

Dynamic tests of SRIM fluid viscous dampers

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ABSTRACT: Fluid viscous dampers having rich energy dissipation capacity have been widely used in building and bridge structures. SRIM fluid viscous dampers have been used in over hundred projects worldwide. For the Japanese market demand of velocity exponent coefficient with the range of 0.1 to 0.3, we conducted fundamental property tests at first using the same damper model according Japanese regulations. Then we conducted temperature dependent tests and cycle fatigue tests under earthquake and wind loads respectively. We also conducted over-design large velocity tests and long duration fatigue tests based on real earthquake record. The dampers worked well as design in all tests. The low velocity test was conducted to make sure the resistance is small enough at extremely low velocity.

1 INTRODUCTION

In the 2011 earthquake off the Pacific coast of Tohoku ($M_w=9.0$) occurred on 11 March 2011 in Japan, the earthquake lasted about longer than five minutes. In the 2016 Kumamoto earthquake, there occurred two earthquakes having JMA Intensity 7 at one day interval. Viscous dampers have to keep good performance and continuously function well to make sure the structures safe.

Shanghai Research Institute of Materials (SRIM) has manufactured viscous dampers for about 20 years (Qian, F., *et al.*, 2012). SRIM fluid viscous dampers have been used in over hundred projects in China, Japan, Taiwan and South Korea etc. world widely. Fluid viscous dampers having velocity exponent coefficient of 0.1(Yamazaki, N., *et al.*, 2014) to 0.3(Sasaki, Y., *et al.*, 2007) are most popular and can be achieved by the proper blend of silicone fluid.

We conducted fundamental property tests at first using the same damper model. Then we conducted temperature dependent tests and cycle fatigue tests under earthquake and wind loads respectively. We confirmed the long-time duration performance of the damper by inputting response displacement due to strong motions recorded at K-NET Sendai station. We also conducted over-design large velocity tests up to 1.5m/s and extremely low velocity test such as 0.004m/s.

2 TEST METHOD

2.1 Outline of the viscous damper

An illustration of the viscous damper is shown in Figure 1. The damper is usually attached to the structure by clevises at two ends. When the piston head moves in the silicone fluid, the damping force will occur between two ends. The damping force is designed being proportional to α velocity exponent shown in Equation 1. The maximum damping force can be achieved easily by adjusting the space between the cylinder and the piston head, width of the piston head. The α exponent coefficient can be achieved by blend of silicone fluid. The most popular exponent coefficients are from 0.1 to 0.3. The demand to fluid viscous dampers increased more and more since they had good performance during the earthquakes. They have been widely used in new or retrofitting building and bridge structures.

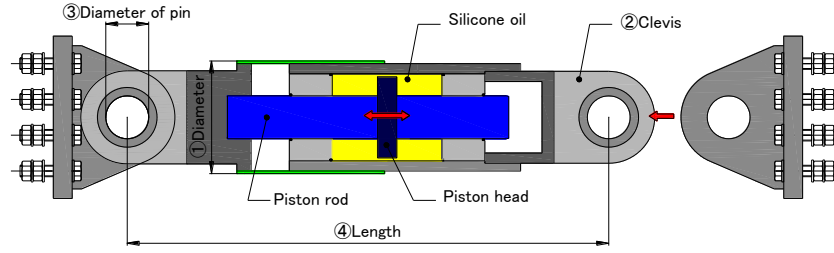


Figure 1. An illustration of the SRIM viscous damper.

$$F = CV^\alpha \quad (1)$$

where F = damping force; C = damping coefficient; V = velocity; and α = exponent coefficient

2.2 Test specimens and test schedules

We conducted various dynamic tests to confirm the performance of the viscous dampers. Dampers having the nominal maximum damping force from 500kN to 2000kN with strokes from ± 100 to ± 600 . The exponent coefficients from 0.1 to 0.3 are most popularly used. Due to the limitation of the paper, the typical test specimens are shown in Table 1. The exponent velocity coefficients were designed as 0.3 and 0.1. Test schedules for VD type dampers are shown in Table 2. The dampers' maximum velocity values are designed from 0.05m/s to 1.0m/s by the combination of amplitude and frequency of the excitation. Due to the test machine's limitation, the test amplitude was usually smaller than the designed stroke. Static tests were conducted to check the limit of the stroke. A sine wave excitation having four (VD) or ten (NESD) cycles was used in the dynamic test. The third cycle data was used to evaluate the performance of the damper. The velocity value was obtained from the differential of the relative displacement between two ends. The maximum damping force and the maximum velocity were evaluated at both compression and stretch direction.

Table 1. Test specimens.

Specimen	Design Formulation	Stroke (mm)	Nominal maximum velocity (m/s)	Nominal maximum damping force (kN)
VD-500	$450 V^{0.3}$	$\pm 500/\pm 600$	1.0	500
VD-1000	$900 V^{0.3}$	$\pm 500/\pm 600$	1.0	1000
VD-1600	$900 V^{0.3}$	± 600	1.0	1600
NESD-500	$536 V^{0.1}$	± 250	1.0	500
NESD-2000	$2144 V^{0.1}$	± 250	1.0	2000

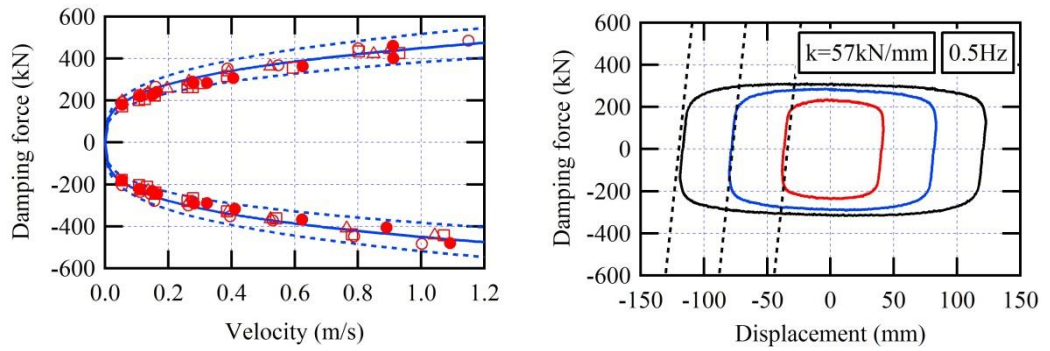
Table 2. The maximum velocity V of test schedules for VD type dampers.

V (m/s) A (mm)	Frequency f (Hz)			
	0.2	0.5	1.0	1.4
40	0.050	0.126	0.251	-
80	0.101	0.251	0.503	-
120	0.151	0.377	0.754	1.056

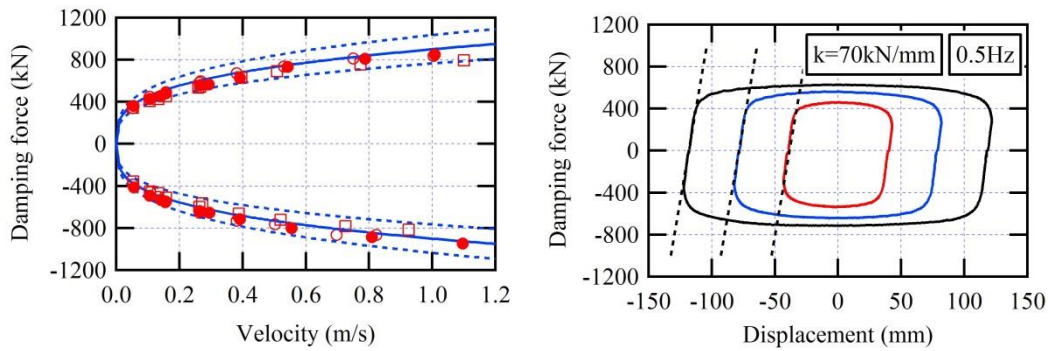
3 TEST RESULTS

3.1 Fundamental properties

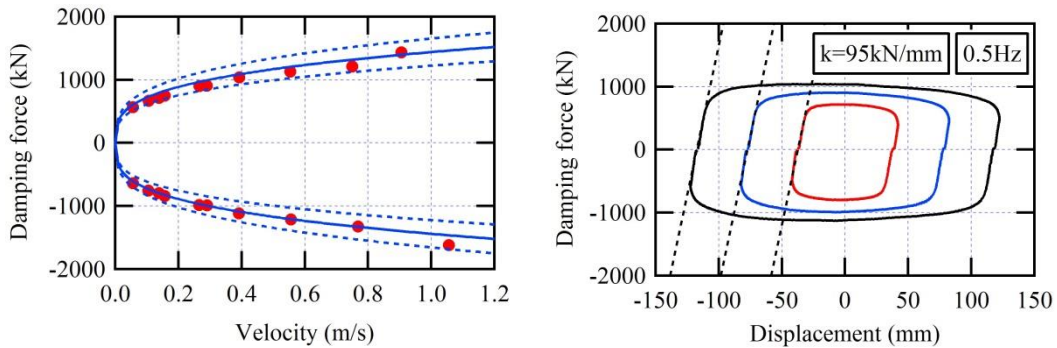
The fundamental properties of VD-500, VD-1000 and VD-1600 type dampers are shown in Figure 2. At the left side, the test results are shown comparing design values with the dot lines showing 15% dispersion from Equation (1). All test results were within $\pm 15\%$ of the design values. There used four VD-500, three VD-1000 and one VD-1600 specimens, which had stroke of $\pm 500\text{mm}$ or $\pm 600\text{mm}$. In the figures, the open mark means $\pm 500\text{mm}$ stroke type, while the solid mark means $\pm 600\text{mm}$ type. The tests agreed very well with the design values. At the right side, the hysteresis loops, relationship between damping force and displacement at the amplitudes of 40, 80 and 120mm as shown in Table 2, are shown with the stiffness used in a Maxwell model, where all specimens' stroke is $\pm 600\text{mm}$. The stiffness takes a fixed value at different displacement or velocity for one type specimen.



(a) VD-500 (four specimens)



(b) VD-1000 (three specimens)



(c) VD-1600 (one specimen)

Figure 2. Fundamental properties of VD-500, VD-1000 and VD-1600 type dampers. The open mark means $\pm 500\text{mm}$ stroke type. The solid mark means $\pm 600\text{mm}$ type.

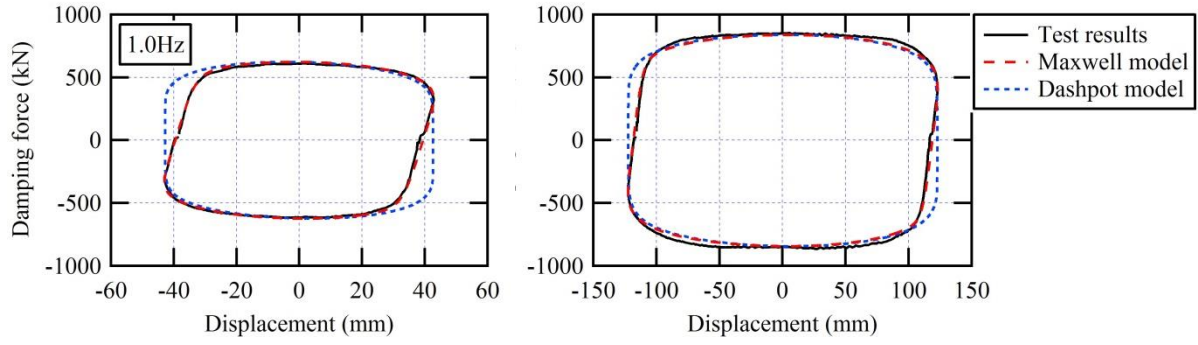


Figure 3. Test results at the maximum velocity values of 0.25m/s and 0.75m/s comparing with analysis models: dashpot and Maxwell model for VD-1000±600mm type specimen.

In Figure 3, the test results at the maximum velocity values of 0.25m/s and 0.75m/s are compared with analysis models: dashpot and Maxwell model for VD-1000±600mm type specimen. The test results agreed well with the Maxwell model at both cases. At the dashpot model comparison, though they did not agree well at the small displacement, it is practically useful at the large displacement.

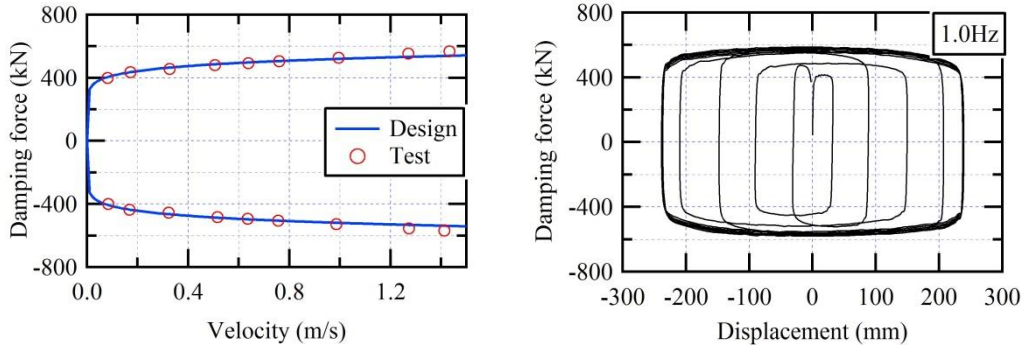


Figure 4. Fundamental and large velocity properties of NESD-500 type damper.

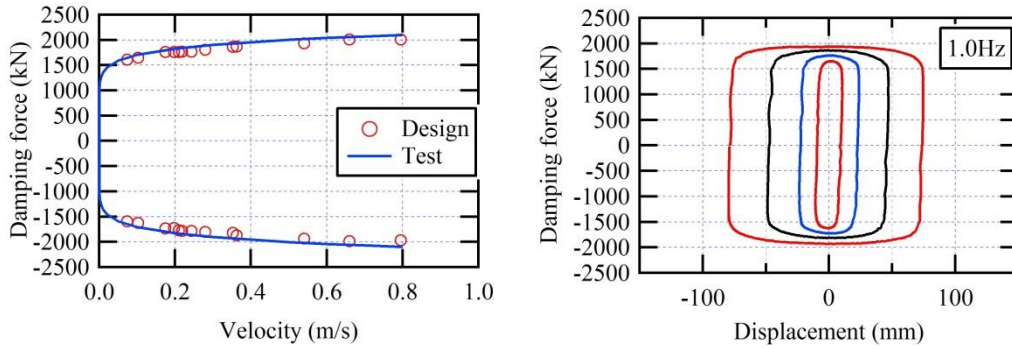


Figure 5. Fundamental properties of NESD-2000 type damper.

The fundamental properties of NESD-500 and NESD-2000 type dampers are shown in Figure 4 and Figure 5, respectively. The dampers' maximum velocity values are designed from 0.06m/s to 1.5m/s to confirm both the fundamental properties and over-design large velocity properties. All test results were within $\pm 10\%$ of the design values. At the left side, the test results are shown comparing design values. The tests agreed very well with the design values even at velocity values of 1.26m/s and 1.51m/s extremely larger than the designed velocity 1.0m/s. At the right side, the hysteresis loops, relationship between damping force and displacement at the velocity of 1.51m/s, showed very stable.

We demonstrated that SRIM has the capacity to manufacture from 0.1 to 0.3 velocity exponent viscous dampers. The dampers have stable properties even at over-design large velocity values.

3.2 Temperature dependent property

The silicone fluid is usually considered to have temperature dependent property. But in the SRIM viscous damper, the silicone fluid is confined by the steel cylinder and subjected to a pre-pressure. Thus, the viscous damper has little temperature dependent property.

We used a VD-500±500mm specimen shown in Figure 2 to conduct temperature dependent property test. The temperature was designed at seven steps: -20,0,20,30,40,60,80°C. A sine wave excitation which had $f=0.5\text{Hz}$, $A=80\text{mm}$ ($V=0.251\text{m/s}$) was used at all test cases. The test results were evaluated by the change of equivalent damping coefficient. The change was very little, showed in Figure 6 as between -2.1% to 8.7%. The damping force increased slightly with the increasing of temperature.

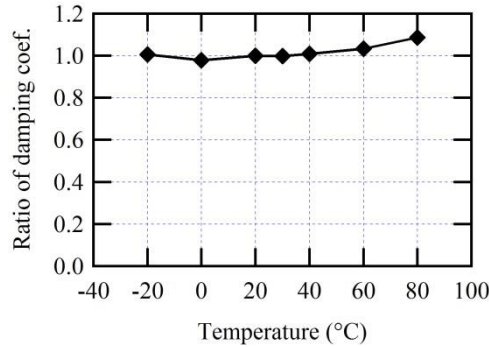


Figure 6. Relationship between the change of equivalent damping coefficient and temperature.

3.3 Fatigue Test

We used the same VD-500±500mm specimen with the temperature test to conduct two type fatigue tests: earthquake and wind loads. The test schedule is shown in Table 3. Total accumulated movement in earthquake and wind loads was 24m and 72m, respectively. The test results are shown in Figure 7. In the earthquake load fatigue test, the temperature at the specimen's surface increased from 33 to 50°C, and the damping force changed less than 5%. In the wind load fatigue test, the temperature at the specimen's surface increased from 31 to 78°C, and the damping force changed about 8%. The characteristics of the SRIM viscous damper changes little at both fatigue tests.

Table 3. Schedules of earthquake and wind loads fatigue test.

Load type	Frequency (Hz)	Amplitude (mm)	Cycle numbers	Accumulated movement (m)
Earthquake	0.25	80	75	24
Wind	0.25	10	1800	72

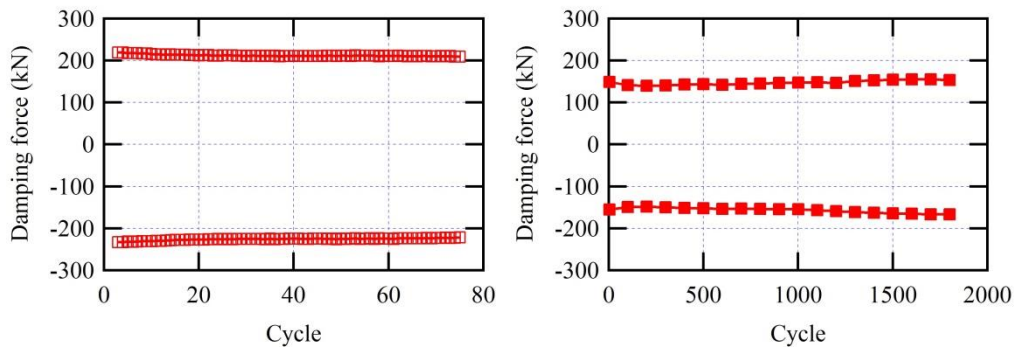


Figure 7. Test results of earthquake and wind loads fatigue test.

3.4 Earthquake motion test

In the 2011 earthquake off the Pacific coast of Tohoku ($M_w=9.0$) occurred on 11 March 2011 in Japan, the earthquake lasted about longer than five minutes. In the 2016 Kumamoto earthquake, there occurred two earthquakes having JMA Intensity 7 at one day interval. Viscous dampers have to keep good performance and continuously function well to make sure the structures safe.

The response of a typical bridge, having a natural period of one second, was calculated based on the strong ground motion at Sendai station (NS direction) recorded in the earthquake. Since the stroke of NESD-500 is 250mm, the response displacement was normalized to be used as the excitation. In Figure 8, the response of the specimen NESD-500 is shown. The response displacement was almost same with the input excitation. Then, velocity values were obtained from the differential of the relative displacement. Although there was some dispersion in the small velocity range, the damping force-velocity relationship agreed well with the design value. Total accumulated movement in this test was up to 9.7m. The accumulated input energy was very high which was converted to heat eventually. Although the temperature at the specimen's surface increased from 22 to 162°C, the damping force-displacement relationship showed very stable.

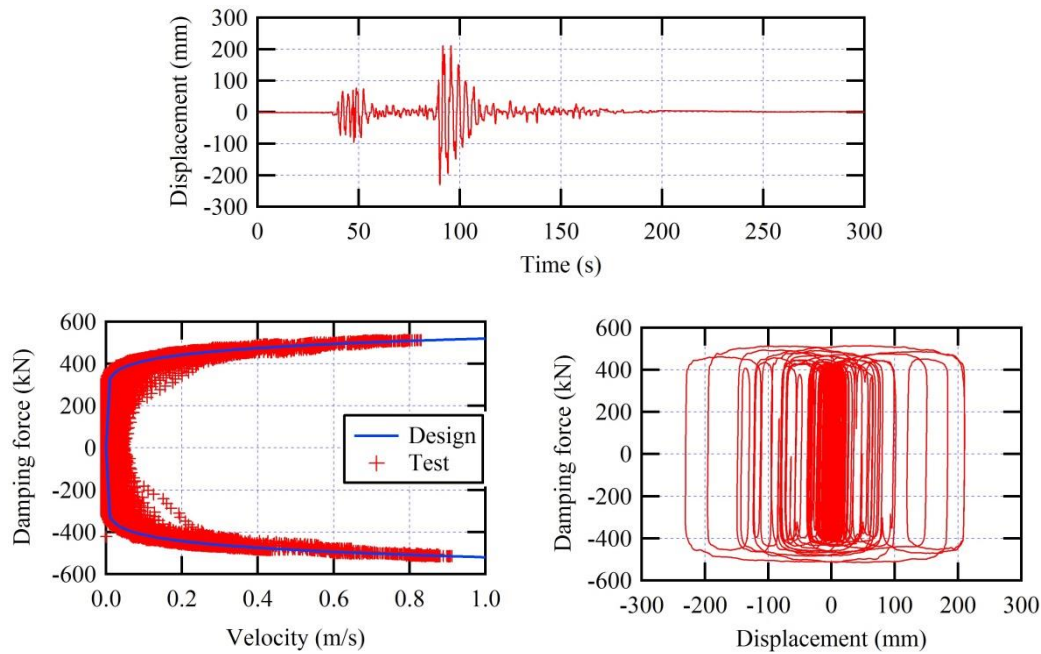


Figure 8. The response of the NESD-500 specimen.

3.5 Low velocity test

When the viscous damper is used in a bridge structure, the girder will expand or shrink very slowly due to the thermal environment. The test is to evaluate the axial resistance of the damper. If the girder is supposed having length of 300m, the movement will be $\pm 18\text{mm}$ at the temperature change of 10°C . The low velocity test schedule is shown in Table 4. The most slow test frequency was set to 0.00004Hz due to the limitation of the test machine.

Table 4. The low velocity test schedules for NESD-500 type damper.

Amplitude A (mm)	Frequency f (Hz)	Maximum velocity (mm/s)
20	0.00004	0.005
	0.0008	0.1
	0.01	1.3
	0.05	6.3

The test results are summarized in Table 5 and shown in Figure 9. It can be seen, in the very low velocity, the damper had extremely small resistance comparing the design value.

Table 5. Test results of the low velocity test.

Maximum velocity (mm/s)	Damping force (kN)	
	Test	Design
0.004	19.5	154.7
0.1	118.5	213.4
1.6	257.9	281.6
8.4	324.0	332.3

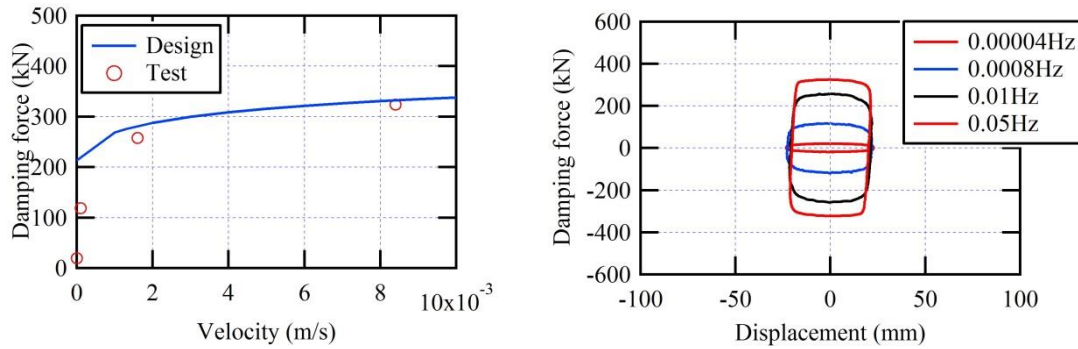


Figure 9. Test results of the low velocity test.

4 CONCLUSIONS

The most popularly used 0.1 to 0.3 velocity exponent viscous dampers were studied. Fundamental property tests were conducted first using 500kN to 2000kN dampers. Then we conducted temperature dependent tests and cycle fatigue tests under earthquake loads and wind loads respectively. We also conducted over-design large velocity tests and long duration fatigue tests based on real earthquake record. The dampers worked well as design in all tests. The low velocity test was conducted to make sure the resistance is small enough at extremely low velocity.

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