ORIGINAL RESEARCH

Structural Rehabilitation Based on the Reliability Analysis with Consideration of Concrete and Steel Frames

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Abstract:

The erosion and deterioration of buildings in Iran, driven by factors such as corrosion, fatigue, and creep, have become increasingly widespread over the past few decades, posing significant risks to urban security. Concrete and steel structures under corrosive conditions exhibit various inconsistencies during the corrosion process. As such, assessing the safety and reliability of aging structures has become a critical issue in civil infrastructure management systems. This article explores strategies for renovating and refurbishing old buildings, presenting the best improvement methods based on the reliability of aging structures. The primary aim of the article is to enhance the reliability of concrete and steel structures through a comprehensive review, enabling more effective and accurate retrofitting of older buildings. The proposed methodology involves modeling steel and concrete structures using ETABS software, making necessary modifications within the software, calculating the reliability coefficient, and presenting optimized improvement techniques. The results obtained from the modeling indicate that the reliability index of structural components in all models consistently decreased over time. Furthermore, it can be concluded that throughout this process, special steel bracing models proved to be more effective than other structural types, offering greater potential to enhance safety for people.

Key words:
Coefficient of reliability; improvement; corrosion; fatigue.

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1. Introduction:

Considering the extensive cost of renovating the structures, strengthening and restoring weak and damaged structures in order to bear more loads than the design, to improve the deficiencies caused by erosion, and to increase the resistance or the formability of the structure by using different materials and various implementation methods have been proposed on a wide level (Wang L et al., 2017) [1]. Since the mechanical and geometric properties of structural materials and members are not certain parameters, therefore, in the design of the structure, fluctuations in the attributes of the materials and loads are taken into consideration as probabilities (F.Biondini et al., 2016)[2]. On the other hand, during its useful life, the behavior of the structure undergoes changes in the loading and resistance characteristics of the structure. So, the decrease in resistance or the increase in the intensity of loading that occurs during the life of the structure will cause a decrease in the safety index of the structure. Thus, reconstruction and improvement of the structure during its life is essential for evaluating it. [3-5].

This study is aimed to provide a solution for the improvement of structures based on probabilistic methods by focusing on the reliability method. The old metal and concrete structures were both investigated by considering the changes in resistance and loading during the lifetime of them. We examined fatigue and corrosion in metal structures and creep and fatigue in concrete structures and then suggested improvement methods based on reliability to provide the desired safety index of the structure. Since the earthquakes are one of the most significant factors in destroying the structures, we tried to simulate the response of structures in comparison with the real situation and to review and present different solutions to introduce to the relevant translators for paying attention to this issue as a passive defense for financial protection and security of life in line with the progress and development of the country.

In short, the objectives of this study included: 1) reliability assessment of existing structures, 2) changes in the reliability of the structure based on the useful life of the building, 3) building improvement based on target reliability coefficient. At the end of the study, we answered the following questions: 1) what is the relationship between the influencing parameters in the passage and the behavior of the structure? 2) Does the use of different strengthening methods in structures improve the stability of the structure? 3) What is the most effective type of structure design in its dynamic response to earthquake load? In addition, the following research assumptions were also investigated: a) the behavior of concrete is modeled linearly, b) the behavior of steel is linear, c) the park model is used as the corrosion model, d) the fatigue model is used as the reduction method. Among the various design criteria such as yielding, buckling, fatigue, creep and corrosion, the phenomenon of fatigue is the most important and common cause of failure and breakage, which should be avoided by proper design [6-7]. Common methods for fatigue life prediction can be classified into life-stress, life-strain, methods of fracture mechanics and fatigue crack growth. The most direct and simplest method to determine the fatigue life is the life-load analysis method [8-10].

In their research on the strengthening of structures by surface mounting methods with resistant polymer fibers and reinforcement with external connection, Ayesha Siddika et al. (2018) [11] found that increasing in resistance in the surface installation method was more than the method of arming with external connection. E. Gudonis et al. (2014) [12] in their research on the interaction diagrams of hollow reinforced concrete columns enclosed with FRP showed that the increase of FRP layers up to a size was effective in increasing the resistance of the column, but increasing the layers to more than 5 layers was not economical. They also found that increasing the dimensions of the hole, resulted in reducing the ultimate strength of the columns. Comparison of columns with square and circle holes showed that columns with circular holes had better performance. In their research, Nihad Tareq Khshain and Al-Saadi et al. (2019) [13] compared new methods of reinforcing concrete beams (FRP with NSM method) with old methods. The results showed that increasing in resistance in the NSM method was more than the EBR method and the ruling mechanism of separation turned into failure of the beam with the surrender of FRP. In some researches, researchers investigated the strengthening of concrete structures by using FRPs with the approach of reducing energy waste. The results showed that the transverse and longitudinal FRP covering in the cut areas of the longitudinal rebars in the columns could transfer the location of bending failure to the maximum anchor point [14-15]. McCormac. J (2019) [16] examined the effect of geogrid in increasing flexibility acceptance of concrete beams without reinforcement. A. Remennikov (2016) [17] compared the strengthening of concrete structures in seismic areas with the use of steel bars and reinforced polymer bars. Reinforced concrete sample GFRP, while its energy loss was low, showed a major elastic behavior against destruction and the efficiency of this system that was favorable in terms of the relative displacement of floors. In their research on the behavior of concrete circular columns, reinforced with steel jacket, they found that avoiding the concrete section with a steel jacket by preventing the lateral strain of concrete, not only increased the capacity e.g. the column bearing capacity, it also improved the formability and strength of the column under the breaking load in a seismic interval with time duration up to 300 seconds [18-20]. Researchers found that one of the Predominantly utilized construction materials, concrete holds a specific place in today's construction industry. While concrete has consistently demonstrated excellent performance in various structures, the corrosion of steel reinforcements has considerably diminished its durability over the past 30 years, even in environments with high and moderate levels of corrosion [21-26]. Corrosion and its related costs have increasingly become a significant area of interest [27].El Meski. F (2014) [28] tested the bending and shearing behavior of geogrids that isolated by RC with steel fiber in reinforced concrete. The results indicated that the appropriate applications of geogrids with metal fiber reinforced concrete columns not only increased the behavior of structures, but also prevented their destruction. Aslani and Dehestani [29] briefly reviewed the life-cycle reliability-based optimization, with a focus on both civil and aerospace buildings. Moradi et all's proposed stochastic process [30] was employed to analyze the influence of spatial variation on the structural vulnerability due to pitting corrosion and the bending reliability of reinforced concrete (RC) beams. The chance of a structural collapse was calculated by Santos AF, Santiago A, Latour M, Rizzano G [31] by using the improved corrosion model published by Goodarzi M.J et al. [32] that suggested for RC structures subject to diffusion attacks from aggressive external agents. Ghasemi and Nowak (2006) [33] investigated the use of reinforcing fiber pre-tensioned bars installed near the surface with a rectangular section. By applying pre-stressing force with the amount of 21% to 81% of the ultimate strength of composite rods, they concluded that this method has a very good effect on increasing of the leaving load and the delivery load of the samples. In this study, researchers looked at the effects of different types of concrete (light concrete and regular concrete), the type of rebar (steel or glass made from polymer reinforcing fibers), and the type of adhesive over 10 beam samples were examined. The results showed that, in general, the reinforcement of beams by the surface-mounted method using glass reinforcements made from these fibers reduced the change in the final shape and increased the bending stiffness and bending capacity of the beams [34-37].

2. Materials and Methods:

This study aimed to investigate the improvement of structures based on probabilistic methods by focusing on the reliability method in the reinforced concrete buildings, steel buildings with bracing system, and steel buildings covered with braced frames. To do so, the analysis and design of buildings were based on the 2800 standard of earthquake and topics 3 and 10 of the national building regulations. We employed ETABS software (2017 version) to analyze and design the structures, as it analyzes and designs the members linearly based on the methods of analytical instruments. We studied modeling, analyzing, and designing special bending frames in three buildings with 6, 12, and 16 floors which heighted 19.2, 38.4, and 51.2, respectively. The height of each floor in all models was 3.2 meters. The length of the buildings was equal to 24 meters and width equal to 14 meters. For the sake of simplicity, all openings were considered 4 meters long. Every model incorporated 5 longitudinal openings and 3 transverse openings. Figure 1 shows the plan of all the models. The geometric models of each structure are also shown in figures 2 to 4.

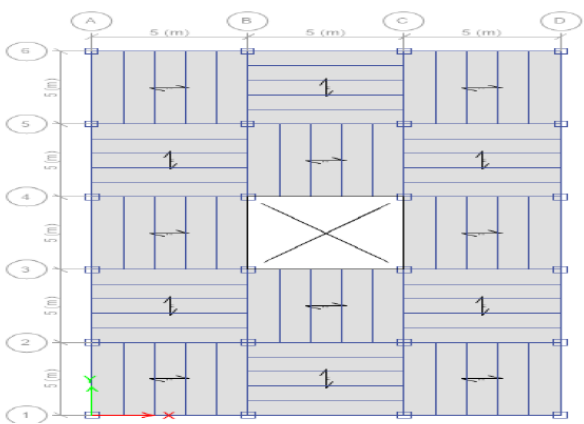

Figure 1: Floor plans for all selected models

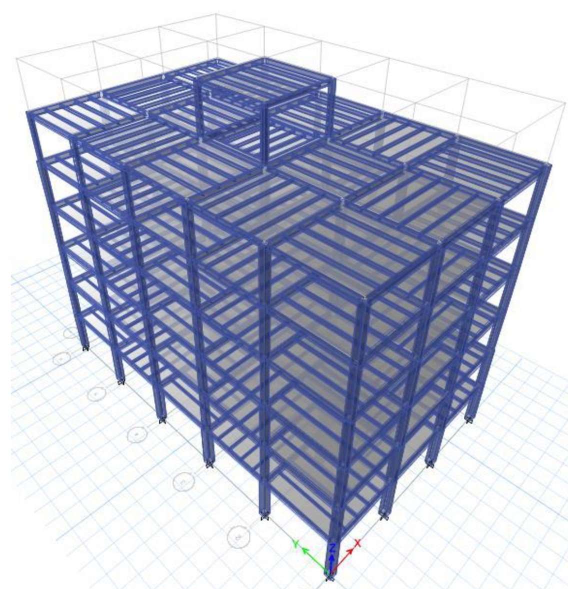

Figure 2: Geometric model for the 6-story structure

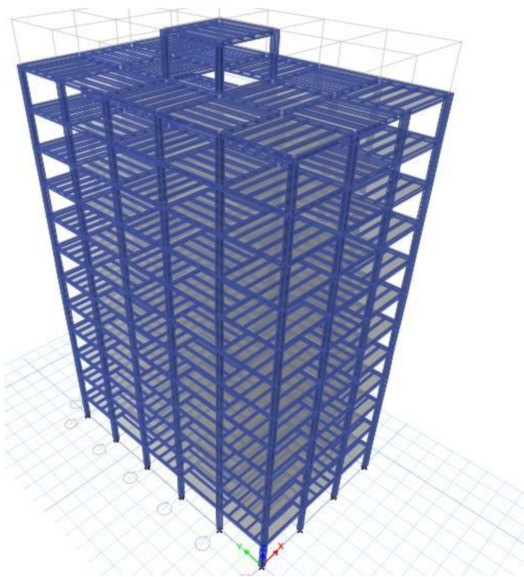

Figure 3: Geometric model for the 12-story structure

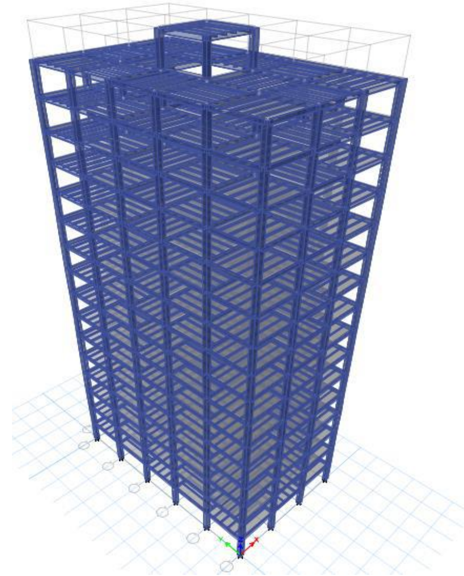

Figure 4: Geometric model for the 16-story structure

In this study, we used the topic 6 of the National Building Regulations, published in 2012, and the earthquake standard of 2800, third edition, to calculate the loads on the building. We also applied the topic 10 of the National Building Regulations and ASCE 360-05 regulations to design the frames. CSI ETABS 2017 software was used to analyze and design the structures. Since composite roof system is one of the vertical load-bearing systems in structures, we employed composite roof with the specifications of Figure 5 for the models. The surface unit weight for the surface concrete, shown in the software as Super Dead load, was equal to 230 $kg/cm2$ for ceiling and 250 $kg/cm2$ for floors. The thickness of the floor used in the ceiling was equal to 10 cm.

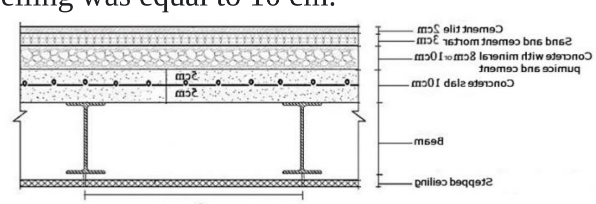

Figure 5: Details of the composite roof used in the models

The first chapter of the 10th topic of the National Building Regulations emphasizes the conventional requirements of steel as a construction material. These steels should have the ultimate tensile strength 1.2 times the yield strength. It means:

$Fu>1.2Fy$

In this study, the specifications of the steel used were as follows:

Fy = 2400 kg/cm2
Fu = 3700 kg/cm2
Es = 2.1×106 kg/cm2
υs = 0.3
γs = 7850 kg/cm3

The effective mass on the seismic behavior of the structure has been obtained from one hundred contribution of dead load and weight of the building members plus 20% participation of the live load of the building, considering the application of the building. Furthermore, the effective mass contribution coefficient of earthquakes was used to take different ratios of live load to dead load into consideration. The loading combinations for the design of this structure were in accordance with the 10th topic of the National Building Regulations. We used the load combination of LRFD method. The combination of gravity and lateral loads used, according to the tenth topic, was as follows:

$1.4\,D$
$1.25\,D + 1.5\,L$
$D + 1.2\,L \pm 1.2\,E\,X$
$D + 1.2\,L \pm 1.2\,E\,Y$
$0.85D \pm EX$
$0.85D \pm EY$

Also, the combination of intensified loads, according to the seismic requirements section of the 10th topic, was as follows:

$0.85D + 1.2\Omega 0E$
$D + 1.2L + 1.2\Omega 0E$

In these relationships, Ω0 is the additional coefficient and equals to 3 for steel bending frames. According to the definition of standard 2800 and the tenth topic of the National Building Regulations, it is necessary to consider second-order effects in the analysis and design of all structures. So, D+L load combination was used in the second order analysis. We also used the method of direct analysis to consider the second-order effects in designing the steel buildings. In this new method, a hypothetical lateral load can be applied to the floors of the building to consider the primary geometric defects, instead of considering primary geometric defects in modeling. In this study, we employed the National loads type equal to 0.002 gravity load with coefficient in each floor, imported only in the combination of gravity loads. More stringent completion requirements were considered for the design of members and connections of braced frames than the moderate bending frames. In other words, in the design of special bending frames, according to topic 10 of the National Regulations, the selected section should also meet the intensive seismic conditions in addition to the compactness of the section. We used the compact seismic type which, in relation to the lateral restraint of seismic and load-bearing side beams in medium and special bending frames, it had to meet the following requirements: a) All lateral seismic load-bearing beams had to have sufficient lateral bracing at Lb distance, so that they prevented any lateral buckling, twisting, and side-twisting during the meta-elastic shape change. The lateral restraint of the beams should be installed in such a way that at the place of their connection to the beam, the lateral location of both wings would not change or the twisting of the entire section was effectively prevented, b) It was necessary to install the lateral restraint at the place of external concentrated loads along the length of the beam and at the place of beam cross-section change, (c) Lateral restraints of seismic lateral load-bearing beams should be designed according to the following relationship for a force at least equal to P_{bu}:

$P_{bu} = 0.06\,R_y\,F_y\,Z_b/h_o$
Z_b = base of the plastic section of the beam section
H_o = distance from the center to the beam wings

(d) The maximum value of L_b for seismic lateral load-bearing beams in systems with many shapes was equal to $0.86\,r_y\,E/F_y$, where r_y the radius of gyration of the beam section was weak around the axis. Table 1 presented the regulations, assumptions, and gravity and lateral loads in the models 6, 12, and 16 floors of special braced frame.

<table>
<tr><td rowspan="6">The regulations used</td><td>Gravity loading</td><td colspan="6">The sixth topic of the national regulations</td></tr>
<tr><td>Side loading</td><td colspan="6">The earthquake regulations 2800- the third edition</td></tr>
<tr><td>Designing</td><td colspan="6">The 10th topic of the national building regulations, AISC 360-05</td></tr>
<tr><td>Location of the project</td><td colspan="6">Very high risk of earthquake</td></tr>
<tr><td>Application</td><td colspan="6">Residential</td></tr>
<tr><td>Soil type</td><td colspan="6">Type III</td></tr>
<tr><td rowspan="7">Basic assumptions</td><td>Number of floors</td><td colspan="6">6, 12, and 16</td></tr>
<tr><td>Structural system</td><td colspan="6">Special braced steel</td></tr>
<tr><td>Materials specifications</td><td colspan="6">ρ=7850 kg/m2 ,E=2.1×106 kg/cm2,fy=2400kg/cm2</td></tr>
<tr><td>Roof type</td><td colspan="6">Composite</td></tr>
<tr><td>Loading</td><td>Amount</td><td colspan="5">Unit</td></tr>
<tr><td>Roof dead load</td><td>550</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td>Roof live load</td><td>200</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td rowspan="4">Gravity loading</td><td>Floors deal load</td><td>500</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td>Floors live load</td><td>500</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td>Overhead equivalent to partitioning</td><td>200</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td>Side walls load</td><td>275</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td rowspan="4">Calculations related to linear static analysis</td><td></td><td>Periodicity (T)</td><td>Reflection coefficient (B)</td><td>Importance coefficient (I)</td><td>Behavior coeffient (R)</td><td>Acceleration based on design (A)</td><td>Earthquake coefficient (C)</td></tr>
<tr><td>6-story</td><td>0.92</td><td>2.3</td><td>1</td><td>7.5</td><td>0.35</td><td>0.1071</td></tr>
<tr><td>12-story</td><td>1.54</td><td>1.62</td><td>1</td><td>7.5</td><td>0.35</td><td>0.0758</td></tr>
<tr><td>16-story</td><td>1.91</td><td>1.41</td><td>1</td><td>7.5</td><td>0.35</td><td>0.0656</td></tr>
</table>

Table 1: Specifications of the selected models in the special braced system

2.1 Analysis and design of steel bracing models:

Braced frames are generally divided into two types: convergent and divergent. In this study, we used convergent X bracing frame for special bracing models including three models for 6, 12, and 16 floors. Table 2 shows the selected models. Figures 6 to 8 manifested the geometric models of buildings with 6, 12, and 16 floors.

Table 2 presented the regulations, assumptions, and gravity and lateral loads in the models 6, 12, and 16 floors of special braced frame.

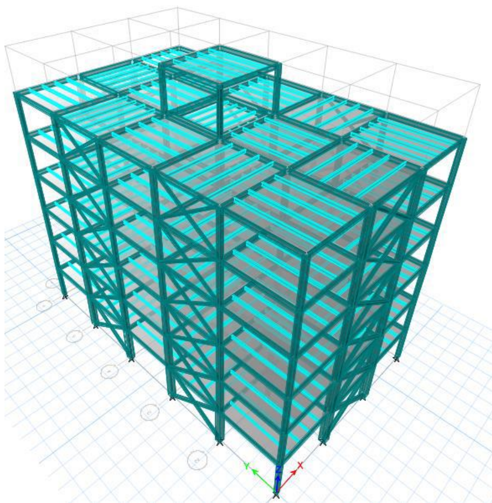

Figure 6: Geometric model of the 6-story structure with special convergent bracing

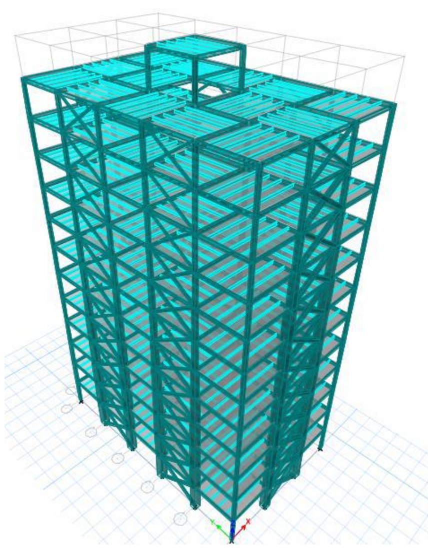

Figure 7: Geometric model of the 12-story structure with special convergent bracing

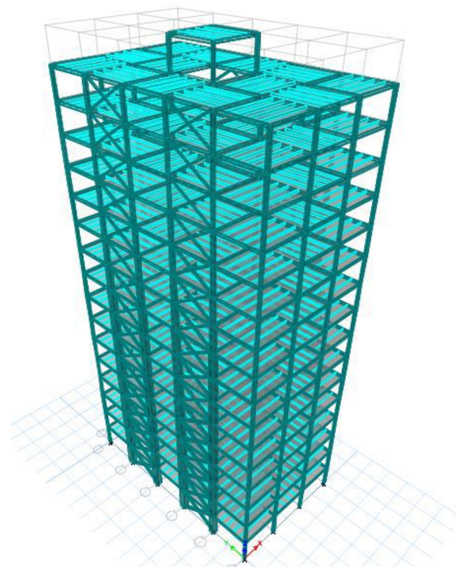

Figure 8: Geometric model of the 16-story structure with special convergent bracing

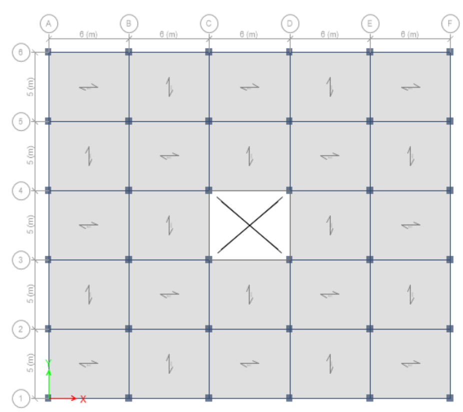

Figure 9: Floor plans for all selected models

The regulations used	**Gravity loading**	**The sixth topic of the national regulations**					
	Side loading	The earthquake regulations 2800- the third edition					
	Designing	The 10th topic of the national building regulations, AISC 360-05					
	Location of the project	Very high risk of earthquake					
	Application	Residential					
	Soil type	Type III					
Basic assumptions	Number of floors	6, 12, and 16					
	Structural system	Special convergent braced frame					
	Materials specifications	ρ=7850 kg/m^2, E=2.1×10^6 kg/cm^2, fy=2400kg/cm^2					
	Roof type	Composite					
	Loading	**Amount**	**Unit**				
	Roof dead load	550	Kg/ m^2				
	Roof live load	200	Kg/ m^2				
Gravity loading	Floors deal load	500	Kg/ m^2				
	Floors live load	500	Kg/ m^2				
	Overhead equivalent to partitioning	200	Kg/ m^2				
	Side walls load	275	Kg/ m^2				
Calculations related to linear static analysis		**Periodicity (T)**	**Reflection coefficient (B)**	**Importance coefficient (I)**	**Behavior coeffient (R)**	**Acceleration based on design (A)**	**Earthquake coefficient (C)**
	6-story	0.57	2.5	1	5.5	0.35	0.159
	12-story	0.96	2.22	1	5.5	0.35	0.141
	16-story	1.20	1.20	1	5.5	0.35	0.122

Table 2: specifications of the selected models in the special braced frame system

2.2 Analysis and design of braced models for reinforced concrete:

In this study, the selected models included 4, 8, and 12 floors heighted 14.1, 26.9, and 39.7, respectively. The height of each floor in all models was equal to 3.2 meters and the height of the ground floor was 4.5 meters. The length of the buildings was 30 meters and its width 25 meters. All models included 5 openings of 6 meters in the longitudinal direction and 5 openings of 5 meter in the transverse direction. Figure 9 showed the plans of all models. Figures 10 to 12 outlined the geometry of each structure.

We employed topic 6 of the National Building Regulations, the edition 1392, and the earthquake standard of 2800, the third edition, to calculate the loads on the building. Furthermore, the topic 3 of the National Building Regulations and ACI 318-08 regulations were used to design the frames. We also used CSI ETABS 2015 software to analyze and design the structures. The block beam roof system is one of the common vertical load bearing systems in structures. In this study, we used this type of roof in the selected model. The equivalent static analysis method was employed to analyze and design the models. The effective mass on the seismic behavior of the structure was obtained from the 100% participation of the dead load and the members' weight of the building plus the 20% participation of the live load considering the use of the building. Table 3 shows the specifications of the final models and the summary of the analysis and design process.

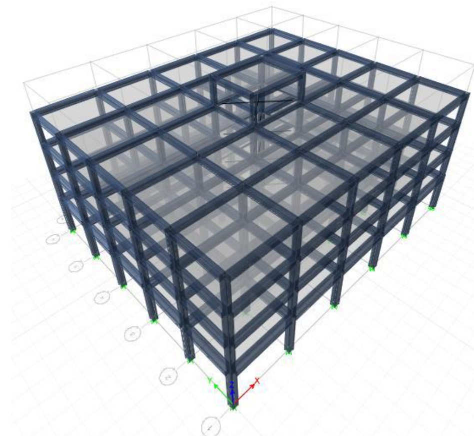

Figure 10: Geometric model of the 4-story structure

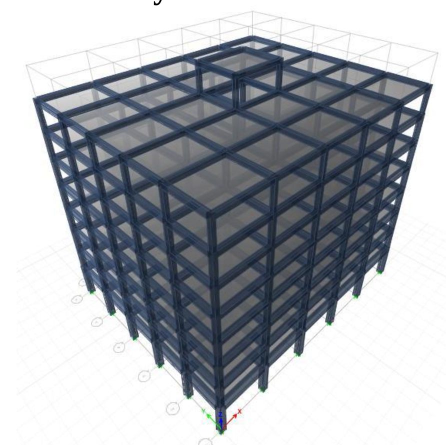

Figure 11: Geometric model of the 8-story structure

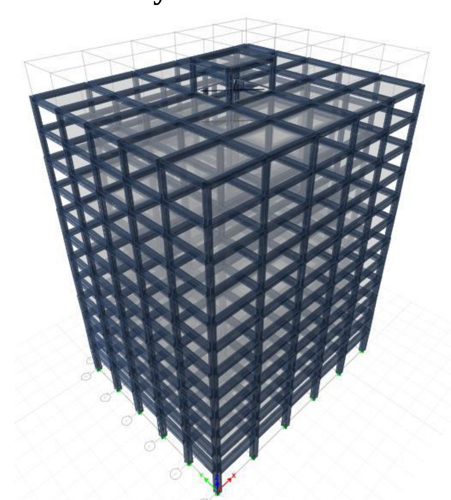

Figure 12: Geometric model of the 12-story structure

<table>
<tr><td rowspan="6">The regulations used</td><td>Gravity loading</td><td colspan="6">The sixth topic of the national regulations</td></tr>
<tr><td>Side loading</td><td colspan="6">The earthquake regulations 2800- the third edition</td></tr>
<tr><td>Designing</td><td colspan="6">The 9th topic of the national building regulations, ACI318-08</td></tr>
<tr><td>Location of the project</td><td colspan="6">Very high risk of earthquake</td></tr>
<tr><td>Application</td><td colspan="6">Residential</td></tr>
<tr><td>Soil type</td><td colspan="6">Type II</td></tr>
<tr><td rowspan="7">Basic assumptions</td><td>Number of floors</td><td colspan="6">4, 8, and 12</td></tr>
<tr><td>Structural system</td><td colspan="6">Special braced concrete</td></tr>
<tr><td>Materials specifications</td><td colspan="6">ρ=7850 kg/m2 ,E=2.1×106 kg/cm2,fy=2400kg/cm2</td></tr>
<tr><td>Roof type</td><td colspan="6">Block joist</td></tr>
<tr><td>Loading</td><td>Amount</td><td colspan="5">Unit</td></tr>
<tr><td>Roof dead load</td><td>550</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td>Roof live load</td><td>200</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td rowspan="4">Gravity loading</td><td>Floors deal load</td><td>500</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td>Floors live load</td><td>500</td><td colspan="5">Kg/ m^2</td></tr>
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<tr><td>Side walls load</td><td>275</td><td colspan="5">Kg/ m^2</td></tr>
<tr><td rowspan="4">Calculations related to linear static analysis</td><td></td><td>Periodicity (T)</td><td>Reflection coefficient (B)</td><td>Importance coefficient (I)</td><td>Behavior coeffient (R)</td><td>Acceleration based on design (A)</td><td>Earthquake coefficient (C)</td></tr>
<tr><td>4-story</td><td>0.45</td><td>2.75</td><td>1</td><td>7</td><td>0.35</td><td>0.1375</td></tr>
<tr><td>8-story</td><td>0.75</td><td>2.10</td><td>1</td><td>7</td><td>0.35</td><td>0.1050</td></tr>
<tr><td>12-story</td><td>0.99</td><td>1.74</td><td>1</td><td>7</td><td>0.35</td><td>0.0870</td></tr>
</table>

Table 3: specifications of the selected models in the reinforced concrete system

We calculated the resistance of beams using the following equation:

$R(t)=FyZ(t)$

In this equation, R (t) is the section strength over time and Z (t) is the plastic modulus of the section over time and Fy is yield strength. Park's model was also used to calculate the effects of steel corrosion over time. Figure 13 shows the corrosion diagrams of the model.

3. Results of special steel bracing models:

Considering the reliability index of the steel braced models, the results showed that with the increase in the life of the structure, the reliability of the components of the structure decreased. The reliability index in the beams of the steel braced models in the 6-story structure decreased 27% and 47% and changed from 4.5 to 3.26 and 2.53 after 25 and 50 years, respectively. In the 12-story structure, the reliability index lessened to 18% and 54% and reduced from 5.36 to 4.36 and 2.46 after 25 and 50 years, respectively. In the 16-story structure, the index dropped 17% and 28% and dropped from 5.5 to 4.52 and 3.95 after 25 and 50 years, respectively. In addition, in the columns of the steel braced models in the 6-story structure, the reliability index decreased to 25% and 41 % and changed from 4.58 to 3.39 and 2.68 after 20 and 50 years, respectively. These amounts were 31% and 51% for the 12-story structure and reached 2.84 and 2.02. The columns' reliability index in the 16-story structure reduced to 3.58 and 2.88, about 31% and 51%, respectively. In addition, the modeling results showed that the reliability index in the columns of the steel braced models of a 6-story structure fell down from 4.58 to 3.39 and 2.68, i.e. 25% and 41% after 25 and 50 years, respectively. These amounts were 31% and 51% in a 12-story structure and reduced from 4.17 to 2.84 and 2.02 after 25 and 50 years, respectively. Finally, in the 16-story structure, the reliability index of the columns decreased from 4.71 to 3.58 and 2.88, i.e. 31% and 51% after 25 and 50 years, respectively. Figures 14 to 22 show the diagrams of β - η of the beams and columns under the effect of critical composite load for steel models with bending frame system in the structures with 6, 12, and 16 floors. Only the 1.2D+E+L load combination acts on the beams of the structure and is said to be critical. Seismic loads also act in the x and y directions.

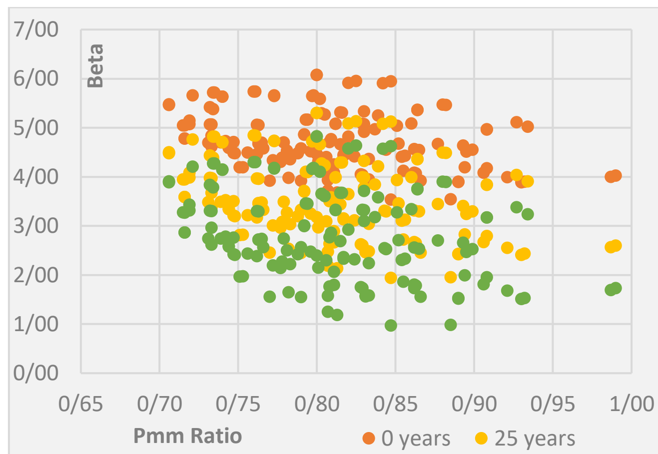

Figure 14: the 6-story steel model beams withbending frame system (critical load combination 1.2D+E+L)

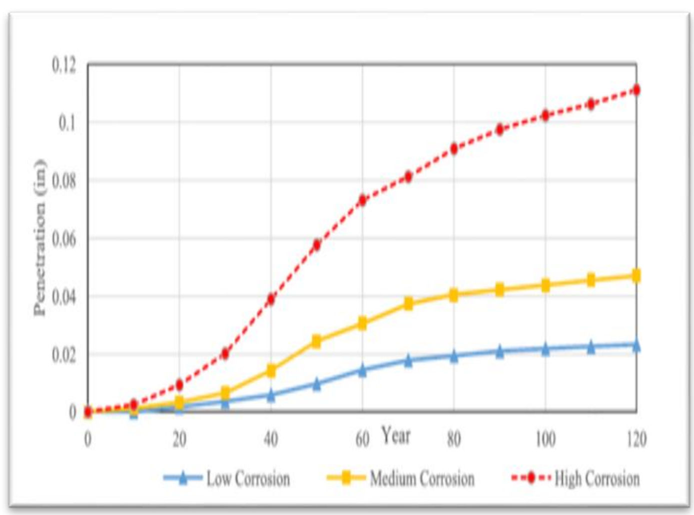

Figure 13: Corrosion model based on Park model

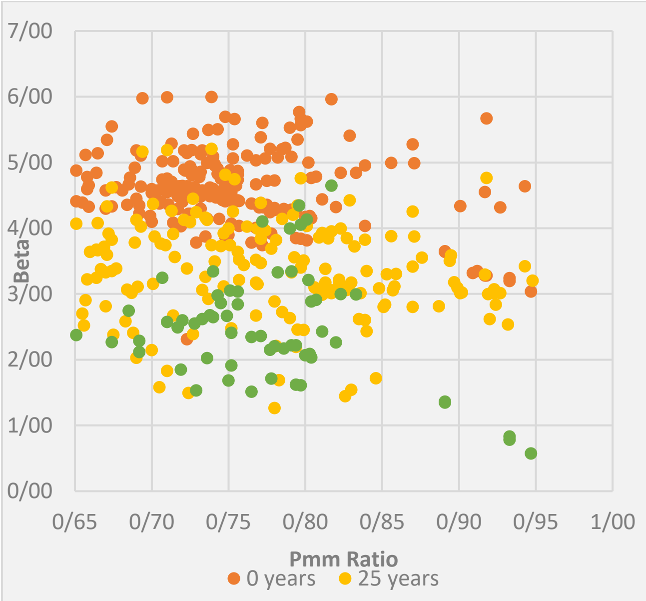

Figure 15: the 12-story steel model beams with bending frame system (critical load combination 1.2D+1.6L)

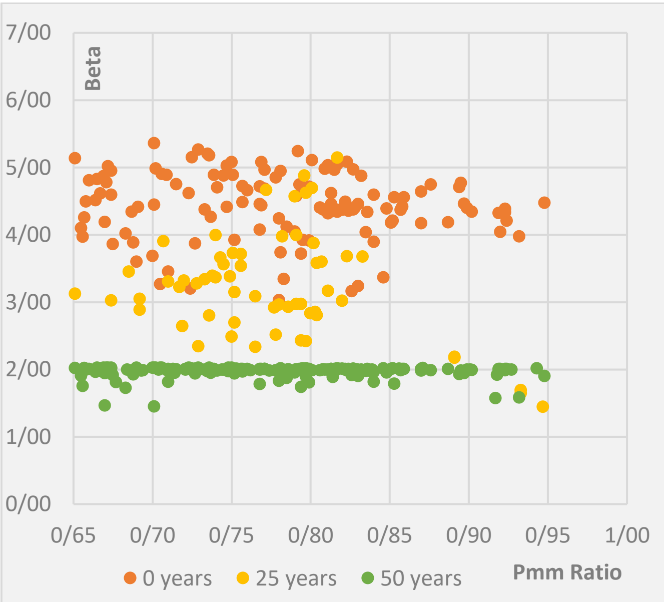

Figure 16: the 12-story steel model beams with bending frame system (critical load combination 1.2D+L+E)

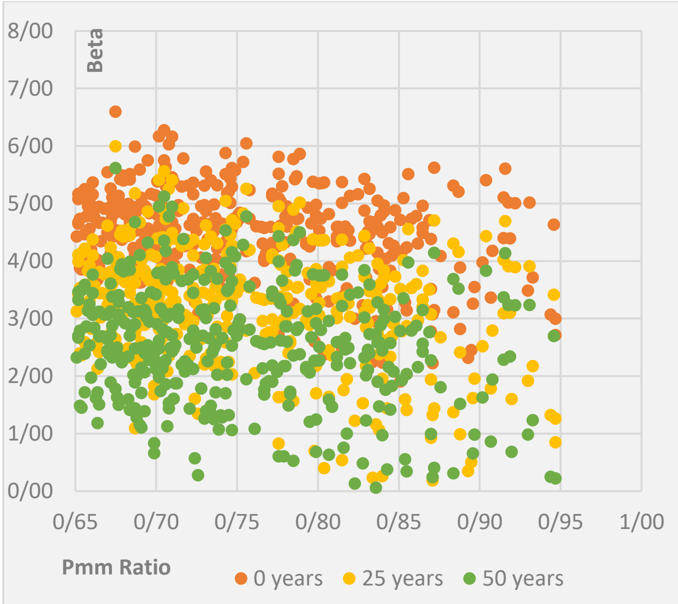

Figure 17: The 16-story model beams with bending frame system (critical load combination1.2D+L+E)

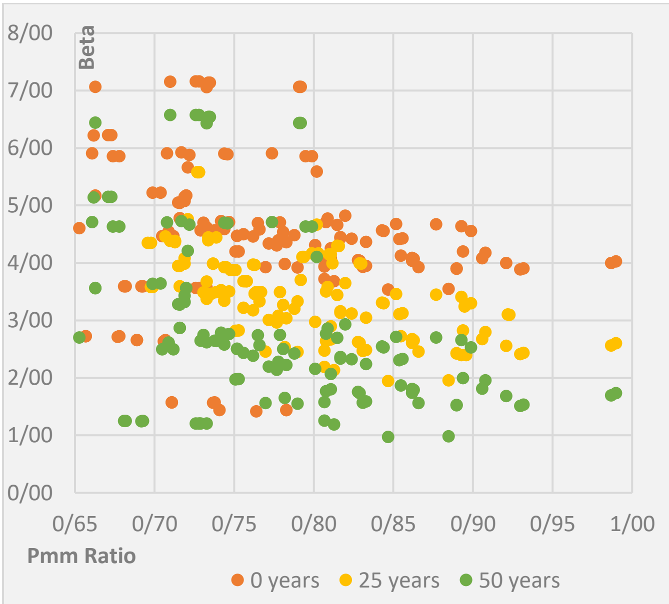

Figure 18: the 6-story steel model columns with bending frame system (critical load combination 1.2D+E+L)

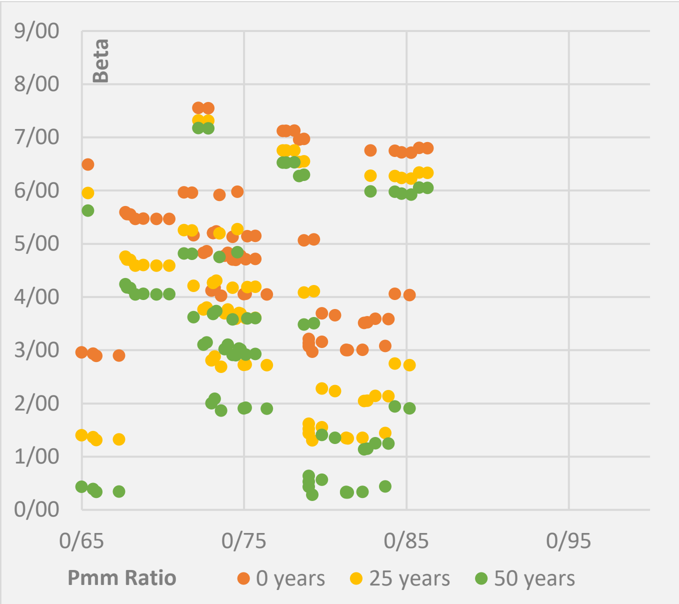

Figure 19: the 12-story steel model columns with bending frame system (critical load combination 1.2D+1.6L)

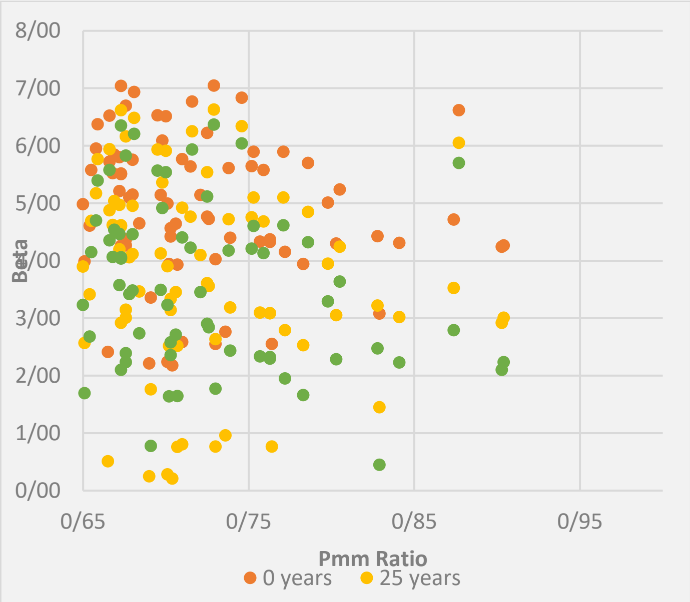

Figure 20: the 12-story steel model columns with bending frame system (critical load combination 1.2D+E+L)

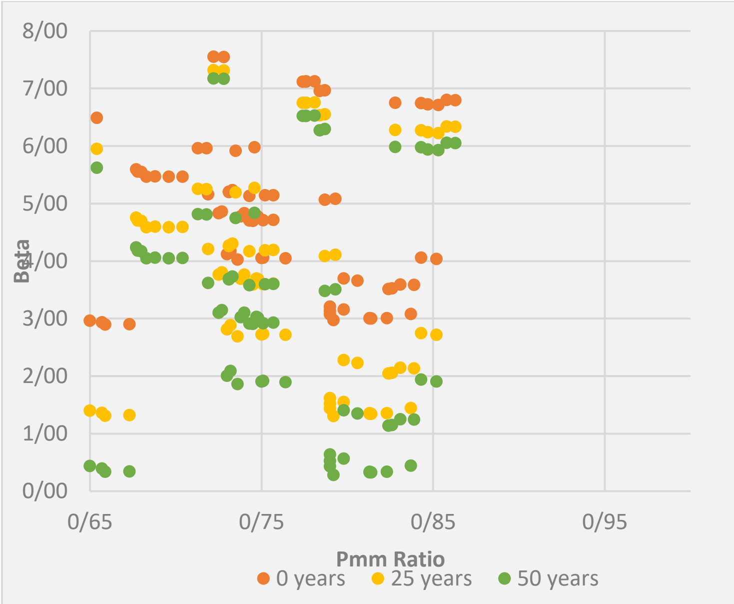

Figure 21: the 16-story steel model columns with bending frame system (critical load combination 1.2D+1.6L)

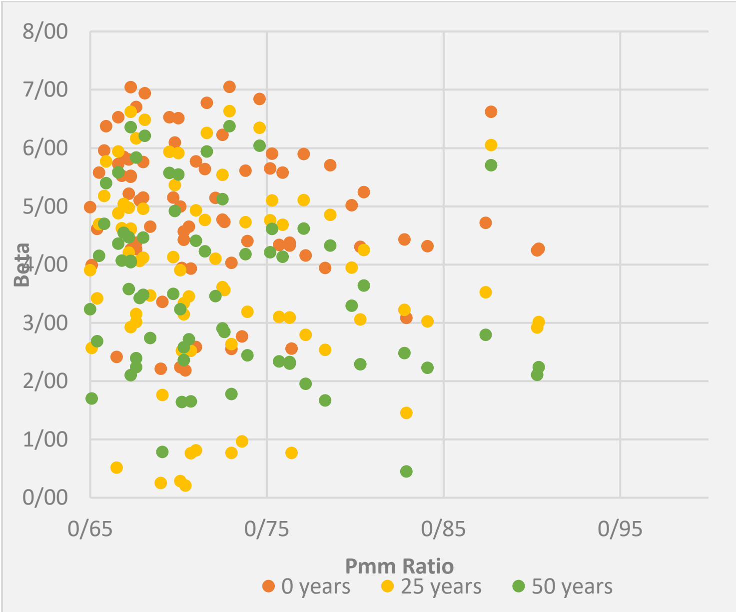

Figure 22: the 16-story steel model columns with bending frame system (critical load combination 1.2D+E+L)

3.1 Results of the braced steel frame models:

The results of the reliability index in the braced steel frame models showed that the more the structure life, the less the reliability index of the structural components. In the 6-story structure, the reliability index decreased from 4.61 to 3.39 and 2.03, i.e. 26% and 55%, after 25 and 50 years, respectively. These amounts were 29% and 46% in the 12-story structure and the reliability index reduced from 4.41 to 3.13 and 2.36 after 25 and 50 years, respectively. Finally, the reductions of the reliability index in the 12-story structure were 33% and 35%, reduced from 4.17 to 2.78 and 2.70 after 25 and 50 years, respectively. In addition, the results of the modelling proved that the reliability index of the columns in the braced steel frame models in the 6-story structure decreased from 4.72 to 3.84 and 3.63 about 18% and 23% after 25 and 50 years, respectively. In the 12-story structure, it reduced from 4.79 to 3.71 and 2.99, i.e. 22% and 37% after 25 and 50 years, respectively. Finally, the reliability index of the 18-story structure dropped from 4.71 to 3.58 and 2.88 about 31% and 51% after 25 and 50 years, respectively. Figures 23 to 28 show the diagrams of β - η of the beams and columns under the effect of critical composite load for steel models with bending frame system in the structures with 6, 12, and 16 floors.

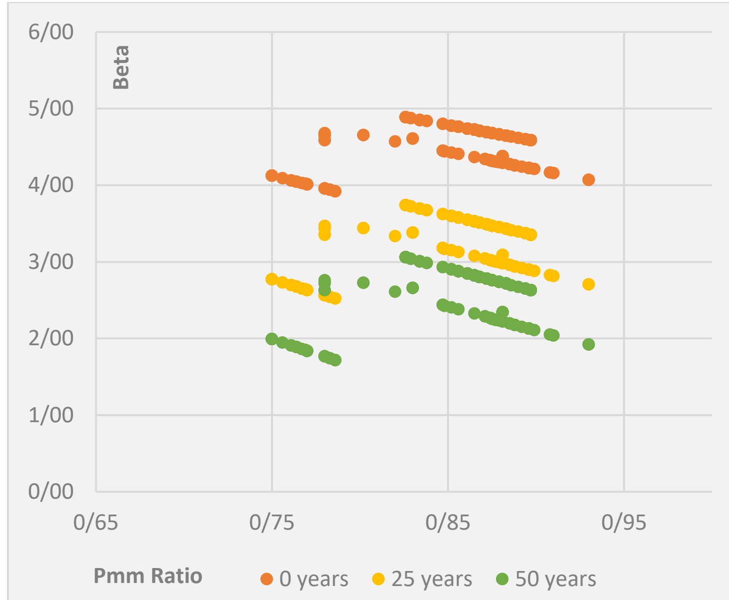

Figure 23: The 6-story steel model beams with braced system (critical load combination1.2D+1.6L)

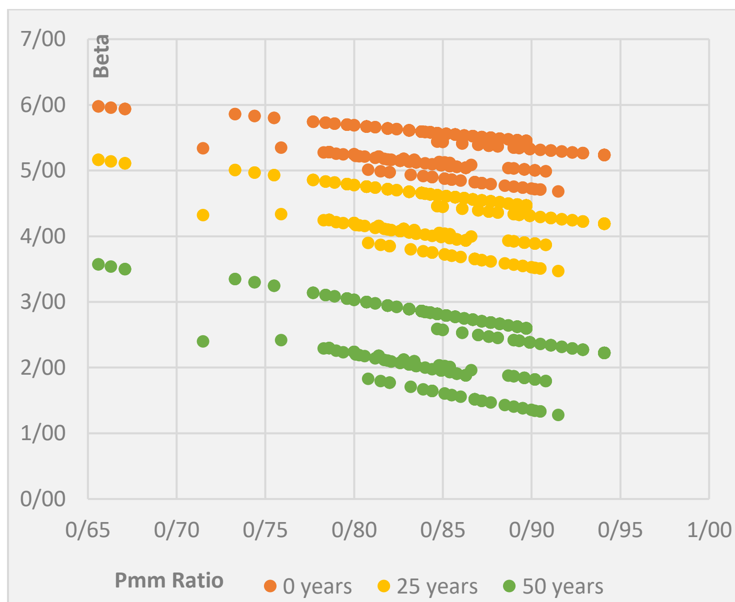

Figure 24: The 12-story steel model beams with braced system (critical load combination1.2D+1.6L)

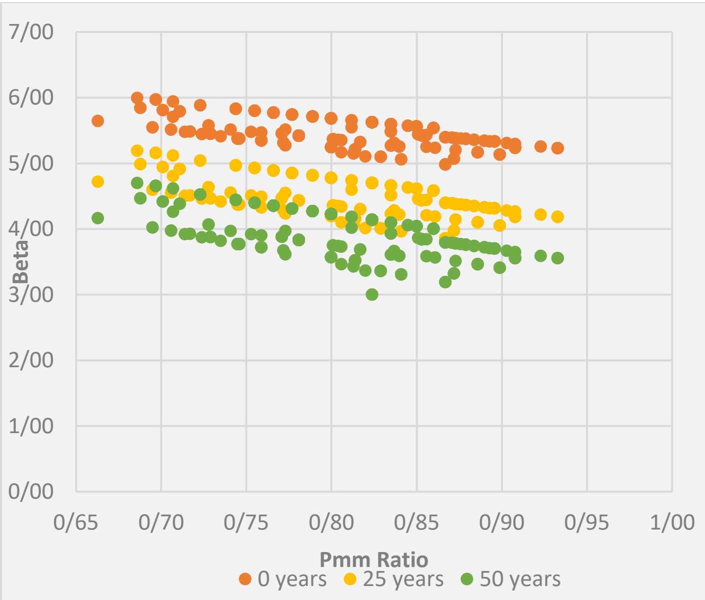

Figure 25: The 16-story steel model beams with braced system (critical load combination1.2D+1.6L)

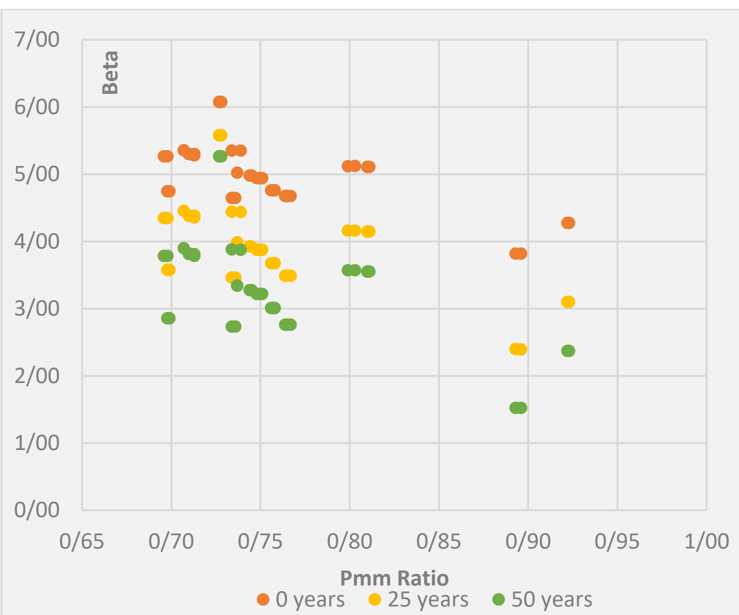

Figure 26: The 6-story steel model columns with braced system (critical load combination1.2D+1.6L)

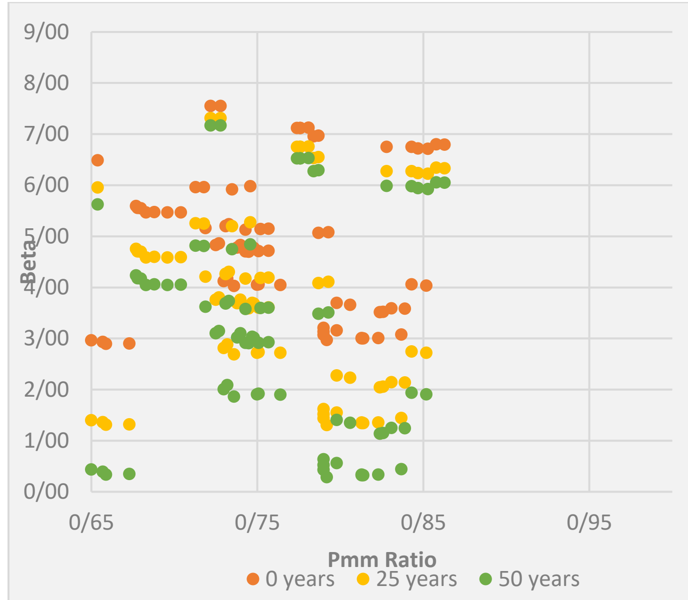

Figure 27: The 12-story steel model columns with bracing system (critical load combination1.2D+L+E)

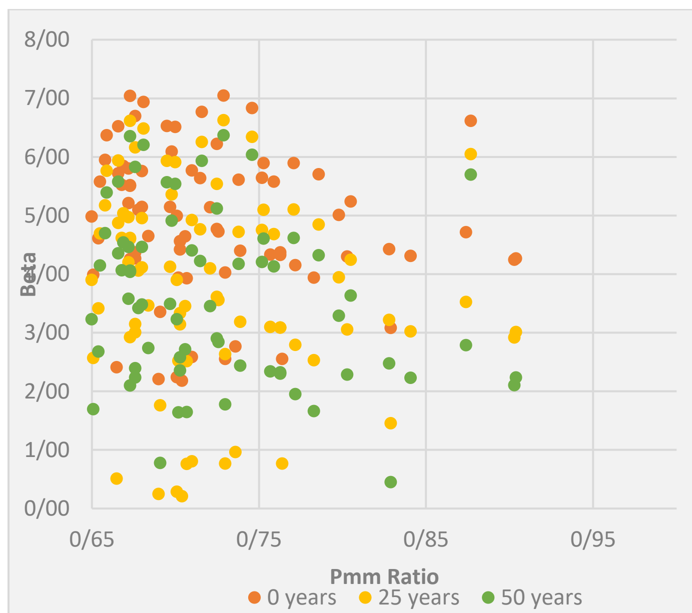

Figure 28: The 16-story steel model columns with bracing system (critical load combination1.2D+L+E)

3.2 Results of reinforced concrete bending frame models:

Regarding the reinforced concrete bending frame models, the results showed that the increase in the life of the structure decreased the reliability index of the components of the structure. In the 4-story structure, the reliability decreased 27% and 47% and reached from 4.5 to 3.26 and 2.53 after 25 and 50 years, respectively. These amounts were 18% and 54% in the 8-story structure which changed from 5.36 to 4.36 and 2.46 after 25 and 50 years, respectively. Finally, the reliability index of the columns in the 12-story structure reduced from 5.5 to 4.52 and 3.95, i.e. 17% and 28% after 25 and 50, respectively. Figures 29 to 31 show the β - η diagrams of the columns under the effect of critical composite load in the reinforced concrete bending frame models in the structures with 4, 8 and 12 floors.

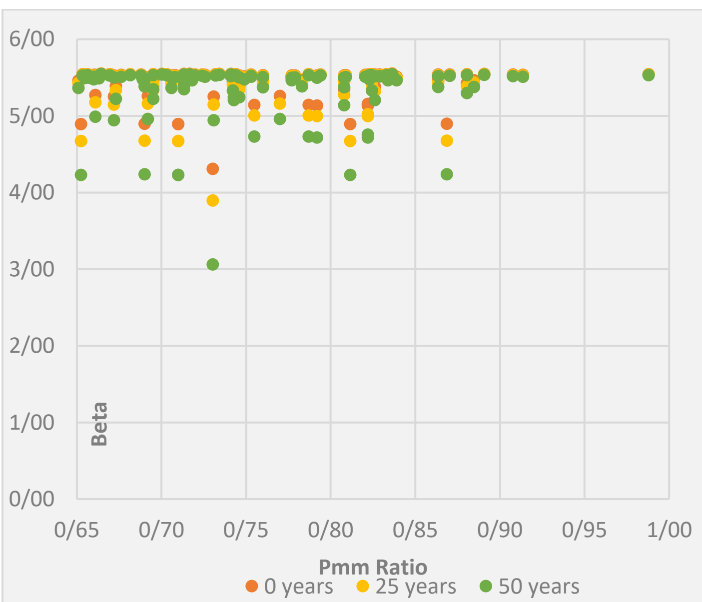

Figure 29: The 4-story concrete model columns with bending frame system (critical load combination)

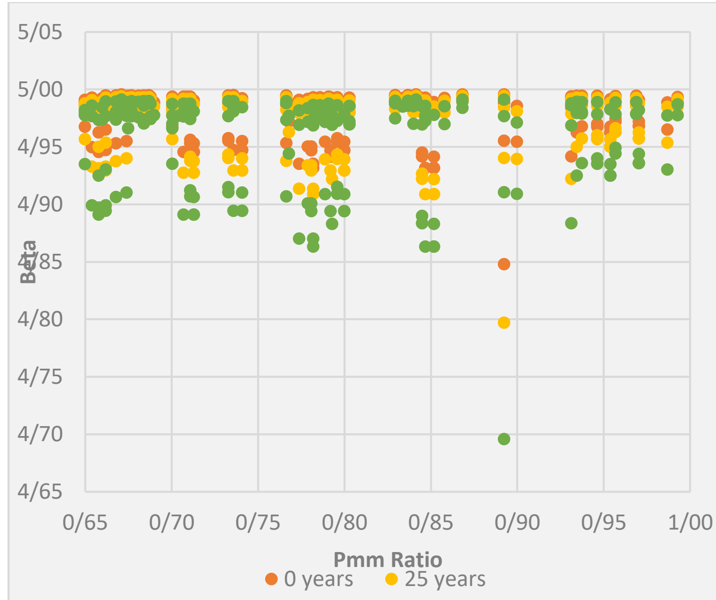

Figure 30: The 8-story concrete model columns with bending frame system (critical load combination)

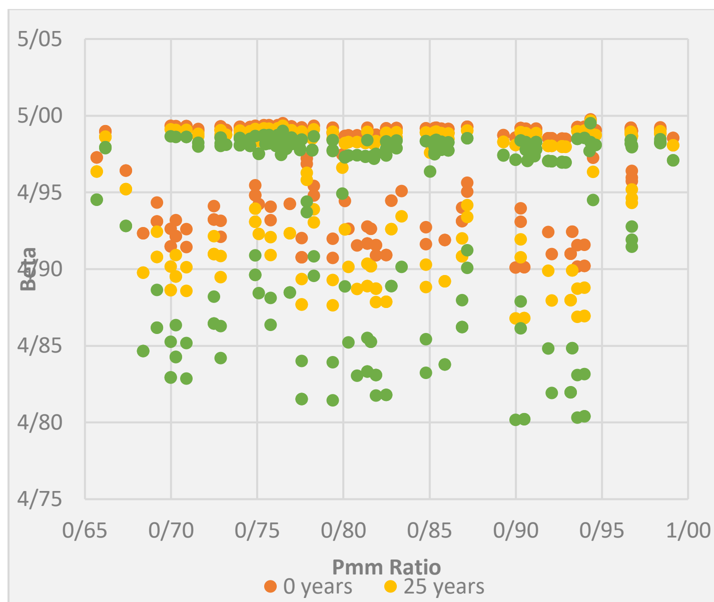

Figure 31: The 12-story concrete model columns with bending frame system (critical load combination)

4. Conclusion:

In this paper, considering the results of the modelling, we concluded that the reliability index of the structures 'components in all models decreased through time. Furthermore, as the number of the floors increased, the reliability index increased, too. In the 6-story structure, the bending frame models had higher reliability index than the steel brace frame models, but in the structures with 12 and 16 floors, it was vice versa. Table 4 shows the reliability index in different models. It can be argued that concrete structures, when designed with reliability factors in mind, are more efficient and adaptable to rehabilitation processes compared to steel buildings. Moreover, in certain steel bracing models, the beams of 16-storey structures require more frequent adjustments than the columns over time. In contrast, for steel-braced frame buildings, it may be more practical to regularly address both beams and columns as time passes. For reinforced concrete bending buildings, it is observed that they can bear all loads for up to 25 years; however, after 50 years, they typically require strengthening.

		0 year	25 year	50 year
Concrete	C4	4.9	4.08	3.58
	C8	4.97	4.37	3.99
	C12	4.97	4.26	3.74
Steel beam	6SCBF	4.5	3.26	2.53
	6SMF	4.61	3.39	2.03
	12SCBF	5.36	4.36	2.46
	12SMF	4.41	3.13	2.36
	16SCBF	5.5	4.52	3.95
	16SMF	4.17	2.78	2.7
Steel column		0 year	25 year	50 year
	6SCBF	4.58	3.39	2.68
	6SMF	4.72	3.84	3.63
	12SCBF	4.17	2.84	2.02
	12SMF	4.79	3.71	2.99
	16SCBF	4.16	2.84	2.02
	16SMF	4.71	3.58	2.88

Table 4: The reliability index for different models

According to the results of this research, the following items can be useful for future studies: 1. To model structures with different geometrical specifications, 2. To use nonlinear dynamic analysis through different analysis records, 3. To investigate the methods of strengthening and increasing the reliability in structures with low reliability.

References:

[1] Wang L, Su RKL, Cheng B, Li LZ, Wan L, Shan ZW. (2017). Seismic behavior of preloaded rectangular RC columns strengthened with precambered steel plates under high axial load ratios. Eng Struct.

[2] F. Biondini, D.M. Frangopol, (2016). Life-cycle performance of deteriorating structural systems under uncertainty, J. Struct. Eng. 142 (9) F4016001.

[3] Parghi A, Alam MS. (2017). Seismic collapse assessment of non-seismically designed circular RC bridge piers retrofitted with FRP composites. Compos Struct.

[4] K.A.T. Vu, M.G. Stewart. (2000). Structural reliability of concrete bridges including improved chloride-induced corrosion models, Struct. Saf. 22 (4) 313–333.

[5] Gholampour A, Hassanli R, Mills JE, Vincent T, Kunieda M. (2019). Experimental investigation of the performance of concrete columns strengthened with fiber reinforced concrete jacket. Constr Build Mater.

[6] Ziyuan Fan, Yongming Sun. (2019). Detecting and evaluation of fatigue damage in concrete with industrial computed tomography technology, Construction and Building Materials
Volume 223, 30 October 2019, Pages 794-805

[7] Qiuyu Zhang, Licheng Wang. (2021). Investigation of stress level on fatigue performance of plain concrete based on energy dissipation method, Construction and Building Materials
Volume 269,121287.

[8] Ruofan Gao, Jie Li & Alfredo H.-S. Ang (2019). Stochastic analysis of fatigue of concrete bridges, Structure and Infrastructure Engineer.

[9] Junzu Sun a, Zhiheng Ding a, Qiao Huang. (2019). Corrosion fatigue life prediction for steel bar in concrete based on fatigue crack propagation and equivalent initial flaw size, Construction and Building Materials 195208–217

[10] Ghasemi, S.H., Nowak, A.S., (2016). Statistical parameters of in-a-lane multiple truck presence and a new procedure to analyze the lifetime of bridges, Structural Engineering International. Vol. 26, No. 2, pp.150–159

[11] Ayesha Siddika, Md. Abdullah Al Mamun, Rayed Alyousef, Y.H. Mugahed Amran. (2019). Strengthening of reinforced concrete beams by using fiber-reinforced polymer composites: A review, Journal of Building Engineering Volume 25, 100798.

[12] E. Gudonis, E. Timinskas, V. Gribniak, G. Kaklauskas, A.K. Arnautov, V. (2014). Tamulėnas, Frp reinforcement for concrete structures: state-of-the-art review of application and design, Eng. Struct. Technol. 5 147–158.

[13] Nihad Tareq Khshain Al-Saadi, Alyaa Mohammed, Riadh Al-Mahaidi & Jay Sanjayan. (2019). Performance of NSM FRP embedded in concrete under monotonic and fatigue loads: state-of-the-art review, Australian Journal of Structural Engineering, 20:2, 89-114.

[14] Arduini M, Nanni A. (1997). Parametric study of beams with externally bonded FRP re-inforcement. ACI Struct J 1997;94(5):493–501.

[15] Rafeeq RA. (2016). Torsional strengthening of reinforced concrete beams using CFRP
composites MSc thesis Portland State University.

[16] McCormac, J. Brown, R. (2016). Design of Reinforced Concrete, 10th ed.; Wiley: Hoboken, NJ, USA; ISBN 1118879104.

[17] A. Remennikov, M. Goldston, M. Neaz Sheikh. (2017). Impact performance of concrete beams externally bonded with carbon FRP sheets, Mech. Struct. Mater. Adv.Challenges - Proc. 24th Australas. Conf. Mech. Struct. Mater. ACMSM24, pp. 1695–1699.

[18] Cascardi, A.; Verre, S., Ombres, L., Aiello, M.A. (2024). Carbon Fabric Reinforced Cementitious Mortar confinement of concrete cylinders: The matrix effect for multi-ply wrapping. Compos. Struct. 332, 117919

[19] Fei Yan, Zhibin Lin, Mijia Yang. (2016). Bond mechanism and bond strength of GFRP bars to concrete: A review, Composites Part B 98 56e69.

[20] Micelli, F.; Cascardi, A.; Aiello, M.A. (2023). A removable use of FRP for the confinement of heritage masonry columns. Mater. Struct. 56, 184.

[21] Haji M, Naderpour H, Kheyroddin A. (2019). Experimental study on influence of proposed FRP-strengthening techniques on RC circular short columns considering different types of damage index. Compos Struct 209:112–128.

[22] Javidan MM, Kang H, Isobe D, Kim J. (2018). Computationally efficient framework for probabilistic collapse analysis of structures under extreme actions. Eng Struct 2018;17:440–52.

[23] Hosseinlou, F., Moradi, M., Sadrianzade, M. et al. (2025). An energy-based method for calculating the fragility curve of bridges: a case study. Iran J Sci Technol Trans Civ Eng

[24] Hajikazemi M, Mohebi B, Montazeri-Pour M. (2020). Analysis of steel special moment frames including damaged column subjected to far and near-field ground motions. Aust J Struct Eng 2020;21(3):193–207.

[25] Moradi M, Tavakoli H, Abdollahzadeh G. (2023). Probabilistic evaluation of failure time of reinforced concrete frame in post-earthquake fire scenario. Structural Concrete. Volume 25, Issue 5 p. 3487-3504.

[26] Kang H, Kim J. (2017). Response of a steel column-footing connection subjected to vehicle impact. Struct Eng Mech 2017;63:125–36.

[27] H. Tabatabai, M.D. Pritzl, A. Ghorbanpoor, (2009). Evaluation of select methods of corrosion prevention, corrosion control, and repair in reinforced concrete bridges, Wisconsin Highway Research Program.

[28] El Meski F, Chehab GR. (2014). Flexural behavior of concrete beams reinforced with different types of geogrids. J Mater Civil Eng 2014;26(8):04014038.

[29] Fatemeh Aslani, Mehdi Dehestani. (2020). Probabilistic impacts of corrosion on structural failure and performance limits of reinforced concrete beams, Construction and Building Materials.

[30] Moradi, M., Tavakoli, H., Abdollahzadeh, G. (2022). Collapse Probability Assessment of a 4-Story RC Frame under Post-Earthquake Fire Scenario. Civil Engineering Infrastructures Journal, 55(1), pp. 121-137.

[31] Santos AF, Santiago A, Latour M, Rizzano G. (2020). Robustness analysis of steel frames subjected to vehicle collisions. Structures 2020;25:930–42.

[32] Goodarzi M.J., Moradi M., Jalili P., Abdolmohammadi M., Hasheminejad S.M. (2023). Fragility assessment of an outrigger structure system based on energy method. The Structural Design of Tall and Special BuildingsVolume 32, Issue 11-12 e2017.

[33] Ghasemi, S.H., Nowak, A.S. (2016). Statistical parameters of in-a-lane multiple truck presence and a new procedure to analyze the lifetime of bridges, Structural Engineering International, Vol. 26, No. 2, pp.150–159

[34] Sui, L., Luo, M., Yu, K., Xing, F., Li, P., Zhou, Y., Chen, C. (2017). Effect of Engineered Cementitious Composite on the Bond Behavior between Fiber-Reinforced Polymer and Concrete, Composite Structures.

[35] Fathizadeh SF, Dehghani S, Yang TY, Noroozinejad Farsangi E, Vosoughi AR, Hajirasouliha I, et al. (2020). Trade-off Pareto optimum design of an innovative curved damper truss moment frame considering structural and non-structural objectives. Structures 2020;28:1338–53.

[36] Dorri F, Ghasemi S.H, Jalilkhani M. (2023). Performance-based system reliability analysis for steel moment frames. Structures Volume 51, Pages 472-483

[37] Cascardi, A. (2024). Special Issue: Advances in Structural Analysis and Rehabilitation for Existing Structures. Eng, 5(3).