# EXPERIMENTAL INVESTIGATION ON BOX-UP COLD-FORMED STEEL COLUMNS IN FIRE

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**ABSTRACT:** Cold-formed steel is a popular material with various advantages. Its easy production and assembly give engineer an option to speed the construction process. However, thinness relates to the major issue of buckling, especially when dealing with high temperature. The unprotected cold-formed steel behaviour under fire is expected to have a little strength as compared to hot-rolled steel. Information on such behaviour is still limited. Fire resistance testing on built-up box CFS column was presented in this paper. Two fire resistance tests were carried out under compression load. The Standard ISO 834 Fire Resistance Test under 50% and 70% degree of utilisation measured the temperatures at several points of the steel column surface by using a surface thermocouple and axial column deformation. For reference purpose, one same static test at ambient temperature was carried out to assess the load bearing capacity. Results found that the failure temperature of built-up CFS could reach up to 515 ℃ and 443 ℃ within 8 minutes and 7 minutes resistant time for 50 % and 70% degree of utilisation, respectively. Based on deformation analysis, buckling temperature of the column was 448 ℃ and 394 ℃ with a critical time of 7 minutes for 50 % and 70% degree of utilisation, respectively. This concluded that the higher degree of utilisation results in lower critical temperatures of the columns.

*Keywords: Cold-formed steel, Standard ISO 834 fire, Buckling temperature, Buckling time.*

## 1. INTRODUCTION

In the event of a fire, much loss was identified, such as people injury, huge damage, loss of life, loss of capital, and production. Data from the Malaysian Fire and Rescue Department reported that Malaysia was faced with 5,248 fire cases in 2011. Housing was recorded as the highest cases at 2,761 and was dramatically increased from 2001 to 2007 [1]. An efficient method of construction involving innovate building material is the main considerations to support modern building design requirement. Hence, the use of cold-formed steel (CFS) as the main structure, i.e. column, is broadly significant due to its various advantages. The fire safety information about this material is still limited and somehow still unavailable in any practical design guideline. Usually, the technical time is 20 minutes for other structure type, but it was unsuitable for the CFS type of structure. Moreover, CFS failure gives little or even no warning on unlike wood structure with cracking and moaning sounds [2].

Currently, the design of structure on fire is applied as fire safety factors that proposed based on fire testing such as for stainless steel column design under fire condition. Most CFS related research was done under elevated temperature, but not under direct fire, such as real fire stimulation [3] - [8]. This research trend happened because the required information is on the performance of wall made up with an embedded CFS wall which may be covered with a fire retention material. Hence, information on elevated temperature is fairly enough. Moreover, the local buckling failure was observed as similarly as a failure mode in ambient temperature. [9]. Research on CFS at high temperature was broadly explored on the material strength models according to various parameters, such as thickness and steel grade by using CFS from different countries. Hence, the strength of CFS structure was predicted based on these models. Currently, the EN 1993-1-2: 2005 is meant for hot-rolled steel material is also practiced for CFS. The section always considered as Class 4 section. Annex E has stated the reduction factor material property for Class 4 section. The limiting temperature stated in National Annex is 350 ℃ for all degrees of utilisation.

The ISO 834 fire curve is widely used to test the fire resistance of materials under the category "A" fire hazard, i.e. with the fire hazard rating based on the burning rate of general combustible building materials and contents. The study of the cold-formed structural column under fire was conducted by [10] using stainless steel material. A fire design multiplier of 1.37 was used for design buckling resistance. It was valid for stainless steel

hollow column with utilising the buckling resistance design equation in EC3–1.2. The research on cold-formed steel under ISO 843 standard fire was conducted by [11]. The column section was an open channel and built-up I (2C). It was loaded under compression and the heat was generated from an electric furnace. The exposed temperature was lower temperature from the Standard ISO 834 fire curve in the early fire state, might result in column fail at a longer duration. The results show that the CFS had lower resistant time and temperature and the exposed temperature was slightly lower. It has produced a conservative finding. Research conducted by [12] reported that the unprotected restrained column for section factor (F/V) of 424.6 m−1 experienced a temperature increase very quickly, almost the same as the atmospheric temperature. The buckling temperature is the temperature at which the axial deformation reaches a maximum value, while the column failure temperature is defined as the temperature at which the axial force in restrained column returns to its initial value.

Previous studies found very limited information of cold-formed steel column exposed to the Standard ISO 834 fire. This research evolution trend may be due to a thickness of cold-formed steel is thin and may fail due to various buckling modes which are unsuitable for column structure. However, adopting the current design guideline, which is mainly used for hot-rolled steel and has clearly different production method, this practice is barely inappropriate. A practical solution for this issue is by conducting a fire test on a cold-formed steel column. The test was conducted in the Construction Research Centre (CRC) at Universiti Teknologi Malaysia in Skudai, Johor. The test involved a box-up column. Two columns with different degree of utilisation were studied. The column was supported on constant constrain. The objective of this study is to evaluate the temperature rise behaviour of CFS column when exposed with the Standard ISO 834 fire.

## 2. MATERIAL AND METHOD

A channel with lipped column was supplied by a local manufacturer in Johor, Malaysia. The channel size is 200 mm depth, 73 mm width of flanges, 17 mm lipped size, the thickness is 1.9 mm, round corner is 2.5 mm and the centroid is 20.38 mm from the web. The column height is 3 m. Each column was constructed as a built-up section by using two identical lipped channel sections. Two of the channel sections were connected at their flanges by using self-drilling screws, at 400 mm c-c spacing along the length. It will form a box-up section with a self-drilling screw in the middle of the flange.

The end column was screwed to the two steel angles at both column webs as in Fig. 1 (a). It used to restrain lateral movement of the column. A circular steel plate was used to place the bottom and top end of the column. It is used to ensure the load was uniformly distributed over the column cross-section**.** Column top was attached in the same manner at the bottom. Meanwhile, fire test support was improved to prevent support expansion due to fire. All steel-end plates, angle and steel-based, were coated with 3 mm high temperature coating paint. 20 mm ceramic fibers, which were covered with steel-based and thermocouple were placed at the bottom of the column to monitor the temperature as shown in Fig. 1 (b) and (c). Temperature measured was less than 100°C.
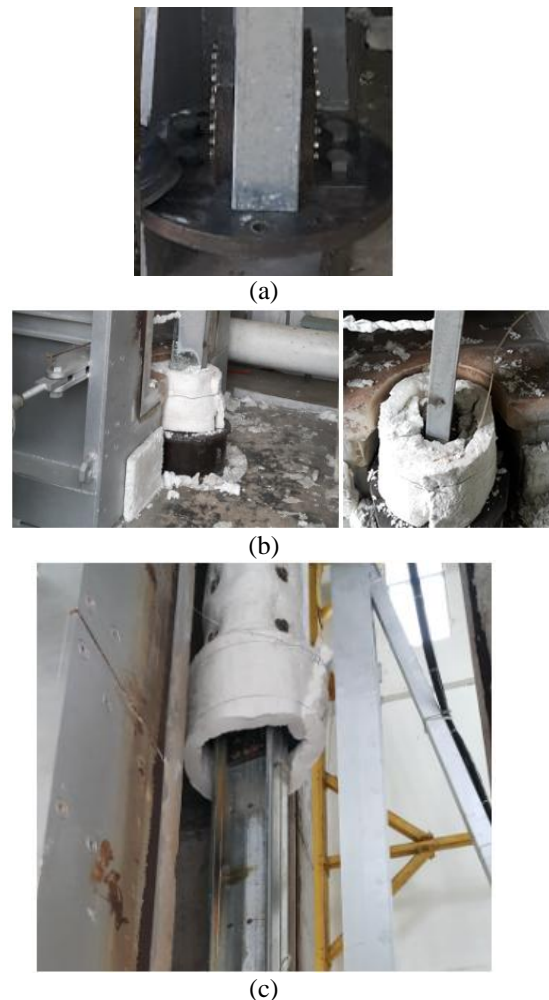

(a)


(b)


(c)

Fig. 1. Support condition of the column.

The rise of temperature data in the column was captured by a surface type K thermocouple. The thermocouple position along the length of the column and in the column section was according to BS EN 13381-4:2013 (E) recommendation. Fig. 2 shows the of the thermocouples position on the column height and at the cross-section. Fig. 3

shows the actual thermocouples attach to the column. Since the column is unrestraint, the axial deformation was allowed during fire exposure. The axial deformation of the column was also monitored based on the actuator movement. The ambient and a series of fire tests were conducted under the same actuator and loading frame. At ambient test, the CFS column was loaded until it failed. During the fire test, the column was loaded till reach a constant load level for 5 to 10 minutes before the fire was introduced into the furnace. The test was stopped until the load dropped, which was considered that the column had failed. A hydraulic jack loading system with a maximum load of 1000kN was used to load the column with a loading rate of 0.25 kN/s.
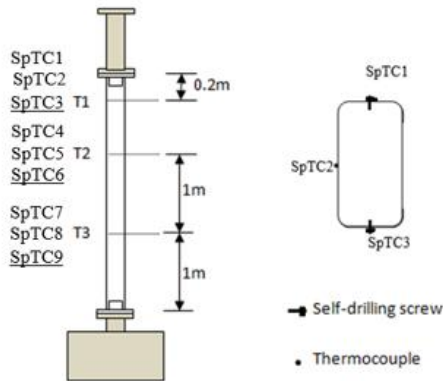


Fig. 2. Location of thermocouple on the column



Fig. 3. Attachment of the thermocouple on the column.

ISO 834 standard fire curve and 15 % percentage deviation (de) from a standard fire curve, as shown in Fig. 4(a), was according to BS EN 1363-1:2012 (E). The graph also plots the furnace average temperature curve for all samples during testing. The furnace consists of six blowers. 3 blowers located at left and right side of the furnace, which by location were at the top side, middle side and bottom side of the furnace. Furnace fire was produced by a gas furnace which transfers heat to the CFS through radiation and convection. Convection will cause the air particles (gases) to spread out and become dense, causing a movement of gases. Cooler gas is dense and warmer gas is less dense and thus causes warmer gases to rise up. Radiation does not require a medium to transfer heat. The CFS shiny surface is poor in absorbing radiation heat.

The furnace pressure should be approximately 8.5 Pa per-metre height within ± 5 Pa after 5 minutes during fire, as recommended in BS EN 1363-1:2012 (E). The pressure inside the furnace was presented in Fig. 4 (b), which shows that the furnace pressure during the fire test was within an acceptable range.
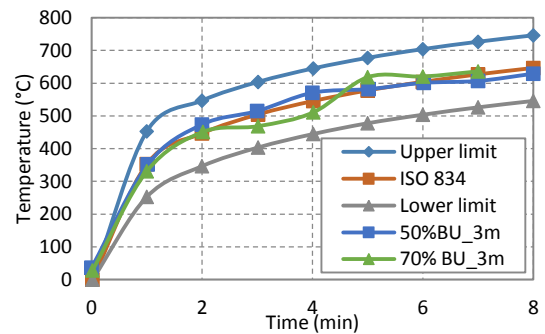


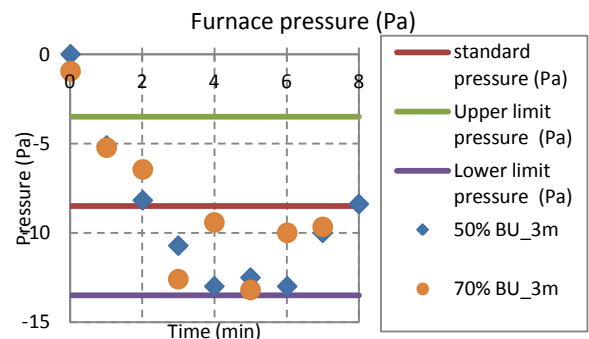Fig. 4(a) Furnace average temperature during testing for Box-up column.



Fig. 4(b) Furnace pressure

## 3. RESULTS AND DISCUSSION

This section explains the step in determining the mean temperature of the CFS column and its

failure time and failure temperature.

## 3.1 Compression strength of cold-formed steel column

The strength test of the column at ambient temperature results that the ultimate compression load is 170 kN. The calculation ultimate load prediction from EC3-1.3 is 162.34 kN. Loading for 50% and 70% degree of utilisation were 85 kN and 119 kN, respectively. It was calculated bases on normal strength test.

## 3.2 Temperature rise in CFS column

Nine thermocouples gave reliable results, whereby the steel temperature rise over time of fire exposure was observed. It was found that the CFS temperature rise was propositional to the fire exposure time for all stations. Thermocouples located at 200 mm from top support and loading were known as SpTC1–SpTC3. The rise of temperature at this location was lower the Standard ISO 834 fire for all degrees of utilisation until the column failed. The rate of temperature rise of 50% and 70% degree of utilisation was similar for all the thermocouples except for SpTC6. This may happen due to uneven fire blow during testing. The rate of temperature rise was also similar for different degrees of utilisation. It can be concluded that the rate of temperature rise of the BU CFS column was constant for CFS and independent to the degree of utilisation. It was found that rise of temperature at the bottom was faster as compared to the top. This may happen because the heat in the furnace was pressured to the bottom of the furnace and may be due to some heat losses from the ceramic fibre on top of the furnace. A technician can feel the temperature around the outer furnace top. The 70% load utilisation failed at lower temperatures as compared to the 50% load utilisation. In addition, the 70% load utilisation had a lower failure temperature than Standard ISO 834 fire curve in contrast with the 50% load utilisation, was failed when approaching the ISO 834 fire curve.

SpTC5, SpTC7, SpTC8, and SpTC9 for 50% degree of utilisation rose up to the Standard ISO 834 fire curve at failure while for 70% degree of utilisation, the column failed at lower temperatures.

SpTC7, SpTC8, and SpTC9 were temperatures at the lower column. SpTC5 was the temperature at 2m from the bottom, specifically at the web of the box-up CFS. SpTC4 and SpTC6 were located at the flanges which had a double thickness, resulting in a lower failure temperature. The greater web thickness and thermal conductance between the two CFS profiles have caused these

respective behaviours [11].

Fig. 5 shows the temperature evolution of CFS column due to different load utilisation. At the beginning of fire exposure until failure time both columns evolved at a uniform temperature and slightly higher temperature at the bottom. The evolution of temperature was independent to the degree of utilisation of the column.
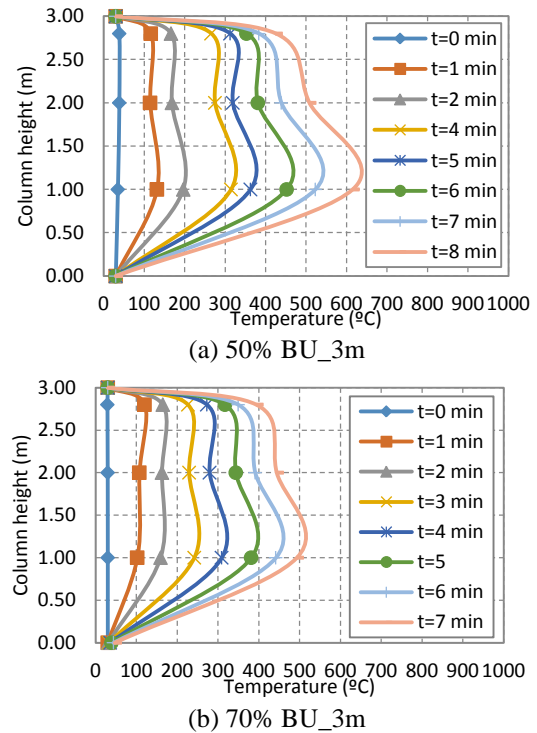


(a) 50% BU_3m



(b) 70% BU_3m

Fig. 5. Temperature evolution along the length of Box-up column

## 3.3 Mean temperature

This section explains the analysis of a mean temperature for the column. The evaluation of mean temperature along the column was calculated by using the weightage area methods in which the temperatures recorded were multiplied to the area of column surface and divided by the total area of the column. This method was applied to account for the area coverage near the thermocouple that represented the flange and web surface temperature. Figure 6 and Figure 7 shows the temperature for 50% and 70% load utilisation, respectively.

Level T1 for 50% load utilisation recorded a similar value for all surfaces as in Fig 6(a). Hence, the average is directly determined by a simple average. As the lower side of the column was high in temperature at, a difference in temperature at respective levels was found. The temperature at web was higher than at the flanges due to the thicker thickness as in Fig 6(b) and (c). However, the difference in temperature was less than 10%, hence the calculated simple average can be

accepted. The analysis was continued with depth detail on the average TL for each column. TL3 resulted in a higher average followed by TL2 and TL1 as in Fig. 6(d). This behaviour was similar to the 70% degree of utilisation. All columns had the same temperature rise behaviour where the upper thermocouple registered a lower temperature until column failure. This may be caused by the thermocouple located nearer to the ceramic fibre which supported the column end. The heat was shielded by a ceramic fibre that restricted the conductance of heat to this position.

To select the appropriate mean temperature for the column, the minimum, maximum and average temperature for each level was plotted. Again, the difference between all values was small, hence the average value was selected. Table 1 shows the mean temperature for each degree of utilisation.
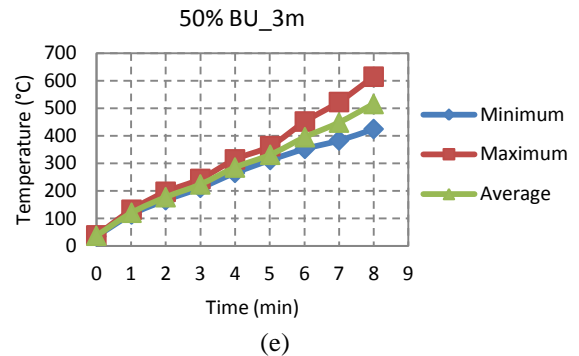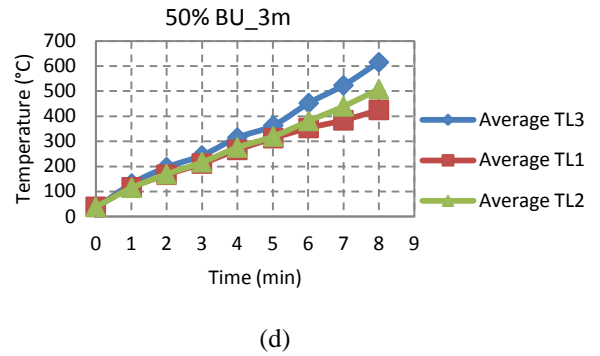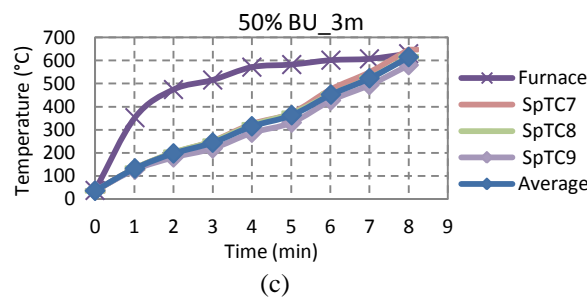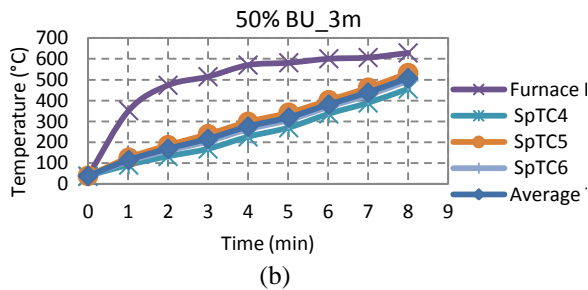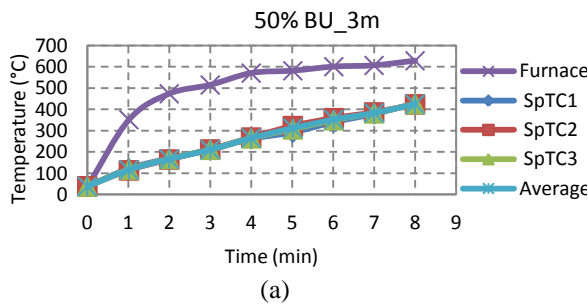
(a)

(b)

(c)

(d)

(e)

Fig. 6    Evaluation of mean temperature along the column for 50 % degree of utilisation

Table 1. Mean temperature of the column

| Time | Degree of utilisation (%) | |
|---|---|---|
| | 50 | 70 |
| 0.0 | 30 | 30 |
| 1.0 | 121 | 110 |
| 2.0 | 177 | 162 |
| 3.0 | 224 | 233 |
| 4.0 | 285 | 287 |
| 5.0 | 331 | 347 |
| 6.0 | 395 | 394 |
| 7.0 | 448 | 444 |
| 8.0 | 515 | - |

**3.4 Failure time and failure temperature**

The consideration in fire safety design is concerned about preventing structural failed before resistant period. The evaluating of the critical temperature steel column is characterised as a uniform temperature all over the column surface. The critical temperature was determined by evaluating the results of the maximum temperature gain from the experiment, the highest values of the average temperature for each thermocouple level, and the highest value from the mean temperature. Fig. 7 plots the temperature values against degrees of utilisation. Furthermore, the safe temperature

value in selecting the critical limiting temperature, the smallest value was considered. As expected, the resistant time was decreased as the degree of utilisation was increased. Then, both the initial and average heating rates were calculated by using the temperature at the first 1 minute, meanwhile the value of the average heating rate was according to the temperature and time of the column at failure. The load applied on the column does not affect the heating rate of the column and this was also reported by [11]. The heating rate of 60 ℃/min was constant for all box-up column. The initial heating rate of 84 ℃/min is higher at for the column due to the rate of Standard ISO 834 was higher at 329 ℃/m at the first 1 minute. The critical temperature of the box-up column was 515.95℃ and 443.77 ℃ and the critical time was 8 and 7 minutes for 50% and 70% degree of utilisation, respectively. The degree of utilisation was increased results in decreasing of critical temperature and time.
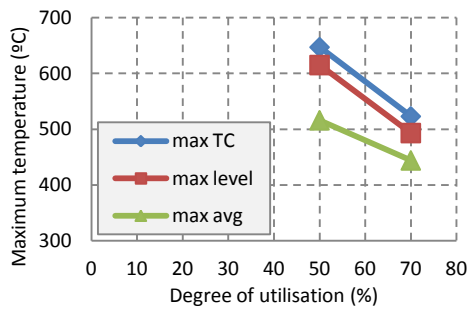


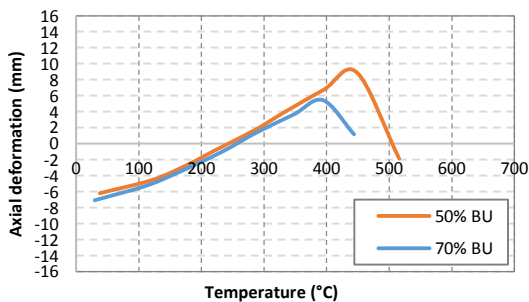Fig. 7 Evaluation of critical temperature



Fig. 8. Variation of axial deformation over the box-up CFS column means temperature.

The axial deformation of the column was analysed against the mean temperature rise of the column and the results were presented in Fig. 8. The column had an initial deformation due to load level application of 50% and 70% load utilisation. The axial deformation was accounted after the column was fired. According to the buckling temperature definition given by [12], the buckling temperature is considered at the maximum axial deformation of the column. It was found that the buckling temperatures of the column were 448 ℃ and 394

℃, with a critical time of 7 minutes for 50 % and 70% degree of utilisation, respectively. This concluded that the higher degree of utilisation resulted in lower buckling temperatures of the columns. Both values, critical temperature and buckling temperature, would be significant in predicting future CFS fire resistance design. Fig. 9 shows the testing configuration and buckling failure of the CFS column under Standard ISO 834 fire exposure.



(a)  (b)

Fig. 9 (a) Test set-up (b) buckling of box-up column

## 4. CONCLUSION

This paper found that the temperature rise in cold-formed steel is independent to the degree of utilisation for box-up CFS columns. According to the recorded analysis for all degrees of utilisation, it can be concluded that there was a constant rate of temperature rise of the Box-up CFS column. The heating rate was 60 ℃/min and the initial heating rate was 84 ℃/min. The temperature behaviour of BTB column showed both degrees of utilisation, the flanges recorded a lower temperature as compared to the flange due to the greater thickness. It was found that critical temperature was 515.95℃ and 443.77 ℃ and critical time was 8 and 7 minutes for 50% and 70% degree of utilisation, respectively. While buckling temperature was 448 ℃ and 394 ℃ with a critical time of 7 minutes for 50 % and 70% degree of utilisation, respectively. Thus, findings concluded that the higher degree of utilisation resulted in lower critical and buckling temperatures of columns. The buckling resistance time was not dependent on the degree of utilisation.

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