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EXPERIMENTAL INVESTIGATIONS OF NORMAL DEFORMATION CHARACTERISTICS OF FOUNDATION CHOCKS USED IN THE SEATING OF HEAVY MACHINES AND QEVICES

Part II. EXPERIMENTAL INVESTIGATIONS OF A CHOCK CAST OF EPY RESIN

Paweł Grudziński , Konrad Konowalski

Summary

This paper concerns in general the problem of the so-called rigid seatings of heavy machines and devices on foundations, by using foundation chocks traditionally made of steel, and now being more frequently replaced by foundation chocks cast of polymer materials specially developed for this purpose. It is a continuation and development of this problem tackled in Part I [1]. In that part, the technical and scientific aspects of the so-called rigid fastenings of machines to foundations have been discussed, and it has been shown that they are not perfectly rigid. Next, a description of the method and results of experimental studies of deformations carried out for a traditionally used steel chock has been presented. In Part II, described in this paper, the results of similar studies carried out for a chock cast of EPY resin, used nowadays more frequently for this purpose have been presented. Subsequently, a comparative analysis of the test results obtained for the two chocks investigated have been made and an explanation why the foundation chocks cast of polymer plastic fulfil better their tasks in machinery seatings than the traditionally used for this purpose steel chocks has been given.

Keywords: seating of machines, foundation chocks, deformations, experimental investigations

Badania charakterystyk odkształceń podkładek fundamentowych stosowanych w posadawianiu ciężkich maszyn i urządzeń

Część II. Badania podkładki z tworzywa EPY

Streszczenie

Praca dotyczy analizy sztywnych posadowień ciężkich maszyn i urządzeń na fundamentach, przy zastosowaniu stalowych podkładek fundamentowych. Obecnie podkładki stalowe są zastępowane często przez podkładki fundamentowe odlewane ze specjalnych materiałów polimerowych. Problematyka podjęta w części I [1] jest kontynuowana i rozwinięta. W części I omówiono techniczne i naukowe aspekty sztywnego mocowania maszyn do fundamentów. Wykazano, że nie są doskonale sztywne. Przedstawiono opis metody i wyniki doświadczalnych badań odkształceń, wykonanych dla tradycyjnej podkładki stalowej. Natomiast w części II przedstawiono wyniki analogicznych badań, wykonanych dla podkładki fundamentowej odlanej z polimerów EPY, stosowanych obecnie. Wykonano analizę wyników badań uzyskanych dla podkładki stalowej i polimerowej. Przedstawiono zalety

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podkładek fundamentowych odlewanych z materiałów polimerowych. Spełniają w większym stopniu zadania w posadowieniach maszyn w porównaniu z tradycyjnie stosowanymi podkładkami stalowymi.

Słowa kluczowe: posadawianie maszyn, podkładki fundamentowe, tworzywo EPY, badania doświadczalne

1. Introduction

The development of chemistry and materials engineering that has been made in the last decades of the 20th century has created great opportunities to develop new materials and technologies, the use of which in engineering practice can give you great technical, economic and operational benefits. A good example of this can be the special epoxy resins used for foundation chocks and the modern technology of seating of heavy machines and devices on the foundations with their use. Traditionally, the seating of heavy machines and devices on foundations is performed using chocks made of metal (usually steel). This technology is outdated and has many significant disadvantages [2, 3]. The use of foundation chocks poured-in-place of their application from plastics specially developed for this purpose, does not only simplify and facilitate the assembling technology and reduce the time and cost of its implementation, but also greatly improves the technical and operating quality of the seatings [4]. The main objective of the studies presented in this paper was a scientific explanation as to why the foundation chocks cast of resin in the seatings of machinery are better technical solutions than the traditionally used for this purpose foundation chocks made of steel.

To achieve this objective the characteristics of normal deformations for a foundation chock made traditionally of steel and an identical chock cast of epoxy resin EPY have been experimentally determined and a comparative analysis has been made. The test material EPY, was developed (in the Technical University of Szczecin) specifically for this purpose. It belongs to the world leaders in this field (it has 31 certificates of various institutions of European countries, the USA and Russia) and is now applied ever more widely in engineering practice for foundation chocks in the seating of different machines and technical devices on maritime vessels, offshore platforms and on land. In total using this material over 11000 different machines and technical equipment have been insalled, including over 2100 engines for main propulsion of ships and dozens of large reciprocating compressors operated in the chemical industry and natural gas compressor stations.

The whole range of the studies performed and the results are presented in two parts, which are separate publications. Part I [1] discusses the technical and scientific aspects of the so-called rigid seatings of heavy machines and equipment on foundations, describes a method and provides detailed results of experimental studies carried out for a traditionally used steel chock. In Part II presented now, a description and detailed results of similar studies carried out for a chock cast of EPY resin are given. Then, a comparative analysis of the measurement results obtained for both chocks were made and theoretical and practical conclusions were formulated.

2. Preparation of the resin chock and the investigation method

For comparison purposes, the same tests as in Part I for the steel chock were now carried out also for the foundation chock made of the EPY resin, developed specially for this purpose. The chock made of this material for testing purpose, had the same shape and dimensions (ϕ80/ϕ30x25) as the previously tested steel chock. However, it was not machined. It has been cast in situ between two steel discs, representing some segments of the foundation and the base of the machine. To prepare this chock a special casting mould was made which is shown in Figure 1a.

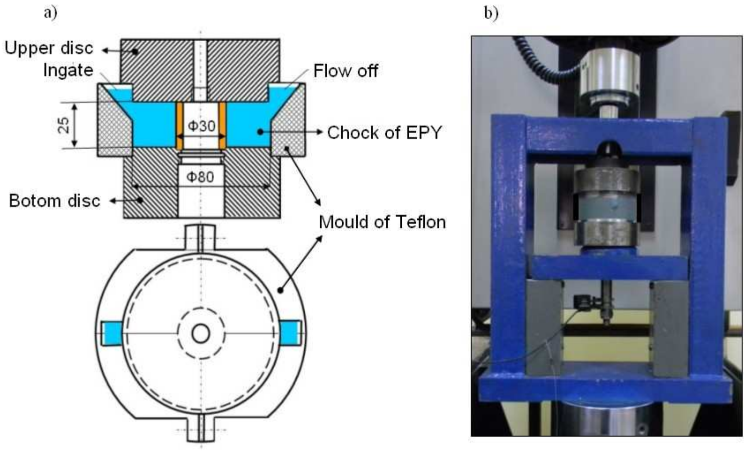

Fig. 1. Mould with a foundation chock cast in it of EPY resin (a) and the compression test of the system on a strength machine (b)

Casting conditions for this chock were adopted the same as they are most commonly used in the casting of this kind chocks in practice. It was cast at room temperature (22 ± 1°C) and cured at this temperature for 48 h. The applied casting traps ensured complete filling of the mould, and accurate automatic adjustment of the chock to the surface unevenesses of the metal disks. After curing of the resin, the Teflon mould and the casting traps were removed. A system created in this way, consisting of two steel discs and the cast between them resin chock was placed in a special instrumentation and subjected to compression tests on a strength machine. A general schematic of compression test and deformation measurements of the system has been shown in Part I ([1], Fig. 1a), and a fragment of its implementation on the test stand – is shown below in Fig. 1b.

3. Experimental studies and results

The main task of these studies was to determine the deformation characteristics for the resin chock subjected to different loads varying in time, for the purpose of cognitive and comparative analysis with the results of previous studies carried out for the steel chock and described in Part I [1]. With that in mind, the same software programs of loading and test conditions were applied. Brief descriptions of the tests carried out and the obtained results are given below.

Test 1. As before in the studies of the steel chock, first compression tests of the resin chock were performed with a load varying linearly in time, according to an isosceles triangle gradually increasing in height. Time course and results of these tests are presented in Fig. 2.

The behaviour of the resin chock differs substantially from the behaviour of the previously tested steel chock. In this case, the relationship between the loads and deformations has a clearly linear-elastic character. The deformations occurring at the first and subsequent further cycles of the same load do not differ. The test system is stable from the beginning. The mechanism of deformations occurring in this case is different from that occurring in the system with a steel chock. The deformations ΔH measured in this case are entirely due to the deformations of the chock's material. The cast chock adheres closely to the rough surfaces of the steel discs, and there are no noticeable effects of contact deformation (occurring in a contact interface of two metal surfaces). It can be assumed here that the true contact area is equal to the nominal contact area, which is very important in engineering practice for the transmission of the mechanical loads and also in the vibration analysis.

The effective elasticity modulus for the test chock can be easily determined from the following relationship (Fig. 2).

$$E_{EPY} = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{\Delta\sigma \cdot H}{\Delta H} = \frac{15 \cdot 25}{0{,}050} = 7500 \text{ MPa}$$

Note: The value of this modulus is greater than its catalogue value (E = 4915 MPa), which is determined in a standard compression test of a short material sample (ϕ20x25) with machined end faces. In such cases, additional contact deformations are created which underestimate the real value of the modulus. The value of this modulus determined on longer samples, by measuring the deformations with an extensometer [2], is larger and comparable with the value determined for the tested chock.

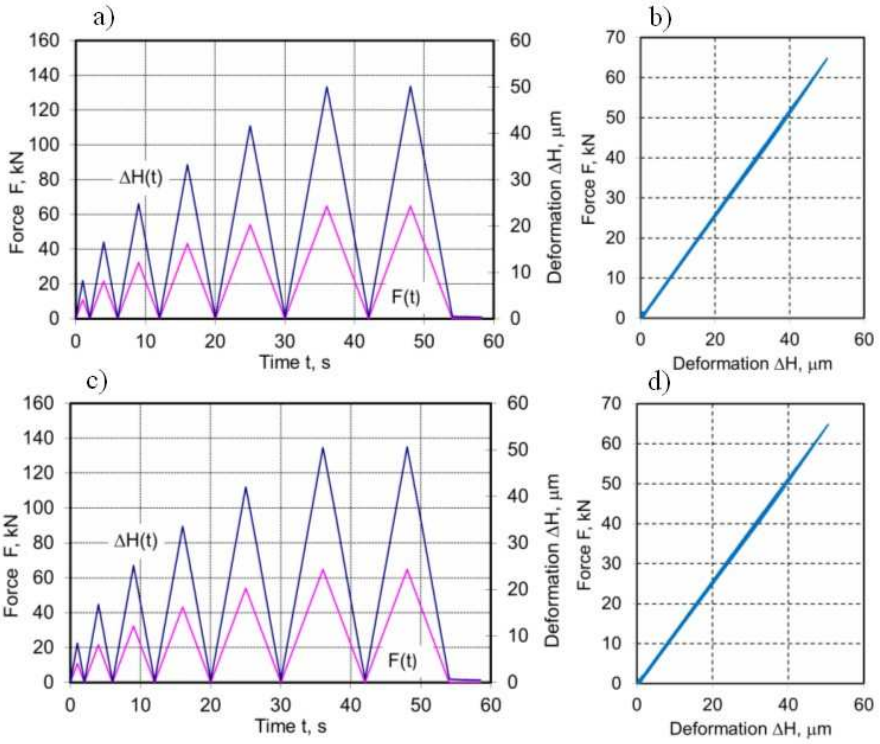

Fig. 2. Time runs of the given compressive loads $F(t)$ and the deformations $\Delta H(t)$ caused by them for the first (a, b) and third (c, d) loading cycles (having the same runs); (the maximum values of the surface pressures amounted sequentially to: σ_i = 2.5, 5.0, 7.5, 10.0, 12.5 and 15.0 MPa)

Test 2. In this test, the system studied was loaded with a linear increasing force and gradually unloaded, wherein the unloading was only partial. The time runs of the given load $F(t)$ and the deformations $\Delta H(t)$ caused by it are shown in Figure 3a. Figure 3b shows the same measurement results in the co-ordinate system F–ΔH. This test confirms the fully linear-elastic behaviour of the system under study as well as the same values of deformations as in the test 1, and also their total disappearance after unloading.

Tests 3 and 4. The next two tests were performed at loads varying sinusoidally. The time runs of these loads and the deformations caused by them are shown in Figures 4a and 5a. Figures 4b and 5b show the results of the same experiments in the co-ordinate systems $F - \Delta H$. Figure 4 illustrates the influence of the amplitude of the exciting force (with a constant mean value), and Figure

5a – the influence of the mean value of the exciting force (with a constant amplitude), on the deformations of the chock. In both cases under the sinusoidally varying loads the tested system behaves linear-elastic. The exciting forces and the deformations caused by them have harmonic waveforms. The values of these deformations are proportional to the amplitude of the exciting forces. After unloading the deformations vanish to zero (Fig. 4 and 5). The system is fully stable.

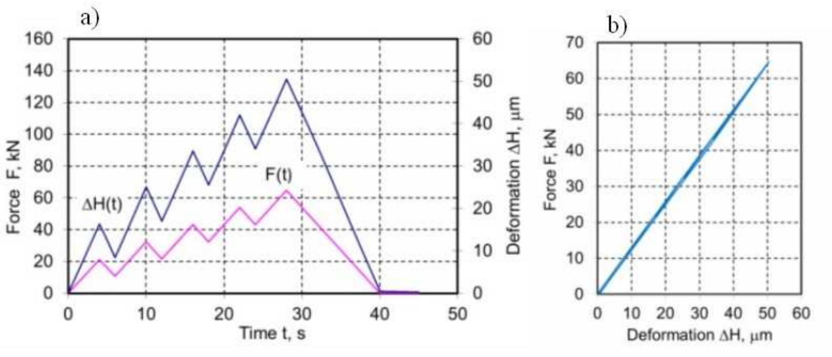

Fig. 3. Time runs of a linearly varying force $F(t)$ and the deformations $\Delta H(t)$ caused by it (a) and their mutual relationship in the co-ordinate system F - ΔH (b)

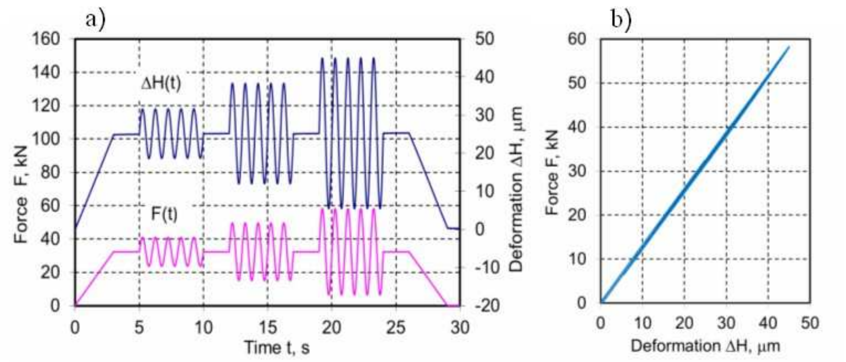

Fig. 4. Time runs of the sinusoidally varying force with a constant mean value (σ_m = 7.5 MPa) and three different amplitudes (σ_a = 2, 4, 6 MPa) and the deformations caused by it (a); in Fig. b) - results of the same measurements in the co-ordinate system F - ΔH

Test 5. In this test the effect of frequency of a sinusoidally varying load with fixed mean value and amplitude (σ_m = 7.5 MPa, σ_a = 2 MPa), on the behaviour of the system has been studied. The results of these studies are presented in Figure 6a. Figure 6b is a part of Figure 6a on an enlarged time scale. They illustrate the time courses of the selected loads and the deformations (vibrations) caused by them in the test system, at frequencies f = 1, 5, 10, 15 and 20 Hz (that could be achieved on the testing stand).

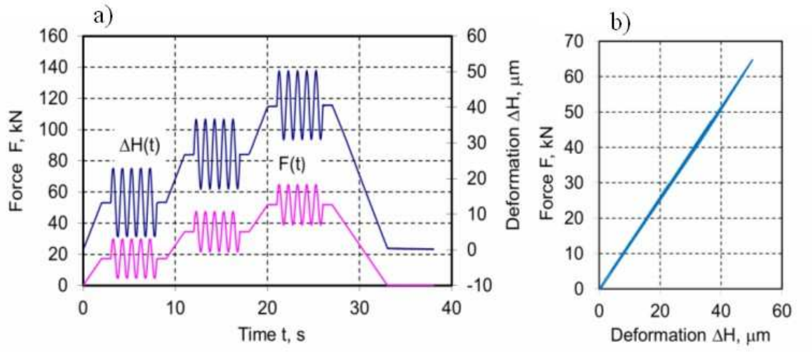

Fig. 5. Time runs of the sinusoidally varying force with a constant amplitude (σ_a = 3 MPa) and three different mean values (σ_m = 4, 8, 12 MPa) and the deformations caused by it (a); in Fig. b) – results of the same measurements in the co-ordinate system F – ΔH

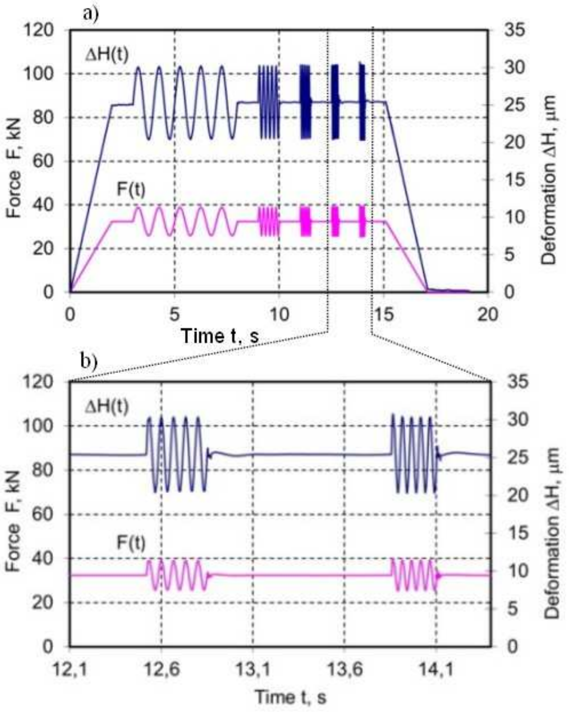

Fig. 6. Time characteristics of the given sinusoidal loads of different frequencies and the deformations caused by them in the system under study; Fig. b) is a part of Fig. a) in an enlarged time scale

These studies indicated that the scope of deformations for all selected excitation frequencies was practically identical, which means that the flexibility of this system does not depend on the frequency of the excitations (over the range of its variation as was possible to achieve on the testing machine). The system behaves linear-elastic and is stable. This is clearly visible in Figure 6a. The deformations occurring in it are linearly dependent on load. They disappear almost entirely without delay after unloading.

4. A comparative analysis

Figure 7 compares the characteristics of normal deformations determined empirically for the test system with the steel chock (curve 1) and for the system with the EPY resin chock (curve 2). The figure also shows the deformation characteristic of the steel chock, determined from the classical Hooke's law (curve 1'). The results are characterized by a large discrepancy in terms of quality and quantity.

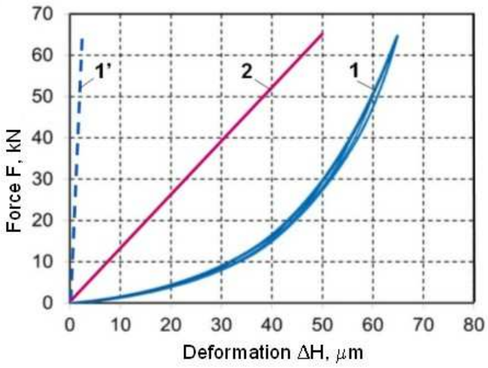

Fig. 7. Comparison of the deformation characteristics determined for the studied foundation chocks made of steel (curves 1 and 1') and cast of resin (curve 2)

In the system with the steel chock, a decisive role is played by contact deformations, which are intrinsically non-linear elastic and have values several times larger than the deformations of the material of this chock. They are a result of the significant deformations of the asperity summits of the interacting surfaces. Due to the roughness, waviness and form errors, the true contact areas in such interfaces are only a very small percentage of their nominal contact areas. In these cases, there are very marked differences and concentrations of stresses in a microscopic scale. This has an important impact on their behaviour under operating loads.

A chock cast of resin adheres closely to the uneven rough metal surfaces. There are no noticeable contact deformations that are characteristic for the contact interface between two machined surfaces of metal. In this case the measured values of deformations are entirely due to the deformations occurring in the material of the chock. They are linear-elastic, and their values coincide well with the deformations calculated according to the Hooke's law. They are easy to model and analyze.

Figure 8 shows the study results of the influence of multiple sinusoidal loading on the deformations of the chocks made of steel and cast of EPY resin. These studies were performed at a mean value of compressive stress σ_m = 5 MPa, amplitude σ_a = 2.5 MPa and frequency f = 5 Hz. The number of load

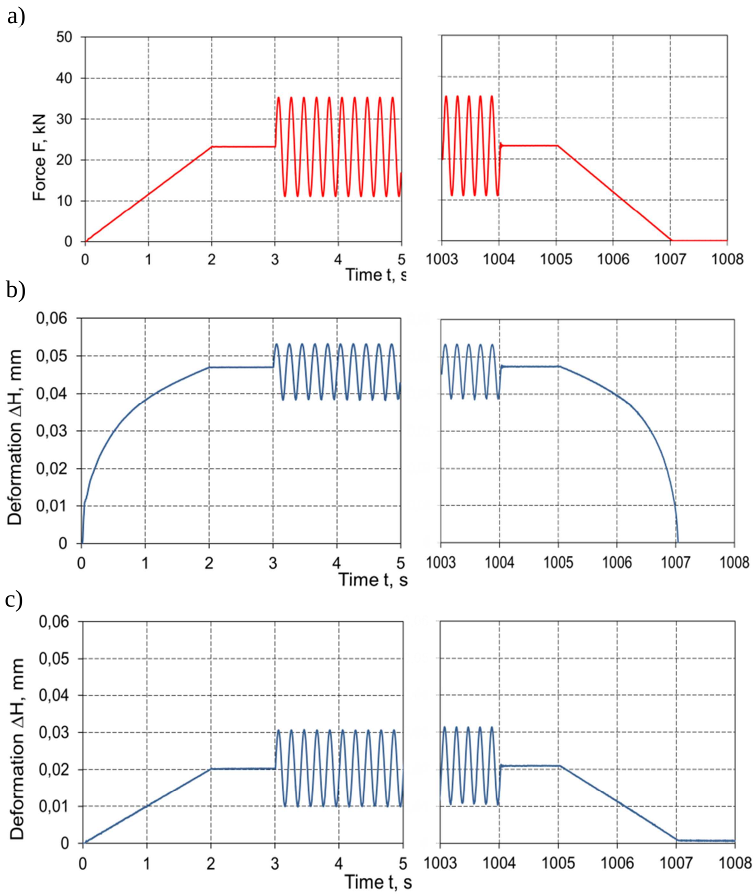

Fig. 8. Influence of the number of sinusoidal load cycle s (a) on the deformations of the systems investigated with a chock made of steel (b) and cast of EPY resin (c)

cycles amounted to 5005. The time course of the loading force is shown in Figure 8a and the time courses of the deformations caused by it, for the chocks made of steel and cast of resin, are shown in Figures 8b and 8c, respectively.

In both cases a good resilience and stability of the systems studied can be seen, with the difference that for the system with the steel chock the relationship between load and deformation is clearly non-linear (Fig. 8b), and for the system with the resin chock this relationship is linear (Fig. 8c). It is clearly visible in the diagram sections of loading and unloading as well as at the asymmetric or symmetric deflections from the equilibrium position, respectively. In the system with the steel chock the time varying deformations take place at a slightly higher mean level and have smaller deflections than in the system with the resin chock. In both cases, the deformation characteristics are very clear and significant. Foundation bolted joints, in which such kind of chocks are present, shout not be treated as rigid connections.

5. Summary and conclusions

This paper presents the results of experimental studies which allow us to understand and explain scientifically why foundation chocks cast of resin in machinery seatings better fulfil their tasks than chocks made of steel traditionally used for this purpose. The main technical advantages of the foundation chocks cast of resin are their perfect match and strict adherence to the rough surfaces of the foundation and the machine base. This ensures a good load distribution over the entire nominal contact area, which in turn provides smooth operation, high reliability and durability of such a connection.

From the analysis conducted follows an overall conclusion that the foundation bolted joints of machines and equipment, both with metal chocks and cast of resin, in the modelling and analysis of their strength and vibration should not be treated as perfectly rigid connections. They have clear and significant deformation characteristics which depend very much on the type of foundation chock. The creation mechanisms and characteristics of these deformations are in both cases different and have a major influence on the operation quality (vibrations), reliability and durability, not only of the bolted connections, but often also of the entire mechanical system in which they are present.

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