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INCREASING THE DUCTILITY OF BEAM-TO-COLUMN CONNECTIONS IN REINFORCED CONCRETE STRUCTURES USING DIAGONAL BARS AND PROVIDING A DAMAGE INDEX USING ARTIFICIAL INTELLIGENCE

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Abstract:
Beam-to-column connection is of particular importance because the connection dimensions are very small and the density of bar placement is extremely high due to negative moments and maximum shear forces and it causes execution problems in stirrup placement at the connection. This research investigates the behavior of concrete beam-to-column connection by replacing the existing stirrups in the beam-to-column connection with diagonal bars and changing the type of bend, size and number of diagonal reinforcements and its effects on the ductility of the connection relative to the connection with and without stirrup at the connection node. Analytical study was carried out using Abacus software and laboratory results as well as previous research. Based on the study and comparisons, the results obtained from the analytical method are relatively well consistent with the laboratory results. The results show that the the required ductility in the beam-to-column connection can be provided using diagonal bars and that changing the angle of diagonal bars is effective on the connection behavior. Therefore, in this study, a solution was proposed that is based on the decision tree and the support vector machine. This hybrid method is able to achieve a higher accuracy than either of these methods alone by combining these two methods. The proposed method was compared with the decision tree, SVM and Bayesian methods and it was observed that the proposed method is able to make predictions with much higher accuracy and lower computational overload

Keywords: Concrete beam-to-column connection, ductility, diagonal bars, hysteresis diagram

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抽象的：

梁柱连接特别重要，因为连接尺寸非常小，并且由于负弯矩和最大剪力而导致钢筋放置的密度非常高，并且会导致连接处箍筋放置的执行问题。本研究通过用对角钢筋替换梁柱连接中现有的箍筋并改变对角钢筋的弯曲类型、尺寸和数量及其对混凝土延性的影响，研究了混凝土梁柱连接的行为。连接相对于连接节点处有和没有箍筋的连接。分析研究是使用 Abacus 软件和实验室结果以及以前的研究进行的。通过研究和比较，分析方法得到的结果与实验室结果比较吻合。结果表明，使用对角钢筋可以提供梁柱连接所需的延性，并且改变对角钢筋的角度对连接行为是有效**的。因此，在本研究中，提出了一种基于决策**树和支持向量机的解决方案。通过将这两种方法结合起来，这种混合方法能够获得比单独使用这两种方法中的任何一种方法更高的精度。将所提出的方法与决策树、SVM **和**贝叶斯方法进行了比较，结果表明所提出的方法能够以更高的准确度和更低的计算量进行预测

关键词：混凝土梁柱连接，延性，对角钢筋，滞后图

1. Introduction

In order to achieve the safety of structures against earthquakes, it is necessary to know more about their seismic behavior and to study the factors affecting their response. Researchers have long strived to identify the above factors through theoretical research or laboratory research and using appropriate models and determine and provide the effect of each of them in a simple and understandable way for use in the design of structures. One of the most important problems of seismic design of structures is the unpredictability of seismic force, the complexity of seismic behavior of materials, the difficulty of seismic analysis of structures and its special design method. What is certain is that the scope of discussion in the above cases is very extensive and the study of the effect of each of them on the seismic design requires extensive information and research. The main goal in seismic design of buildings is that the behavior of the building against the forces caused by small earthquakes remains undamaged and in the linear range and bear structural and non-structural damage against the forces caused by severe earthquakes while maintaining its overall stability. By increasing the lateral displacements, damage to structural and non-structural members begins and the stability of the structure is compromised, therefore, it is important to control lateral displacements of the structure [1-5]. Since most conventional designs are done through linear analysis, it is possible to estimate the actual deformation and displacement of the structure resulting from nonlinear analyses by finding a coefficient to convert the linear analysis displacements to actual displacements. Since the lateral displacement of the structure is inversely related to its lateral stiffness, the issue of large displacements in low stiffness

structures such as flexural frames or braced frames with weak restraints is more important and these displacements can lead to large deformations and destruction between the frames and structural vertical members such as columns and eventually the collapse of the structure [6-12].

The standard description of the expected behavior of buildings with moderate importance against an earthquake (specific earthquake) is almost similar to the description of the instructions. In both, it is stated that the safety of life must be ensured for the residents. Life safety performance level refers to the performance level in which the earthquake is predicted to cause damage to structural members, but the damage is not so great as to lead to loss of life, and non-structural components do pose a danger to the residents due to the earthquake.

Applying the mutual effects of of the site and the structure built on it is often ignored in the analysis and design of structures. While the study of the seismic response of structures and the analysis of how the lateral forces are distributed in the members of the structure, due to the movement of the free surface due to the passage of seismic waves, require accurate knowledge of the nonlinear behavior of the soil under the structure. The effects of the uplift force of the foundation on the structure[1] and the importance of the changes that occur in the seismic response of the structure through the analysis of this behavioral set are generally non-negligible. These effects may increase or decrease the seismic response of the structure or other seismic parameters due to the seismic force, these effects in turn depend on the characteristics of free field motion, dynamic properties of the structure (including the main vibration period, damping, etc.), and the flexibility of the support. Likewise, it is possible that as these changes occur, the force on the structural members also changes (decreases or increases) and affects their safety, efficiency, or durability [13-21].

2. Sample of the concrete beam-to-column connections

In order to investigate the effect of placing the diagonal reinforcement in the concrete beam-to-column connections, several models with various changes will be considered. The considered models are selected based on laboratory samples from the reference article and are modeled in Abacus software. The dimensions of the beams and columns for the samples considered are the same in all models and changes are made on their reinforcements. Table 1 shows the specifications of the connections considered in this section. Table 1 shows the specifications of these connections in the connection area.

Table 1. Specifications of the considered connections

Sample	Column			Beam		
	Column dimensions (mm)	Longitudinal reinforcements (mm)	Transverse reinforcements (mm)	Beam dimensions (mm)	Longitudinal reinforcements (mm)	Transverse reinforcements (mm)
C1-14X	300×200	8φ14	Φ8@100	300×200	8φ12	Φ8@100
C1-16X	300×200	4φ14+4φ16	Φ8@100	300×200	8φ12	Φ8@100
C1-10X	300×200	12φ10	Φ8@100	300×200	8φ12	Φ8@100
C2-14	300×200	8φ14	Φ8@100	300×200	8φ12	Φ8@100
C3-14	300×200	8φ14	Φ8@100	300×200	8φ12	Φ8@100
C1-bX	300×200	8φ14	Φ8@100	300×200	8φ12	Φ8@100
C1-14X60	300×200	8φ14	Φ8@100	300×200	8φ12	Φ8@100

Table 2. Specifications of the considered connections in the connection area

[1] SSI

Sample	Column				Beam			
	Longitudinal reinforcements in the connection area	Diagonal reinforcements in the connection area	Transverse reinforcements	Bend angle in the diagonal area	Longitudinal reinforcements in the connection area	Diagonal reinforcements in the connection area	Transverse reinforcements	Bend angle in the diagonal area
C1-14X	4φ14	4φ14	-	45	8φ12	-	-	-
C1-16X	4φ14	4φ16	-	45	8φ12	-	-	-
C1-10X	4φ10	8φ10	-	45	8φ12	-	-	-
C2-14	8φ14	-	-	-	8φ12	-	-	-
C3-14	8φ14	-	Φ8@50	-	8φ12	-	-	-
C1-bX	8φ14	-	-	-	-	8φ12	-	45
C1-14X60	4φ14	4φ14	-	60	-	8φ12	-	-
C1-14X30	4φ14	4φ14	-	30	-	8φ12	-	-

Sample C1-14x is the prototype of the modeling that is considered. Other modeling is based on this model. In model C1-16x, the diameter of the column longitudinal reinforcements increases compared to the original model. In model C1-10x, the diameter of the column longitudinal reinforcements decreases compared to the original model and its number increases. In model C2-14, longitudinal reinforcements are considered to be continuous and without bend in the connection area, and there is no stirrup in the connection area. In model C3-14, longitudinal reinforcements are considered to be continuous and without bend in the connection area, but there is also stirrup in the connection area. In model C1-bx, bend in the connection area is considered instead of column reinforcements in beam reinforcements. In model C1-14x60, the bend angle of the reinforcements in the connection area changes compared to the original model, and this angle is considered to be 60 degrees instead of 45 degrees. Finally, in model C1-14x30, the bend angle of the reinforcements in the connection area changes compared to the original model, and this angle is considered to be 30 degrees instead of 45 degrees.

All these models are modeled in Abacus software and the effect of the changes considered in them on the behavior of connections will be investigated.

3. Specifications of materials

Specifications of the materials used in various members of the connections for concrete and steel materials are listed in Tables 3 and 4. The steel used for the bars will be s400 and the concrete used for beams and columns will be c35.

Table 3. Mechanical specifications of the used steel bars

Materials	Modulus of elasticity (Mpa)	Poisson's ratio	Yield stress (Mpa)	Ultimate stress (Mpa)	Ultimate strain
Longitudinal bar	210	0.3	400	600	0.15

Table 4. Specifications of the considered concrete

Materials	Compressive strength (Mpa)	Tensile strength (Mpa)	Poisson's ratio
Concrete C35	350	35	0.2

4. Modeling hypotheses in the software

In order to model each of the above samples in Abacus software, the following hypotheses are considered in each of the different parts of the software and modeling will be performed.

Connection of the considered sample is modeled in three dimensions in the software. For modeling, in order to model the concrete connection area, the three-dimensional element of SOLID in the form of C3D8R (i.e. solid three-dimensional three-node element with reduced integral) is used. In order to model the steel members (reinforcements), the beam element will be used. This element is a two-node element that has the capability of plasticization, stress hardening, and large deformations, and any desired section can be used for this element. As we know, the materials used in the models are steel and concrete.

Figure 1 shows the compressive stress-strain curve of concrete in general.

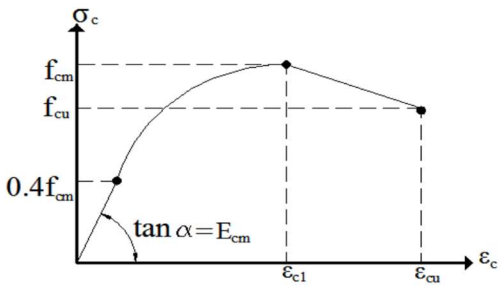

Figure 1. Compressive stress-strain curve of concrete [17]

For the compressive part of the concrete, the curve consists of three areas. The onset of the curve changes linearly with an ECm slope until a stress of 0.4 fcm is reached. The second area starts at the end of the linear area and continues until the ultimate stress is reached. In the third area of the compressive stress-strain diagram of the concrete, after reaching the maximum strength, until the strain εcu is reached, the diagram changes linearly to reach the stress fcu [17].

E_{cm} = Modulus of elasticity of concrete (MPa)

F_{cm} = Ultimate strength of concrete (MPa)

ε_c = Modulus of elasticity of concrete

ε_{c1} = Modulus of elasticity of concrete fcm

In order to define the specifications of concrete in the software, the plastic damage model is used, which is one of the capabilities of Abacus software that was described in the previous sections. In Abacus finite element software, the nonlinear behavior of brittle materials can be defined by three methods: smeared crack model, brittle cracking model, and concrete damage plasticity model. Each of these models has advantages that can be used as needed. The concrete damage model is the only model that can be used in both static and dynamic analyses. In this model, it is assumed that tensile cracking and compressive crushing are the two main aspects of the concrete rupture mechanism and is designed to model the failure of brittle materials under cyclic loads (intermittent intermittent tension and pressure) so that hardness can be recovered during reciprocating loads. In the plastic damage model, due to the lack of rupture criteria, it is not possible to remove the elements during analysis or crack creation, but this model has the ability to predict the location and direction of crack formation.

Specifications of metal materials such as metal mesh and beams and columns are also defined by a two-line stress-strain diagram. Figure 2 shows the stress-strain curve of steel modeled in two lines.

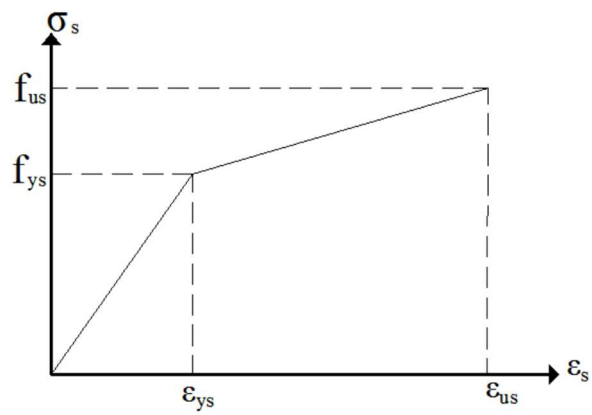

Figure 2. Two-line steel stress-strain curve

The first area is linear and continues until the yield stress f_{ys} is reached in its corresponding strain ε_{ys}. The steel then enters the nonlinear area and the strain increases until the ultimate stress fus is reached and the steel ruptures when the strain ε_{us} is reached.

In order to make a connection between the metal grid and the concrete wall, embedded constraints have been used. By this constraints, a piece can be placed inside other pieces so that the degrees of freedom of the

inner piece can be internalized from the outer piece using its degrees of freedom.

The sample will be loaded by applying incremental displacement to both ends of the columns. This load is defined as the control of displacement (increasing displacement with increasing time) to the software. In order to apply the support conditions, a rigid piece to which models are attached at the end of the beam is used. The model support in this area is also defined by joints.

5. Results of the analysis

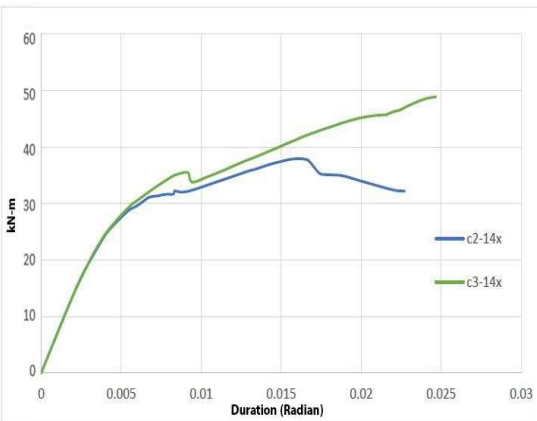

Figure 3. Comparison of moment-rotation curves for the sample connections with and without stirrups

Comparison of the above curves shows that the placement of longitudinal reinforcement without bend and reinforcement severely has reduced the connection performance and that the connection has lost its bearing capacity much earlier than the prototype.

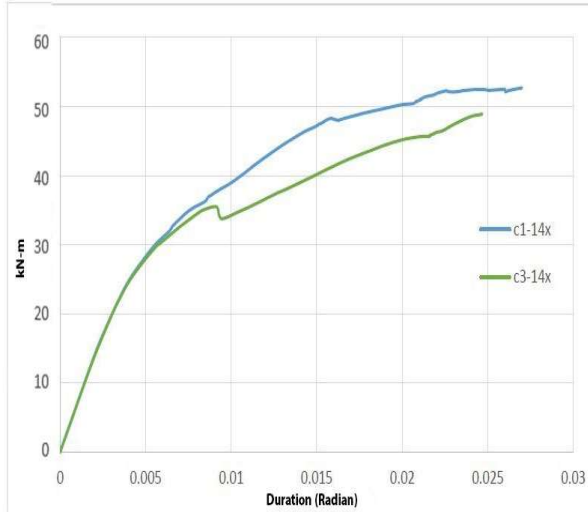

Figure 4. Comparison of moment-rotation curves for the sample connections modeled with stirrups and 45 ° diagonal reinforcement

Comparison of these curves shows that the placement of diagonal reinforcement in reinforced concrete columns has improved their performance. The prototype with diagonal reinforcement had a better performance and showed more load-bearing capacity than the sample with straight longitudinal reinforcement with stirrup in the connection area.

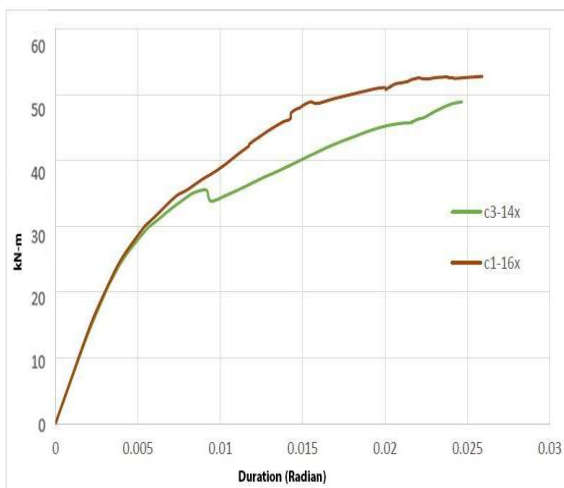

Figure 5. Comparison of moment-rotation curves for the sample connections modeled

with stirrups and diagonal reinforcement with larger diameter

Comparison of these curves shows that increasing the diameter of longitudinal reinforcements has increased its bearing capacity, which is not very significant.

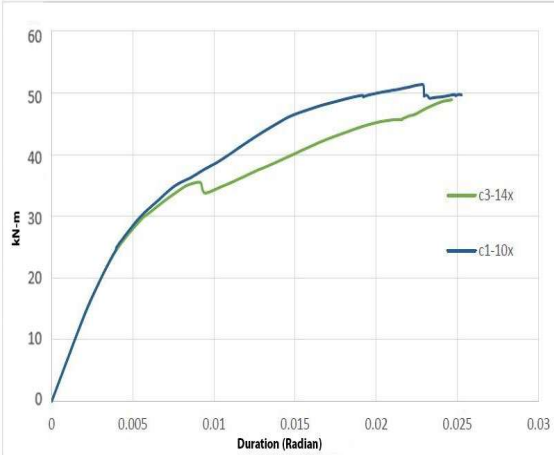

Figure 6. Comparison of moment-rotation curves for the sample connections modeled with stirrups and diagonal reinforcement with more number

Comparison of these curves shows that with decreasing diameter and increasing the number of reinforcements, the bearing capacity of these columns has slightly decreased. (However, it should be noted that in the sample modeled in this section, the increase in the number of reinforcements was associated with a decrease in the amount of longitudinal reinforcements in the column.)

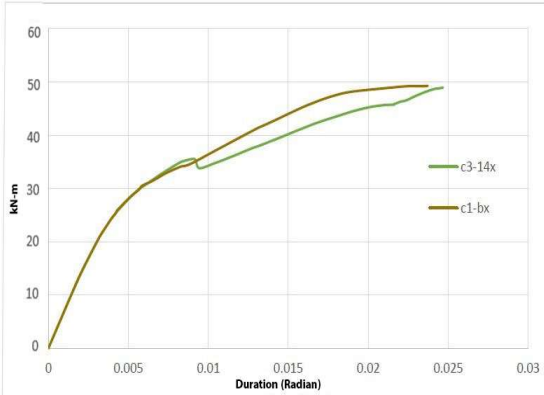

Figure 7. Comparison of moment-rotation curves for the sample connections modeled with stirrups and with diagonal reinforcement in the beam

Comparison of these curves shows that the sample with diagonal reinforcement in the column had better performance than the sample with diagonal reinforcement in the beam.

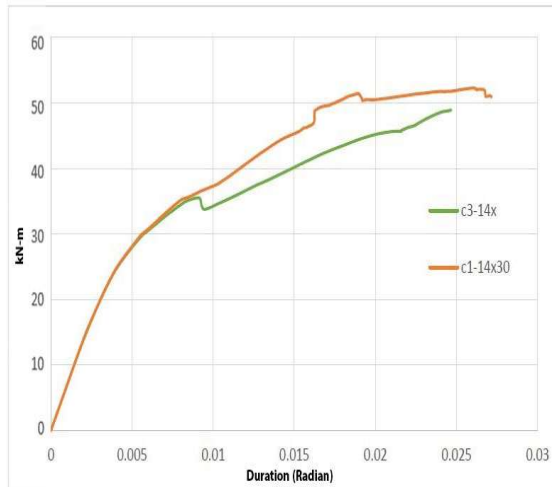

Figure 8. Comparison of moment-rotation curves for the sample connections modeled with stirrups and 30 ° diagonal reinforcement

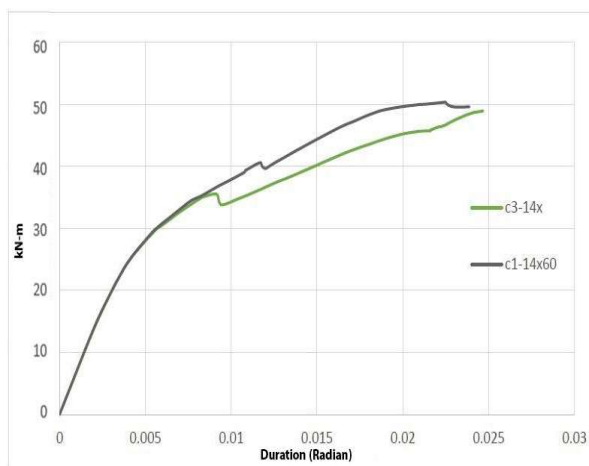

Figure 9. Comparison of moment-rotation curves for the sample connections modeled with 60 ° diagonal reinforcement

Comparison of these curves shows that the sample in which the bend of reinforcements

was in the 45 ° connection area had better performance and higher load capacity than the sample in which the bend of reinforcements was in the 60 ° and 30 ° connection area.

6. Reciprocating loading on samples

In this section, we will address the reciprocating loading of three samples without stirrups, with stirrups and with diagonal reinforcements (the sample that had better behavior against incremental loading).

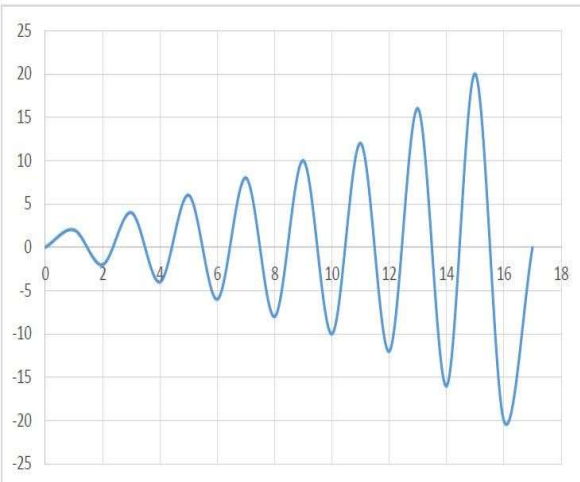

Figure 10. Reciprocating loading pattern

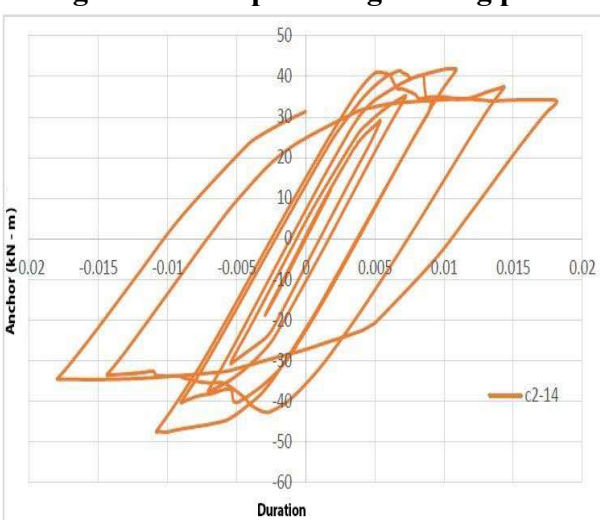

Figure 11. Moment-rotation curve for the sample without stirrups

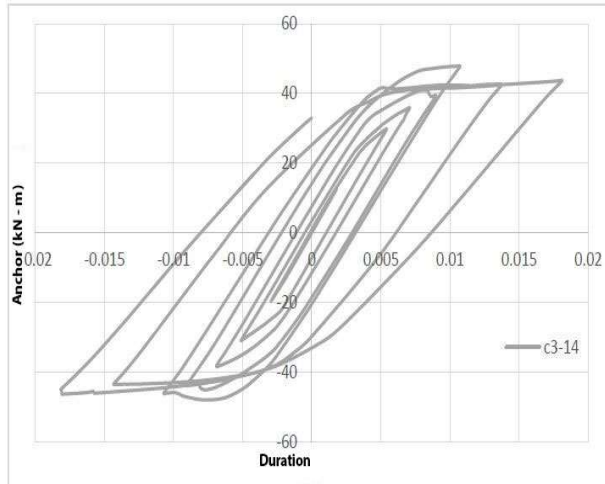

Figure 11. Moment-rotation curve for the sample with stirrups

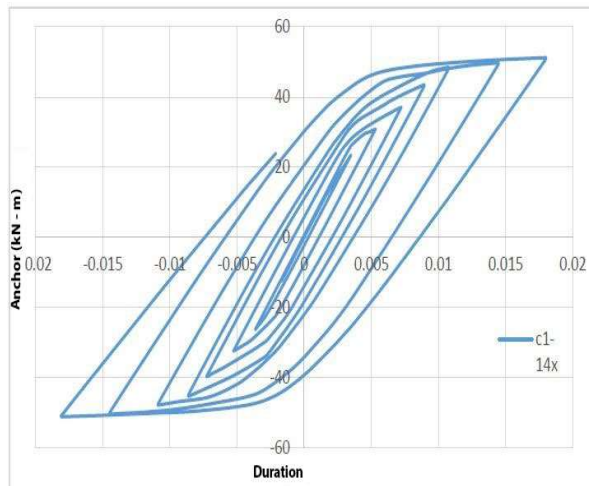

Figure 11. Moment-rotation curve for the sample without diagonal reinforcements

As can be seen, the sample with diagonal reinforcement has better behavior and bear more load against reciprocating load than the two samples without stirrups and with diagonal stirrups. The sample with stirrups also showed a more appropriate behavior and showed more bearing capacity than the sample without stirrups. Actual dynamic behavior is affected by the dynamic behavior of the elements, building configuration, and filler panels. Therefore, the distribution of plastic hinges and cracks as well as the blow-up ratio when the building is based on

nonlinear surfaces affect the dynamic behavior. The Park-Ang damage index considers the hysterical behavior of each element, the degradation energy, and the deformation. In order to complete this damage index and evaluate the actual damage conditions under seismic loads, the fundamental period was considered to investigate the effect of configuration, filler panels, and damage distribution. Fortunately, by achieving the analysis steps, a logical pattern was established between the life of the period and the damage rate. Finally, a new and inexpensive damage pattern can be obtained without initial information to quickly evaluate the seismic behavior of existing RC buildings. Diagonal bars can provide the required ductility in the beam-to-column connection, so that the connection with diagonal reinforcement has a better performance than the connection with stirrups and without diagonal bars and shows more load-bearing capacity. Changing the angle of the diagonal bars affects the behavior of the beam-to-column connection, and the connection in which the bend of the reinforcements is in the 45 ° connection area has better performance and more load-bearing capacity than the connection in which the bend of the reinforcements is in the 60 and 30 ° connection area. Increasing the diameter of the diagonal reinforcement in the area of the beam-to-column connection will increase the load-bearing capacity and ductility. The beam-to-column connection with diagonal reinforcement in the column will have better performance than the the beam-to-column connection with diagonal reinforcement in the beam. The beam-to-column connection without diagonal reinforcement and stirrups in the connection node will lose its load-bearing capacity much sooner than the connection with stirrups and will have very little ductility.

7. Confirmation of analyses

In any analytical program, analyses need to respond logically to at least the behavior of a simple structure. Therefore, one must ensure the program that extracts the information. Hence, a comparison was made between analytically extracted data and experimentally extracted data (Masoumi, 2004). The results are shown in Figure 1. These results are acceptable on an engineering scale. The slight discrepancy between the data is due to experimental error in the laboratory environment and simplification assumptions in numerical analyses. In this section, the correlation between the damage rate and the percentage change of the nonlinear fundamental period is introduced step by step. Six wave-shaped RC frameworks were studied. In analytical modeling, the input hysterical behavior of elements plays a key role in the overall seismic behavior of the building. If inappropriate hysterical curves are chosen as elements of a building, the final results of analytical modeling will be unrealistic. In this research, a multi-linear hysterical model has been selected for beams and columns that is consistent with the experimentally extracted laboratory data to provide the real seismic behavior.

8. Investigation of the proposed model

Here, the intention is to achieve a method to diagnose Parkinson's disease in a high percentage among people because it was said

that Parkinson's disease is very difficult to diagnose. Using the method described here, we intend to provide a solution that is based on the decision tree and machine learning algorithm. The main objective here is to provide a solution that can be used to make important decisions in diagnosing and preventing Parkinson's disease. In this research, in order to achieve higher accuracy in the proposed method, the system must first be trained using data mining.

The data set used in this study is related to Parkinson's patients and a group of healthy people collected by UCI University in California. These collected data are labeled, so they can be used in this research.

The method used in this research is a hybrid method that can greatly increase the accuracy of the method. Here, the optimal support vector machine algorithm and the decision tree are used. Using this proposed solution, a weight is considered for each of these algorithms, and to calculate and predict the value calculated by each of these algorithms, it is multiplied by the weight of that algorithm, and in the end, the real result is obtained, which will have higher accuracy. Because it has used the benefits of both of these algorithms.

The proposed method has various steps, which are:

1. Data preprocessing operation
2. Selecting the effective features using the rough set
3. Training and calculating the weights of decision tree and support vector machine algorithms
4. Building a decision tree
5. Building a backup vector machine

In this section, the proposed model is compared with ID3 algorithm, support vector machine algorithm [1] and Bayesian network [2]. The data is divided into two parts: training and test. The proposed system is trained using training data and evaluated using test data.

The method used to select training and test data is the cross fold K validation method. Here the value of k is set to 10, which is a standard value in the field of data mining.

In this implementation, in order to evaluate other algorithms and the proposed algorithm, very valid and standard error checking parameters have been used, which are:

- Mean squared error (MSE): This criterion obtains the mean squared error using the following equation and this criterion can be used to accurately measure the prediction and calculate the value of prediction error.

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(r_i - p_i)^2 \quad (1)$$

- Mean absolute error (MAE): It is calculated using the following equation:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|r_i - p_i| \quad (2)$$

- Root-mean-square deviation (RMSD) or root-absolute error (RAE) is the difference between the value predicted by the model or statistical estimator and the actual value. RMSD is a good tool for comparing prediction errors by one data set and is not used to compare multiple data sets. These distinct differences are also called residuals, and has the root-mean-square deviation is used for gathering them in a number. In the root-mean-square deviation, a statistical estimator p_i according to the predicted

parameter r_i is defined as the root-mean-square deviation:

$$RAE(\hat{\theta}) = \sqrt{MSE(\hat{\theta})} = \sqrt{E((r_i - p_i)^2)} \quad (3)$$

- True positive (TP) criterion: If the answer obtained from the prediction is p and the actual value is p, then 1 unit is added to TP, so this value is added to the data set used for the test.
- True negative (TN) criterion: If the answer obtained from the prediction is n and the actual value is n, then 1 unit is added to the TN, so this value is added to the data set used for the test. The difference between this part and TP is that in TP we count the positive answers and here we count the negative answers.
- False positive (FP) criterion: If the answer obtained from the prediction is p and the actual value is n, then 1 unit is added to the FP, so this value is added to the data set used for the test, this means that in general, the answer obtained from the prediction is different from the actual value.
- False negative (FN) criterion: If the answer obtained from the prediction is n and the actual value is p, then 1 unit is added to Fn, so this value is added to the data set used for the test, this means that in general, the answer obtained from the prediction is different from the actual value. The difference between this part and the previous part is that in the previous part, we considered the negative answers that were mistaken for positive, and here we consider the positive answers that that are mistaken for negative.

After running the program, the outputs can be accessed, each of which are evaluated in the following.

Table 1. Percentage of prediction correctness and prediction error

	Percentage of prediction correctness	Percentage of prediction error
Proposed algorithm	90.902%	29.09%
Bayesian algorithm	60.016%	39.983%
ID3 algorithm	66.970%	33.029%
SVM algorithm	66.225	33.774%

According to the obtained results, it can be clearly seen that the proposed algorithm with 90.902% accuracy has the highest correctness and with 29.09% error has the lowest error rate. Here, in general, the accuracy is not very high and this is due to the data used, and because the data were the same for all methods compared, these methods can be compared properly. It is clear that the proposed algorithm performs much better than the others and is much better than the ID3 and the support vector machine algorithms, which are the basic algorithms of the proposed method, and also performs better than the Bayesian algorithm compared. According to these accuracies, it is quite visible that the proposed method has performed much better than other methods, and meanwhile, the SVM algorithm has also performed better than the ID3 and Bayesian algorithms. The Bayesian algorithm also performed better than the ID3 algorithm.

The mean squared error for the studied methods is shown in 0.

Table 2. Mean squared error (MSE) for different methods studied

	Mean squared error (MSE)
Proposed algorithm	0.452
Bayesian algorithm	0.582
ID3 algorithm	0.488
SVM algorithm	0.581

It can be seen in 0 that the proposed method has the lowest mean squared error and this shows better performance and higher accuracy of the proposed method. It can be seen that the proposed method is better than

ID3, Bayesian is better than SVM, and finally all methods performed better than Bayesian.

The mean absolute error (MSE) for the various methods studied in this study can be seen in 0.

Table 3. Mean absolute Error (MAE) for different methods studied

	Mean absolute Error (MAE)
Proposed algorithm	0.342
Bayesian algorithm	0.405
ID3 algorithm	0.384
SVM algorithm	0.337

It can be seen from the point of view of absolute mean error, the SVM algorithm has less error and the proposed method performed only better than the Bayesian and ID3 algorithms. However, it should be noted that each of these error criteria has a solution for itself in this study, which were addressed at the beginning of this chapter.

The root-absolute error (RAE) for the different methods studied in this research is calculated in 0.

Table 4. Root-absolute error (RAE) for different methods studied

	Root-absolute error (RAE)
Proposed algorithm	69.795
Bayesian algorithm	82.650
ID3 algorithm	78.465
SVM algorithm	68.879

The root-absolute error of the proposed method is less than other methods in 0.In the following, the diagrams obtained from the program are investigated. The first diagram is about the percentage of correct prediction among the test data, which can be seen in 0.

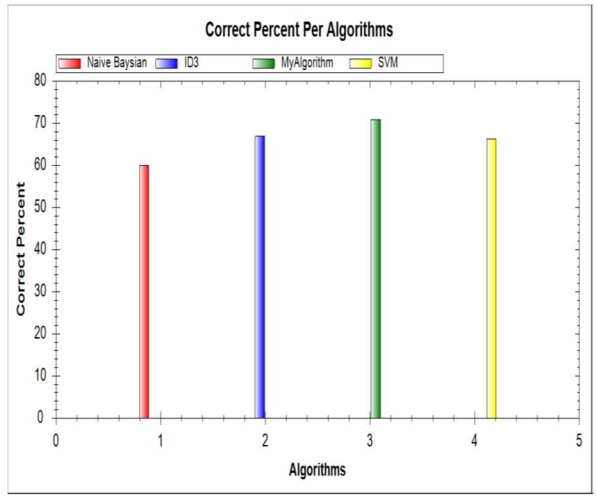

Figure 14. Percentage of correct prediction among test data for the proposed algorithm and other algorithms

As can be seen in this diagram, our proposed method has more correct prediction accuracy than the other algorithms studied, namely Bayesian network, SVM algorithm and ID3 algorithm. This is because in our prediction method, we only considered the items of test data that had a greater effect on the output and therefore did not use data that had no effect on the output, thus greatly reducing the analysis time, while the other algorithms are less accurate due to the use of all parameters because some parameters may have distance values that may have no effect on the output. but because these parameters have been used in the other algorithms to build a model for prediction, they cause noise and reduce accuracy, and in our proposed method, because these these useless parameters did not exist, the accuracy of our proposed method increased and performed better than other algorithms. Also, a hybrid method is used in the proposed algorithm, which can be seen to have performed well, and has performed much better than other methods, and has also performed better than the methods it is based on. In the diagram

presented in 0, the percentage of inaccurate prediction can be seen. According to this diagram, it can be understood that the proposed method has a lower value than the other methods due to the reason that was mentioned earlier regarding the percentage of accurate prediction, i.e. it has less wrong predictions, therefore, the proposed method performed better than the other methods.

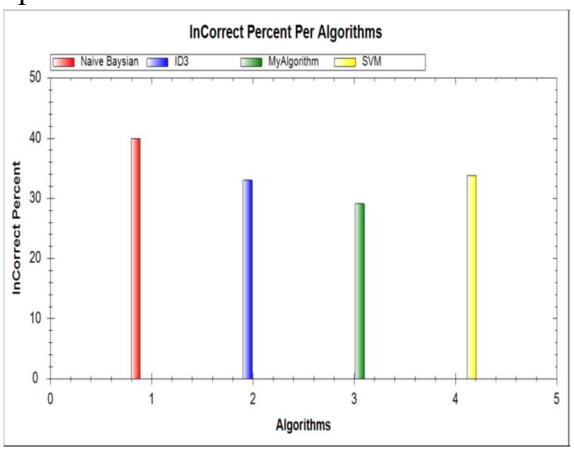

Figure 15. Percentage of incorrect prediction among test data for the proposed algorithm and other studied algorithms

According to the diagram, it can be found that the prediction error in the studied algorithms is almost equal and close, but the proposed algorithm is less because the higher the accuracy rate, the lower the error rate, and this indicates the proper performance of the proposed method. It can be seen that the mean squared error (MSE) in the proposed method is lower than all other methods and the ID3 algorithm is lower than the SVM algorithm and meanwhile, the Bayesian algorithm has a higher error rate than the SVM algorithm. This error rate not only checks for inaccuracy but also calculates the distance of the predicted answer from the actual answer, in which case it is observed that the proposed algorithm behaves much better than other algorithms. If we pay attention to this diagram, we can understand this issue because the ID3 algorithm has more wrong predictions than the SVM algorithm, but because the distance was not considered, ID3 was worse than the SVM algorithm.

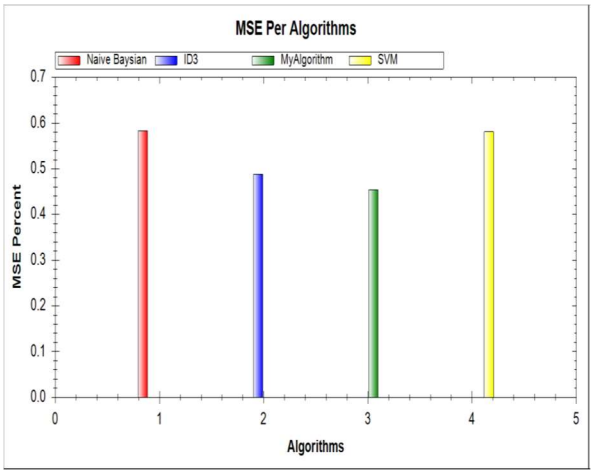

Figure 16. MSE criterion among the proposed algorithm and the other similar algorithms studied

Then, the MAE and RAE error criteria were calculated, which are used in many data mining algorithms, and therefore were considered in this study.

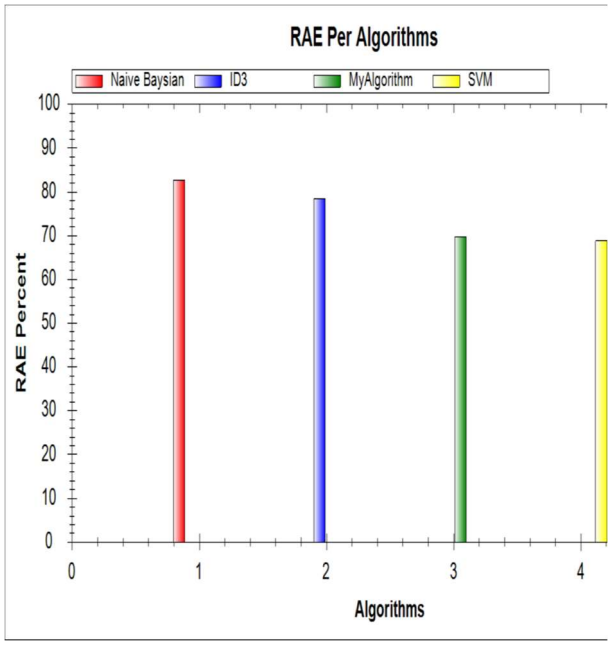

Figure 17. RAE criterion among the proposed algorithm and the other similar algorithms studied

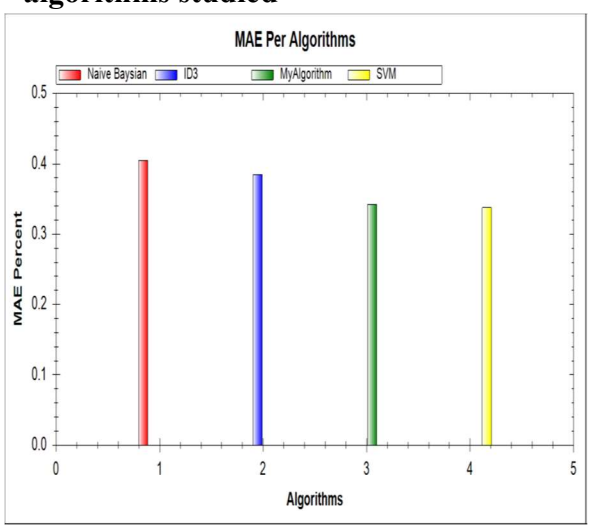

Figure 18. MAE criterion among the proposed algorithm and the other similar algorithms studied

TP, TN, FP and FN have also been calculated to investigate the proposed method and other studied methods more accurately.

Table 5. Investigation of TP, TN, FP and FN parameters for the proposed method and the other methods

	TP	TN	FP	FN
Proposed algorithm	335	522	185	166
Bayesian algorithm	215	510	305	178
ID3 algorithm	290	230	169	519
SVM algorithm	220	300	108	580

It can be seen in 0 that the proposed method has a higher total TP + TN than the other methods because in fact the higher the number of TP and TN, the more correct predictions are made. And the lower the number of FPs and FNs, the less wrong predictions are made. The total number of data used is 1208 records and since the cross k fold method is used, i.e. all parts of the data are used for both training and testing, in this case, if each row is added to 0, it will lead to 1208, because 1208 records have been tested. Two of the important parameters in data mining science is false positive rate (FPR) and true positive rate (TPR) of performance, which are shown through the equations in 0 and 0.

$$FPR = \frac{FP}{FP + TP} \tag{4}$$

$$TPR = \frac{TP}{FP + TP} \tag{5}$$

These two parameters are calculated for the proposed method and other methods studied in this research and are shown in 0.

Table 6. False positive rate and true positive rate for the proposed method and the other studied methods

	FPR	TPR
Proposed algorithm	0.355	0.644
Bayesian algorithm	0.586	0.413
ID3 algorithm	0.557	0.442
SVM algorithm	0.576	0.423

According to 0, it can be seen that the proposed method has a higher true positive rate but has the lowest false positive rate. This means that the proposed method has very little error, so it can be said that it is definitely more accurate. It can be clearly seen here that the proposed algorithm has a low false positive rate and a high true positive with a large distance, while the other algorithms have close values.

Another very important parameter is accuracy, which has been used in most articles to compare methods, which in this study has been calculated for different methods. Accuracy is obtained using Equation 0.

$$ACC = \frac{TP + TN}{TP + TN + FP + FN} \quad (6)$$

The accuracy of calculation for the proposed method and other methods studied in this research is shown in 0.

Table 7. Accuracy calculated for the proposed method and the other studied methods

	Accuracy
Proposed algorithm	0.709
Bayesian algorithm	0.600
ID3 algorithm	0.669
SVM algorithm	0.662

As can be seen in the results, the proposed method has a higher accuracy than the other methods studied and also the accuracy or TPR of the proposed method is higher than the Bayesian method, which indicates the proper performance of the proposed method compared to the Bayesian method and other methods. Here it can be seen that all hypotheses have been proven because the solution in this study is a combination of the SVM and ID3 methods and it was observed that each of these methods is more accurate and it was observed that it has a higher prediction accuracy rate than the other studied methods.

9. Conclusion

Today, knowledge is considered as a valuable and strategic resource as well as an asset for evaluation and prediction, and the presentation of these solutions in identifying the damage index has become a hot topic today, and various solutions have been proposed in this field. Normally, the identification of the damage index requires close human supervision that examines full time, i.e. the building should be under the supervision of an engineer, but with the solution proposed in this research, the system itself can intelligently do this and provide information. In the past, many solutions were proposed for purposes such as those discussed in this study, but these solutions were not accurate enough and also had a high overload. Therefore, a solution for evaluating past information and a hybrid system for identifying a damage index with high accuracy are provided in this study. The proposed solution is a hybrid method of the SVM and decision tree methods. Then, the proposed method, which is a combination of two methods, was compared with each of these methods and compared with the methods of Article [2] and Article [1]. It was observed that the proposed method performs much better than any of these methods alone. In this proposed method, the rough set

method, which is combined with the hierarchical analysis method, has been used to identify the features affecting the damage index. This reduction in features and the selection of effective properties will reduce the computational overload and also reduce the number of levels of the decision tree because only effective features are used and not all features are used. The method proposed in this research was investigated using the Bayesian network, decision tree, and SVM algorithm algorithms and it was observed that the proposed method performs much better than these algorithms and has higher accuracy and lower error rate. In data mining science, data is very important because it is the data that creates science and prediction. Here the data was initially pre-processed and events were transferred until the data became the input data required by the proposed algorithm. The obtained results show a complete improvement of the proposed method.

In this research, we tried to answer the research questions by using the evaluation method, which can provide a solution to increase the accuracy of the proposed method that can be used to achieve the highest accuracy rate, and this proposed hybrid algorithm has higher accuracy and lower computational overload than any of the methods used and combined. The approach proposed in this research is optimized compared to the SVM method and decision tree which are the basic methods of the proposed method for 7.06% and 5.87%, respectively, and it preforms better in combination than each of these methods alone.

References

[1] A. Karbassi, B. Mohebi, S. Rezaee, P. Lestuzzi, “Damage prediction for regular reinforced concrete buildings using the decision tree algorithm”, Computers and Structures, 2014

[2] Mehrdad Aghagholizadeh, Ali Massumi, “Relation between Dynamic Characteristics and Damage Index of RC-MRFs Using Non-Linear Incremental Dynamic Analyses”, School of Engineering, Kharazmi University (Tarbiat Moallem of Tehran),Tehran, Iran, 2012

[3] Haoxiang He, Maolin Cong, Yongwei Lv, “Earthquake Damage Assessment for RC Structures Based on Fuzzy Sets”, Beijing Key Lab of Earthquake Engineering and Structural Retrofit, Beijing University of Technology, Beijing 100124*, China,* 2013

[4] K. Yazdannejad and A. Yazdani, “Bayesian updating of the Park-Ang damage index for RC frame buildings under near-fault ground motions”, Department of Civil Engineering, University of Kurdistan, Sanandaj, P.O. Box 416, Iran, 2016

[5] Mehrdad Aghagholizadeh, Ali Massumi, “A new method to assess damage to RCMRFs from **International Journal of** ”, Ang damage index using IDA–period elongation and Park2016, **Advanced Structural Engineering** ower Based L-Damage Index, “Nikos D. Lagaros, Giuseppe C. Marano, Chara Ch. Mitropoulou

] 6[2018, Innovative Approaches in Computational Structural Engineering”, Bound Structural Design

[7] Chara Ch. Mitropoulou, Giuseppe C. Marano, Nikos D. Lagaros, “Numerical calibration of damage indices”, Advances in Engineering Software, 2014

[8] Maryam Samimifar, Ali Massumi, "Simplification and Assessment of Modal-Based Story Damage Index for Reinforced Concrete Frames Subjected to Seismic Excitations", **Journal of Earthquake Engineering**, 2016

[9] VUI CAO VAN, "SEISMIC DAMAGE ASSESSMENT AND FRP RETROFIT OF REINFORCED CONCRETE STRUCTURES", A thesis submitted for the degree of Doctor of Philosophy at The University of Queensland, 2014

[10] Claudiu Tudose, "Comparative study on damage index evaluation for new and existing reinforced concrete structures", : Civil Engineering & Architecture, 2013

[11] Roberto Pimentela, Tulio Guedesa , Lucas Meloa , Gabriel Ferreiraa , Márcio Gonçalvesa, "Damage detection assessment in reinforced concrete slabs using impact tests", International Conference on Structural Dynamics, 2017

[12] Sergiu Andrei Baetu, "Seismic damage evaluation of reinforced concrete slit walls", **ENGINEERING COMPUTATIONS**, 2015

[13] Susanta Banerjee, Sanjaya Kumar Patro, "Estimation of the Park-Ang Damage Index for Floating Column Building with Infill Wall", International Journal of Civil and Environmental Engineering, 2014

[14] Siddhartha Ghosh , Debarati Datta, Abhinav A. Katakdhond, "Estimation of the Park–Ang damage index for planar multi-storey frames using equivalent single-degree systems", Engineering Structures, 2011

[15] H. J. JIANG, L. Z. CHEN, Q. CHEN, "Seismic Damage Assessment and Performance Levels of Reinforced Concrete Members", Procedia Engineering, 2011

[16] Mario E. Rodriguez, "Damage Index for Different Structural Systems Subjected to Recorded Earthquake Ground Motions", Earthquake Spectra, 2018

[17] Mario E. Rodriguez, "A Damage Index for the Seismic Analysis of Reinforced Concrete Members", Journal of Earthquake Engineering, 2009

[18] *Yong Zhai, Yuye Zhang, "Damage index analysis of prefabricated segmental bridge columns under cyclic loading", Latin American Journal of Solids and Structures,* 2018__

[19] Mortezaei, A. (2013). Plastic hinge length of RC columns considering soil-structure interaction. Earthquakes and Structures, 5(6), 679-702.

[20] Mortezaei, A. (2014). Plastic hinge length of RC columns under the combined effect of near-fault vertical and horizontal ground motions. Periodica Polytechnica Civil Engineering, 58(3), 243-253.

[21] Mortezaei, A., & Motaghi, A. (2016). Seismic assessment of the world's tallest pure-brick tower including soil-structure interaction. Journal of Performance of Constructed Facilities, 30(5), 04016020.