Journal of History Culture and Art Research (ISSN: 2147-0626)
Special Issue
Tarih Kültür ve Sanat Araştırmaları Dergisi
Revue des Recherches en Histoire Culture et Art
مجلة البحوث التاريخية والثقافية والفنية
Vol. 6, No. 1, February 2017

http://kutaksam.karabuk.edu.tr

DOI: 10.7596/taksad.v6i1.702

Citation: Shokri, M., & Edalati, M. (2017). Comparison of Twisting Angle-Torsional Moment in Unstrengthened Reinforced Concrete Beams with Reinforced Concrete Beams Strengthened with CFRP Sheets. Journal of History Culture and Art Research, 6(1), 43-58. doi:http://dx.doi.org/10.7596/taksad.v6i1.702

Comparison of Twisting Angle-Torsional Moment in Unstrengthened Reinforced Concrete Beams with Reinforced Concrete Beams Strengthened with CFRP Sheets

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Abstract

One of the most important strengths of concrete structures is their torsional strength in different loads. This strengthening could have a significant impact on increasing tolerability of structure relative to lateral and vertical loads and vibrations. In order to withstand the additional loads, reinforced polymers (FRP) are used today. The present study investigated the effect of using polymer composite sheets CFRP on the torsional strength and ultimate deformation of beam. Research method is practical and in this study, four types of beams with different dimensions are used to examine the effect of different loads on the torsional strength.

Keywords: Torsional strength**,** Beam, Concrete structure, Refractive index.

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Introduction

Retrofitting structures using composite materials FRP is one of the new techniques that has been considered by researchers and industrialists recently. With the invention of composite materials reinforced by polymer fibers FRP, a new step in strengthening and improvement of damaged and vulnerable structures was taken that among these features such as ease in manufacturing and transportation, formability of these materials, resistance against corrosive environmental conditions, high strength and at the same time there are very small weight than other materials have helped to the increasing development of these materials. Composite FRP due to having super convenient physical and mechanical characteristics such as low weight and high strength to weight, high modulus of elasticity, high resistance to tension and shear, resistant to moisture, high flexibility, high durability and stability and corrosion resistant has special applications in structures to increase resistance [1].

Currently, twisting angle is predominantly used to increase the strength of the beam-column connection. Many studies have shown that this explanation of angle of twist and explanation of resistances to reduce torsional load have had a great effect on the stiffness and lateral strength of buildings and therefore their effects on seismic behavior of structures must be considered during the analysis and design. Existence of the issue calculation of the angle of twist in structural system of a building reinforces it against the earthquake lateral loads. Also these elements raise energy absorption of a building during an earthquake [2].

The comparison between the results of experimental and numerical analyzes show that the conducted numerical analysis can predict the torsional angle-torsional moment diagram, strain distribution and failure mode of concrete beams reinforced with FRP accurately. In order to determine the effect of different factors on the results of numerical analysis and also to determine the optimal conditions of numerical modeling, sensitivity analysis has been performed on some samples [3]. One of the most important factors influencing in numerical analysis is failure energy which plays a decisive role in predicting failures resulting from FRP separation. The effect of parameter failure energy obtained from nonlinear analysis of concrete gravity dams by choosing failure mechanics model as a failure criterion in concrete was examined. With the increase in failure energy, cracks created in upstream part are removed and no damaged element can be seen in this part. The amount of failure energy affects the cracked elements and when it increases the damaged area will be smaller [4].

1. Literature Review

In 2013, Dionysios and et al. in order to achieve the more ultimate torsional strength in concrete beams strengthened with FRP sheets used a series of experiments for achieving their own aims. In this study the torsional capacity and rotation of reinforced concrete beams strengthened with CFRP sheets have been investigated. The results of this study imply on increased torsional of reinforced beams to 92.62 percent compared to the unreinforced beams [5].

In 2014, Chai and Allawi in order to achieve the more torsional strength in reinforced concrete beams strengthened with CFRP composites used a series of experiments for achieving their own aims. In this study the torsional capacity of reinforced concrete beams strengthened with CFRP sheets has been investigated. The experimental results showed that increase the torsional capacity of beams strengthened with FRP in one layer at a rate of 54% has been up to 91 percent and to strengthen beams in two layers at a rate of 60% has been up to 111 percent [6].

In 2012, Watson in order to achieve the more torsional strength in reinforced concrete beams strengthened with CFRP composites used a series of experiments for achieving their own aims. In this study the torsional capacity and twisting angle of reinforced concrete beams strengthened with CFRP sheets have been investigated. The results of this study show performance improvement of torsional capacity up to 116.7 percent in rectangular beams strengthened with CFRP sheets than unstrengthened concrete beams and meanwhile has increased twisting angle in beams to 66.4 percent [7].

In 2014, Garcia in order to achieve the more torsional strength in reinforced concrete beams strengthened with FRP sheets used a series of experiments. The results of this study show that the torsional capacity of beams strengthened fully is 20 percent more than U-shaped beams and on the other hand has increased torsional capacity of beams strengthened with a strip to 6 percent. Using two layers of sheets wrapped fully with FRP has increased torsional capacity to 30%.

Inelastic torsion is related to torsion of beams that the materials don’t follow Hooke's Law. This phenomenon appears when stresses in beam exceed the proportional limit [8].

2. Research methodology

In this study the author intends to investigate the effect of polymer composite sheets FRP on torsional strength and ultimate deformation of the beam in two ways: the use of single-layer sheets and multilayer sheets in order to determine the increase in the strength of each of the beams.

For this purpose, the methodology of the study has been practical and the method of data collection is field-work. In this study the author intends to simulate and evaluate the conditions of using single layer and multilayer sheets in order to determine the increase in the torsional strength of each of concrete beams resulted from load application and investigate the torsional behavior of beam [9].

3. Modeling for structure analysis

For nonlinear analysis of structures, the enhanced version of software ABAQUS 6.14.1 is used. To get information of modeling and comparison of the results of software with experimental results, after calibrating more than 350 models and hours of effort and precision, the most appropriate response is examined. It is also mentioned that ABAQUS software doesn’t have a special unit and the user must initially enter numeric values based on the same units. For modeling and assigning materials’ properties to each element, properties of the materials should be available [10].

4. Numerical modeling and validation

For validation of the used beams in this thesis, reference experimental samples are used. CHALIORI in an experimental research evaluated the torsional behavior of reinforced concrete beams strengthened with CFRP sheets, and tested 2 reinforced beams strengthened with CFRP sheets. Then based on the modeling sequence (order), experimental specifications of each of the used materials are explained completely [11].

For modeling concrete, initially it is necessary to determine materials specifications such as elastic and plastic range of concrete. Using the Hagnestad curve and with the help of formulas chapter 3, compression and tensile stress and strain values of concrete in inelastic situation are determined. Elastic specifications of materials can be derived easily through the compressive strength of concrete. Table 1 shows the specifications of elastic range of concrete [12]:

Table 1: Elastic specifications of concrete

Model	**Poisson's ratio**	**Young's Modulus of concrete**
Characteristic in Software	Poisson's ratio	Young's Modulus
numerical value	0.2	25E9

To define plastic specifications of concrete, concrete plastic - damage combined model is used. In ABAQUS software to access this model we pass the route Mechanical> Plasticity> Concrete damaged Plasticity. In this section, we enter elastic and plastic specifications of concrete. As shown in Table 2, we enter the specifications of each of the parameters. The numbers in this table are based on the results of other researchers and the sensitivity of the model is more to parameters: internal dilation angle and viscosity. The amount of internal dilation angle is equal to the materials’ volume strain-shear strain ratio. The internal dilation angle for concrete is assumed between 20 to 40 degrees. By increasing the internal dilation angle, the ductility increases.

Table 2: Plastic specifications of concrete

Dilation Angle	**Eccentricity**	**fb0/fc0**	**K**	**Viscosity parameter**
30.5	0.1	1.16	0.67	0.0005

For elastic specifications of composite with carbon fibers according to Table 3 and damage specifications of composite materials many techniques can be used that for FRP failure we use elastic specifications of composite with carbon fibers and the specifications of composite materials are defined in Table 4.

Table 3: Definition of orthotropic specifications of composite in Hashin Damage

Transverse shear strength	**Longitudinal shear strength**	**Transverse compressive strength**	**Transverse tensile strength**	**Longitudinal compressive strength**	**Longitudinal tensile strength**
1428	2504	2504	0.29	6489	37035

Table 4: Definition of elastic specifications of composite

E1(Mpa)	**E2(Mpa)**	**N_u 12**	**G12(Mpa)**	**G13(Mpa)**	**G23(Mpa)**
15500	1210	0.25	4400	4400	3200

5. Material's meshing in software

In modeling, for each material unique element is used. After segmenting materials and assigning materials properties in defining meshing, specifications of each element is defined based on Table 5.

Table 5: Materials' meshing

Composite		**Steel bar**		**Concrete**	
Element dimensions	Element type	Element dimensions	Element type	Element dimensions	Element type
15	Shell-S4R	10	T3D2	21	C3D8R

6. Specifications of beams used in modeling

In experimental samples 28-day compressive strength of concrete has been reported 27 MPa. For validation of modeling, the accuracy of reinforced and unreinforced Ra-beams strengthened with a wrapping CFRP has been investigated. In this beam two shear bars with diameter of 6 mm in 2 points with a distance of 50 mm from the support, two compressive bars with diameter of 8 mm on the top of the beam and two tensile bars with diameter of 8 mm on the bottom of the beam and for a beam section with dimensions of the width 100 mm and height of 200 mm, have been used. Figures 2 and 3 show the details of reinforcement and dimensions of R- beam. In addition, during the modeling we have considered that the twisting angle is constant [13].

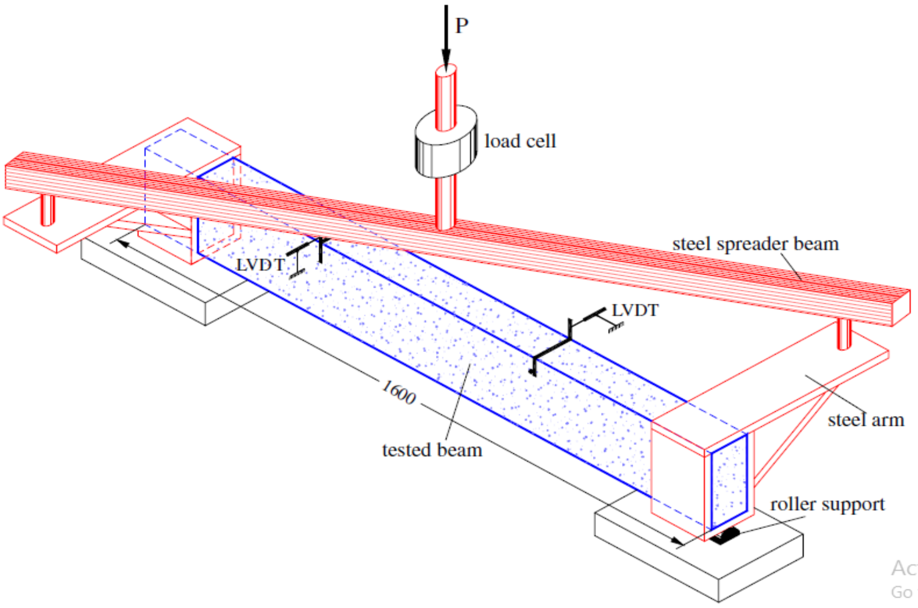

Figure 1: Beam used in validation test

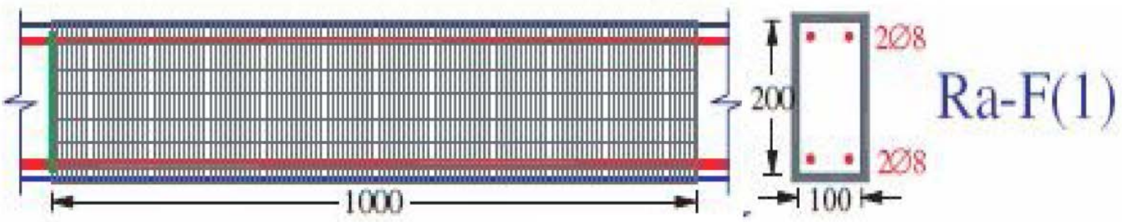

Figure 2: RA-F(1) beam

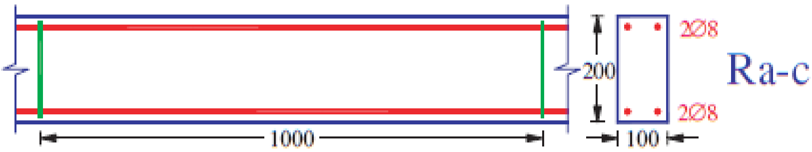

Figure 3: RA-F(c) beam

The reinforcement conditions of beams are in such a way that their failure is of torsional. After modeling and nonlinear static analysis of samples, the accuracy of numerical model was confirmed based on the twist-twisting angle diagram and mode of torsional shear failure. The diagrams under the twist-twisting angle cure of mentioned beams in finite element method and with the help of ABAQUS software have been drawn.

Ra-c diagram is the amount of twisting angle in the range of 0.10 rad/m and the maximum obtained torsional moment has been 2.54 N.mm. In experimental beam the amount of twisting angle and torsional moment have been reported 0.1 rad and 2. 4 N.mm, respectively. Difference in results of experimental sample and the modeled beam in this range is about 1.5%. And also in the maximum amount of twisting angle equal to 0.10 rad/m, this difference of torsional moment reaches to 7% [14].

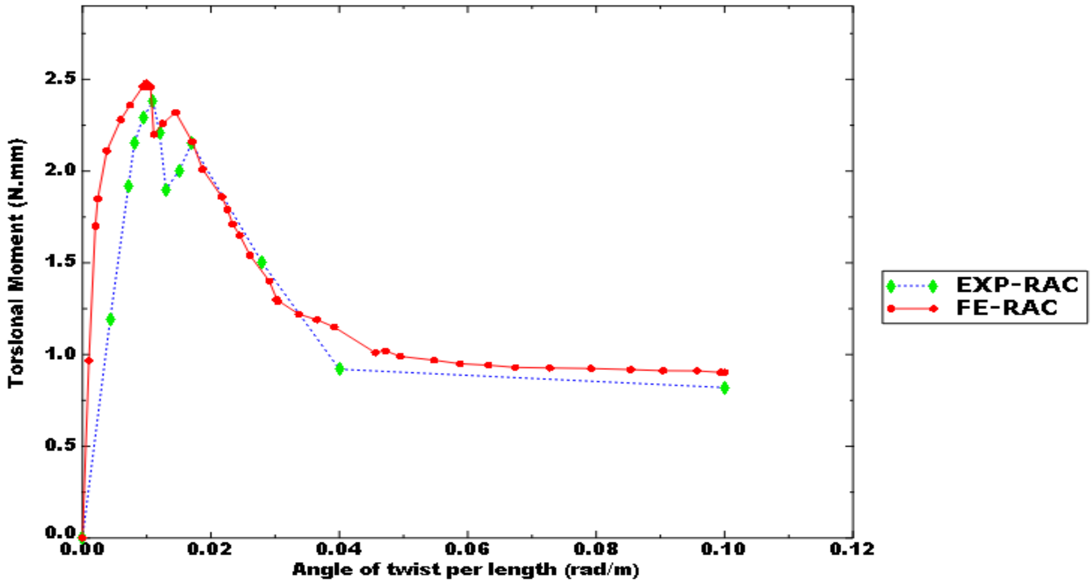

Diagram 1: Validation of beam RA-F (C)

In diagram related to RA-F 1 the amount of twisting angle is 0.072 rad and the obtained torque (twisting force) at maximum twisting angle has been 4.53 N.mm. In experimental beam the amount of twisting angle and torsional moment are 0.072 rad and 4.86 N.mm, respectively. Difference between the results of experimental sample and the modeled beam in this range is 7 percent. And also at minimum twisting angle equal to 0.043 rad/m, this difference of torsional moment reaches to 12%.

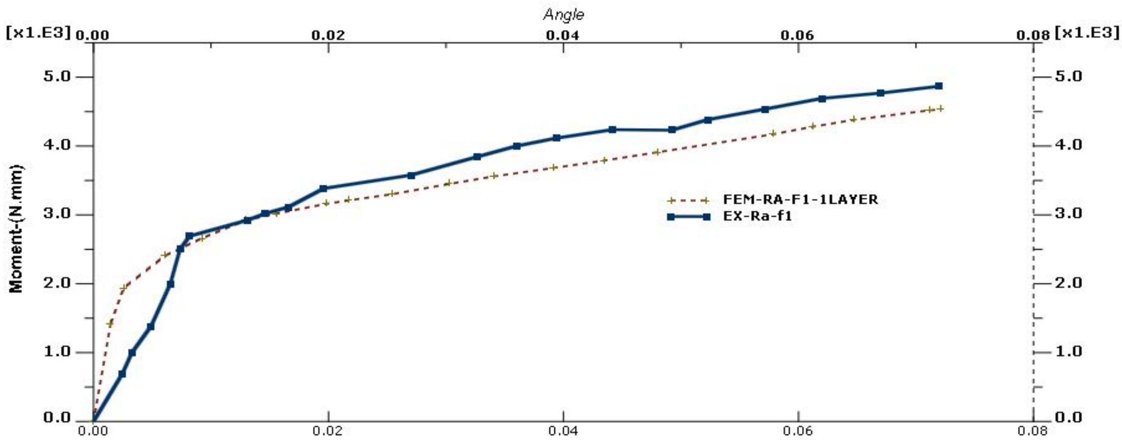

Diagram 2: Validation of beam RA-F (1)

7. Modeling of beams strengthened in twist with CFRP composites

After validation of the control beams, we focus on the modeling of reinforced beams. In laboratory, all beams have been strengthened in terms of twist with CFRP sheets and by attaching them to outer side of the beam. In numerical modeling by knowing the elastic specifications and failure model of Damage FRP, we assign these specifications to the strengthening sheets. The following Figures show the strengthening of beams using CFRP sheets.

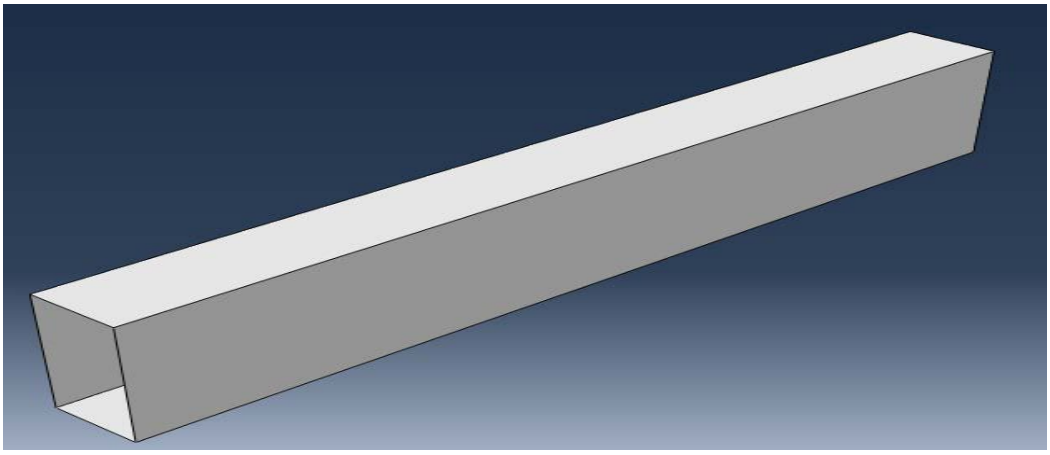

Figure 4: RA (3)

Beam RA-3 that in terms of shape is completely wrapped and has been strengthened with 2 layers of CFRP could withstand the most torsional moment equal to 6.13 N.mm at twisting angle of 0.072 rad/m.

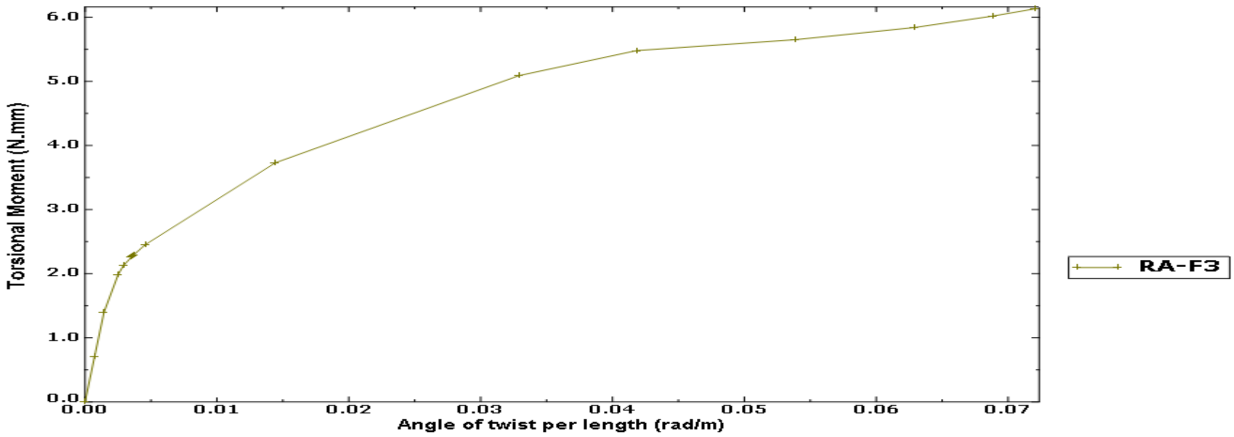

Diagram 3: Twisting angle- torsional moment of Ra-3

Beam RA-f 3.1 that in terms of shape is completely wrapped and has been strengthened with 3 layers of CFRP could withstand the most torsional moment equal to 7.9 N.mm at twisting angle of 0.072 rad/m.

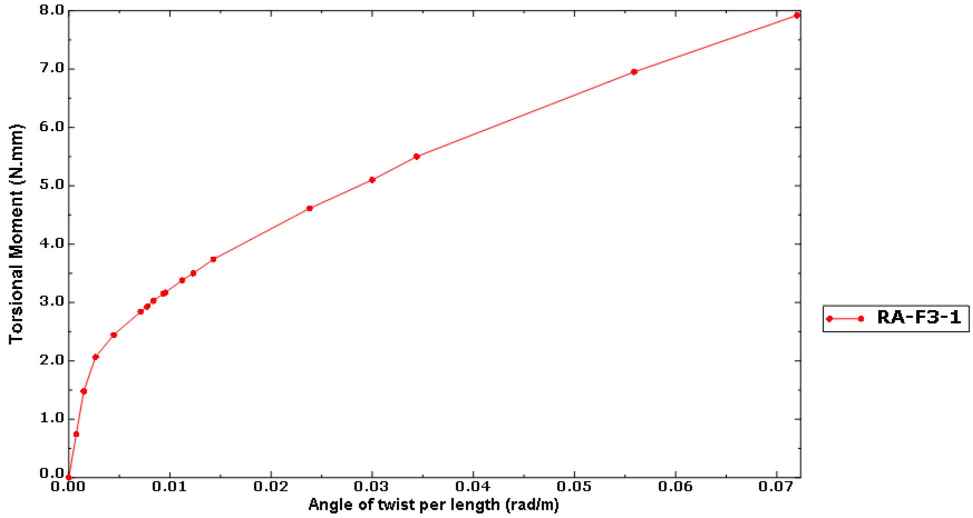

Diagram 4: Twisting angle- torsional moment of RA-f 3.1

8. Specifications of beams used in the actual modeling

In modeling, we have investigated the beams strengthened with a fully wrapped layer of CFRP. In this beam two shear bars with diameter of 8 mm in 2 points with a distance of 50 mm from the support, two compressive bars with diameter of 10 mm on the top of the beam and two tensile bars with diameter of 10 mm on the bottom of the beam and for a beam section with dimensions of the width 100 mm, height of 200 mm and length 3000 mm, have been used. All specifications of concrete, steel and CFRP sheet have been brought in previous chapter. Twisting angle has been considered constant that by means of obtained studies is 0.03 rad/m and 0.09 rad/m for simple real beams (without composite) and strengthened beams, respectively (we call real beams as RB).

Beam Rb-1 that in terms of shape is without FRP, could withstand the most torsional moment equal to 40.33 N.mm at twisting angle of 0.03 rad/m.

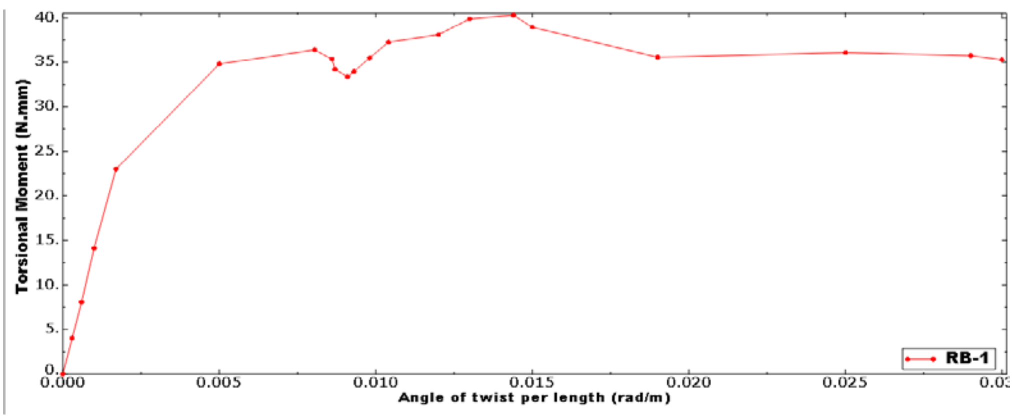

Diagram 5: Twisting angle- torsional moment of simple real beam RB-1

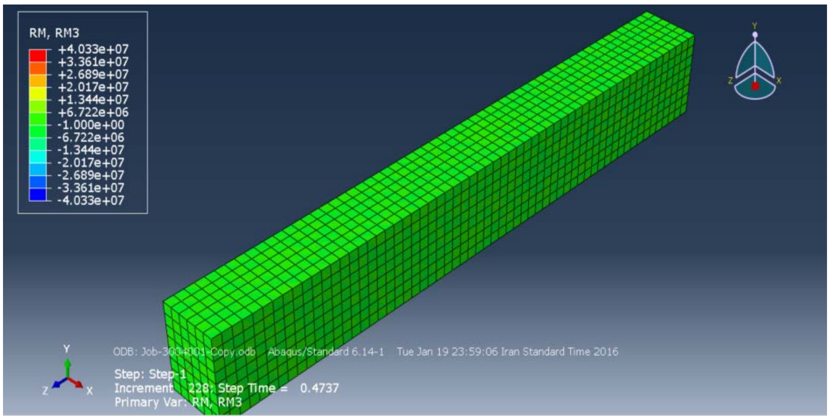

Figure 5: Torsional moment of RB-1

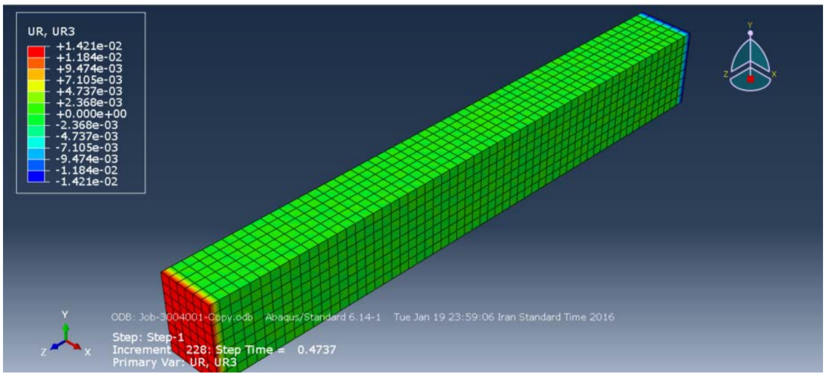

Figure 6: Twisting angle of RB-1

Beam Rb-2 that in terms of shape is completely wrapped and has been strengthened with a layer of CFRP, could withstand the most torsional moment equal to 53.15 N.mm at twisting angle of 0.09 rad/m.

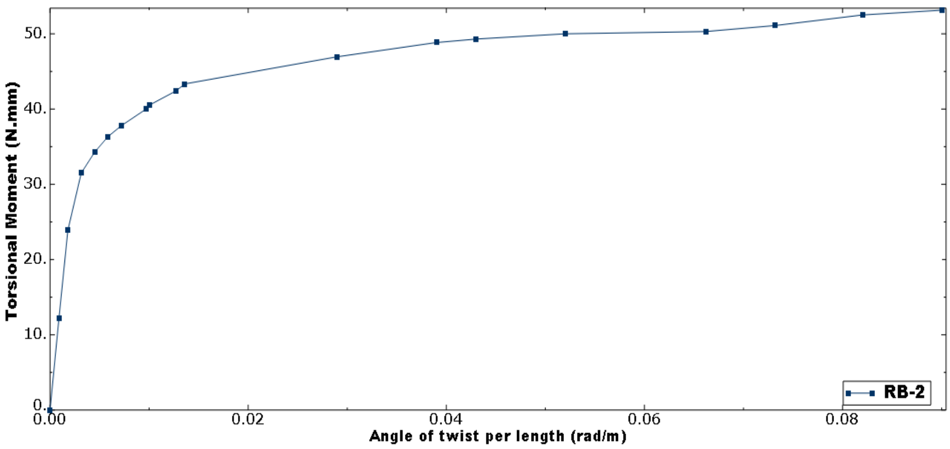

Diagram 6: Twisting angle- torsional moment of real beam RB-2

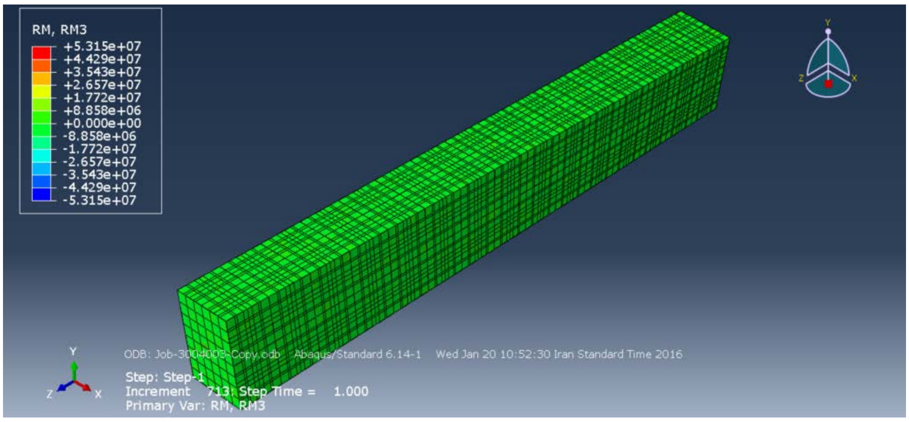

Figure 7: Torsional moment of RB-2

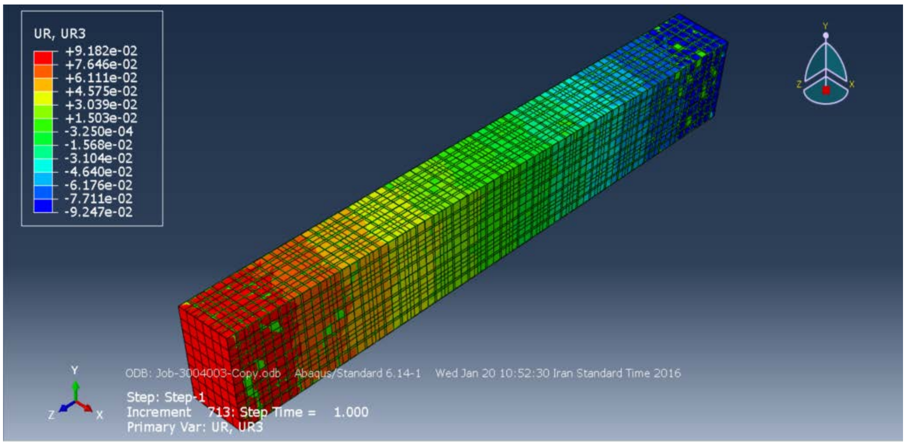

Figure 8: Twisting angle of RB-2

9. The Use of Hashin Damage

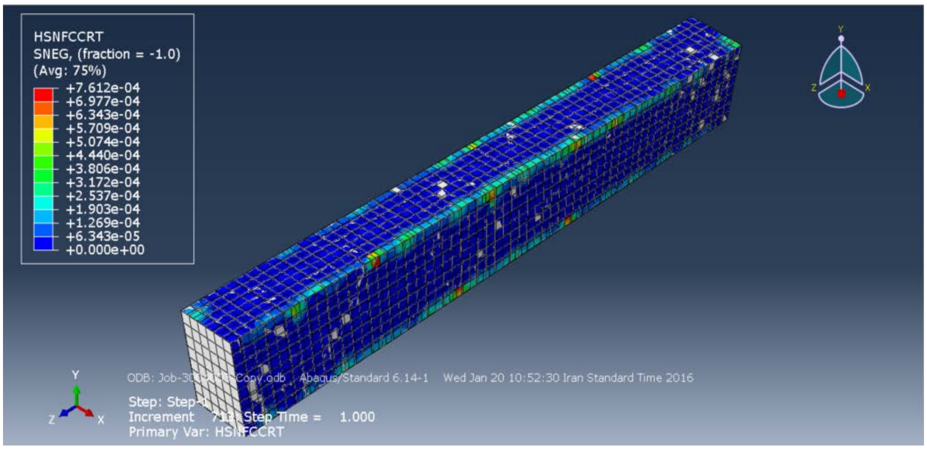

Figure 9: Compressive failure of fibers RB-2

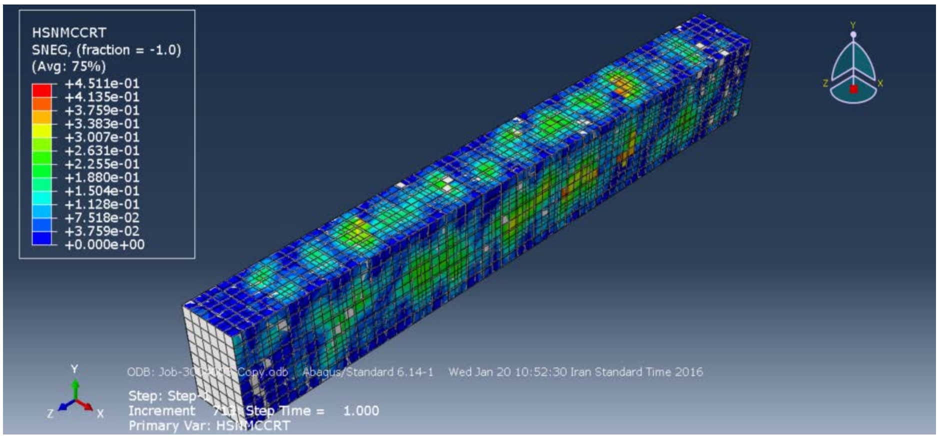

Figure 10: Compressive failure of matrix RB-2

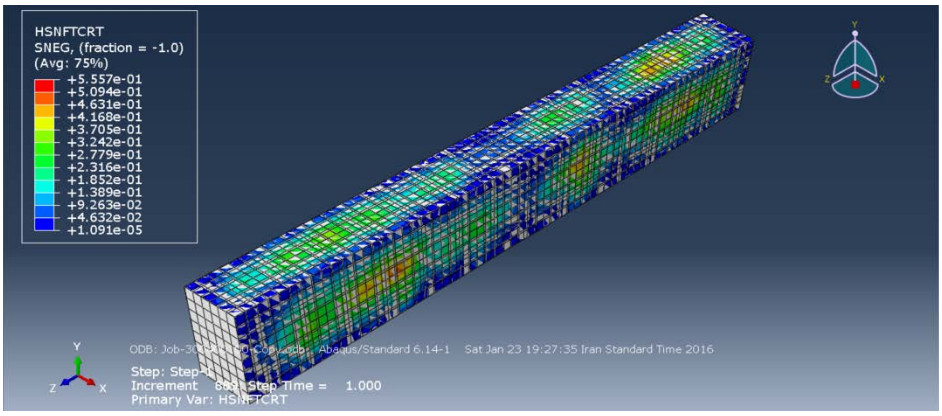

Figure 11: Tensile failure of fibers RB-2

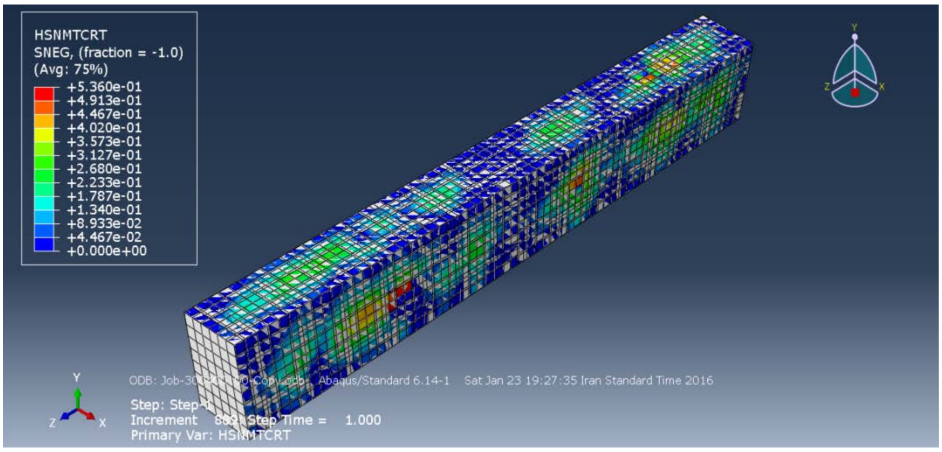

Figure 12: Tensile failure of matrix RB-2

Beam RB-3 that in terms of shape is completely wrapped and has been strengthened with 2 layers of CFRP, could withstand the most torsional moment equal to 64.41 N.mm at twisting angle of 0.09 rad/m.

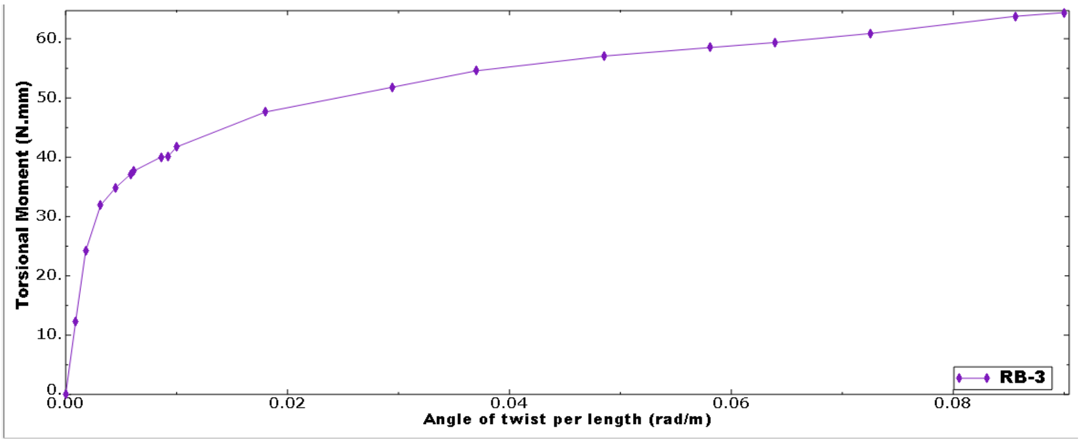

Diagram 7: Twisting angle- torsional moment of real beam RB-3

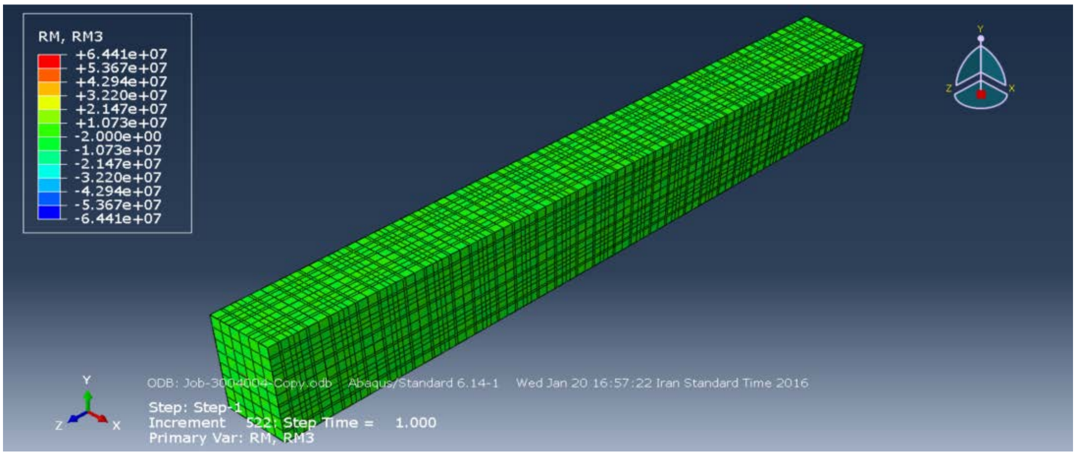

Figure 13: Torsional moment of RB-3

Beam RB-4 that in terms of shape is completely wrapped and has been strengthened with 3 layers of CFRP, could withstand the most torsional moment equal to 74.71 N.mm at twisting angle of 0.09 rad/m.

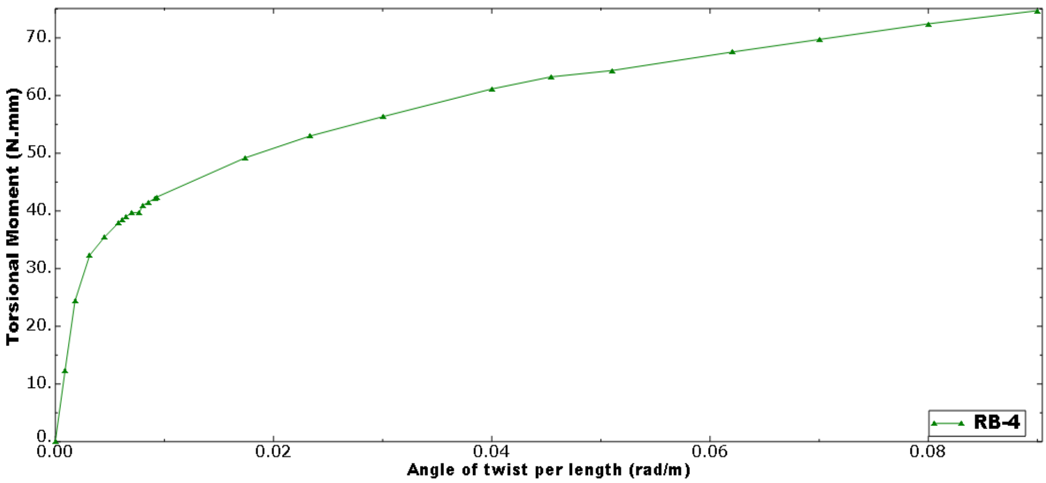

Diagram 8: Twisting angle-torsional moment of real beam RB-4

Conclusion

Comparison of beams RA-1, RA-3 and RA-3.1 shows that in conducted strengthening, RA-3.1 withstands the most torsional moment which is 7.9 N.mm. Also the torsional moments in beams RA-1 and RA-3 are 4.53 and 6.13 N.mm, respectively.

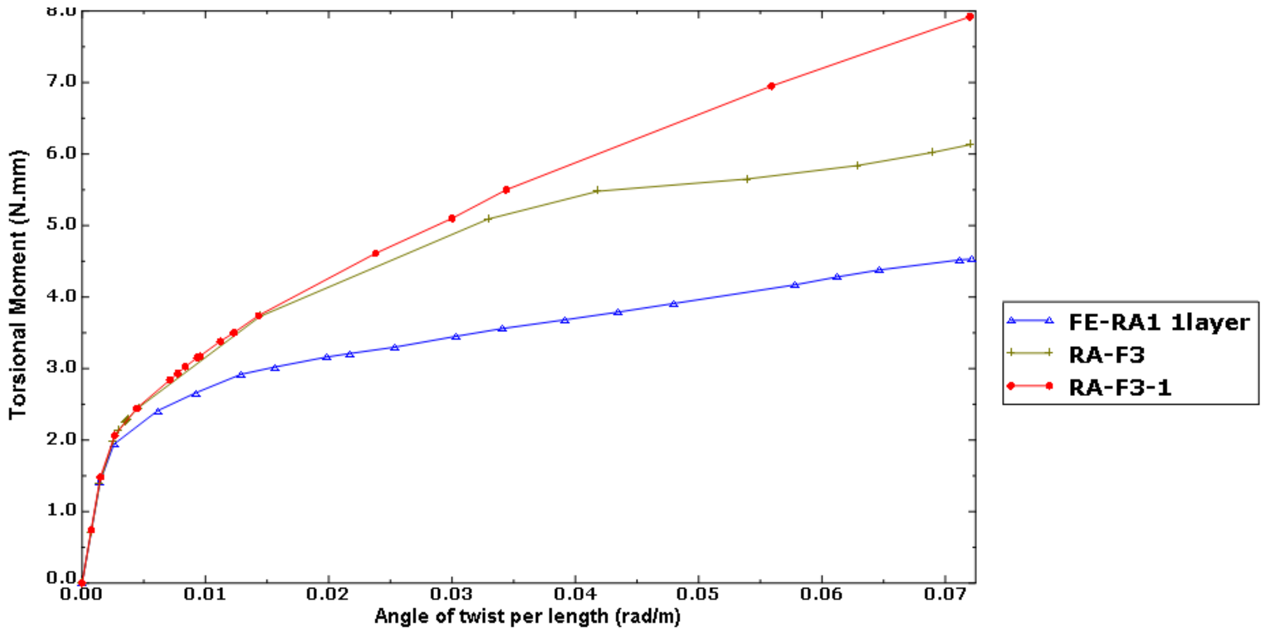

Diagram 9: Twisting angle-torsional moment of RA-1, RA-3 and RA-3.1

Comparison of beams RB-2, RB-3 and RB-4 shows that in conducted strengthening, RB-4 withstands the most torsional moment which is 74.71 N.mm. Also the amount of reduction in resistance of torsional moments of beams RB-2 and RB-3 relative to RB are 19 and 40 percent at the time of beam failure.

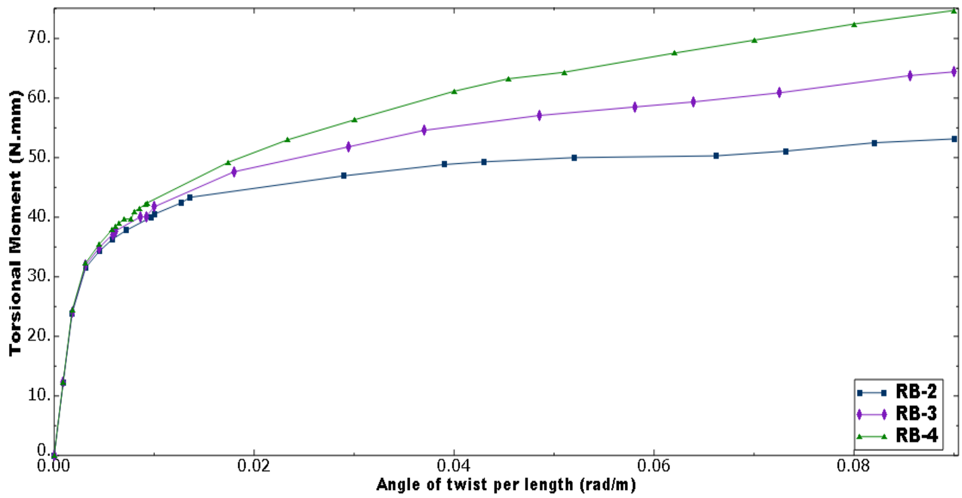

Diagram 10: Twisting angle-torsional moment of real beams RB-2, RB-3 and RB-4

1- Control chart of unstrengthened beam experienced torsional failure.
2- In beam RA-3.1 after strengthening with 3 layers, torsional capacity of beam is 211% more than unstrengthened control beam RA-c.
3- In beam RA-3 after strengthening with 2 layers, torsional capacity of beam is 141% more than control beam.
4- In beam RA-F1 after strengthening with a layer, torsional capacity of beam is 78% more than unstrengthened control beam.
5- In beam RA-3 compared to beam RA-3.1 by increasing wrapped layer from 2 to 3, the increase in torsional capacity is 28%.
6- In beam RB-2 that has one wrapped layer than beam RB-1 that is a control beam without strengthening, torsional strength has increased 32%.
7- In beam RB-3 that has two wrapped layers than beam RB-1 that is a control beam without strengthening, torsional strength has increased 60%.
8- In beam RB-3 that has one wrapped layer than beam RB-1 that is a control beam without strengthening, torsional strength has increased 85%.

Footnotes

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