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The Behavior of Reinforced Concrete Beams Added Cold-Formed-Steel as Shear Reinforcement

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Abstract: This paper presents an experimental study of concrete beams with cold-formed steel added as shear reinforcement. Cold-formed steel (CFS), also called light gauge steel or metal studs, is cold-formed into "C" or "Z" shaped members, capable of holding heavy loads. "Cold-Formed" means the sections are shaped at room temperature by guiding the steel through a series of rollers. Previous researchers have shown that CFS generally has a yield stress of 350 MPa to 550 MPa, but its use is mostly focused on anticipating beam bending. The purpose of this study was to determine the behavior of concrete beams with CFS added as a stirrup to increase the shear capacity of the beam. Two beams have been made with a size of 150x250x860 mm using the same 6D10 flexural reinforcement. One as a control beam (SB-C) using steel bar stirrups Ø5-200mm, the other as a beam added to CFS as stirrup reinforcement (SB-CFS) with a CFS cross section 20 mm wide, 0.75 thick mm and 120 mm CFS stirrup spacing. The test is carried out by applying a one-point loading in the middle of the span of the beam so that the a/d ratio is 1.36. The parameters to be recorded are the capacity of the beam, the deflection that occurs, and the stiffness of the beam. The test data have been compared with the theoretical analysis results using the numerical software Response-2000. The results have shown that the increase in the shear capacity of the beam with the addition of CFS is 12.7% even though, according to Response-2000 analysis, it is 38.7%. The failure that occurs is shear failure according to the predetermined a/d ratio.

Keywords: Shear capacity, cold-formed steel, stirrup, Response-2000

1. Introduction

Structurally, concrete does not have high strength, particularly in resisting shear stress due to bending. According to [1], failure in reinforced concrete is generally caused by flexural, shear, or torsional stress. The shear stress that occurs is generally in the form of a combination with other stresses. In order for the beam to withstand shear strength, the shear bar in the form of inclined reinforcement or stirrup is required.

Many studies have been carried out on the types of reinforcement and materials that can withstand the shear stress of the beam, starting from adding fiber to the beam [2, 3, 4] replacing the stirrup bar with sago fiber [5], comparing the behavior of the beam with and without stirrup bar [6], varying the angle of installation of stirrup reinforcement with a/d beam ratio [7], and finally checking the shear capacity of the beam using high strength concrete [8].

Increasing the capacity of concrete structural elements has recently become a concern, this is because structural elements are often found that have decreased capacity. This decrease was caused by extreme environmental conditions, overload, poor quality of materials, and poor construction execution.

As a result of excessive loading, shear stress arises, which will cause shear cracks which are generally found in the beam support. Furthermore, the shear crack will spread diagonally toward the center of the beam span. One method that can be chosen to fix this problem is by strengthening. [9] conducted a study on adding stirrup reinforcement to external

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beams as strengthened. The result was only an increase in shear capacity of 31% from the target increase of 137% but could increase the beam's stiffness. [1] perform strengthened by adding beam dimensions, flexural, and shear reinforcement. The result can increase the shear capacity by 196% and increase stiffness but not increase ductility.

The increase in the shear capacity of the beam is also carried out by strengthening using FRP on the outside of the beam by [10-12]. However, the presence of epoxy resin in the FRP strengthening systems results in some drawbacks including low compatibility with the concrete substrate, poor performance at elevated temperatures, and irreversibility [13]. In addition, the failure that often occurs is the release of FRP from the concrete. This causes an increase in capacity with external additions to the beam using FRP to be ineffective.

On the other hand, CFS is one of the materials with a yield or tensile strength higher than reinforcing steel. CFS has a general yield stress of 350 MPa to 550 MPa [14]. The advantages of using CFS as a material are lightweight, has a variety of shapes and configurations, easy to install and transport, and most importantly corrosion resistant.

Currently, the use of CFS as a building material is still focused on beams on composite beams between CFS and concrete slabs. In addition, several studies have also been conducted on CFS as flexural reinforcement in concrete beams or slabs with various configurations of sizes and shapes of CFS. Become an externally strengthened material with a variety of connectors [15]. Become a cover of square cross-section concrete blocks. And research on the transfer of forces on CFS as a beam element [16].

Referring to some of these discussions, this paper discusses the addition of CFS as stirrup reinforcement in reinforced concrete beams. The hope is that it can solve the problems previously described, especially in increasing the shear capacity of beams to withstand loads because until now, there has been no use of CFS as an additional shear reinforcement.

2. Methods

The stages of the research are carried out as described below:

- Preliminary analysis is carried out to determine the dimensions of the beam and the number of bars. The limitation of the maximum load given by the tool in the laboratory is a priority in determining the dimensions. It also refers to the theory of a/d ratio and shear failure. The results of the initial analysis obtained beam dimensions of 150x250x860mm with 6D10mm as tensile reinforcement, 2Ø5mm as compression reinforcement, Ø5 - 200 mm as stirrup reinforcement, and 20x0.75mm CFS as additional stirrups with a spacing of 120 mm.
- Testing the concrete forming material properties such as grading, water content, bulk specific gravity, water absorption, and fineness modulus, as well as the specific gravity of cement.
- Testing the tensile strength of the reinforcing bar and CFS.
- Making test specimen as a control beam (SB-C) with bar stirrup, as shown in Fig. 1.

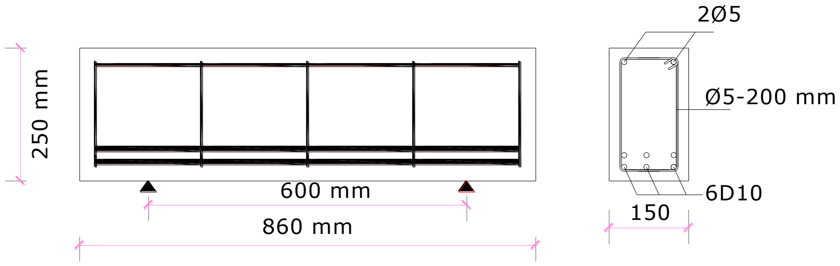

Fig. 1 - SB-C reinforcement sketch

- Making of beam specimens with CFS added as stirrup (SB-CFS). CFS stirrups were made into a rectangular cross-section measuring 20 mm and 0.75 mm thick by cutting CFS C-shape, as shown in Fig. 2 and Fig. 3.

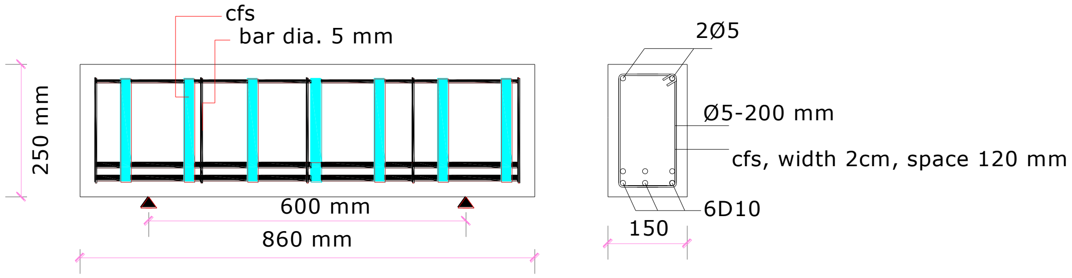

Fig. 2 - SB-CFS reinforcement sketch

Fig.3 - SB-CFS reinforcement

- A cylinder sample with 150 x 300 mm was also made to determine the actual quality of the concrete.
- Flexural testing with one-point load is applied to the beam. The clear span of the beam is 600 mm with the distance from the support to the load is 300 mm. Loading has been carried out with a hydraulic jack equipped with a manometer reading indicator. Tests have been carried out regarding the design load as a result of the initial analysis until the beam collapses. The setting up and loading of beams can be seen in Fig 4. The data taken during this test is data that is commonly used in the form of load and deflection data by reading the deflection that occurs every 2 kN increase in load until the test object can no longer withstand the load.

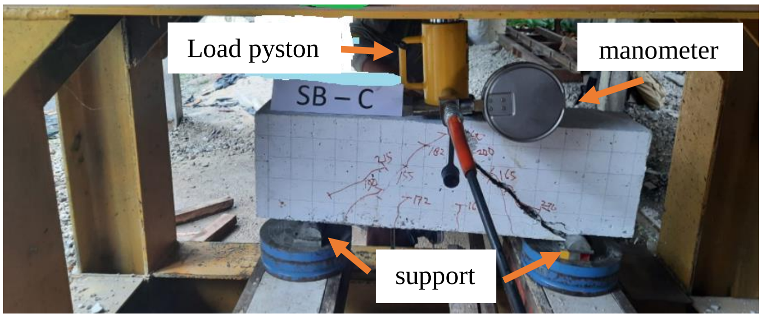

Fig.4 - Setting up of one-point loading

- The results of this experimental test were compared with the analysis results using the Response-2000 software. In Response-2000, beams are modeled in the same way as laboratory test objects, including data on concrete quality, bar and CFS yield stress, and loading with one-point load in the middle of the span.

3. Result and Discussion

3.1 Properties Materials

The results of testing the properties of coarse aggregate, fine aggregate, reinforcing bar, and CFS can be seen in Table 1 and Table 2. The design of the composition of the quality of the cylinder concrete used produces a concrete strength of fck 19.58 MPa.

Table 1 - Test of aggregate

Test	Fine aggregate	Coarse aggregate
Grading size	Zone II	40 mm
Water content	3.43%	3.01%
Bulk Specific gravity on SSD	2.58	2.57
Water absorption	1.32%	0.57%
Fineness Modulus	2.43	7.30

Table 2 - Test of bars and CFS

Type of bars	Yield strength, fy (MPa)	Ultimate strength, fu (MPa)
R5	435.71	600.57
Y10	425.80	606.24
CFS	507.13	518.03

3.2 Response-2000 Analysis

Data on material properties as in Table 2 is used to analyze beam capacity using Response-2000 software. The modeling in Response-2000 is carried out in half the beam span, both for the control beam (SB-C) and the beam with the addition of CFS (SB-CFS). Modeling in Response-2000 was carried out on half of the beam span, both for control beams (SB-C) and beams with the addition of CFS (SB-CFS). The half-span modeling is prepared by Response-2000 because the same geometry of the test object and one-point load in the middle will give the same shear results between the left and right supports. The modeling and results of the analysis can be seen in Table 3, Fig. 5, and Fig. 6. Fig. 6 shows that the shear reinforcement has the yield and this is also the case with SB-CFS.

Table 3 - Response-2000 beam analysis

Specimens	Moment, M_t (kNm)	Shear, V_t (kN)
SB-C	19.56	65.20
SB-CFS	27.12	90.40

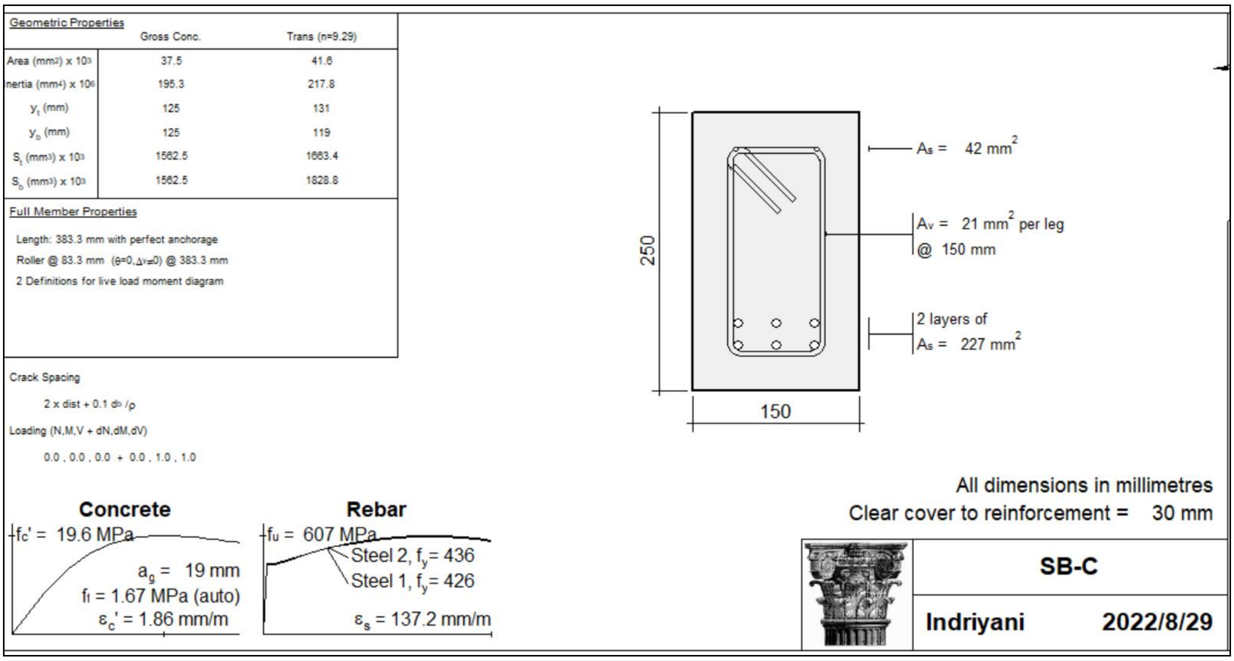

Fig. 5 - Modelling of SB-C with Response-2000

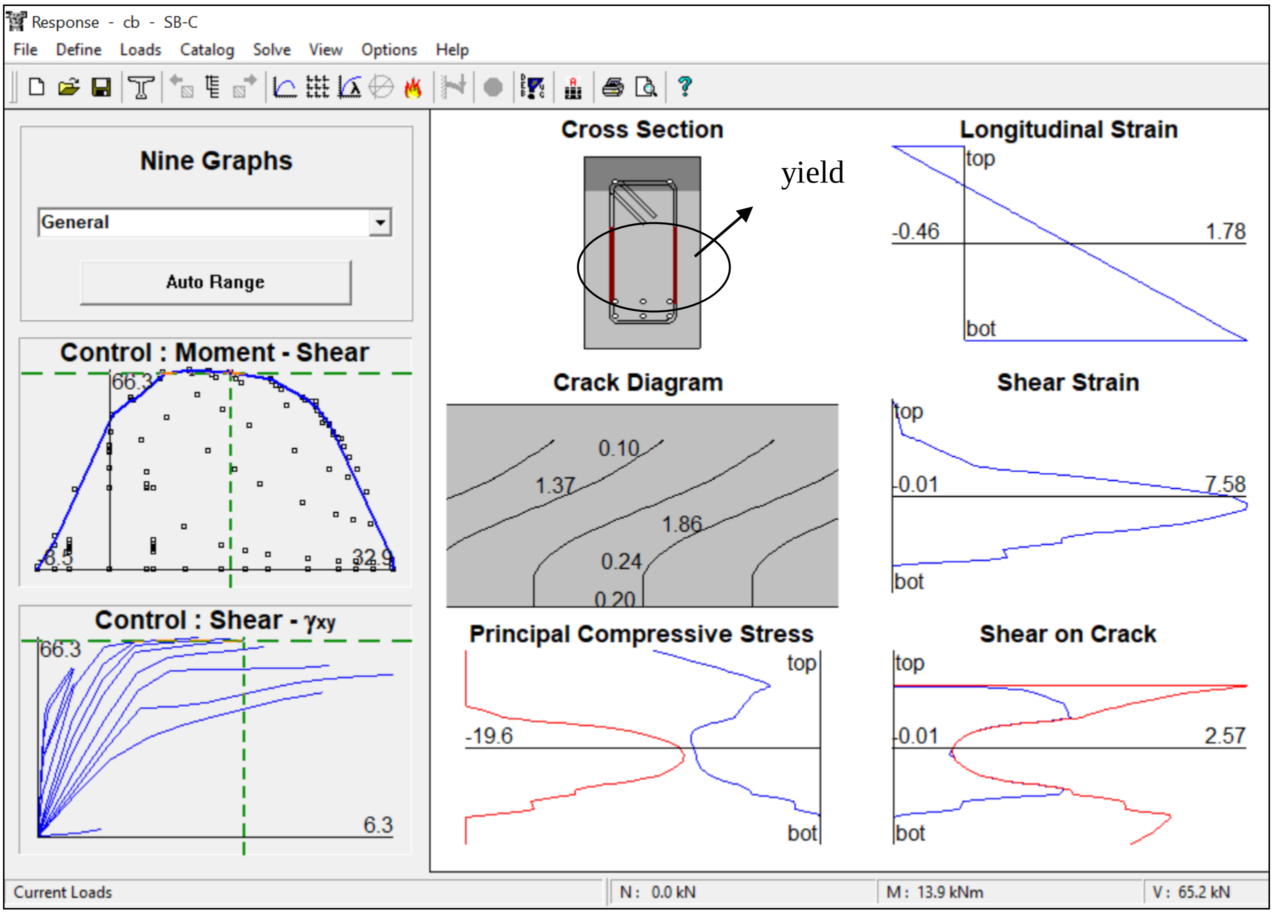

Fig. 6 - Analysis of SB-C

3.3 Beam Capacity Experimental Test

The relationship between load and deflection of the test results can be seen in Fig. 7. Furthermore, it is known that the behavior of the SB-CFS and SB-C beams is almost the same, which can be divided into three stages, pre-cracked, cracked, and post-failure. Pre-crack conditions, the SB-C curve is still linear until it reaches the post-failure stage. Meanwhile, in the SB-CFS beam at the pre-crack stage, the curve still tends to be straight and even coincides with the SB-C curve. As the load increases, the curve becomes slightly sloping and continues to the crack enlargement stage. Then it ends with the post-failure stage, which is marked by a decrease in load-bearing ability and an increase in deflection.

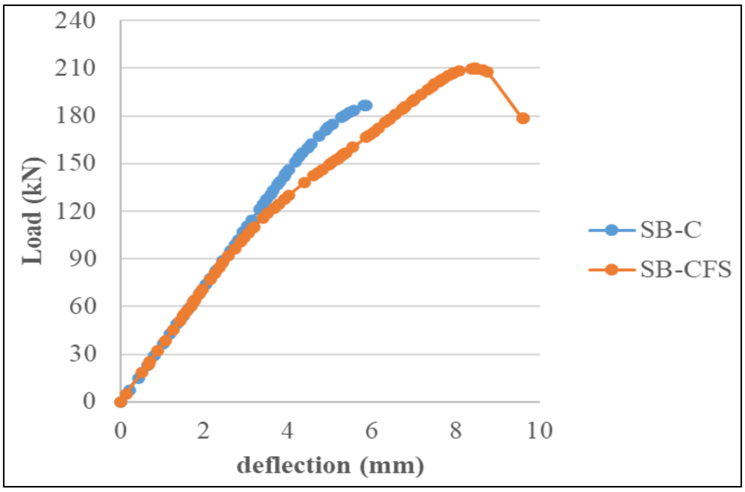

Fig. 7 - Load vs deflection

The SB-C specimen had a sudden collapse when it reached maximum load. This is different from the SB-CFS; the beam still experiences an increase in deflection along with a decrease in the load that occurs. It can be concluded that the SB-C beam is more brittle than the SB-CFS beam.

Table 4 shows the results of experimental studies conducted on both beams. As a result, SB-CFS beams have 12.7% higher capacity than SB-C beams. This means that adding CFS as reinforcement in stirrups can increase the capacity of concrete beams. This increase can be categorized as large when compared to several other studies, such as [17], which only increased by 1,0% in beam reinforcement using Carbon Fiber Wrap, [6] beams with stirrups increased by 5.45% in capacity compared to beams without stirrups.

Table 4 - Beam test result

Specimens	Load (kN)		Shear, Vu	Moment	Deflection
	First crack	Ultimate	(kN)	(kNm)	(mm)
SB-C	110	186.37	93.18	27.95	5.87
SB-CFS	137	210.00	105.0	31.50	8.46

Based on the ratio between the shear span and the effective depth of the beam or a/d, the SB-CFS and SB-C samples were 1.36. This ratio is small because it is smaller than 2.0. The increase in beam shear capacity is inversely proportional to the increase in a/d ratio. The smaller the a/d ratio, the higher the increase in beam shear capacity [8]. The results obtained in this study follow the theory because a small ratio, results in an increase that is categorized as large, namely 12.7%.

3.4 Stiffness

The beam stiffness review is divided into two parts, namely the initial stiffness is the stiffness obtained at the beginning of loading until the first crack (crack stiffness), and the second is the stiffness obtained from the maximum load. The results of the stiffness calculation can be seen in Table 5.

Table 5 - Stiffness of beams

Specimens	Deflection (mm)		Stiffness (kN/m)	
	First crack	Ultimate	First crack	Ultimate
SB-C	3.04	5.87	0.036	0.031
SB-CFS	4.38	8.46	0.031	0.024

Table 5 shows that SB-CFS has less stiffness than SB-C. In the first crack condition, the stiffness of SB-CFS decreased by 13.5% and in the ultimate condition it decreased by 21.8%. This decrease occurred due to the large deflection experienced by SB-CFS at the time of first crack and ultimate even though there was an increase in load. This shows that using of CFS as an additional shear reinforcement can reduce the stiffness value of the beam, or in other words, the addition of CFS on the internal beam makes the concrete beam more ductile.

3.5 Comparison of Experimental Results with Theoretical Results of Response-2000

Test data that has been obtained through experimental, then compared to the theoretical data from Response-2000. Moments and shears that have been obtained experimentally and theoretically can be seen in Table 6.

Table 6 - Experimental vs theoretical result

Specimens	Moment (kNm) and Shear (kN)		Ratio	
	Mu/Mt	***Vu/Vt***	***Mu/Mt***	***Vu/Vt***
SB-C	27.95/19.56	93.18/65.20	1.42	1.42
SB-CFS	31.50/27.12	105.0/90.40	1.16	1.16

Table 6 shows that the increase in the theoretical plan was 38.7% while what occurred in the experiment was only 12.7%. This difference can be caused by the quality of the concrete or the density of the specimens that are not homogeneous as in numerical software. However, adding CFS as stirrups increases the shear capacity of the beam.

3.6 Crack Pattern

The first crack in the SB-C test object occurred at a load of 110 kN, namely a diagonal crack from the support to the load point. As the load increases, cracks appear in the middle of the span from the bottom to the load as shown in Fig. 8. Furthermore, when the load reaches 186.37 kN, the SB-C collapses suddenly or is brittle. It can be seen that the crack pattern that has occurred in SB-C is a shear failure.

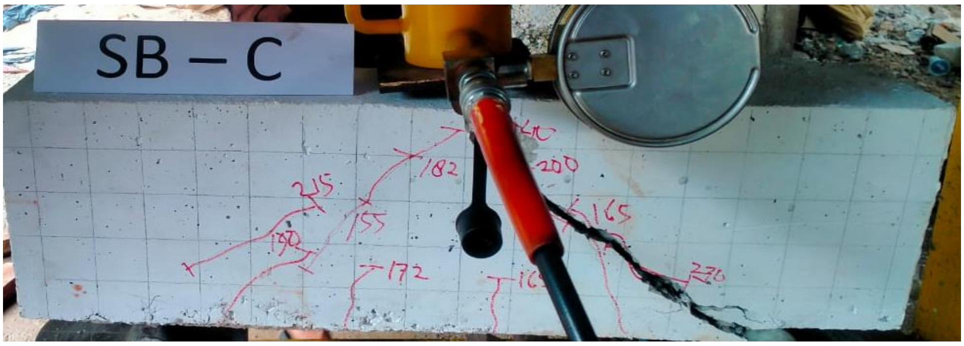

Fig. 8 - SB-C crack pattern

The first crack occurred when the beam received a load of 137 kN for the SB-CFS test object. Cracks are diagonal lines from the support to the load point. As the load increases, diagonal cracks also appear in other parts. Until it reaches the maximum load of 210 kN, the cracks in the SB-CFS continue to widen. Then there was a sudden collapse after the load decreased by 15%. Overall, SB-CFS occurs in shear failure. However, when compared to the cracks that occurred in these two specimens, the crack width in SB-CFS is lesser than that of SB-C, as shown in Fig. 9.

Fig. 9 - SB-CFS crack pattern

4. Conclusion

In this paper, the following conclusions can be drawn:

a. The addition of CFS as a stirrup can increase the capacity by 12.7%.
b. There is a decrease in stiffness of 21.8% in the SB-CFS beam; on the other hand, it makes the beam more ductile.
c. Compared with the results of theoretical calculations, the ratio of the increase in experimental shear capacity and Response-2000 is 32.8%% smaller.
d. Overall, the failure that occurred was a shear failure on the two beam specimens.

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