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The Effect of Mechanical Loading on Conservation of Antique Violins.

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Abstract
A complete system for the in-situ measurement of elastic, viscous and mechano-sorptive behaviour of violins were implemented. The tests were performed on an old violin analogous to the "Cannone" violin made by Giuseppe Guarneri del Gesù dated 1743. The general elastic behaviour of the violin was determined by the use of a 3D scanner and for few selected points the elastic, viscous and mechano-sorptive behaviours were highlighted after normal tuning and by the use of dead weights.

1. INTRODUCTION

In conservation of antique wooden musical instruments one of the most debated questions is if the instruments must be used or not. Those in favour of the regular use sustain that in violinmaking the conflict between usability and conservationism should not have to exist and, to the contrary, the former is indispensable to the latter. On the other hand there are well known examples of instruments that after a long period of disuse were discovered to have a marvellous sound. This aspect becomes much more important when some particular instruments are elevated from their role of "consumer goods" to that of cultural asset, and for which the preservation of the information that they transmit is the crucial issue. In this case a limitation in the use of the instruments for musical purposes has to be considered being the wood of violins subjected, during the performance, to important modification of its steady condition - because of complex interactions between moisture, stress and energy release – that could potentially determine, in a long term, permanent modifications of the wooden structure.

Very limited are the studies on time dependent behaviour of old wood, and of wooden musical instruments in particular, and this paper reports the first results of a research project aimed to verify the presence and the reversibility of viscoelastic creep and MS creep determined by the loading and RH variation that can occur in occasion of the violin use.

Two are the scientific assumptions on which the experimental work has been designed: the role of hemicelluloses in wood's creep and the metamorphosis that is linked to wood ageing. One of the most important aspects evidenced by recent studies in wood ageing [1] is the progressive loss of polysaccharides during the time (mostly hemicelluloses), while studies of creep on modified wood [2-3] have evidenced the dependence of wood creep from the total amount of hemicelluloses (creep decreases as hemicelluloses decrease).

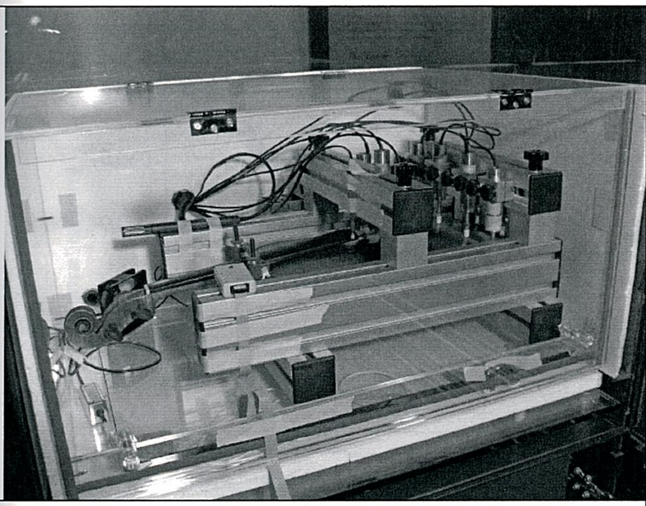
2. MATERIAL AND METHODS

In order to estimate the viscoelastic and mechano-sorptive behaviour of historical violins directly in the conservation location, a special portable equipment was designed and built up as well as a measurement method and a portable climate control system. Tests were performed on an old violin by Giuseppe Guarneri del Gesù dated 1743, and the preliminary tests performed on one copy of it made with recent wood.

In a first stage the antique violin was scanned with a fringe patterns projection triangulation scanner with a ±20 μm resolution in order to understand the general deformation of the instrument and determine the maximal elastic strain zones. In a second stage more accurate measurements were performed in selected points using high precision LVDT transducers with 1 mm of stroke and ±0,5 μm of repeatability and ±1,25 μm of linearity. A total number of 7 transducers placed normally to

the sound table were used, 4 on the ribs and 3 on the sound table itself. The 4 transducers on the ribs allowed to measure the total deflection of the violin and the ribs compression as well as to work as reference for the deformation of the top. The transducers were positioned in two lines, one just in front of the bridge in the centre bout of the violin, the others in the lower bout of the violin in zones identified to be with the higher deformation by the 3D scanner. The measuring frame holding the violin and the LVDT transducers as well as the portable climatic chamber are shown in *Figure 1a*. A particular of the transducer heads in the centre bout is reported in *Figure 1b*.
A strain-gage equipped steel custom bridge was designed and built [4] in order to measure the forces acting on the violin sound table during and after tuning in order to monitor the forces acting and their evolution in time. The experiments were carried out in a box where the relative humidity was controlled by means of a portable active *RH* controller and *T* by a 20 W resistor looped with a controller and with the climatic condition sensor. The experiments were carried out with different methods:

- As in normal violin use conditions by tuning-up the violin and leaving it tuned for ~ 26 hours inside the measuring frame. After the given time the violin was un-tuned and the recovery was measured. With this approach the elastic and viscous behaviour were determined with constant RH, the *T* controller was not implemented yet. Hereafter we will refer to this test as *NTCT – Normal Tuning Creep Test*. The limit of this test was the progressive reduction of the force applied by the strings because of the creep itself. This resulted then in a positive elastic deformation superposed to creep. In order to determine then the mechano-sorptive behaviour of the violin a new approach was implemented using a dead weight placed at the bridge level.
- Using a dead weight at the bridge level instead of tuning-up the violin in order to have a better view of the phenomena. The dead weight was selected in order to have a deformation of about 60%, the deformation reached in normal tuning conditions. This condition was obtained with a mass of 2,109 kg. These tests were carried out in constant temperature conditions of 26°C. In one test the relative load was applied for ~ 6 hours in constant *RH* conditions of 46% (*DWCT – Dead Weight Creep Test*) while in another test during ~ 3 hours of load, starting from the second hour of load an *RH* step of -9,3 % was performed in order to investigate if mechano-sorptive creep arise (*DWMST – Dead Weight Mechano-Sorptive Test*).


(a)

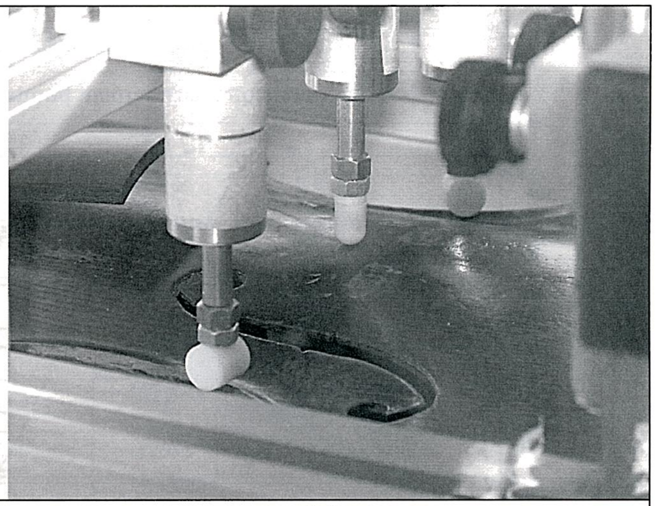

(b)

Figure 1: High precision measuring frame in the portable climatic chamber (a) and a particular of the transducers in the points of the frontal line (b)

3. RESULTS

The 3D fringe projection scanner has shown good effectiveness allowing the computation of local deformation in the violin and helping to determine the points of maximal deformation in order to proceed with further analysis. Moreover the system allowed to study the general deformation of the violin in order to design the holding system of the high precision measuring frame used for the viscous and mechano-sorptive behaviour study. The central behaviour of the sound table as measured with the 3D scanner is highlighted in *Figure 2*. The measurement points are highlighted by a black circle and the measured data are normalised to the first and last measured values that were set to zero. A negative value means that the deformed surface is under the un-deformed surface while a positive value means the contrary. The same reference system will be used for the high precision measurements. It can be observed that the deformation of the sound table is a complex deformation recalling the "cupid arch" as well known by violin makers. This complex deformation is because of the simultaneous action of a transversal force (exerted by the force component acting on the bridge) and of a longitudinal force (exerted by the longitudinal component of the strings force) on a bowed surface as the sound table is. The forces acting on the violin were determined to be 26,13 dN in longitudinal direction and 8,55 dN in transversal direction (on the bridge). As can be seen the central part of the table, under the bridge, is pushed down by ~ - 250 µm while the frontal and the rear parts are lift-up of respectively ~ + 70 and ~ + 170 µm. According to these deformations two high precision measuring lines with LVDT transducers were implemented, one as close as possible to the frontal part of the bridge while the other in the lower bout of the violin. The high precision measuring frame positions are reported in *Figure 2* by the use of black crosses. For the purposes of this paper only the frontal central transducer (*FCT*) will be taken into account. In order to be relative only to the sound table movements the *FCT* were cleaned by the average deformation between the frontal left transducer (*FLT*) and frontal right transducer (*FRT*). The cleaned *FCT* will be called *FCTC* and it is computed as in *Equation (1)*

$$FCTC = FTC - \left(\frac{FTL + FTR}{2} \right) \tag{1}$$

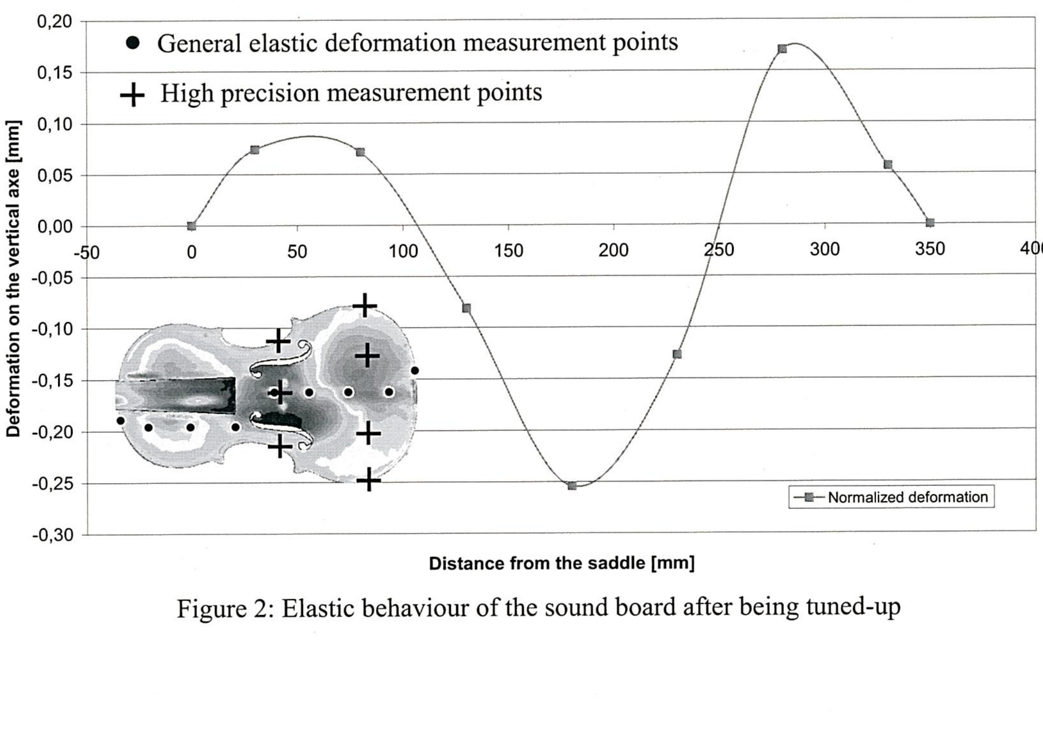


Figure 2: Elastic behaviour of the sound board after being tuned-up

In the *NTCT* the apparatus has shown a very good effectiveness and clearly highlighted the general behaviour of the violin body for the selected point. The RH varied ±0,5% RH on a target of 50%. The temperature varied from 20 to 22,5 °C and the measurements reported here were made at the same environmental temperature in order to avoid an influence of the thermal expansion. A relevant problem during the measurement arise because the creep of the violin, as well as for the strings, resulted in a force reduction of about 6% of the initial load producing an elastic recovery during the creep phase. A correction was then performed according to Hook law by computing the elastic recovery during the creep phase as a function of the force lost, the initial force and the initial elastic deformation. After the correction the creep value was clearly highlighted. The recovery phase did not present this problem and a recovery can be clearly observed. The creep after ~ 24 hours of load resulted in a relative creep of about 15 %. The complete test is shown in *Figure 3*. To an initial force of 8,706 dN corresponds an elastic deformation of -145,9 μm, a measured creep of -12,2 μm, a computed elastic recovery during the creep phase of +9,1 μm and a total computed creep of -21,3 μm. Concerning the recovery after a 6% of force reduction an elastic recovery of 138,6 μm was measured and a viscous recovery of 18,8 μm measured. The main results of the test are summarised in *Table 1*. The residual deformation, computed as a sum of the elastic deformation after load, creep, elastic deformation at unload time and recovery, resulted to be -0,7 μm. The recovery seem still unfinished, in fact as a general rule and according to the previous test performed with the copy of the violin this was already clear. Unfortunately because of a rigid time schedule imposed by the logistic situation it has been impossible to extend the recovery time. Being this value at the limit of repeatability of the transducers used in the tests it can not be concluded that this is a residual deformation. Anyhow a so low value of residual deformation seems to show that the viscous deformation of the tuned violin is completely recoverable. Moreover as can be observed in *Figure 3*, superposed to the deformation data can be observed a trend connected with hygroscopic deformations linked to the small uncontrolled *RH* variations. The following step will then be the implementation of a model for the prediction of hygroscopic behaviour in order to clean the viscous deformation by these undesired effects.

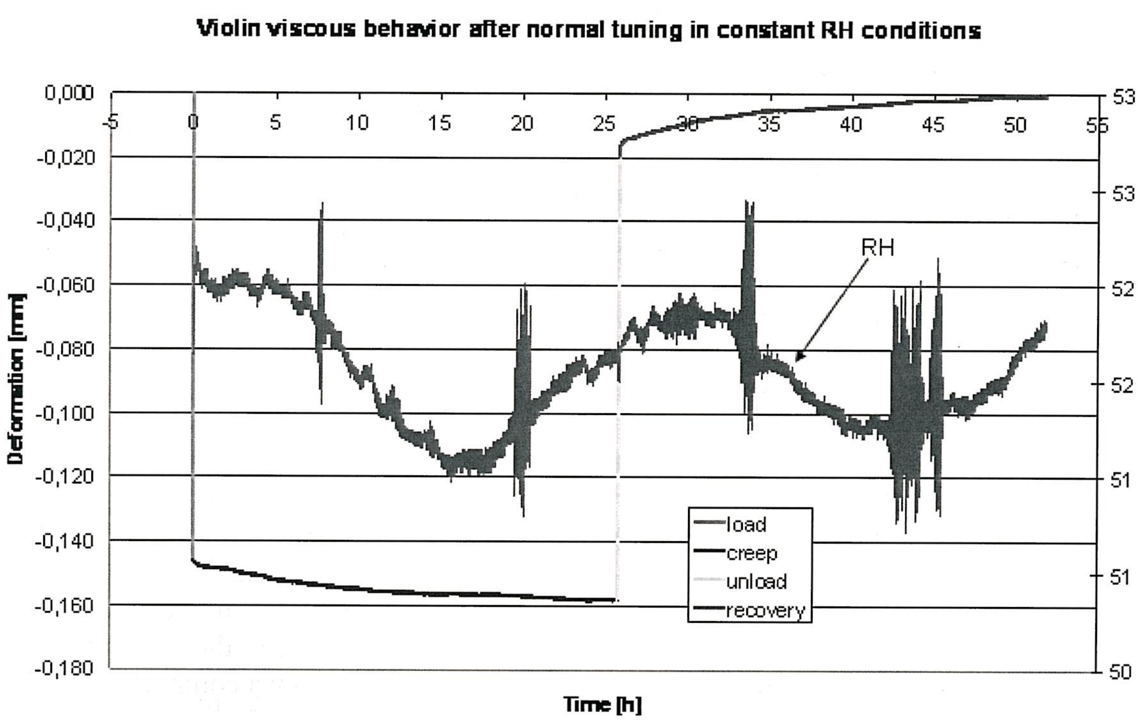


Figure 3: Creep and recovery after ~ 26 hours of creep and ~ 26 hours of recovery after normal tuning up of the violin in constant relative humidity conditions

For the tests performed with a dead weight their aim was to confirm the behaviour highlighted in the *NTCT* without the limit of force reduction during the load phase and to perform a simpler test in order to evaluate the arise of mechano-sorptive creep after an *RH* variation was performed. With this experimental design the creep (*DWCT*) and mechano-sorptive (*DWMST*) phenomena were clearly highlighted and are shown in *Figure 4* and *Figure 5*. To whom it may concern, the *DWCT* (see *Figure 4*) the creep and the recovery are clearly visible and easy to be determined. The dead weight positioning is, in fact, much more rapid then the tuning-up operations and the creep and recovery beginning are much clearer then in normal tuning. The test results are summarised in *Table 1*. As can be observed in this case no correction is needed and after 6 hours of load the relative creep is higher then for *NTCT* after ~ 24 hours of load. This is a clear index of the stiffening effect on the structure produced by the longitudinal force. This idea is made clearer by the fact that with a load applied in *DWCT* being ~ the 24 % of the *NTCT* the 60% of the deformation is obtained. For the *DWCT* test a residual deformation of -0,3 μm is obtained and, as for *NTCT*, no conclusions on residual deformation can be drown being lower then the transducers repeatability. Anyhow this is a clear trace of the possible complete recovery of the viscous deformation.

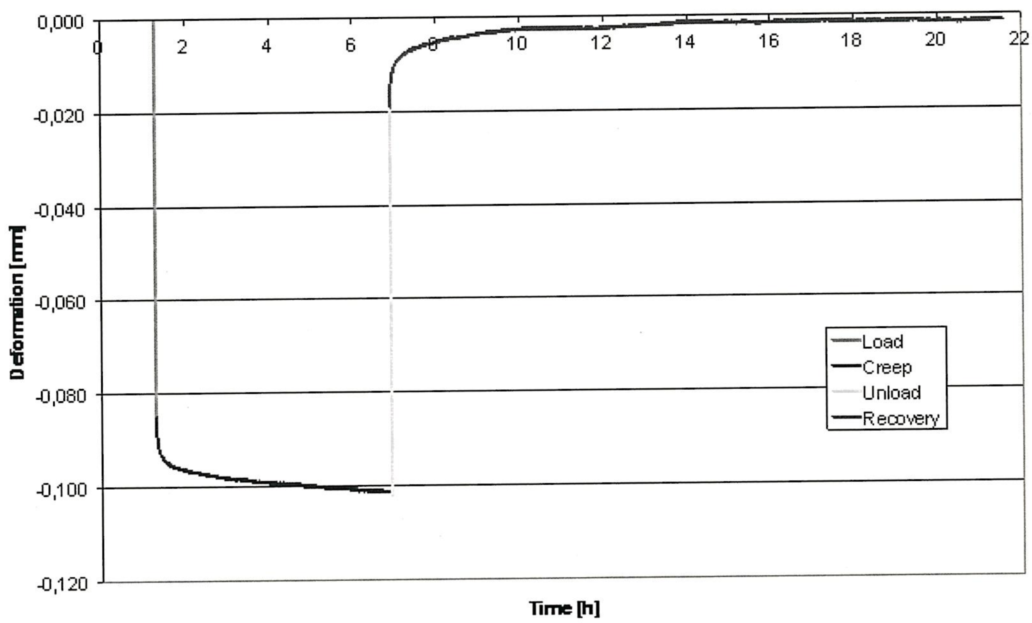


Figure 4: Creep and recovery in a 5 hours and 36 minutes creep test after a dead weight was applied on the violin

Finally, in order to evaluate the mechano-sorptive effects on the violin deformations in conditions similar to a concert, *DWMST* was performed with a *RH* step of -9,3% *RH* for 2 hours. The results are reported in *Figure 5* and clearly show an increase of the deformation because of the mechano-sorptive behaviour. The general deformations measured in the test are reported in *Table 1*. Concerning the mechano-sorptive creep and related recovery the residual deformation as the previous point is very little and close to the transducers resolution. By measuring the creep behaviour after three hours for *DWCT* (12,6 μm) and comparing this value with the same value of the *DWMST* an increment of 1,2 μm due to the mechano-sorptive behaviour can be highlighted. The residual deformation can be quantified in +0,6 μm that once again is the limit resolution of our system. Even for the mechano-sorptive test performed in conditions similar to those of a concert no significant residual deformation can be measured and the test seems to show a complete recovery.

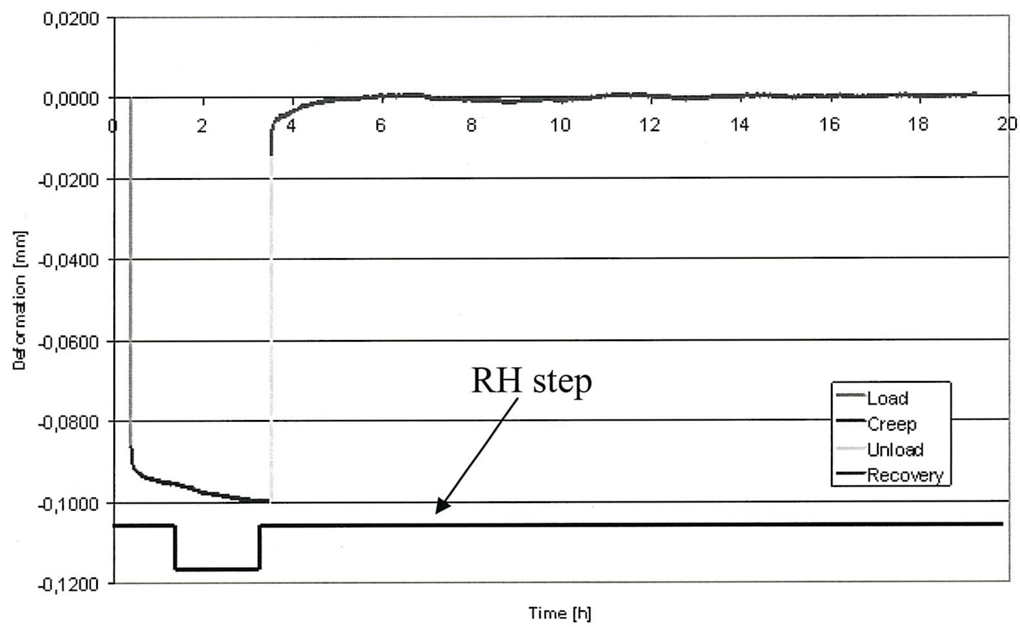


Figure 5: Mechano-sorptive behaviour in a 3 hours test after a dead weight was applied on the violin

Table 1: Main results concerning the violin mechano-sorptive behaviour after a dead weigh was applied

Test:	*NTTC*	*DWCT*	*DWMST*	
Type of load:	Normal tuning	Dead weight	Dead weight	Units
RH conditions	Constant	Constant	Variable	
Transversal force applied at test start:	8,706	2,109	2,109	
Average RH:	51,5	47,2	47,2	[%]
RH step during load:	/	/	-9,3	[%]
RH step duration:	/	/	~ 2	[hh]
Force application time:	~ 26	~ 6	~ 3	[hh]
Elastic deformation after tuning (a):	-145,9	-86,8	-85,9	[µm]
Creep at unloading time (b):	-12,2	-15,4	-13,8	[µm]
Elastic recovery during creep:	+9,1	/	/	
Real creep:	-21,3	-15,4	-13,8	
Increment of creep because of mechano-sorptive behaviour:	/	/	1,2	[µm]
Relative creep:	14,6	17,7	16,1	[µm]
Elastic deformation at unloading (c):	+138,6	+83,2	+85,6	[µm]
Recovery (d):	+18,8	+17,7	+14,7	[µm]
"Residual" deformation computed as (a+b+c+d):	-0,7	-0,3	+0,6	[µm]

Conclusions

In conclusion a complete system for in-situ evaluation of elastic, viscous and mechano-sorptive deformation of violins was implemented and the measurements were performed on an old violin similar to the "Cannone" from Guarneri del Gesù. The relative creep especially after a normal tuning test for 26 hours of load showed to be about 15 % and the recovery almost complete. Some little errors could arise because of narrow fluctuations of the *RH* controller that could lead to very low limited hygroscopic deformations. An *RH* step of -9,3 % *RH* resulted in an increase of deformation evaluated in 1,2 μm due to mechano-sorptive behaviour. The viscous and mechano-sorptive deformations have shown to be almost completely recoverable. A further step could be done by correcting the deformation values after modelling the hygroscopic deformations.

Acknowledgements

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