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Gorlov Water Turbine Application in Ambon, Kepulauan Maluku; A Hypothetical Project

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ABSTRACT

As energy demand increases, it must be balanced with sufficient energy sources to support the growth of Indonesia's electrification ratio. No exception with the development of energy demand and supply on Ambon, Maluku Islands. This study uses a Renewable Energy Power Plant, a water turbine that uses ocean currents from the flow path of an artificial canal plan in Ambon, Maluku Islands. The shape of the area is interesting things to make an artificial canal as a flow path for ocean currents from the different height at that location. Due to the height difference cannot be determined with certainty, in this study, the authors vary the height difference between the sea in the east and west, it's 1m to 5m. Current modelling uses a numerical approach using the Surface-Water Modeling System (SMS) 8.1 software simulation. Then the average current velocity in the canal in each height variation obtained. The experimental data from journal references are used in calculating the turbine torque for a full-scale afterwards adjusted to the current speed generated in each variation. The turbine with the greatest torque is selected, owned by the 4-blades Gorlov NACA0012 with 25% efficiency and 9.5m turbine diameter totaling 1 unit.

Keywords: *canal, Gorlov turbine, current, Surface-Water Modelling System*.

1. INTRODUCTION

National energy demand in 2019 has increased by 174 kWh/capita since 2015. The Ministry of Energy and Mineral Resources projects that national energy demand in 2020 will reach 1,142 kWh/capita. The statistical data in Figure 1. shows that people's need for electrical energy is getting higher every year. [1]

Currently, the electrification ratio in the Maluku Islands has only reached 82.66%, even though in 2020 the government plans to increase this ratio to 100%. Most of the electricity needs are supplied through conventional electrical energy supplies. Seeing this problem, we have to look at other alternatives as a source of electricity supply for the Maluku Islands.

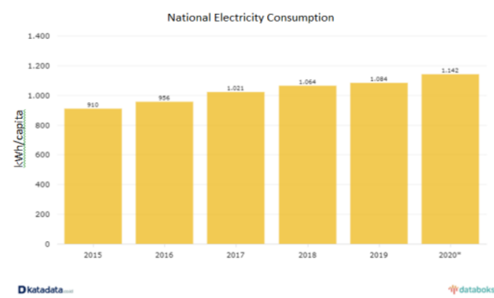


Figure 1. National Electricity Consumption Chart.

The use of renewable energy power plants can fulfill part of the Maluku Islands' target electrification ratio to reach 100%. One of the uses of renewable energy power plants is by utilizing water turbines using ocean currents from the flow path of the canal construction plan in the Ambon area, the Maluku Islands, shown in Figure 2.

Figure 2. Map of the Ambon, Maluku Islands

The construction of this canal is almost the same as the Suez Canal and the Panama Canal but has a different function. The Suez Canal, west of the Sinai Peninsula, is a 163 km long boat canal located in Egypt, connecting Port Said on the Mediterranean with Suez on the Red Sea. Furthermore, the Panama Canal is a canal that cuts across the isthmus of Panama for 82 km, cuts through North

America and South America, and connects the Pacific and the Atlantic Ocean. The mean sea level on the Pacific side is higher than on the Atlantic side due to differences in ocean conditions such as water density and weather.

Whereas in this study, the shape of the Ambon region location is one of the interesting things to make a canal as a canal for the flow of ocean currents from the difference in height at that location. In this study, the authors vary the height difference between the East and West seas because the difference in elevation at the location cannot be determined. Therefore, the shortest distance that can be taken for a canal length is estimated to be approximately 2 km. Then the turbine will be placed in the canal so that the current with the resulting speed can drive the turbine and generate electrical energy.

This research is a hypothetical project designed to study the Gorlov Type Water Turbine, which is considered appropriate in supporting the growth of renewable energy sources in Ambon with regional development, namely making canals. This paper will discuss the application of these turbines in the locations reviewed.

2. BASIC THEORY

2.1 Literature

A canal (Moat) is a wide and deep canal, both dry and inundated, which is excavated around a castle, fortress, building or city, and historically served as a foremost defensive structure. In some places, canals were developed into very extensive water defense structures, including natural or man-made lakes, dams, and slides. The canal can also function as a sanitation canal. In this research, the canal construction is functioned as an ocean current flow pathway to drive ocean currents turbines that are placed in the canal.

With fossil fuel sources slowly shrinking, there is still an urgent need to exploit other energy resources. The fact that the energy of ocean currents is renewable and predictable makes it a promising alternative resource. However, research on the use of ocean current energy is still meaningful due to the lack of supply of fossil energy and environmental sustainability in the future. [2].

Ocean current conversion technology, namely ocean current turbines, is a device that can produce large enough electrical energy. The Gorlov type turbine is another type of vertical axis turbine that is very different from conventional turbines and is believed to generate power from low-head marine hydro currents efficiently. Despite their advantages, vertical axis or cross-flow hydrokinetic turbines have not received as much attention as their more attractive horizontal-axis counterparts, perhaps because of their inferior hydrodynamics and complex fluid-structure interactions.

2.2 Ocean Current

Ocean currents are the movement of masses of seawater from one place to another. In essence, the energy from the mass movement of seawater comes from the sun. The difference in location on earth in receiving the sun's hot light will result in wind movement. The movement of the wind then causes the movement of seawater on the surface. [3]. Wind power exerts an effect on surface currents of about 2 percent of the wind speed itself. The current speed will decrease according to the increasing depth of the water until finally the wind has no effect at a depth of 200 meters. The deeper it goes, the wind factor will also get smaller. [4].

2.3 Tidal

In determining and calculating the sedimentation rate, one factor that is no less important is the change in water level due to the rise and fall of sea level. Tides are fluctuations in sea level due to the attraction of objects in the sky, especially the sun and moon, to the masses of seawater on earth. Variations in the water level give rise to currents known as tidal currents, which carry large amounts of seawater masses. Tidal changes have no direct effect on sedimentation rates. Tides affect the elevation of the wave height that carries sedimentary material to and from the coast. Besides that, the tides also affect the speed and direction of the currents. The currents generated by the tides are strong enough to carry a large enough amount of sedimentary material. Thus the effect of tides cannot be ignored. [5].

2.4 Surface-Water Modelling System

One of the BOSS SMS (Surface-water Modeling System) software modules, namely RMA2, is a numerical model for calculating the hydrodynamic process of two-dimensional flow at the depth average. The SMS software is a post and pre-processing unit, while the RMA2 is a running execution program. The equations describing flow in rivers, estuaries, and other water bodies are based on the classical concepts of conservation of mass and momentum. The horizontal 2-D flow equation (depth-averaged) is derived by integrating the three-dimensional equations of mass and momentum transport with respect to the vertical coordinates from the bottom to the water's surface, assuming that the vertical velocity and acceleration are neglected. Equation of continuity and momentum in the x and y axes for the two-dimensional flow mean depth [6].

2.4 Water Energy

Hydropower plants capture energy from moving water to generate electricity. First, turbines convert the kinetic energy of moving water into mechanical energy. Then the generator converts the mechanical energy from the turbine into electrical energy. The kinetic energy of water is the product of the speed or flow rate of water. The relationship for the kinetic energy per unit volume of water is proportional to its velocity, so it can be stated by the following equation:

$$\frac{E_k}{V} = \frac{1}{2}\rho v^2 \quad (1)$$

where :
Ek = kinetic energy of water (J / $m3$)
V = volume of water ($m3$)
ρ = density of water (kg / $m3$)
v = fluid velocity (m / s)

From this kinetic energy, the amount of power utilized can be formulated by the following equation:

$$P = \frac{1}{2}\rho A v^2 \quad (2)$$

where :
P = Power (Watt)
ρ = density of water (kg/$m3$)
A = cross-sectional area of water flow ($m2$)
v = fluid velocity (m/s)

2.5 Gorlov Turbine

The Gorlov turbine is one type of water turbine developed by Alexander M. Gorlov in 1995. This turbine was developed from the Darrieus turbine type, but the blade on the Gorlov turbine is helical.

The performance of the water turbine is obtained by comparing the comparison or ratio parameters. This comparison value is divided into two, namely the Aspect Ratio (μ) and Solidity Ratio (σ) which is obtained from the dimensions of the size of the water turbine. The size dimension scheme of the Gorlov Type Vertical Axis Water Turbine is shown in Figure 3 below:

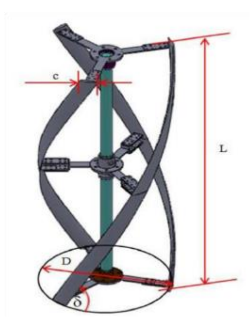


Figure 3. Dimensional schematic of the Gorlov Type Vertical Turbine; D: turbine diameter; c: chord width; L: turbine length; δ: helical angle.

The Gorlov turbine has a cross-flow rotor with hydrofoil blades that provide a reaction thrust at a higher speed than the velocity of the water current itself. Unlike the Darrieus rotor, the number of blades of this turbine consists of one or more blades and is arranged helically along the surface of the cylindrical rotor. This helical arrangement of the rotor blades eliminates vibrations in the turbine, simultaneously increasing its speed and efficiency.

2.6 Turbine Parameter

The tip speed ratio is the ratio between the wind speed and the speed of the blades.
TSR (Λ) = (Blade tip speed)/(Fluid flow velocity)
TSR (Λ) = ωR/Vo
Where :
ω = angular speed of the turbine (rad/s)
R = blade radius from the turbine shaft (m)
Vo = fluid velocity (m/s)

The power coefficient is also very important to know in designing a turbine. Measurement of turbine efficiency is closely related to the power coefficient and TSR.

$$Cp = \frac{Pt}{Pa} = \frac{M\omega}{\frac{1}{2}\rho S Vo^3} \quad (3)$$

Where :
Pt = the output power of the turbine
Pa = available power of ocean currents
M = the total moment generated by the turbine
ω = angular speed of the turbine
Vo = fluid flow velocity (ocean current)
S = turbine cross-sectional area

3. METHODOLOGY

3.1 Flow Diagram

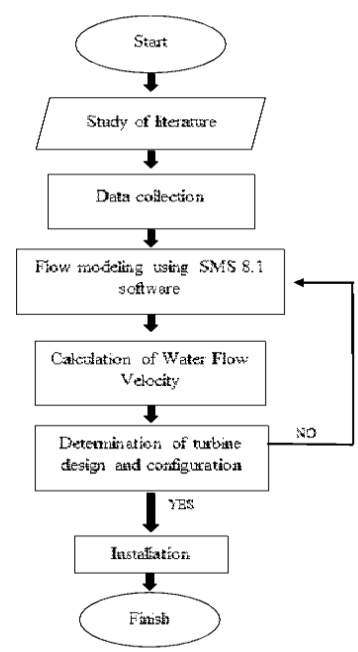


Figure 4. Research Methodology Flowchart

3.2 Implementation of Flow Modeling Using SMS 8.1 Software

1. Topographic map depiction in SMS 8.1 and depicts the coordinate points using the arc feature referring to bathymetric contour lines in the .dxf file. Then define the depth with scatter set according to the elevation of the contour lines of the bathymetry data. The bathymetry data were obtained from the NAVIONICS website.
2. Create a polygon by providing a boundary on the topographic map that has defined depth.
3. Convert the map to a mesh wherein SMS 8.1 the mesh elements should not be more than 10000 elements and nodes should not be more than 30000 nodes.
4. The created mesh is saved in * .GEO format. In SMS 8.1, SMS automatically saves files with the format * .GEO.
5. Determination of boundary conditions is done by making a node string on the outer line of the mesh.
6. Input boundary condition in this study is water surface elevation, which is to enter tidal data for transient conditions. The tides.big.go website is available for tides.
7. Determine the model control by determining the type of flow, namely dynamic flow, the number of time steps to be simulated, and the convergent depth parameter.
8. Execution of GFGEN that is, no errors are found in the geometry model.
9. Running RMA2.

4. RESULTS AND DISCUSSIONS

4.1 Tidal Data Analysis

Tidal data processing is done using Microsoft Excel software. Tidal data is processed to determine the tidal constants using the Admiralty Method calculation. The results show that the research area has a mixed tidal type that tends to double daily (mixed, mainly semidiurnal). This type of tide occurs twice a day and two times the tide, but sometimes temporarily occurs one tide and one ebb with different heights and periods. The tide elevation data are as follows; HWL = 0.9 m; MSL = 0.001 m; and LWS = -1.3 m.

4.2 Flow Modeling Results

The running carried out in this simulation is a 360-time step (1-time step is measurement per hour) or equal to 15 days of measurement per hour. It includes one tidal cycle, which includes a full moon and bandages. The highest tide (HWL) occurs at time step 150 with an elevation of 0.9 m, the mean tide (MSL) occurs at time step 11 with an elevation of 0.004 m, and the lowest tide condition (LWS) occurs at time step 157 with an elevation of -1.3 m. The modeling results show the direction of the current flowing from the right side of the canal towards the left side of the canal, as shown in the current direction vector in Figure 5.

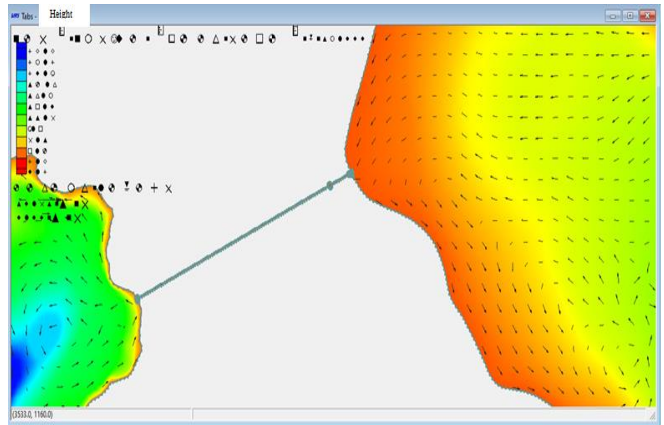


Figure 5. Current Flow Direction Modeling Results

4.3 Flow Velocity Results

In this study, modeling was carried out in 5 variations of the height difference between the eastern and western seas in the Ambon region, Maluku Islands. This is done because the author cannot determine how much the height difference occurs at the research location. There are five variations in the height difference as a hypothetical, namely variation 1 with a height difference of 1 meter, variation 2 with a height difference of 2 meters, variation 3 with a height difference of 3 meters, variation 4 with a height difference of 4 meters, and variation 5 with a height difference of 5 meters. The canal dimensions are made with a canal width of 10 meters and a depth of 10 meters. The results of the current velocity for each variation were observed at the exact coordinates, namely 3214.7 x coordinates and 1958.8 y coordinates. The graph of the current velocity for each variation can be seen in the Appendix.

The overall summary graph of the simulation results in the form of current velocity in each variation is shown in Figure 6 and Table 1 for the maximum speed, minimum speed, average speed, and h1/ 3 speed of each variation.

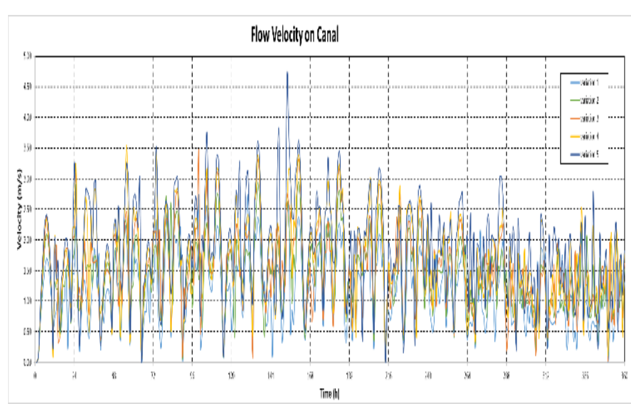


Figure 6. Flow velocity summary graph on the canal

Table 1. Summary of the Results of Flow Velocity on the Canal for Each Variation of Height Difference

	VARIATION 1	VARIATION 2	VARIATION 3	VARIATION 4	VARIATION 5
Max Velocity (m/s)	2.71	2.94	3.43	3.52	4.72
Min Velocity (m/s)	0.01	0.01	0.01	0.01	0.01
Average Velocity (m/s)	1.17	1.42	1.51	1.65	1.86
h1/3 Velocity (m/s)	1.46	1.67	1.77	1.97	2.22

4.4 Turbine Selection

The turbine selection in this study uses turbine data from CFD simulation results of variations in the number of Gorlov NACA0012 turbine blades carried out in the final project research (Pratama, 2020), which will be used as a reference for selecting a full-scale turbine in this study. Research on this turbine is being developed a lot [13-16]. In the study (Pratama, 2020), the 5-blades and 6-blades Gorlov turbine variation experienced a decrease in the efficiency value. So, in this study, the authors used efficiency data from the 4-blades, 3-blades, and 2-blades Gorlov turbine variations. Then the turbine selection parameter data in this study are presented in Table 2.

Table 2. Turbine Selection Parameter Data (Pratama, 2020)

	Simulation Turbine	*Full-Scale Turbine*
Turbine Diameter	300 mm = 0,3 m	4,5 m dan 9,5 m
TSR (Tip Speed Ratio)	1,7	1,7
Efficiency (Cp) NACA 0012 4 Blades	25%	25%
Efficiency (Cp) NACA 0012 3 Blades	20%	20%
Efficiency (Cp) NACA 0012 2 Blades	19%	19%

In the calculation, it is assumed that the efficiency or power coefficient of the full-scale turbine is the same as the efficiency or power of the simulation turbine with the following equation:

$$C_P\ (model) = C_P\ (full\ scale)$$

So the results of the torque calculation for a full-scale turbine for each variation, the largest turbine moment is obtained, namely the turbine with an efficiency (CP) of 25% owned by the 4-blades Gorlov NACA0012 turbine. In variation 1, two turbines with a diameter of 4.5 produce a moment of 2200.60 N.m, and with a turbine with a diameter of 9.5, one unit produces a moment of 2322.85 N.m. In variation 2, 2 turbines with a diameter of 4.5 produce a total moment of 2892.92 N.m, and 1 turbine with a diameter of 9.5 produces a total moment of 3053.64 N.m. In variation 3, 2 turbines with a diameter of 4.5 produce a total moment of 3257.48 N.m, and 1 turbine with a diameter of 9.5 produces a total moment of 3438.45 N.m. In variation 4, 2 turbines with a diameter of 4.5 produce a total moment of 4030.59 N.m and 1 turbine with a diameter of 9.5 produces a total moment of 4254.51 N.m. In variation 5, 2 turbines with a diameter of 4.5 produce a total moment of 5096.75 N.m and 1 turbine with a diameter of 9.5 produces a total moment of 5379.90 N.m.

4.5 Turbine Configuration

In determining the turbine configuration based on the calculation results in Table 4.4, a full-scale turbine was selected for each variation, namely the 4-blade Gorlov NACA0012 Turbine with a diameter of 9.5 m, totaling 1 turbine which will be placed at the right end of the canal. The turbine placement configuration image is shown in Figure 7.

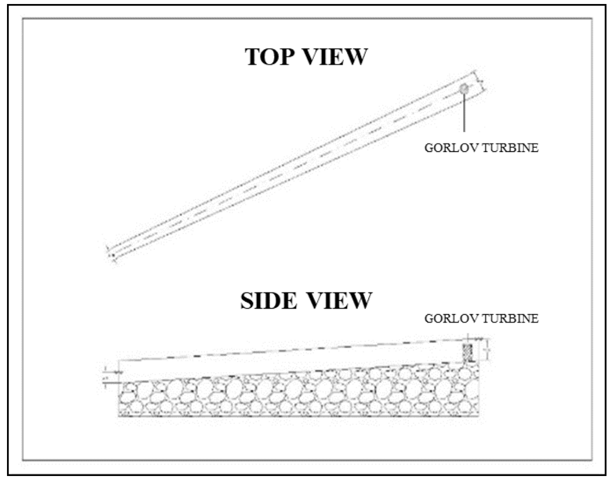


Figure 7. Turbine Configuration

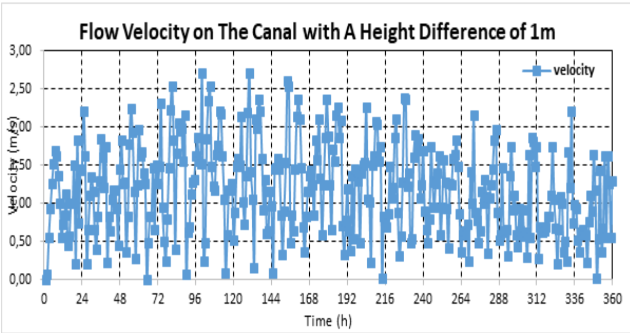
5. CONCLUSIONS

Based on the results of numerical simulation, data analysis, and discussion that the author has done, the following are the conclusions that the authors can give in this final project:

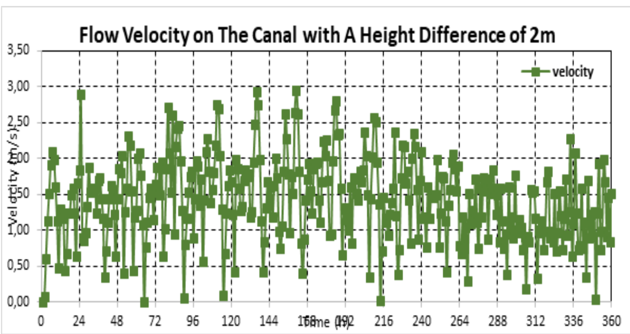
1. The current velocity at each variation in the height difference generated based on the simulation using the SMS 8.1 software shows that the higher the altitude difference, the higher the resulting current speed. In this final project, in sequence, the average current velocity from the difference in the height of 1 m, 2 m, 3 m, 4 m, and 5 m is 1.17 m/s, 1.42 m/s, 1.51 m/s, 1.65 m/s, 1.86 m/s.
2. The largest turbine moment is generated from a turbine with an efficiency of 25%, namely the 4-blades Gorlov NACA0012 turbine with a turbine diameter of 9.5 m totaling one piece.
3. To meet the needs of electric power, a generator that is capable of turning a turbine with a turbine rotating moment is greater than 31.67M (model) or sequentially from the difference in the height of 1 m, 2 m, 3 m, 4 m, and 5 m is 2322.85 N.m, 3053.64 N.m, 3438.45 N.m, 4254.51 N.m, 5379.90 N.m
4. The turbine configuration for each variation will be placed at the right end of the canal according to the current velocity points that have been reviewed in the

current modeling simulation.

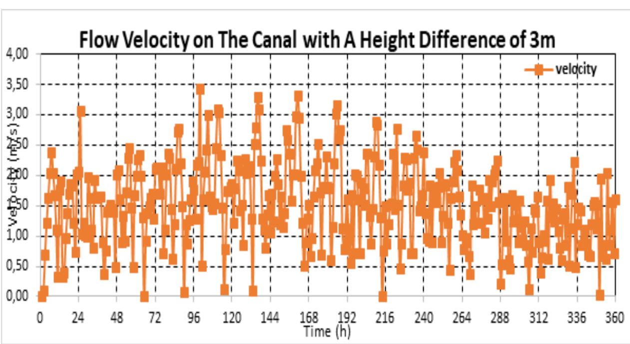
APPENDIX



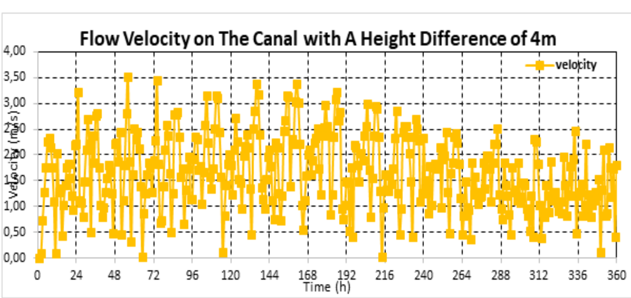
Graph of current velocity in the canal with 1m height variation.



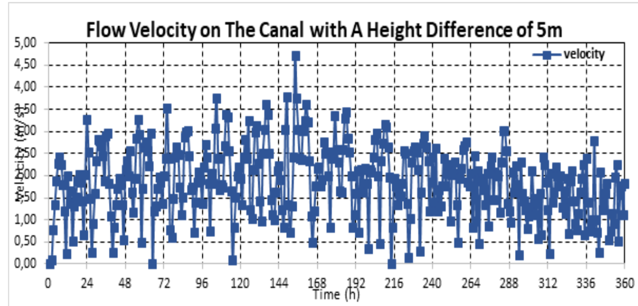
Graph of current velocity in the canal with 2m height variation.



Graph of current velocity in the canal with 3m height variation.



Graph of current velocity in the canal with 4m height variation.



Graph of current velocity in the canal with 5m height variation.

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