9 neurons for best fitting of desired data.

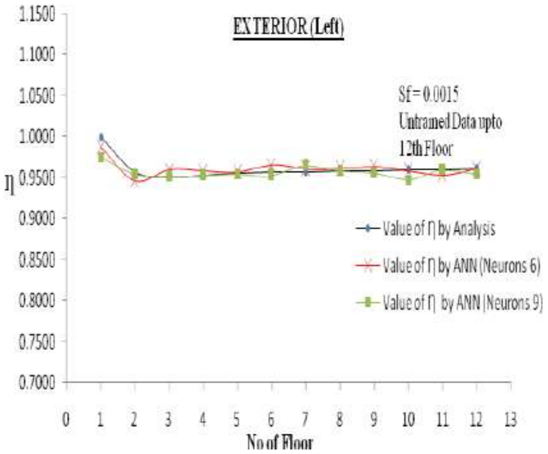

Figure 23.Comparison of obtained value of η from untrained neural network with the actual value obtained from analysis and ANN value (neurons = 6&9) vs. no. of floor for left end (exterior beam)

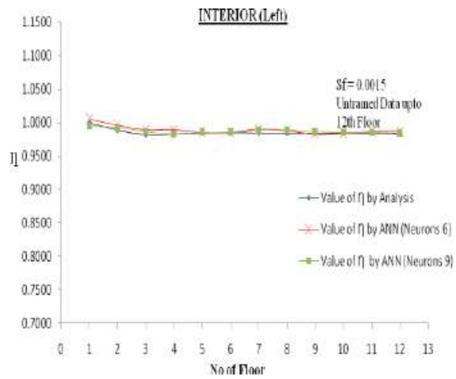

Figure 24.Comparison of obtained value of η from untrained neural network with the actual value obtained from analysis and ANN value (neurons = 6 & 9) vs. no. of floor for left end (interior beam)

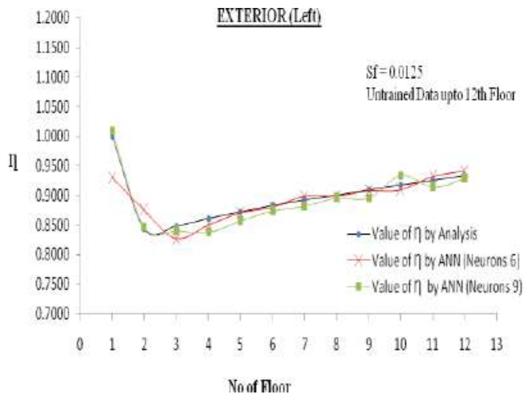

Figure 25.Comparison of obtained value of η from untrained neural network with the actual value obtained from analysis and ANN value (neurons = 6 & 9) vs. no. of floor for left end (exterior beam)

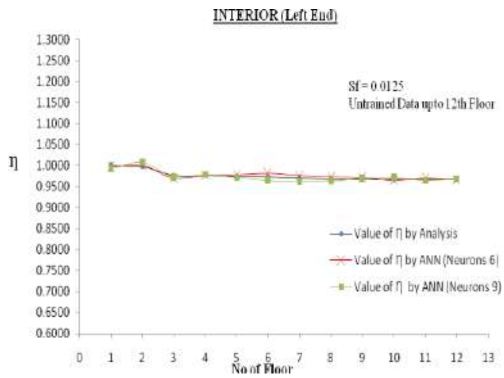

Figure 26.Comparison of obtained value of η from untrained neural network with the actual value obtained from analysis and ANN value (neurons = 6 & 9) vs. no. of floor for left end (interior beam)

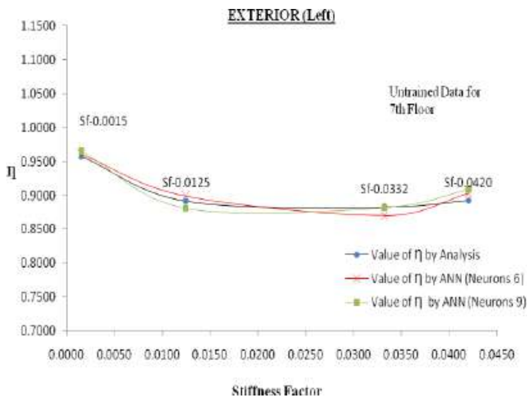

Figure 27.Comparison of obtained value of η from untrained neural network with the actual value obtained from analysis and ANN value (neurons = 6 & 9) vs. stiffness factor for left (exterior beam)

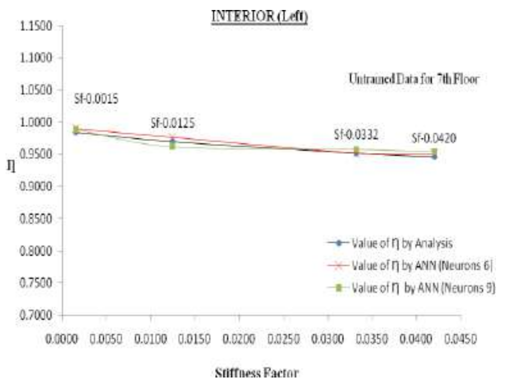

Figure 28.Comparison of obtained value of η from untrained neural network with the actual value obtained from analysis and ANN value (neurons = 6 & 9) vs. stiffness factor for left (interior beam)

A good neural network should also be capable to provide satisfactory solution for the problem in which it has not been trained. The comparison with the ratio having actual value of moment force and computed value of moment force by ANN for the number of hidden layer = 2 and the number of neurons = 6 and 9 is presented. The trained network when trained with either 6 or 9 neurons does not show much variation but in some plots, the best fit result is found by taking 9 neurons into concern. The proposed network model yields the η value to calculate the sequential value of bending moment in beam at any position of any floor.

5. CONCLUSION

The work done is to determine the bending moment in beam by sequential and simultaneous analysis using STAAD pro. The structural parameters which influence the moment force by simultaneous analysis procedure are identified, among which a few are stiffness factor, no. of storey, normalized height, and position of beam, out of which the most influential parameter is the stiffness factor S_f. After performing analysis, six different neural network models are developed for different positions of beam at different bending moments of locations (left, centre, right) to calculate sequential values. The analysis through this model is used to calculate the sequential values of any stiffness factor, floor and position of beam respectively. Neural network reduces the computational time required for the implementation by a significant amount as compared to the existing conventional methods to solve the problems faced with structural analysis.

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