Modelling of RC Frames with Shear walls and Openingsusing ANN and M5P Techniques

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Abstract

Shear wall is a RC structural element that resists lateral loads, majorly due to wind and seismic loads. The aim of the given study is to know the responses of shear walls for 5 to 40 story RC frame structures provided with different percentages of openings. Equivalent static method of seismic analysis in staad pro is performed to collect the data set for 240 models in terms of Maximum Story Displacement (MSD). Also, Machine learning (ML) techniques is being applied to predict the similar model within the given range. The analysis data can be further used directly as modelling of shear walls in staad pro requires a lot of effort, time, and practice, so this predicted model will simply help us to predict the seismic response of any similar RC Frame structures provided with shear walls and various percentages of openings.

Keywords. Shear walls, Equivalent static method, Machine learning, Seismic analysis, Maximum storey displacement

1. INTRODUCTION

In a building structure, along with slabs, beams, and columns, reinforced concrete buildings frequently contain vertical plate like structure made of RCC called shear walls. These RC walls usually began at the foundation and continue to the building's top storey. In high-rise buildings, the thickness can be as low as 150mm or as thick as 400mm. Shear walls are typically installed along the breadth and length of structures. Shear walls resemble vertically oriented wide beams that transport earthquake loads to the base.

To resist the stresses due to seismic hazards, shear walls must have sufficient lateral strength. Also, Shear walls provide lateral rigidity to avoid excessive sway movement of the roof or the floor above. Shear walls that are sufficiently rigid will keep floor and roof framing members from shifting off their supports. In addition, buildings that are sufficiently rigid are less likely to sustain non-structural damage.

Buildings having RC shear walls and those were properly designed and constructed have performed well in past earthquakes. "We cannot afford to build concrete buildings built to withstand severe earthquakes without shear walls," a quote by Mark fintel, sums up the effectiveness of RC structures with shear walls in resisting the strong earthquakes. Mark Fintel is a well-known consulting engineer in the United States. In earthquake prone areas, shear walls demand special attention. Buildings that were not designed for seismic activities but as they consist of enough number of walls with well-distributed reinforcement were also protected from damages in previously occurred earthquakes. Shear wall structures are common in seismic prone countries such as New Zealand, Chile, and the United States. Shear walls are easier to construct since detailing of reinforcement is straightforward and hence simple to execute on site. Shear walls are also useful for reducing earthquake damage caused to both structural and non-structural materials in terms of cost of construction as well as effectiveness for the building [1].

Shear wall provided in apartment complexes will be perforated by rows of openings that are necessary for exterior windows or interior entrances or corridors. The position and size of openings may have a negative impact on the seismic reactions of frame-shear wall constructions. Because lateral forces are transferred to individual shear walls considering their relative stiffness and it plays a significant role in shear walls. Several design guides offer simplified approaches for shear walls with openings for analyzing stiffness. As a designer, you must understand the impacts of opening in shear walls on stiffness, as well as seismic reactions and behavior of the structure, to select an appropriate configuration of openings in the shear wall [2].

In this study shear walls are considered as major earthquake resisting member, and location of shear walls majorly affects the behavior of the buildings. Researchers Studied for different opening conditions for story drift and diaphragm displacement and they concluded that provision of opening in shear wall ultimately helps to achieve the economy [3].So, it is important to provide the shear walls in proper position as it will minimize the effect and damages due to earthquakes, and thus Researchers has concluded that shear walls should be placed symmetrically on the periphery of the buildings [4, 5, 6]. The openings in shear walls also affects the maximum story displacement, on providing shear walls displacement is reduced [7], but on increasing the area of openings Displacement increases [8, 9]. Also, comparison of shear walls with openings with shear wall and without shear walls is done for seismic parameters for twelve storied structures. [10]

Artificial intelligence can be used as a tool in civil engineering for analysis and design of structures, it may be for pavement design, structural damages, Risk analysis etc. [11]. Various ML models for ANN and Decision trees is being analyzed for prediction of strength parameters [12, 13]. Also, A model of prestress concrete is predicted for time in seismic analysis using Machine learning models [14].

2. DATASET

The data used for this study were recorded using staad pro software by modelling of building models for 5, 10, 15, 20, 25, 30, 35 and 40 stories. The data were analyzed for earthquake zones i.e., III, IV and V. The RC structured shear walls and various sizes of square openings in meters (0, 1, 1.5, 1.75, 2, 2.25, 2.5, 2.7, 2.85, 3) were considered. The dataset collected comprises a total dataset of 240 models out of which 168 randomly selected were used for training of models and the rest 72 models used for Testing. Based on the obtained data, six input variables were considered to predict the dependent variable i.e., Maximum story displacement. The analytical parameters of the variables are provided in Table 1 and 2 for training and testing dataset respectively.

Table 1: Details of statistical parameters of training data set

		Minimum	Maximum	Mean	Standard Deviation
INPUT DATA PARAMETERS	**Stories**	5	40	22.55	11.68
	Elevation (m)	20	160	90.2	0.924
	Size of openings (m)	0	3	1.9	0.92
	Openings %	0	45	22.8	14.87
	Zone	3	5	4	0.87
	Zone factor	0.16	0.36	0.25	0.08
OUTPUT DATA	**Max Displacement (m)**	3.453	351.233	99.042	92.528

Table 2: Details of statistical parameters of testing data set

		Minimum	Maximum	Mean	Standard Deviation
INPUT DATA PARAMETERS	**Stories**	5	40	22.36	11.511
	Elevation (m)	20	160	89.44	46.04
	Size of openings (m)	0	3	2.01	0.845
	Openings %	0	45	23.544	14.15
	Zone	3	5	4.01	0.93
	Zone factor	0.16	0.36	0.25	0.086
OUTPUT DATA	**Max Displacement (m)**	3.524	349.962	96.633	77.33

3. METHODOLOGY

The maximum story displacement of RC Frame shear wall systems is a critical parameter to consider while analyzing and designing the structure. As we know the value of MSD varies with variation of different structural parameters. Hence in this study, the effect of parameters like earthquake zone, height of buildings, size of openings in shear walls for 5 to 40 stories has been observed assuming the other parameters to be constant.

The unique properties of ML modelling as artificial neural network (ANN) and M5P Tree model have been used to develop and correlate the models and identify the factors influencing the parameter to predict the model for the same. These machine learning techniques can learn from any complex problem's input output relationship, avoiding the need for any predefined equation form. The ability of model to predict the MSD based on the trained data that determines whether it has been accepted or rejected. To evaluate the performance of the computational approach in predicting displacement, the mean absolute error (MAE), root mean square error (RMSE) and correlation coefficient (CC) are used. The statistical method for non-linear relationships is complicated. In contrast, the modelling approach is more straightforward because mathematical relationship cannot be established between theoutput and input variables.

3.1 Artificial Neural Network

The artificial neural networks using Multilayer perceptron technique is a computational system that models it in the way the brain of a healthy human analyses and operated the information. The model is also a machine learning process that is being utilized in construction engineering for different types of numerical predictions and issues. The input layer, hidden layers, and the output layer constitute an ANN model. Transfer function, weight, and bias helps to connect the hidden layer to the other layers. The inputs for the multi-layer feed forward network were stories, stories heights, seismic zones, and the size and percentages of openings, and the output was maximum story displacement. A standard approach for developing or selecting a network architecture does not exist. As a result, the trial-and-error test was used to determine the optimum number of hidden layers and neurons considering the criteria for lowest average squared error. The second phase in the network design procedure was to determine the optimum number of epochs to use during training to achieve the best mean absolute error (MAE), Root mean square error (RMSE), and Correlation coefficient (CC). The obtained data set (total of 240 data) was divided into two parts after the ideal architecture was designed: the first portion that is(168) used for training the model was 70% of the overall data set, and the rest part was 30% of the total data set (72) for testing the model. To generate the best structure to predict the maximum storey displacement, various transfer functions and ANN models with varying numbers of neurons and hidden layers were tested. One hidden layer modelled on three neurons was employed in each network, as illustrated in Figure 1. The ANN model was utilised in this phase of the study to calculate the maximum storey displacement in various seismic zones for various shear wall models and different percentages of openings.

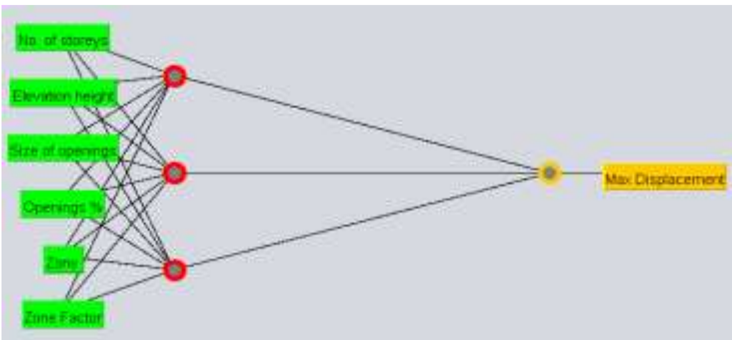

Figure 1. ANN Model

3.2 M5P-tree model (M5P)

The M5P tree model focuses on regression issues using genetic algorithms. The strategy of tree models in M5P adds linear regression characteristics to the nodes at the end and fits into a multivariable model like linear regression at every sublocation by separating various sets of data into numerous sublocations. Instead of discrete segments, the M5P-tree method is used to solve continuous issues of class, and it can handle functions with many dimensions. It shows the result component of every linear model that was developed to represent the non-linear relationship between the datasets. The M5P-tree model tree division criteria, as well as the error estimation, are displayed on each node. To determine the mistakes, the variance of the default value of the class entering the node is used. The parameter at which the expected error reduction is maximised is being considered for evaluation of any function of that node. The M5P-tree model tree division criteria are determined using error computations per node [15] .

The optimized parameters concluded for the ANN and M5P models are-

Modeling Technique	**Parameters**
Multilayer Perceptron	L-0.3 M-0.2 N-500
M5P model tree	M-4

4. RESULTS

Maximum displacement with varied parameters was predicted and evaluated using the ANN and M5P models. Statistical measures such as correlation coefficient (CC), Mean absolute error (MAE), and Root mean square error (RMSE) were used to determine the fitness level of predicted Maximum storey displacement (MSD) values. Figure 2 depict the statistical parameters for training and testing dataset of both the models. Figure 3 shows the scatter line graph between the actual and predicted values of MSD derived from the ANN model and Figure 4 for M5P models with training and testing datasets. According to the representation of data in graphical format, Testing models predicted MSD values correspond linearly with the Trained data, although the M5P model predicts lower values for CC, MAE and RMSE compared to ANN model. Thus ANN (Multilayer perceptron) model shows slightly better performance with CC=0.998, MAE= 11.5, RMSE= 14.79.

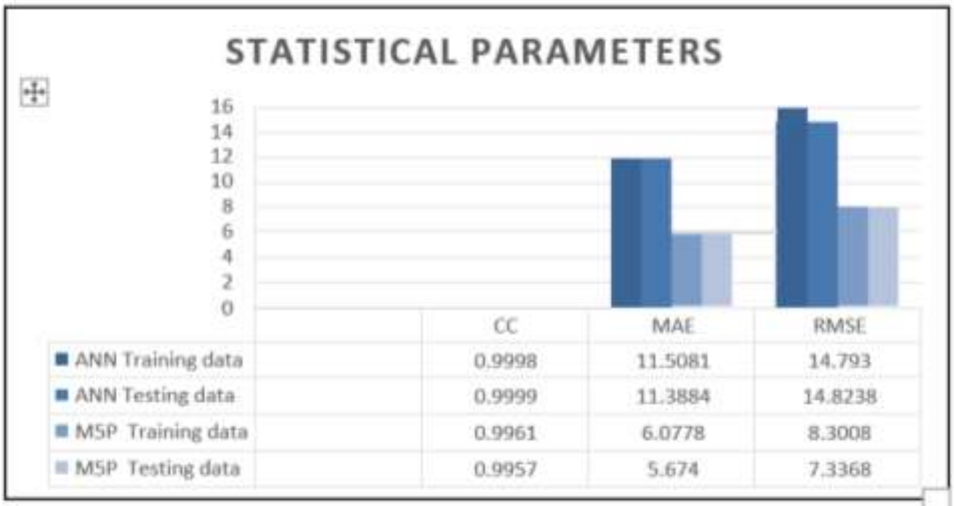

Figure 2. Comparison of statistical parameters of ANN and M5P models

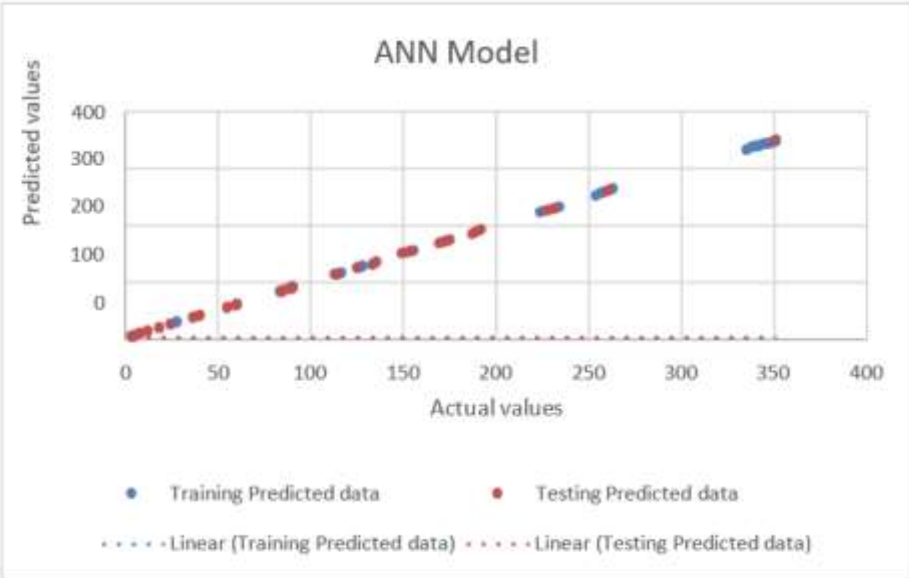

Figure 3. Actual v/s Predicted values of MSD for ANN Model

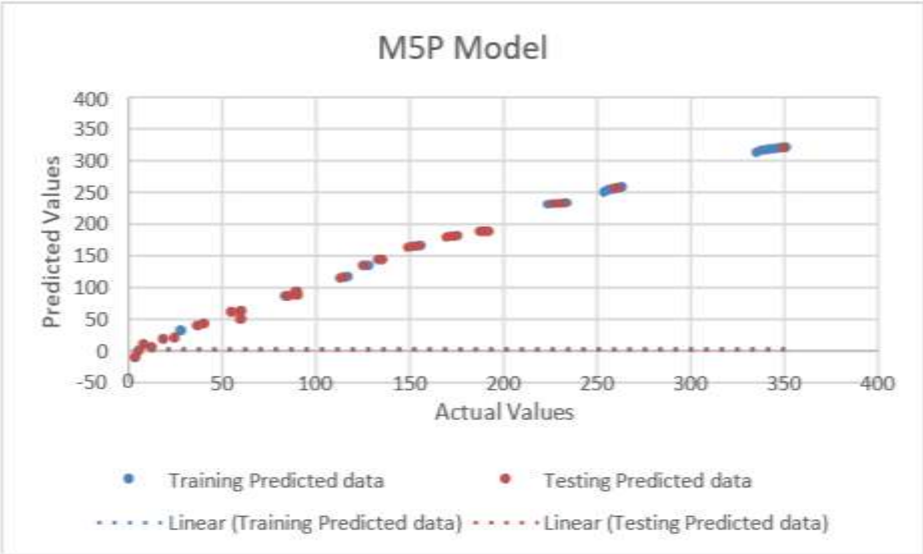

Figure 4. Actual v/s Predicted values of MSD for M5P Model

5. CONCLUSION

In this research, Machine learning approach like ANN and M5P is used to predict the model of Maximum storey displacement. The results obtained from this paper lead us to the following conclusions:

- The ANNs model proposed in this current study showed its ability to predict the MSD based on storey heights in different seismic zones of earthquake. This study will help in predicting the similar model type and thus it will reduce time, cost and labour.
- The statistical parameters obtained shows good results, but ANN model shows more Correlation coefficient (CC), MAE and RMSE for both training and testing models, Thus ANN gives better performance as compared to M5P for MSD results.
- The actual and predicted results are satisfactory and are varying linearly for ANN as well as M5P Models in training and testing datasets, but ANN is again showing more precise graphs as compared to M5P. Thus, the ANNs model is a powerful tool for predicting the Maximum storey displacement of shear walls.
- RC Shear wall have been proved to perform good in earthquakes, the effect of opening provided for architectural aspects considering MSD is being observed in various seismic zones.
- It is concluded that on increasing zones of earthquakes, MSD increases. Also, on increasing opening percentages and number of storeys the MSD values again increases.

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