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DESIGN OF A 10 TONS OVERHEAD CRANE WITH 21 METERS SPAN USING FINITE ELEMENT METHOD

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Abstract

A crane is a lifting equipment widely used to move cargo, construction sites, storage, and unload. The type of crane that is commonly used in industrial environments is the overhead crane. The overhead crane functions as a lifting device. Besides that, it also works as a load transfer tool even though the load being moved is limited to an environment that is not too large (indoor). At PT. A overhead crane is designed to overcome the problem of moving material in the mold storage area due to the area's expansion and the addition of 5-7 tons of mold material. Therefore, proper design is needed so the overhead crane can function properly. The design method uses the VDI 2221 or finite element with SolidWorks software. The results of the structure obtained are double box girder type girders with the dimensions of p = 21 m, t = 1224 mm, and l = 600 mm. The deflection results are 13.75 mm, and the runway uses steel profile I with the dimensions of 400 x 200 x 8 x 13 mm, with a deflection value at the runway stem of 5.6 mm. The type of wire rope used is type 6 x 37, with a diameter of 28 mm. The stress that occurs in the steel rope is 4306.1 kg, less than the maximum allowable tensile stress of 8009.4 kg. The single hook type with a hook diameter of 120 mm is made of material S45C. The tensile stress on the hook is 0.88 kg, and the result is smaller than the allowable tensile stress of 12.72 kg. The pulley diameter is 630 mm, the drum diameter is 604.9 mm, and the drum length is 279 mm.

Keywords: Overhead Crane, Finite Element, Lifting System, Girder, Tensile Stress

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1. Introduction

The increasing demand for tires in the global market has forced several manufacturers to increase their production units. PT. A is one of the manufacturing industries engaged in the automotive sector, namely, producing tires. The tires made are various types, from small tires such as motorbikes and racing motorbikes to car tires and even mine car tires.

The tire production process goes through various stages, from mixing, material, building, and curing to final inspection. In the curing process, there is pressure on the green tire in a mould which aims to make the final shape and stimulate a chemical reaction between the rubber and other materials[1].

Mould is one of the main components in the curing process. Mould can also be interpreted as a mould to shape the tire contour according to the desired design. A lift plane is needed to move the mould, whereas, in the industrial world, the role of a lifting plane is very important in supporting a job. The use of lift aircraft, the addition to facilitating human work, can also increase the quality and quantity of production. The role of lifting equipment in the industry, construction sites, storage and unloading areas, namely cranes. A crane combines a lifting mechanism separately with a frame to lift or simultaneously lift and move loads that can be hung freely or tied to a crane moving materials from one place to another. There are various types of overhead cranes, such as EKKE (Single Girder), ZKKE (Double Girder), ELKE (Beam Single Girder) and so on[2].

At PT A, the location of mould storage is being expanded with an area dimension of 21 x 35 meters which aims to increase the number of moulds themselves. The added mould ranges from 5-7 tons. Therefore, this research will design an auxiliary tool in the form of an overhead crane with a capacity of 10 Tons along with the components of the lifting system mechanism as well as data processing in determining the size or dimensions of each part of the lifting system which aims to prevent failures in selecting supporting elements for the installation of overhead cranes in the mould area. So, the activity of handling mold in the mold storage area can be resolved with the installation of this tool.

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2. Experimental and Procedure

2.1 Design Preparation

In this study, the design parameters included lifting capacity = 7-8 tons, hoist span = 21 meters, and lifting height = 6 meters.

After obtaining the data above, calculations will be carried out regarding the components of the lifting system in order to minimize the occurrence of design errors/failures caused by errors in material selection. With the planned data design included lifting capacity = 7-8 tons, hoist weight = 1.35 tons, hoist block bottom weight = 45 kg, lifting height = 6 meters and lifting speed = 0.1 m/s.

2.2 Design Method

The method used in this study is the VDI 2221[3,4], way or using the finite element method. As for the factors that influence the manufacturing process, such as welding parameters, from several studies that have been carried out, it is evident that many welding parameters affect the mechanical properties of the welded joint, including the electric current strength of the welding[5], the holding time in the treatment post-welding heat[6].

Another factor that needs to be considered is the possibility of failure due to material fatigue. Because it has been proven from studies that even though a material is loaded under its yield stress, one day, it may fail due to fatigue[7]. As for the analysis using SolidWorks software to design the main components of the spring constant test tool for a capacity of 50 N/mm[4,8]. Static structural analysis of deformation or displacement[9,10].

2.3 Girder Design

The girder used is a type of double box girder with a capacity of 10 tons with a span of 21 meters. The material of the box girder is an ASTM A36 iron plate with a stress value of 400 N/mm^2[11]. With variations in plate thickness of 12 mm and 8 mm, with a total girder weight of 7.475 tons, and the moment of inertia of the girder structure is 7592379733 mm^4.

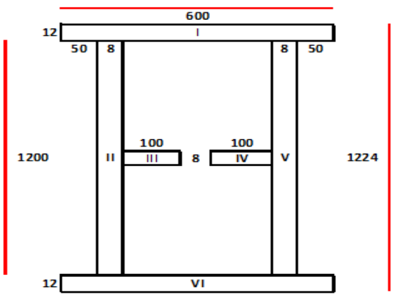

Fig. 1. Box girder structure

$$P(design) = (H_w + L_c) + 25\% (H_w + L_c) \quad (1)$$

where P is the design, H_w is the weight of the hoist, and L_c is the lifting capacity.

So total P = P (design) + p (girder) = 21.655 tons. On the transverse support rod, the load received is assumed to be the same as the load received by the longitudinal rod, namely P = 21.655 Tons if converted equal to 216550 N.

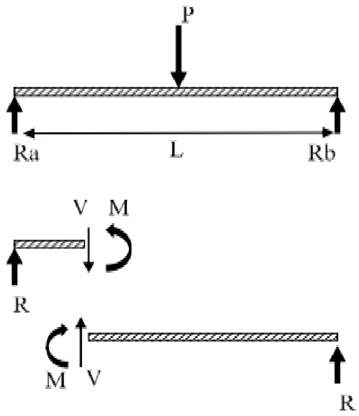

Fig. 2. Moment reaction on girder[12]

$$R_a = R_b = \frac{P}{2} \quad (2)$$

$$= \frac{216550}{2} = 108275 \text{ N}$$

The modulus of elasticity for ASTM A36 materials is 2 x 10^5 N/mm^2. The deflection (δ) formula can be calculated using Equation (3) below[12].

$$\delta = \frac{p \,.\, l^3}{48 \,.E \,.I} \quad (3)$$

$$= \frac{108275 \; x \; 21000^3}{48 \; x \; 200000 \; x \; 7592379733} = 13.75 \text{ mm.}$$

Allowable deflection by Depnaker[13] is

$$\delta = \frac{Span\ Length}{888} \quad (4)$$

$$= \frac{21000}{888} = 23.64 \text{ mm}$$

2.4 Runaway Design

The runway structure uses ASTM A36 with a profile I, often referred to as IWF, with dimensions of 400 x 200 x 8 x 13 mm, with a length of 35 meters and 5 meters.

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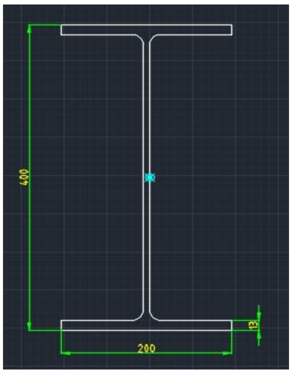

Fig. 3. IWF profile 400

With the value of the moment of inertia of the I profile, which is 25440 cm^4. Given that the total P that occurs on the runway rod is 220510 N, the elastic modulus value of the runway rod (ASTM A36) = 2 x 10^5 N/mm^2.

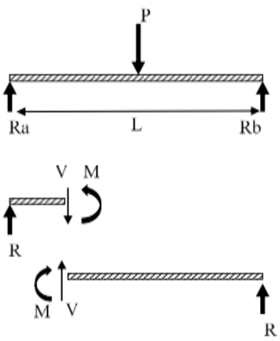

Fig. 4. Moment reaction on runaway[12]

$$R_a = R_b = \frac{P}{2} \quad (5)$$

$$= \frac{220510}{2} = 110225 \text{ N}$$

Deflection that occurs in the runway stem[12] is

$$\delta = \frac{p \, . \, l^3}{48 \, .E \, .I} \quad (6)$$

$$= \frac{110225 \, x \, 5000^3}{48 \, x \, 200000 \, x \, 254400000} = 5.6 \text{ mm}$$

Allowable deflection by Depnaker[13] is

$$\delta = \frac{Span\ Length}{888} \quad (7)$$

$$= \frac{6000}{888} = 6.75 \text{ mm}$$

2.5 Wire Rope Design

A rope, or in an industrial language, it can be called a wire sling, is an aid in lifting work made of materials such as steel or synthetic materials, which are attached to a crane hook to lift objects or loads[11]. The overhead crane design uses a type of wire rope with a structure of 6 x 37 = 222 + 1c. The pulley system uses multiple pulleys, as shown in Fig. 5, with three arches. In addition to determining the type of rope used, data such as the safety factor is also needed in the wire rope design.

Table 1. Number of bends[14]

Number of bends	D_{min} d	Number of bends	D_{min} d
1	16	5	26.5
2	20	6	28
3	23	7	30
4	25	8	31
9	32	13	36
10	33	14	37
11	34	15	37.5
12	35	16	38

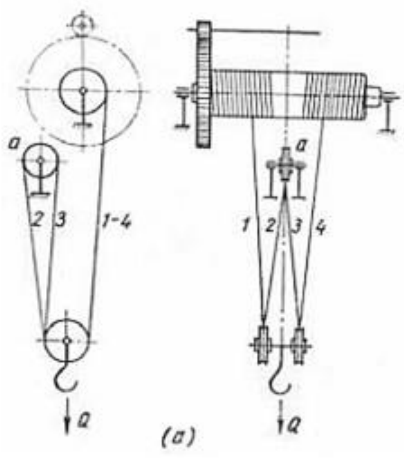

Fig. 5. Pulley construction[11]

Table 1 shows that the value of D_{min}/d with the number of bends three is obtained = 23[14]. Then the wire rope design uses a safety factor of 5.5 and a pulley efficiency of η_p = 0.94.

a. Tensile force due to load

The first step in designing a wire rope is to find the tensile force that occurs in a wire rope with a lifting capacity (Q) of 10 tons[14].

$$S = \frac{Q + G_0}{n \, . \, \eta_p} \quad (8)$$

$$= \frac{10000+45}{4 \, . \, 0.94} = 2671.54 \text{ kg}$$

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b. Cross-sectional area of the steel rope

$$F_{(222)} = \frac{S}{\frac{\sigma b}{K} - \frac{1}{Dmin} \cdot 36000} \quad (9)$$

$$= \frac{2671.54}{\frac{1900}{5.5} - \frac{1}{23} \cdot 36000} = 2.44 \text{ cm}^2 = 244 \text{ mm}^2$$

c. Wire diameter

$$F_{(222)} = \frac{\pi}{4} \text{ x } \delta^2 \text{x } 222 \quad (10)$$

$$\delta = \sqrt{\frac{4 \, x \, F}{222 \, x \, \pi}}$$

$$= \sqrt{\frac{4 \, x \, 244}{222 \, x \, 3.14}} = 1.18 \text{ mm}$$

d. Diameter of steel rope

$$D = 1.5 \cdot \delta \cdot \sqrt{i} \quad (11)$$

$$= 1.5 \cdot 1.18 \cdot \sqrt{222} = 26.3 \text{ mm}$$

e. Tensile stress that occurs in the wire rope

Based on the results of the diameter of the steel rope obtained, the diameter of the steel rope on the list of steel ropes on the market was chosen, namely 28.00 mm. It is known that the actual breaking strength of the string is 44051.73 kg.

$$P = \frac{S \cdot \sigma b}{\frac{\sigma b}{K} - \frac{1}{Dmin} \cdot 36000} \quad (12)$$

$$= \frac{2671.54 \cdot 1900}{\frac{1900}{5,5} - \frac{1}{23} \cdot 36000} = 4301.6 \text{ kg}$$

f. Maximum allowable tensile strength

$$S_{mak} = \frac{P}{K} \quad (13)$$

$$= \frac{44051.73}{5.5} = 8009.4 \text{ kg}$$

2.6 Hook Design

A hook is a component commonly used to hang loads on crane-type lifting aircraft. Generally, hook made of cast steel which is made in shape resembling the shape of a hook. The shape of the hook varies depending on the function or use[14]. Fig. 6. shows the profile of a single hook.

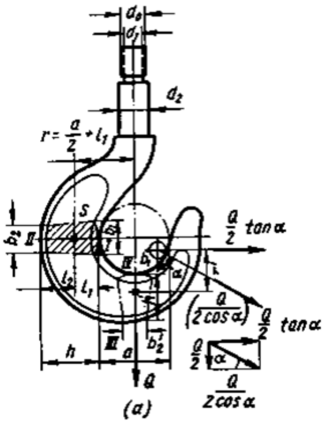

Fig. 6. Single hook construction[14]

The hook that will be used in the design of the overhead crane is a single hook type with S45C material, which has a tensile strength of σ_t = 7000 kg/cm^2. The method of the hook dimensions from the standard hook N 661 (single hook) made of steel for a lifting load of 10 tons utilizing interpolation calculations. The dimensions of the hook diameter = 120 mm.

$$\sigma_1 = \frac{4 \, x \, Q}{\pi \, x \, d^2} \quad (14)$$

$$= \frac{4 \, x \, 10000}{3.14 \, x \, 120^2} = 0.88 \text{ kg/mm}^2$$

With the above calculation results and known tensile strength of 7000 kg/cm^2 = 70 kg/mm^2 and taking the factor of safety = 5.5, the allowable tensile stress is obtained.

$$\sigma_1 = \frac{Q}{Sf} \quad (15)$$

$$= \frac{70}{5.5} = 12.72 \text{ kg/mm}^2$$

2.7 Girder Design

Pulley is a round piece made of metal or non-metal, which is also called a disc. The edge of the disc is given a groove that transmits force and motion on the rope. A construction of the cross-section of a pulley is shown in Fig. 7[11].

It is known that the lift speed is 0.1 m/s. This value is used to determine the amount of pressure on the pulley. Table 2 is a table comparing the value of lift speed with the amount of tension on the pulley.

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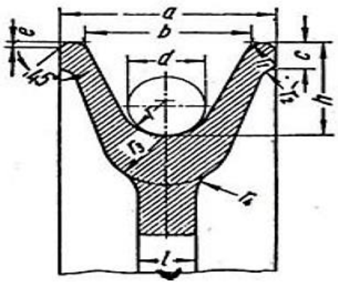

Fig. 7. Pulley wheels for slings[11]

The diameter of the pulley shaft can be found by Equation (16), while the diameter of the pulley can be found by Equation (17).

Table 2. Lifting speed and pressure[11]

Lifting Speed (m/s)	Pressure (kg/cm^2)
0.10	75
0.20	70
0.30	66
0.40	62
0.50	60
0.60	57
0.70	55
0.80	54
0.90	53
0.10	52
0.11	51
0.12	50
0.13	49
0.14	48
0.15	47

$$p = \frac{Q}{l \; x \; d} \tag{16}$$

$$d = \frac{Q}{p \; x \; l}$$

$$d^2 = \frac{10045}{1.8 \;\; x \; 75}$$

$$d = \sqrt{\frac{10045}{135}} = 8.62 \text{ cm} .$$

$$D \; = \; e_1 \; \times \; e_2 \; \times \; d \tag{17}$$

$$= 25 \text{ x } 0.9 \text{ x } 28 = 630 \text{ mm}$$

2.8 Drum Design

The drum on the overhead crane winds the steel rope, made of cast iron, or cast iron, with friction efficiency on the bearings, η = 0.95. For power, drive drums are always equipped with helical grooves to the left or right so that the rope will be wound uniformly. The radius of this helical groove must match the diameter of the steel rope and the same curvature[15]. Shown in Fig. 8.

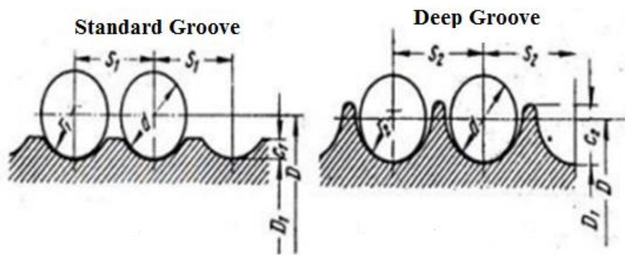

Fig. 8. Drum groove dimension[15]

Based on the number of bends (NB) that occur from the steel rope, a relationship between the pulley and drum's minimum diameter and the string's diameter is obtained. For NB = 23, the drum diameter can be found by Equation (18).

$$\frac{D_{min}}{D} = 23 \tag{18}$$

$$D_{min} = \text{D x } 23$$

$$= 26.3 \text{ x } 23 = 604.9 \text{ mm} = 0.6 \text{ m}.$$

It is known that the lifting height is 6 m, and the ratio of the rope system (i) = 2. The number of turns (z) on the drum is:

$$z = \frac{H \; . \; i}{\pi \; . \; D} + 2 \tag{19}$$

$$= \frac{6 \; . \; 2}{3{,}14 \; . \; 0.6} + 2$$

$$= 8.38 = 9 \text{ coil}$$

After obtaining the number of turns and knowing the market value obtained from the diameter of a rope, which is 31, the length of the drum can be found by Equation (20).

$$l = z \; . \; s \tag{20}$$

$$= 9 \; . \; 31 = 279 \text{ mm}$$

Then look for the stress that occurs in the drum by choosing a cast iron drum material with an allowable pressure of 10197.2 kg/cm^2 and looking for the thickness of the drum first.

$$\omega = 0.2 \text{ D} + (0.6 \text{ until } 1.0) \tag{21}$$

$$= 0.2 \text{ x } 604.9 + 10 = 22.09 \text{ mm}$$

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Equation (22) can find the stress that occurs in the drum.

$$\sigma_{comp} = \frac{S}{\omega\,.\,s} \qquad (22)$$

$$= \frac{2671.54}{2.209\,.\,3.1} = 390.12\ \text{kg/cm}^2$$

3. Results and Discussion

3.1 Results of Calculation Design Girder Hoist

The girder used is a double box girder type with dimensions of p = 21 meters, t = 1224 mm, and l = 600 mm. the result of the deflection that occurs is 13.75 mm, while the simulation results using solid works shown in Fig. 10 the magnitude of the deflection is 5.3 mm. The amount of deflection that occurs is still below the allowable limit.

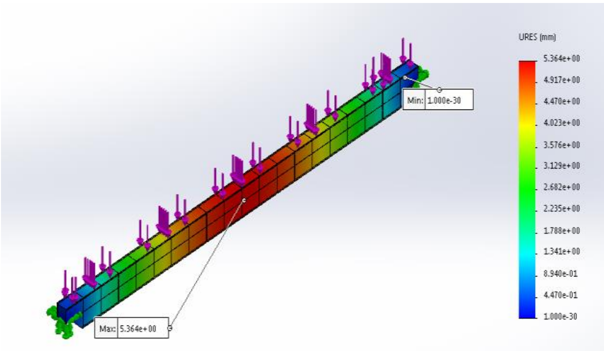

Fig. 10. Deflection of girder

3.2 Result of Calculation Design Runaway

The runway used is steel profile I with dimensions of 400 x 200 x 8 x 13 mm, then the result of the deflection that occurs on the runway rod is 5.6 mm long. While the simulation results using SolidWork are equal to 1.6 mm. These results are still declared safe because they are below the permit limits shown in Fig. 2.

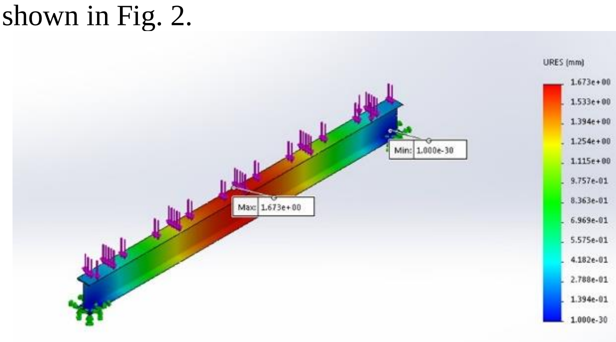

Fig. 9. Deflection on runaway

1.3 Result of Calculation Wire Rope

The diameter of the steel rope obtained from the calculation results is 26.3 mm, then a steel rope is chosen on the list of steel ropes on the market with a diameter of 28 mm. Then, the amount of stress in the steel rope is 4306.1 kg which is smaller than the maximum allowable tensile stress, which is 8009.4 kg.

1.4 Result of Hook

The hook used in the design is a single-type hook made of S45C material. The hook dimensions are obtained from the standard table for hook N 661 with a diameter of 120 mm based on the planned capacity of 10 tons. The tensile stress on the hook is 0.88 kg, which is smaller than the allowable tensile stress of 12.72 kilograms. So hooks with a hook diameter of 120 mm safe for use at a load capacity of 10 tons.

1.5 Result of Pulley

The pulley dimensions obtained from the calculation results are 630 mm in diameter with a pulley shaft diameter of 86.2 mm. shown in Table 3.

Table. 3. Pulley Dimension Standard[15]

Wire Diameter	a	b	c	e	h
4.80	22.00	15.00	5.00	0.50	12.50
6.20	22.00	15.00	5.00	0.00	12.50
8.70	28.00	20.00	6.00	1.00	15.00
11.00	40.00	30.00	7.00	1.00	25.00
13.00	40.00	30.00	7.00	1.00	25.00
15.00	40.00	30.00	7.00	1.00	25.00
19.50	55.00	40.00	10.00	1.50	30.00
24.00	65.00	50.00	10.00	1.50	37.00
28.00	80.00	60.00	12.00	2.00	45.00
34.50	90.00	70.00	15.00	2.00	55.00
39.00	110.00	85.00	18.00	2.90	65.00

Wire Diameter	L	r	r_1	r_2	r_3	r_4
4.80	8.00	4.00	2.50	2.00	8.00	6.00
6.20	8.00	4.00	2.50	2.00	8.00	6.00
8.70	8.00	5.00	3.00	2.50	9.00	6.00
11.00	10.00	8.50	4.00	3.00	12.00	8.00
13.00	10.00	8.50	4.00	3.00	12.00	8.00
15.00	10.00	8.50	4.00	3.00	12.00	8.00
19.50	15.00	12.00	5.00	5.00	17.00	10.00
24.00	18.00	14.50	5.00	5.00	20.00	15.00
28.00	20.00	17.00	7.00	7.00	25.00	15.00
34.50	22.00	20.00	8.00	8.00	28.00	20.00
39.00	22.00	25.00	10.00	10.00	40.00	30.00

1.6 Result of Drum Dimension

The drum dimensions obtained from the calculation results are 0.6 meters in diameter with a drum length of 279 mm. The drum material is cast iron with a stress value that occurs in the drum, which is less than the allowable stress. Therefore, the drum is declared safe.

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4. Conclusions

The results of the structure obtained are double box girder type girders with dimensions p = 21 m, t = 1224 mm, and l = 600 mm. The deflection results are 13.75 mm, and the runway uses steel profile I with dimensions 400 x 200 x 8 x 13 mm, with a deflection value at the runway stem of 5.6 mm. The type of wire rope used is type 6 x 37, with a diameter of 28 mm. The stress that occurs in the steel rope is 4306.1 kg, less than the maximum allowable tensile stress of 8009.4 kg. The single hook type with a hook diameter of 120 mm is made of material S45C. The tensile stress on the hook is 0.88 kg, and the result is smaller than the allowable tensile stress of 12.72 kg. The pulley diameter is 630 mm, the drum diameter is 604.9 mm, and the drum length is 279 mm. Therefore, by obtaining the results of the research above, it can be realized the installation of a lifting system for an overhead crane with a capacity of 10 tons in the mold storage area which aims to handle and transfer molds in that area.

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