Diyala Journal of Engineering Sciences

Journal homepage: https://en.enginmag.uodiyala.edu.iq/

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Investigation on the Seismic Performance of High-Strength Bolt-Rubber (HSBR) Connection in a Steel Frame

Teeba A. Jassim [*1], Amer M. Ibrahim[1], Bozhou Zhuang[2]

[1]Department of Civil Engineering, College of Engineering, University of Diyala, 32001 Diyala, Iraq
[2]Department of Bridge Engineering, Tongji University, Shanghai 200092, China

ARTICLE INFO

Article history:

Keywords:

Earthquake; Damping; Rubber; Steel frame

ABSTRACT

The existing buildings can be improved under the seismic effect by adding rubber to the bolts in the connection. The buildings when maintenance work is happening there is a problem many times and it should be evacuated and requires high cost. This study aims to maintain the building without having to remove it and at a very low cost compared to other methods. This study includes six models divided into two groups. The two groups differ in terms of the number of bolts in the contact area between the column and the beam in the steel frame. The first group models contain four bolts in the connection area and the second group forms contain five bolts in the contact area. Each group includes three models representing the first form of a reference model that has not rubber material around the bolts in the connection area, the second model contains 150% rubber than a bolt diameter around one bolt of the connection area, and all the bolts in the connection area in the third model are warped with rubber. The presence of rubber around one bolt gave a load, displacement, drifting, damping ratio, ductility index energy dissipation close to models where all contact bolts are warped with rubber material.

1. Introduction

The action applied to a structure by an earthquake is a ground movement with vertical and horizontal components. The horizontal movement is the most specific feature of earthquake action because of its strength and because structures are generally better designed to resist gravity than horizontal forces [1]. The earthquake is geophysical phenomena, which is in the form of a wave, produces this wave movement in the earth's crust to the top and below, also result of this movement the movement in the foundations of buildings where this wave is contrary to the main movement of the building and as a result of this process in the movement will occur failure in the base of the building [2]. As a result of the frequent earthquake in Iraq, especially in northern Iraq, so it is necessary to develop new techniques to minimize the seismic effect. Requires to be designed and supported by human works and each part of which to resist the effects of landlocks to protect them from collapse with reduced damage to property and buildings and avoiding human losses and ensuring that the services of important buildings and vital facilities continue as possible [3]. Iraq is located in a relatively active earthquake in the north-eastern border of the Arab panel. Northern Iraq is exposed to earthquakes M7.3 in November 2017 another effect of M6.3 in November 2018 near Iraq. More than 150 buildings were damaged on these earthquakes. Therefore, it is necessary to study the seismic effect and how to reduce this influence on buildings [4].

[*] Corresponding author.
E-mail address: teebalii94@gmail.com
DOI: 10.24237/djes.2021.14210

This study is a numerical study that includes simulation for experimental models for Suhab et. al. [5]. Where the researcher used the contact area specifically because this area is the most influential during the seismic effect for several reasons, including this area is more than one element and these elements are different among them in terms of resistance and steel type and installation of molecules and ultimate resistance. So the design of the connection is more complicated, and the failure of the contact area is the most dangerous among other failures in the building. In general, the detailed failure is the first failure if the connection is exposed to an unexpected force because the behavior of joint material is brittle behavior of some loads and not all [6].

The study aimed at developing a connection through technical work that is absorbing seismic loads that are exposed to joints by the earthquake of the installation bolts of the rubber and this is the basic idea of the search and where the rubber used is a car tire. While rubber has a high value for K factor, and a low value for [G] factor, where the value of [G] varies between (0.5-5) MPA, the Poisson ratio will be about 0.499, and e [e] is equal to three times [G]. These previous determinants are very important in determining the properties used in engineering applications, as due to the increase in the accumulated numbers for wastes in general and laughing in particular, it is necessary to find solutions and methods for recycling this waste (car tire) and do not make them greatly accumulate[7,8].

This study develops a new method that enables the maintenance of the building without having to be completely defeated by packaging one bolt with the rubber on each side of the connection area between the column and beam.

Where many studies have been studying the impact of an earthquake in the contact area, including:

- Qiuhong et al. (2004), [9] Studied using two samples, where each sample consists of Shear Wall, reinforced concrete, and Steel Plate. Where the samples were tested under the quasi-static cyclic load and the effect of each sample under the seismic load was studied. After the completion of the tests and noting the results, it was found that these models bear 17 cycles until failure occurs and allow a drift between floors of the amount of 0.05.
- Schroeder et al. (2012) [10], Studied use the ABAQUS program to determine the rotation of the Shear Tap, this study stipulates that the shear tap can resist moment but depend on the stiffness of the steel frame. Where he reached that the initial stiffness of the connection must be between (2-12) percent. The researcher also reached that if the contact is partially restricted, drift between floors of origin is 22% compared to the shear tap mode is supported to be perfect pin contacts.
- Chang et al. (2012), [11], provides for predicting the behavior of connection when exposed to cyclic-load, blast load, and monotonic load. Since this study is, a numerical study so the experimental models and results were used for chamber & crocker2004 to Mack the validation of this study. The prosed mechanical models obtained to perform the shear connection were in the term of the non-linear curve [M-θ] for the monotonic load, [M-θ] for cyclic load, and [M-I] for blast load.
- Kaltakci et al. (2014) [12], studied using nine models, these models consist of one floor of a steel frame, and the shear tab uses the connection. As the load that was shed is horizontal, reverse cyclic loading. The results showed that there is a relationship between the Lateral Stiffness and Lateral bearing load and energy dissipation of the steel frame, were noting that the displacement of the frame increasing with the increase of the infill walls.
- Daneshvar et al. (2017) [13], using the ABAQUS program has been simulated for experimental models in 2009. The model consists of two beams connected with the Middle Column with the shear tap In this study, the impact of pulp and the diameter of the bolt and rotation capacity were studied. The results show that the increase of the thickness of the plate and increase the diameter of bolts led to improved performance to the connection under the influence of the shear and flexural.
- Masoud et al. (2019) [14], Studied the Shear Tap connection behavior and found that the

main reason for making the Shear Tab with great rotate ability is plastic deformation in the shear tap where the plastic deformation depends on flexural capacity, where this flexural capacity is increase with increase the plastic modulus and that lead to increase the rigidity of the connection. He also concluded that the Shear-Tab maintains the bending moment that occurs at the end of the beam and allows it to rotate, so a connection that contains the Shear-Tab is called semi-rigid.

There are many methods used to reduce seismic effects such as Isolator System, Damping System, Shear Wall, and Steel Bracing. Hayder Fadhil et al. (2018) [15], studied the use of corrugated steel shear wall resistance from the seismic effect. Studied many variables to observe their impact on the performance of the fungal shear wall corrugated under seismic load.

Shamivand et al. (2019) [16], studied aside strengthening system that is in the form of a loop and is called Shami lateral bracing system (SLBs). This system provides a new element that has good softer and capacity over energy. The researcher concluded that this system is an inefficient system of cost but gives good performance under the seismic effect

However, these methods are very expensive and require careful installation on buildings. Therefore in this study, the rubber was applied to the bolt shank to form a high strength bolt-rubber connection (HSBR) which has the advantages of cost-effective, fast, and easy installation compared to conventional energy dissipation methods which are promising to enhance the ductility of the steel beam-column joints.

In this study, the effect of adding one bolt enveloped with rubber material in the contact area between the column and column. This study aims to maintain the building without the need for its entirety and thus providing time, effort, and further cost than if all bolts are packed with rubber for dissipation loads of seismic impact.

2. FE modelling and validation

2. 1 Validation of the experimental models

In this part validation is made for a set of models that are related to the study (suhab-2020), this study includes three models that have been practically applied under horizontal quasi-static cyclic load. Models designed to depend on AISC-14Th edition [17]. Each model consists of two columns HW125×125 with 1500 mm length and one beam IEP160 for 1000 mm. The beam is connected with the column by Shear Tab on each side, the dimensions of the shear tap are110 ×90 ×8mm, the shear tap is connected with a column by welled and bolted with the beam. One of the columns is a pin column and the second column is a fixed column. The fixed column contains the four Stiffeners to strengthen the column. The bolt diameter of the reference model is 7 mm, but the bolt diameter varies for the other two models where the bolt is enveloped with rubber. Where symbolizes the reference experimental model by (H-0-STD-1), symbolized for the second model that contains rubber in the connection in the rate of 50% of the bolt diameter by (H.50.OVD.2), the diameter of the composite bolt, in this case, is 10.5 mm and, symbolized for the third model that contains rubber in the connection in the rate of 150% of the bolt diameter by (H.150.LSL.3) the diameter of the composite bolt, in this case, is 17.5 mm.And the thickness of the rubber is 5.25 mm on each side.The shape of the experimental model and numerical model is shown in Figure 1.

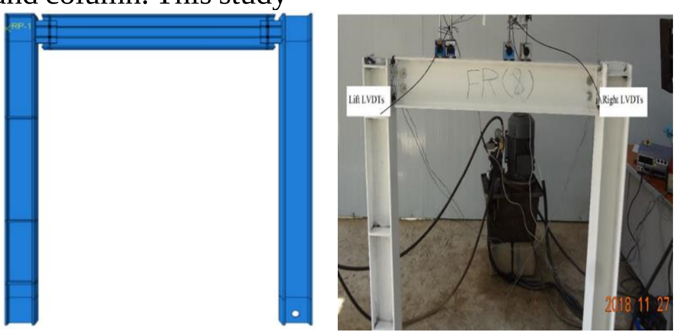


Figure 1. The experimental and FE models A: FEM model B: experimental model

2.1 The geometry of the section

The representation of the sections in the ABAQUS program requires drawing them with the same dimensions and shapes corresponding to the real section to give a correct and accurate representation. The drawing of these sections is done by determining the type of section to be drawn and in this study, the solid type sections are used because the thickness of the section compared to other dimensions is not small.

2. 2 Properties of material

The properties used in the ABAQUS program must be the properties converted from the engineering to true stress and strain. These values are converted by the equations below:

$$\sigma_{True} = \sigma_{Engineering} * [1 + \varepsilon_{Engineering}] \quad (1)$$

$$\varepsilon_{True} = \ln[1 + \varepsilon_{Engineering}] \quad (2)$$

$$\varepsilon_{Plastic} = \ln[1 + \varepsilon_{Engineering}] - [\sigma_{True}/E_{Modulus}] \quad (3)$$

Therefore, Table 1 shows the mechanical characteristic of the model sections, and Table 2 shown the true character of the model.

Table 1: The mechanical characteristic for ABAQUS program [5]

The Sections	Density	Elastic Modulus MPa	Elongation Ratio
Steel Beam	7.83 e -09	1.95 e +05	0.3
Steel Column	7.83 e -09	1.87e +05	0.3
Shear Tap	7.83 e -09	2.11e +05	0.3
Steel Bolt	7.83 e -09	2.75e +05	0.3
Steel Washer	7.83 e -09	2.75e +05	0.3
Rubber	1.52e -09	91.120	0.5

Table 2: The true value of the properties [5]

Steel Section	Yield-stress MPa	Plastic-Strain
Steel Beam	250.4375	0
	400.7	0.301135883mm/mm
Steel Column	250.4375	0
	400.7	0.283362250mm/mm
Shear Tap	312.546	0
	422.7385Mpa	0.283242381mm/mm
Steel Bolt	588.6MPa	0
	648MPa	0.073721041mm/mm

As for the properties related to rubber, which is considered to be a type of material that is known as hyperplastic material, the way to represent it is by defining a hyperplastic material from the properties in the ABAQUS program, and then by entering the stress and strain values related to the rubber to define it in the program. The properties of the rubber were taken from the results of a process related to testing the rubber under compression, in the Table 3 the properties for the rubber that were used in the ABAQUS program.

Table 3: The properties of rubber under compression test [5]

Compression _Stress MPa	Strain mm/mm
0	0
20	0.124
28	0.396
36	0.872

2. 3 Mesh design and boundary condition

At the beginning of the meshwork for each section, the section must first be divided into pieces for these to be uncomplicated section Also, this division must be based on the manual of the ABAQUS program. Other sections should be divided into cubic and rectangular shapes. The mash size for Beam, Column, Shear Tap, Stiffeners, Bolt, Nut, Washer, and Rubber is (50, 100, 25, 100, 10, 10, 10, and 10) mm respectively. In Figure 2, the final mesh shape of one of the study models.

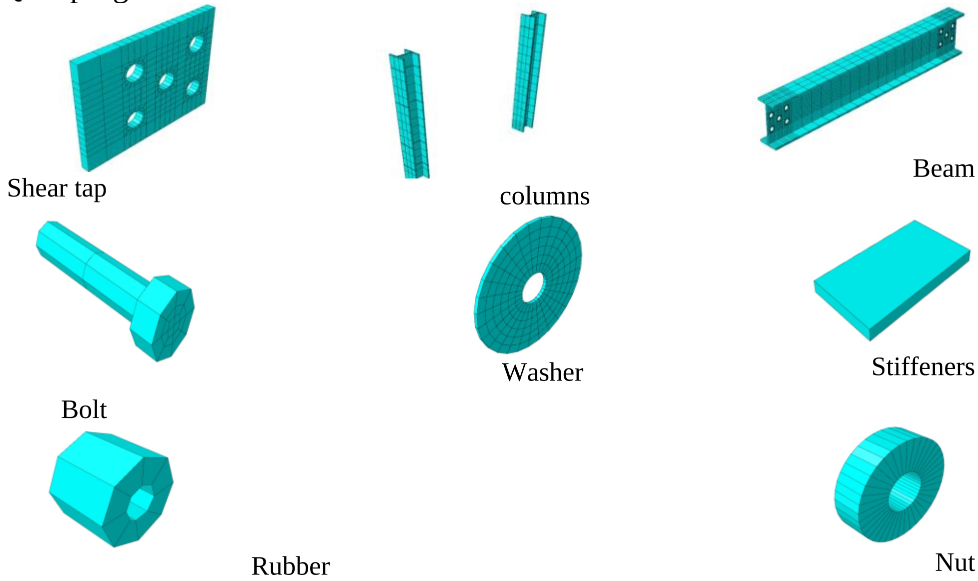


Figure 2. The final mesh shape of the study models

The type of load that is used is horizontal_ quasi _ static cyclic load. Where the type of load is applied based on the protocol (ATC_24_1992)[18] that similar to the protocol used in the experimental study. The curve for the loading protocol used is shown in Figure 3.

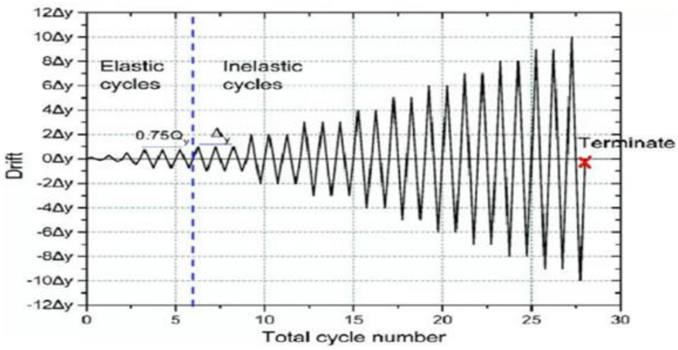


Figure 3. The loading protocol [18]

Depending on the Loading protocol, the Loading location for all models is at the top edge of the two columns, as shown in Figure 4. Boundary Condition consisted of a fix and a pin, as also shown in Figure 4.

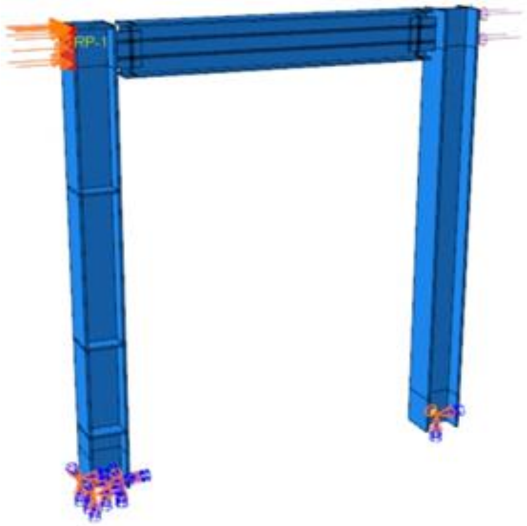


Figure 4. load case and boundary condition in the ABAQUS program

2. 4 Contact interaction

In this type of contact, the friction between the two contact surfaces must be determined. The coefficient of friction between the two surfaces is determined through the interaction property and then given a special value in the friction coefficient, in this study a value of 0.7 was used, this value is taken due to the Try and Error analysis. Contact interaction with the Coefficient of Friction of the models of this study was explained in detail in the following points:

1. Interaction between the beam and nut, where the beam is the master surface and the nut is the slave surface.
2. Interaction between the beam and shear tap, where the beam is master surface and the shear tap are slave surface.
3. Interaction between the bolt and rubber, where the bolt is master surface and the rubber is slave surface.
4. Interaction between the plate and bolt, where the plate is master surface and the bolt is slave surface.
5. Interaction between the washer and bolt, where the washer is master surface and the bolt is slave surface.
6. Interaction between the rubber and holes, where the rubber is master surface and the holes are slave surface

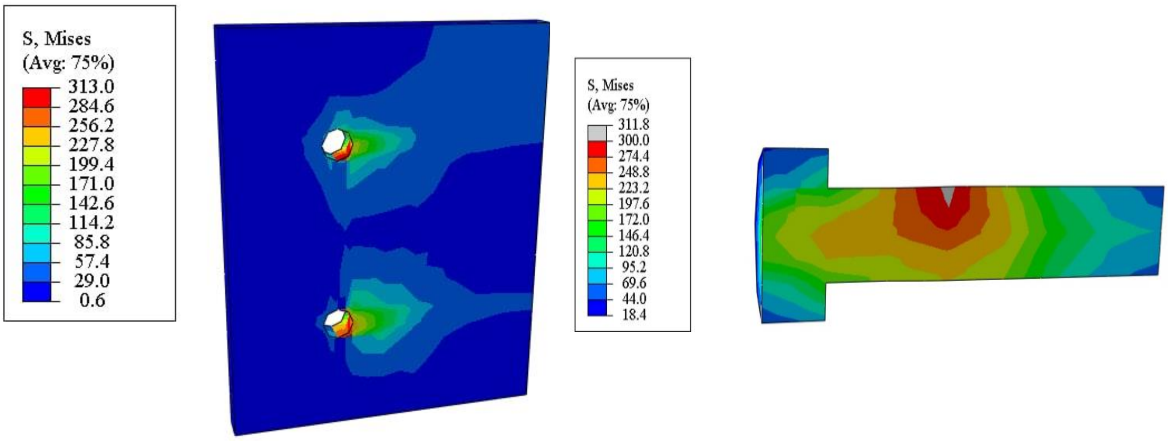
2. 5 The tie constrain

This type of connection uses when the two surfaces are no movement between them. Where the master surface is the surface of the main part of the largest part to which it is installed, while the second surface is of the slave type. In this study, this type of connection is used to connect the shear tap with the columns, where the column is the master surface and the shear tap is the slave. This type is also used to connect the fixed column with the stiffeners.

2. 6 Validation results

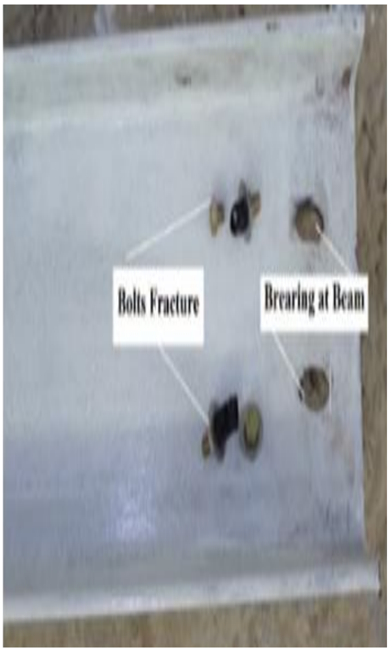
Through the numerical representation of the model and then comparing the form of failure and the results of the numerical analysis with the experimental test, it was found that there is a great convergence in the form of failure between the experimental and numerical models. Whereas in the experimental model the failure is concentrated in one area, which is the contact area between the column and the beam, and a fracture occurs in the bolts for most models, as it induces a fracture of the rubber that covering the bolt. To clarify the form of convergence, the shape of failure in the experimental and numerical test of three models is presented from Figure 5 to Figure 7.

(A)

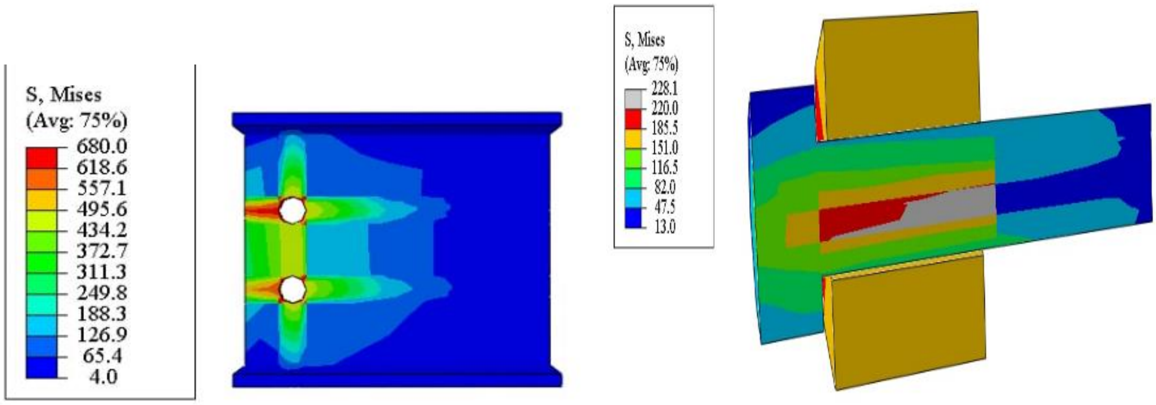


(B)

Figure 5. A: Experimental failure of the plate and the bolt of the H.0.STD.1, B: Numerical failure in the FE model



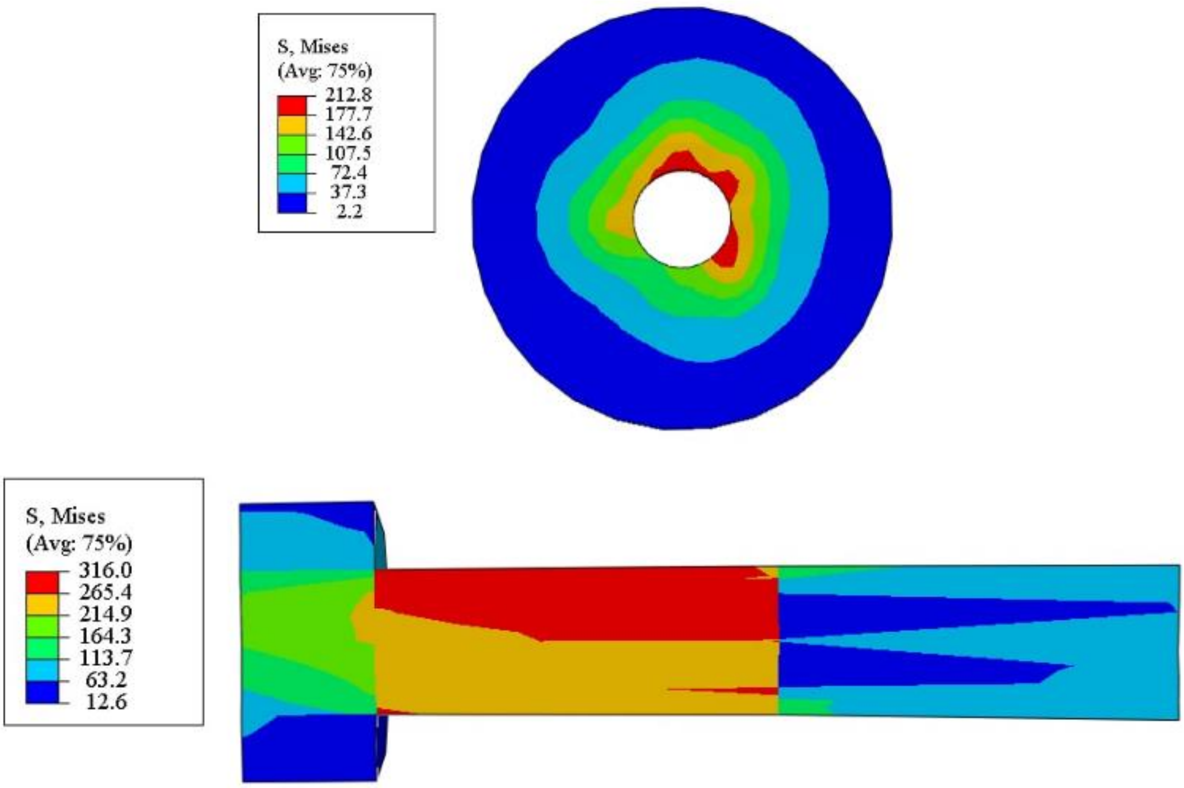
(A)

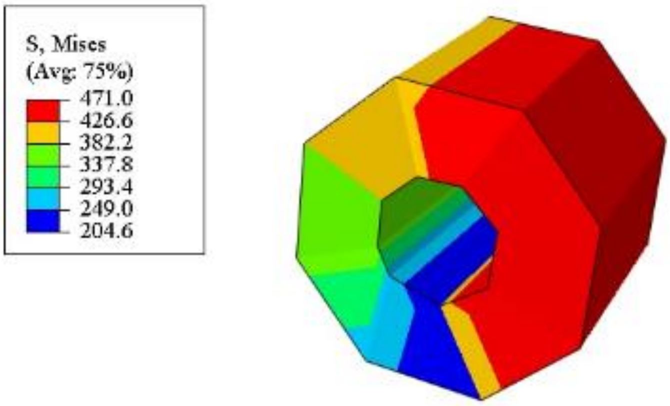


(B)

Figure 6. A: Experimental failure of the plate and the bolt of the H.50.OVS.2, B: Numerical failure in the FE model

(A)





(B)

Figure 7. A: Experimental failure of the plate and the bolt of the H.150. LSL.3, B: Numerical failure in the FE model

The results obtained from the numerical analysis are accurate approximating the results obtained from the experimental testing. When comparing the results obtained from the Numerical program with the results obtained from the experimental results, the comparison by drawing an envelope curve of the results that shown from the Figure 8 to Figure 10.Where the envelope curve is the highest point of the Hysterics curve for each cycle and is the same as the push over curve.

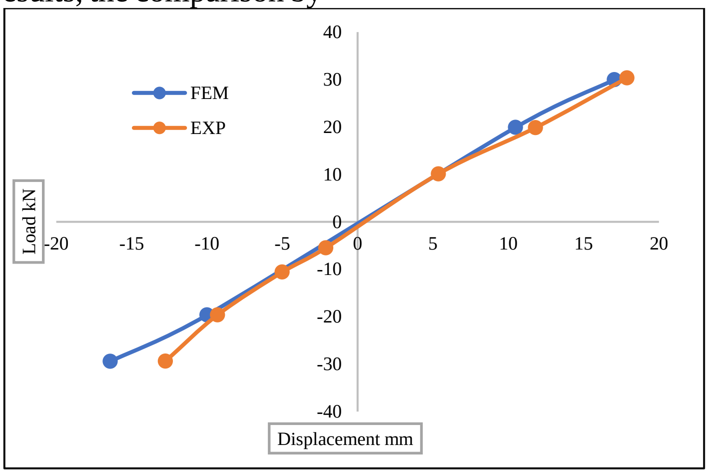


Figure 8. Envelope curve for experimental and numerical analysis of the H-0-STD-1 model

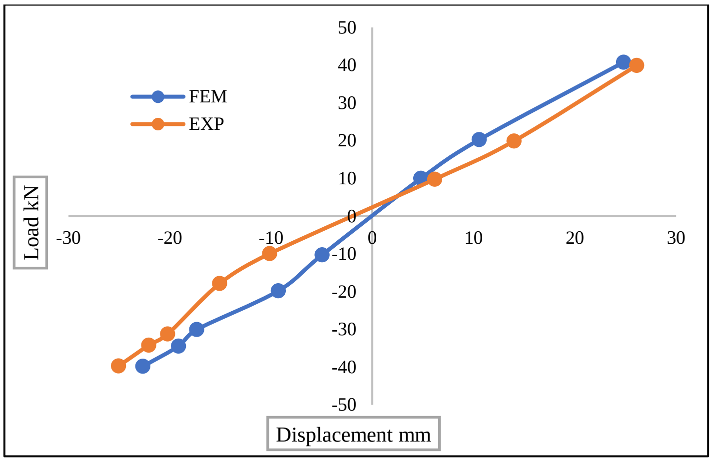


Figure 9. Envelope curve for experimental and numerical analysis of the H.50.OVD.2 model

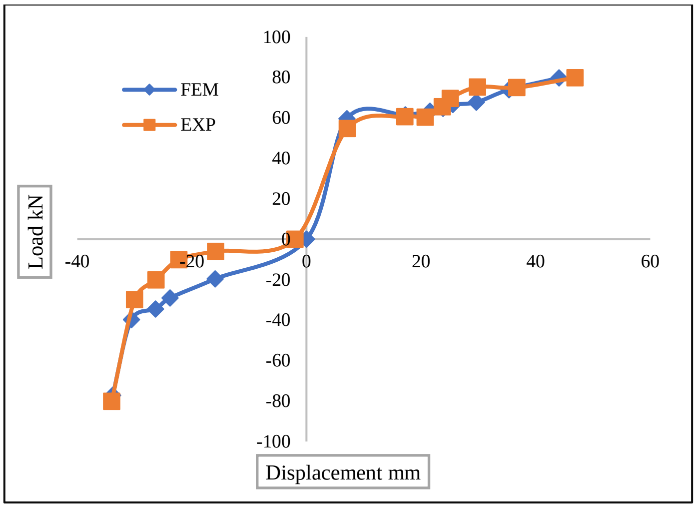


Figure 10. Envelope curve for experimental and numerical analysis of the H.150.LSL.3 model

Finally, the above curves can prove that the convergence is too large between the results of experimental analysis and numerical analysis. Also, this convergence is shown in Table 4, which includes the results of the experimental and numerical models in terms of displacement and loading.

Table 4: Displacement and load result for experimental and numerical analysis

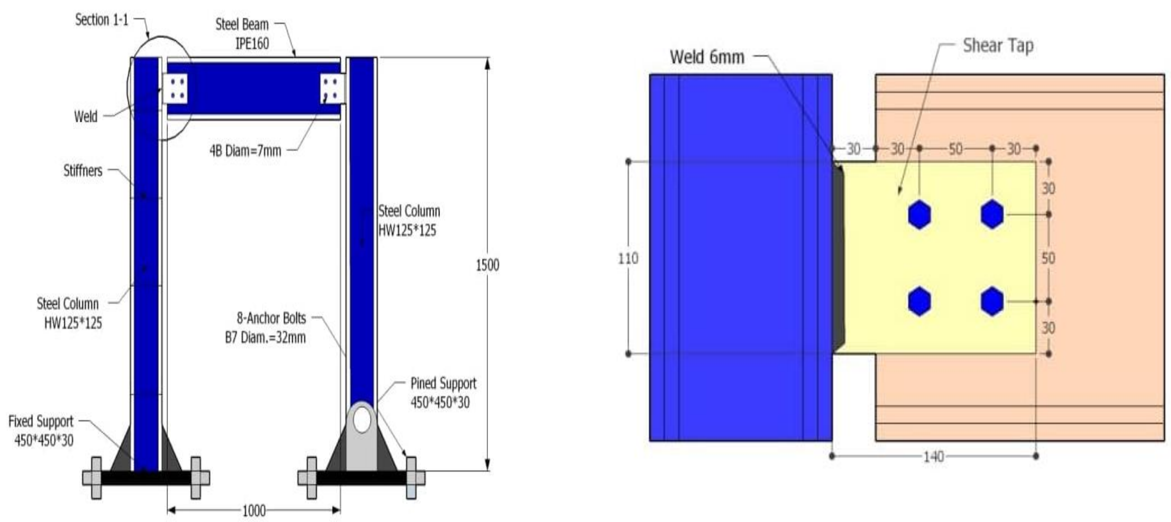
Model name	Load kN		The ratio of convergence of load (FEM/EXP)	Displacement mm		Ratio of convergence of displacement (FEM/EXP)
	FEM	EXP		FEM	EXP	
H.0.STD.1	29.962	30.323	0.988	17.046	17.878	0.953
H.50.OVS.2	39.933	40.773	0.979	22.825	26.121	0.874
H.150.LSL.4	79.630	79.872	0.996	44.102	46.878	0.941

3. Case study

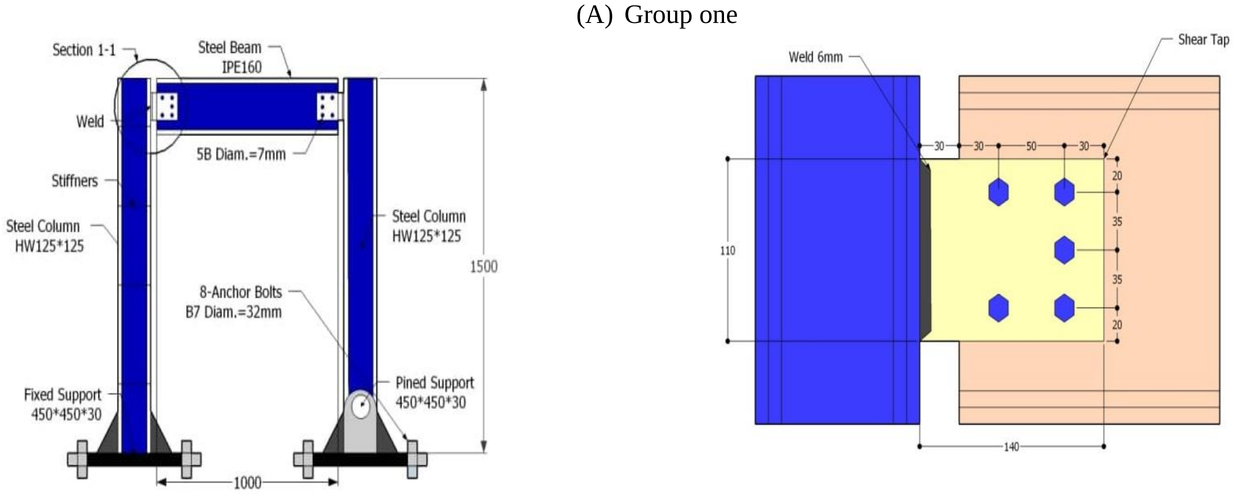
In this study, two groups have been taking the difference between them is the number of bolts in the connection area between the column and the beam. Where the number of bolts in the connection area of the first set is four bolts. The number of models was tested in the group is four models that the difference between them is the number of bolts coated with rubber material in the contact area. The second group's models contain five bolts in the contact area; among them is the number of rubber bolts in the contact area. It should be referred to, the rubber-envelope bolt is the bolt in which the stress and strain are high compared to other bolts. The symbolize of all models that study in this paper are listed in the Table 5. In all models that contain rubber there are two washers, the position of the first washer is under the head of the bolt and the position of the second is above the nut and at the end of the hole in the back of the beam, the function of this two washer is to prevent the rubber from escaping from the bolt holes, over a larger area, and thus no-load concentration occurs at the bolt head, nor does a direct failure occur in the bolt holes. The sections are designed to depend on AISC Manual [17]. The details of the two sets used are described in Figure 11.

Table 5: The symbolize all models

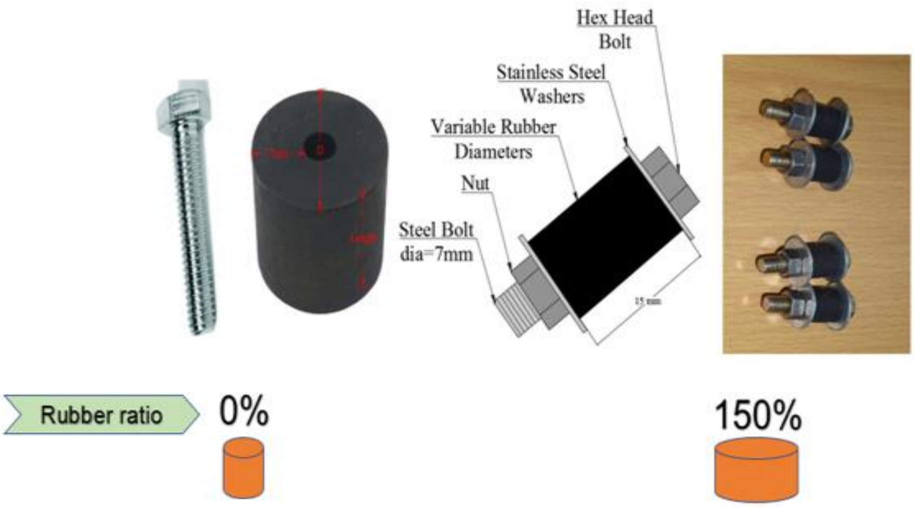
No.	Name of Specimens	Type of load	Number of bolts	Number of bolts coated with rubber	Rubber ratio%
1	R.H.4B.0.1	Horizontal-cyclic-load	Four Bolts	Zero Bolt.	0%
2	F.H.4B.1.150.1			One Bolt.	150%
3	F.H.4B.2.150.1			Two Bolts.	
4	F.H.4B.3.150.1			Three Bolts.	
5	F.H.4B.4.150.1			Four Bolts.	
6	R.H.5B.0.1		Five Bolts	Zero Bolt.	0%
7	F.H.5B.1.150.1			One Bolt.	150%
8	F.H.5B.2.150.1			Two Bolts.	
9	F.H.5B.3.150.1			Three Bolts.	
10	F.H.5B.4.150.1			Four Bolts.	
11	F.H.5B.5.150.1			Five Bolts.	150%



(A) Group one



(B) Group two



(C) Detail of the composite steel bolt
Figure 11. Details of the specimen

4. Numerical results

4. 1 Results of the load and displacement

The presence of rubber, in general, has worked to increase the displacement and load for models containing rubber compared to the reference model due to flexible rubber properties The model containing the rubber around one bolt gave a load and displacement two approaches to the loading and displacement of the model containing four rubber-coated bolts. The same is the case for the other two models that contain two bolts and three bolts on each side covered with rubber; these models give a similar load and displacement. By noting Figure 12 shows the comparison between adding rubber around one bolt, two-bolt, three bolts, four bolts, and reference models for the four bolts group.

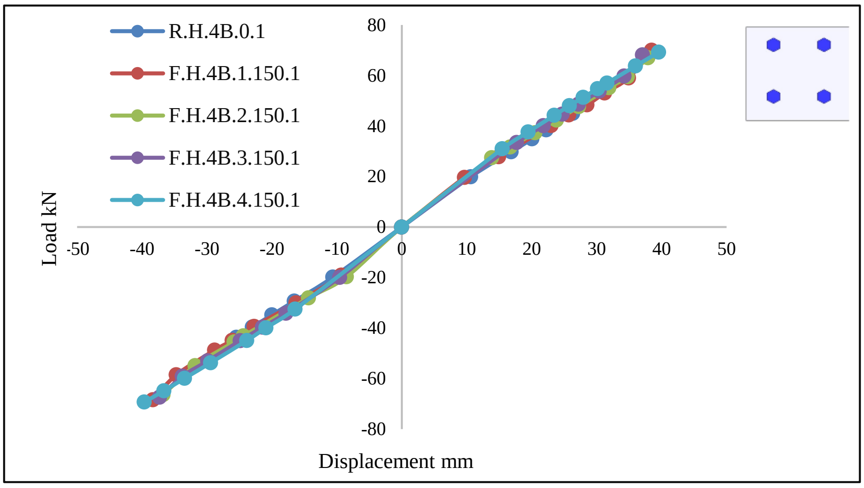


Figure 12. Comparison of gradually adding rubber to the fixing bolts of the 4-bolt group

From the observation of the results, it was found that adding rubber around one bolt gives a displacement and load close to the displacement and load of the model that contains four rubber-coated bolts. Therefore, the comparison in other accounts has been done between the model that contains one bolt coated with rubber and the model to contains four bolts coated with rubber. Also, rubber is gradually added to models that contain 5 bolts in the contact area, where this group includes 6 models, a comparison was made between the six models shown in Figure 13.

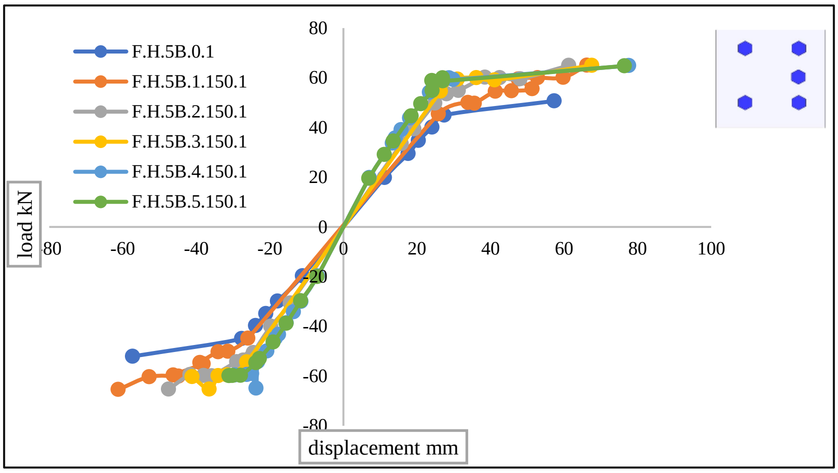


Figure 13. Comparison of gradually adding rubber to the fixing bolts of the 5-bolt group

Note that the load for all models in this case of the 5bolt group is close, but the difference is the difference in displacement between the models because the presence of rubber around five bolts increased the flexibility of the connection, so the model containing five bolts gave a higher displacement compared to the other models. From that, we can prove that adding rubber around one bolt on each contact gives a load similar to that of a model that contains 5 rubber-coated bolts, but the displacement between the two models are different by 15% and this means that it is possible to add rubber around one bolt on each side, to save time and cost more than the case of wrapping the 5 bolts with rubber.

Therefore, the comparison in other accounts has been done between the model that contains one bolt coated with rubber and the model to contains five bolts coated with rubber.

The displacement and load values of all models are shown in Table 6.

Table 6: The displacement and load values of all models

Model name	Max. Load kN	Max. Displacement mm
R.H.4B.0.1	45.041	26.344
F.H.4B.1.150.1	69.983	38.475
F.H.4B.2.150.1	67.019	37.905
F.H.4B.3.150.1	68.163	37.073
F.H.4B.4.150.1	69.232	39.559
R.H.5B.0.1	50.676	57.364
F.H.5B.1.150.1	65.037	66.225
F.H.5B.2.150.1	64.961	61.297
F.H.5B.3.150.1	64.968	67.564
F.H.5B.4.150.1	64.885	77.608
F.H.5B.5.150.1	64.789	76.463

The model that contains the rubber in the connection gives a higher load and displacement because the presence of the rubber in the connection makes the model more flexible. The increased flexibility of the connection is due to the elastic rubber specifications. Since the origin of the rubber is a component of a group of elastic particles, and these elastic particles are in a movement called Brownian, and this movement is continuous when the temperature is normal. When a load is placed and then this load is removed, the particles return to their original shape and this is because the rubber can be subject to very elastic deformations and then recover from them. After all, these molecules are highly elastic, and they are given the rubber ability to withstand elastic deformations.

4. 2 Residual displacement

This relationship is curved where this curved represented by special equations where the equation for the X-axis represents the ratio of the highest displacement value in each cycle of the hysteresis curve divided by the yield displacement value, which is the value from which the model shifts from the elastic stage to the inelastic stage, where this ratio is called the Displacement Ductility, as the text of the equation is explained below:

Residual displacement ductility $= |dm/dy|$ (4)

where: d_m: − Maximum displacement.

d_y: − Yield displacement.

While the Y-axis represents a ratio of the residual displacement index represented by the value of the intersection of the curve of each cycle of the hysteresis curve with the X-axis divided by the yield displacement value, Where this ratio is called the residual displacement index, as the text of the equation is explained below:

Residual displacement ratio $= |dr/dy|$ (5)

Where: d_r: − Residual displacement.

d_y: − Yield displacement.

Through the above equations, comparison curves were made between the models that containing rubber around one bolt on each side of the connection and the model that containing rubber around all bolt in the connection. Comparison of the four bolts shown in Figure 14. Also, a Comparison of the five bolts shown in Figure 15.

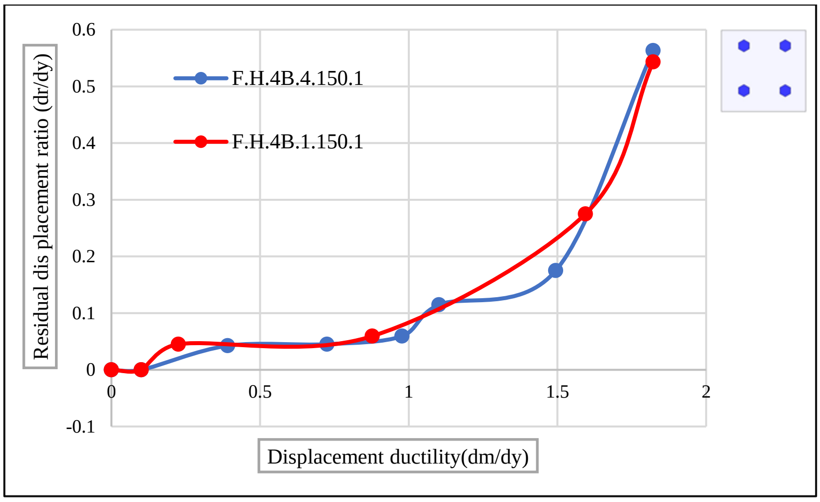


Figure 14. Displacement ductility versus residual displacement index of the first group

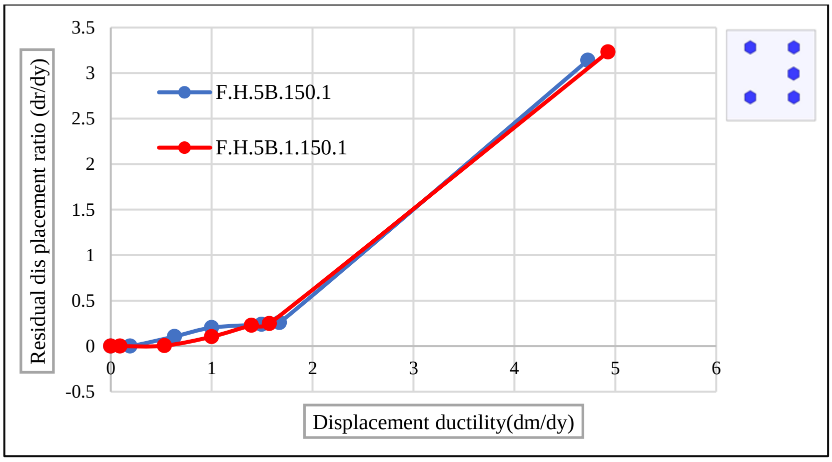


Figure 15. Displacement ductility versus residual displacement index of the second group

Based on the results of the two groups, can prove that it is possible to use one bolt coated with rubber on each side of the contacts, as this bolt gives the same behavior to the model in the case of wrapping all the connection bolts, where the single bolt absorbs stresses and distributes them over a larger area and delays from the time of failure of the model.

4. 3 Drift ratio

Drift ratio for the multi-story buildings, the difference between the displacements of the two stories is divided this different on the height of the story. As for one-story buildings, which are in our study, divide the greatest displacement of the model by the height of the whole model, which is the height of the column. A comparison of the drift ratio was made between the model that contains one rubber-coated bolt and the model in which all the fixing bolts are wrapped with rubber, and this comparison concerns the four and five groups of bolts. The drift values are shown in Table 7.

Table 7: The drift of the models under horizontal cyclic load

Model name	($\delta_y$mm)	Yield drift ($\delta_y/1500$)	$(\Delta_m - \Delta_r/\Delta_r)$ *100%	($\delta_u$mm)	ultimate drift ($\delta_u/1500$)	$(\Delta_m - \Delta_r/\Delta_r)$ *100%
F.H.4B.1.150.1	21.007	0.0140	-	38.475	0.0256	-
F.H.4B.4.150.1	21.62	0.0144	2.857	39.559	0.0264	3.125
F.H.5B.1.150.1	16.052	0.0107	-	66.225	0.0442	-
F.H.5B.5.150.1	16.173	0.0108	0.935	76.463	0.0509	15.158
δ_y: Yield displacement,δ_u: Ultimate displacement. ,(Δ_m): Drift of the model in which all the fixing bolts are wrapped with rubber. , Δ_r : Drift of the mode contains one rubber-coated bolt.						

The results prove that the presence of rubber around one bolt gives a similar drift rate to the case of wrapping all the fixing bolts with rubber except for the 5-bolt group, where the model in which all the fixing bolts are encased gives a higher drift rate due to the increased flexibility of the connection in this case.

4. 4 Ductility-index

It is defined as the ability of a material to have a plastic deformation without fracture in this material. Mathematically, it is defined as the ratio of drift at the highest load to a ratio of drift at yielding. A material with high ductility will be deformed without fail, and this material is called the ductile material, while a material that is of little ductility is referred to as a brittle material and early failure occurs in this material before the deformation becomes of high value compared to the ductile material. A comparison of the ductility index between the models is illustrated in Table 8.

Table 8: Ductility-Index of the models of first and second bolts

Model name	Yield drift Δ_y	ultimate drift Δ_u	Ductility index Δ_u/Δ_{yr}	The difference from the reference model %
F.H.4B.1.150.1	0.0140	0.0256	1.829	-
F.H.4B.4.150.1	0.0144	0.0264	1.886	3.116
F.H.5B.1.150.1	0.0107	0.0442	4.131	-
F.H.5B.5.150.1	0.0108	0.0509	4.757	15.154
Δ_{yr}**: Yield drift of the model includes one bolt coated with rubber.**				

By observing the results, it was found that the ductility of the model that contains one rubber-coated bolt in the case of the 4 bolts is not very different from the model that contains 4bolts coating with rubber, but in the case of the 5 bolts, the ductility of the model that contains 5 rubber-coated bolts is higher than the model that contains one bolt is rubber-coated due to the increase in the displacement of the model in the case of the 5 bolts wrapping and thus this leads to an increase in the drift and an increase in ductility.

4. 5 Damping ratio

Damping is defined as the amount of loss in system energy, and that this loss results from the energy that may be internal or external, such as friction energy. Result and Discussion Result and Discussion As the resulting damping force gives the model the ability to reach the equilibrium point. Moreover, that this energy produced by the damping can result from elastic deformations before the model reaches the stage of final failure, which is the failure of the fracture. Also, that every model or structure must have energy dampers for the structure to have the ability to reach its maximum load and bears the most deformation and then failure. As the damping is produced by dissipating the energy in the oscillation. The damping ratio in the models was calculated by the method used in the special research in researchers [19], as this method depends mainly on the half-power bandwidth in which the frequency of the model is used to determine the value of the damping of the model, which is as shown in the Figure 16).

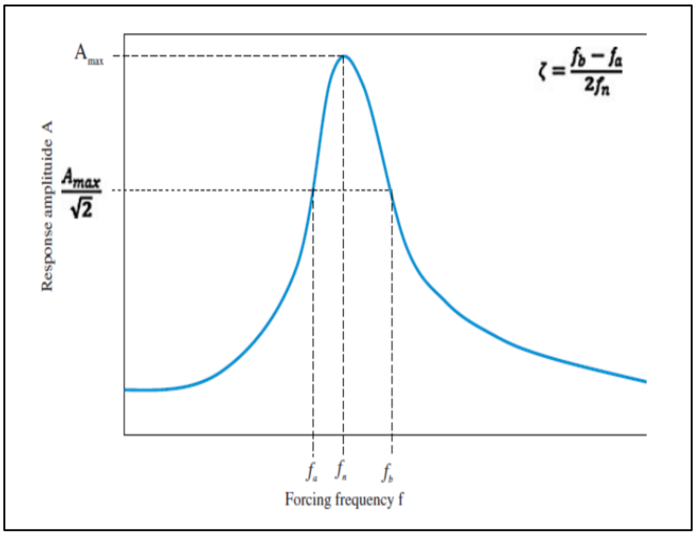


Figure 16. Half power bandwidth method [19]

All damping ratios were calculated for all models by the method described. The damping ratio of the model (F.H.4B.4.150.1) is 3.863% higher than that of the model (F.H.4B.1.150.1). Besides, the damping ratio of the model (F.H.5B.5.150.1) is 16.550% higher than that of the model (F.H.5B.1.150.1). Note that addition rubber around all bolts in the connection improved the damping ratio a little more compared to the model containing rubber around one bolt in each contact of the models, and this is because the rubber works to make the bandwidth large due to the ability of the rubber to maintain its position and the failure to occur in it during the longest possible period as it deforms and then returns to its original position without fail and remains in this state for the longest possible period.

4. 6 Energy dissipation

For models that are subject to seismic effect, it is very necessary to have the ability to dissipate the energy that you gain from the seismic effect because, during an earthquake effect, the ability of the structure to remain stable depends on its ability to dissipate energy. The energy dissipated by the model is calculated from calculating the area under Envelop Curve, according to researcher Seaders et al. [20].

The Energy Dissipation of the model (F.H.4B.4.150.1) is 1455.191 kN. mm and the Energy Dissipation of the model (F.H.4B.1.150.1) is 1312.4 kN. mm. The Energy Dissipation of the model (F.H.4B.4.150.1) is 10.88% higher than that of the model (F.H.4B.1.150.1). Also, the Energy Dissipation of the model (F.H.5B.5.150.1) is 3879.178 kN. mm, and the Energy Dissipation of the mode (F.H.5B.1.150.1) is l2235.48. The Energy Dissipation of the model (F.H.5B.5.150.1) is 73.528% higher than that of the model is (F.H.5B.1.150.1). This means that rubber around one bolt can dissipate a sufficient percentage of energy compared to wrapping all fixing bolts with rubber.

5. Conclusion

Based on the results presented in this research and the observations obtained from the numerical analysis, the conclusions drawn from this work can be summarized as follows:

- When comparing the load and displacement value of the reference model and that contain rubber, note that the displacement value and the load value have increased significantly because the rubber is a hyperelastic material, and one of the properties of this material is to make the rubber within the elastic phase, as the model is deformed and then returns to its original position, where this principle is called (deformation recovery) and the rubber continues in this case until it reaches the stage of yield and then to the ultimate stage and failure occurs.
- The presence of rubber around one bolt gives a similar drift rate to the case of wrapping all the fixing bolts with rubber
- The ductility of the model that contains one rubber-coated bolt in the case of the 4 bolts is not very different from the model that contains 4bolts coating with rubber, but in the case of the 5 bolts, the ductility of the model that contains 5 rubber-coated bolts is higher than the model that contains one bolt is rubber-coated due to the increase in the displacement of the model.
- For damping, the addition of rubber around all bolts in the connection improved the damping ratio a little more compared to the model containing rubber around one bolt in each contact of the models.
- Rubber around one bolt can dissipate a sufficient percentage of energy compared to wrapping all fixing bolts with rubber.
- Finally, through all the above calculations, can verify the validity of this study, which enables us to maintain the buildings by wrapping one bolt with rubber to make the building resistant to seismic effects, and this method will give a greater saving of time and cost than the other method used in building maintenance.

Reference

[1] Earthquake Resistant Steel Structures. ArcelorMittal Europe - Long Products Sections and Merchant Bars. Patented.

[2] Ali, Suhaib J., Amer M. Ibrahim, and Sarmad Shafeeq. "Experimental Study and Numerical Simulation of Plane Steel Frame with Rubberized Connecting Technology Subjected to Seismic Effect." Engineering and Technology Journal 39.3A (2021): 415-425.

[3] Code of building resistance to earthquakes. Iraqi Construction Blog (2017).

[4] Ali, Suhaib J., Amer M. Ibrahim, and Sarmad Shafeeq. "Innovative Steel Connections with Composites Steel Bolts/Rubber Subjected to Horizontal/Inclined Cyclic Loads." IOP Conference Series: Materials Science and Engineering. Vol. 745. No. 1. IOP Publishing, 2020.

[5] Suhaib J.Ali ,Amer M. Ibrahim and Sarmad Shafeeq. Structural Behavior of Plane Steel Frame Under Horizontal/Inclined Cyclic Loading with Smart Connections. (2020). Ph.D. thesis.

[6] Astaneh-Asl, A.. Design of shear tab connections for gravity and seismic loads. Structural Steel Educational Council. (2005). Ph.D. thesis.

[7] Jassim, Teeba A., et al. "Using Wasted Rubber Material for Reducing Loads and Energy Dispersal in Building Industries: State of the Art." IOP Conference Series: Materials Science and Engineering. Vol. 1076. No. 1. IOP Publishing, 2021.

[8] Abd-Ali, N. K. Rubber in Engineering Applications (Experimental Series).

[9] Zhao, Qiuhong, and Abolhassan Astaneh-Asl. "Cyclic behavior of traditional and innovative composite shear walls." Journal of Structural Engineering 130.2 (2004): 271-284.

[10] Schroeder, John M. Moment-Rotation Curves for Shear Tab Connections Using Finite Element

Modeling and Experimental Data. Diss. University of Cincinnati, 2012.

[11] Yim, Hyun Chang, and Theodor Krauthammer. "Mechanical properties of single-plate shear connections under monotonic, cyclic, and blast loads." Engineering Structures 37 (2012): 24-35.

[12] Kaltakci, M. Yasar, and Ali Koken. "The behavior of infilled steel frames under reverse cyclic loading." Advanced Steel Construction 10.2 (2014): 200-215.

[13] Daneshvar, Hossein, and Robert G. Driver. "Behaviour of shear tab connections in column removal scenario." Journal of Constructional Steel Research 138 (2017): 580-593.

[14] Asl, Masoud Hoseinzadeh, Behzad Farivar, and SeyedBabak Momenzadeh. "Investigation of the rigidity of welded shear tab connections." Engineering Structures 179 (2019): 353-366.

[15] Fadhil, Hayder, Amer Ibrahim, and Mohammed Mahmood. "Effect of Corrugation Angle and Direction on the Performance of Corrugated Steel Plate Shear Walls." Civil Engineering Journal 4.11 (2018): 2667-2679.

[16] Shamivand, Abbas, and Jalal Akbari. "Ring-shaped lateral bracing system for steel structures." International Journal of Steel Structures (2019): 1-11.

[17] AISC, 2011 .AISC Manual of Steel Construction, 14th Edition. Am. Inst. Steel Constr. Chicago, AISC, no. February.

[18] ATC 1992 .Guidelines for cyclic seismic testing of components of steel structures. Atc-24.

[19] Olmos, Bertha A., and Jose M. Roesset. "Evaluation of the half-power bandwidth method to estimate damping in systems without real modes." Earthquake engineering & structural dynamics 39.14 (2010): 1671-1686.

[20] Seaders, Peter, Rakesh Gupta, and Thomas H. Miller. "Monotonic and cyclic load testing of partially and fully anchored wood-frame shear walls." Wood and Fiber Science 41.2 (2009): 145-156.

[21] Salman, Wissam D. "Finite element analysis of reinforced concrete slabs with spherical voids." Diyala Journal of Engineering Sciences 6.4 (2013): 15-37.