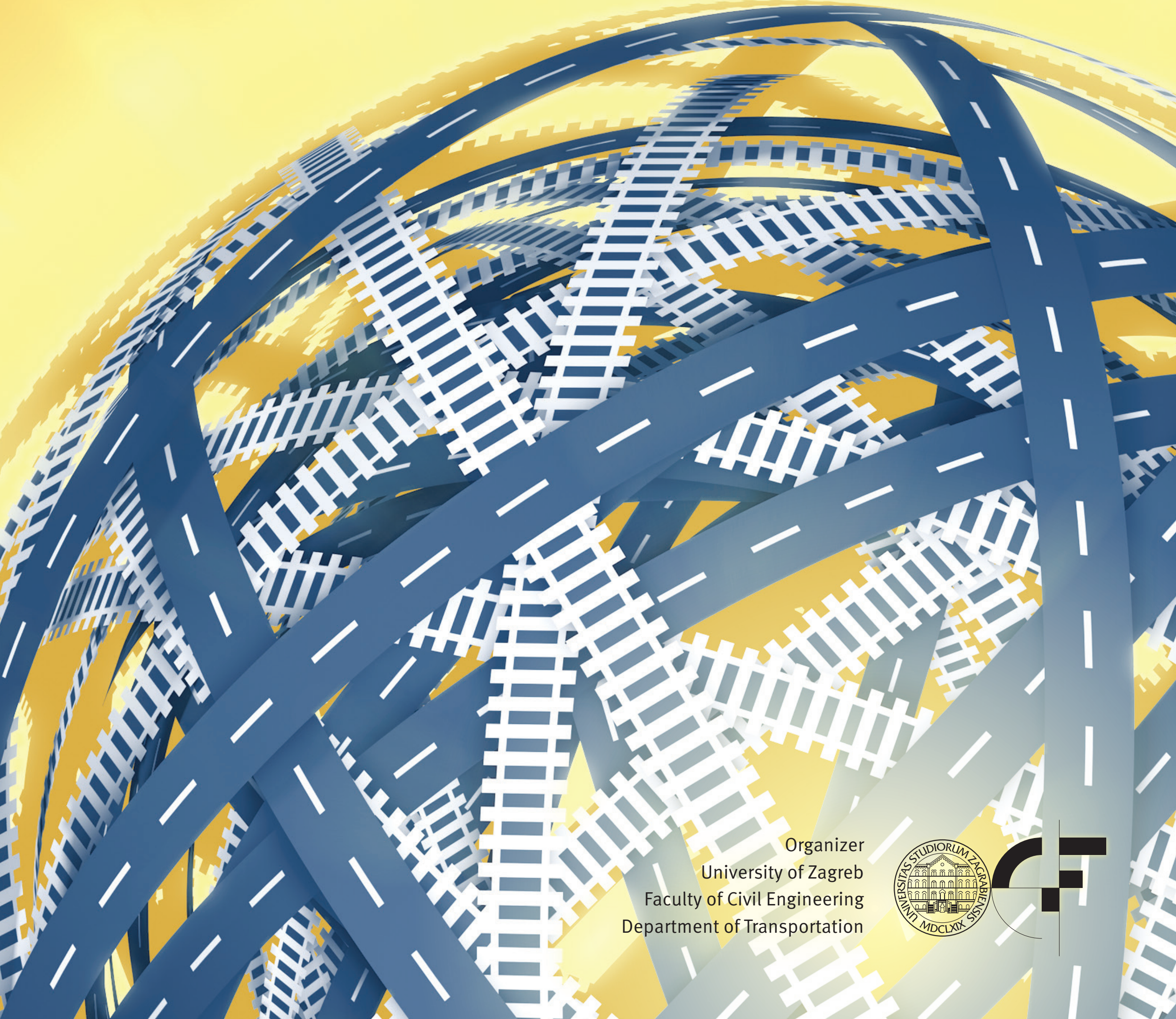
CETRA[2016]

4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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MODEL TEST TO DETERMINE LOAD-SETTLEMENT CHARACTERISTICS ON SOFT CLAY USING PILE-RAFT SYSTEM

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Abstract

Due to the high complexity involved in behaviour of clays the pile-raft system seems to be the most viable approach to carry heavy loads. Very limited research work is available on this in context to soft clays using pile-raft system. Present research aims to study the elastic and non-elastic response of intergrated and non-integrated pile-raft system embedded in soft clay using physical model approach. The pile-raft model system is fabricated using Aluminum material for the slenderness ratio, L/D, 10 with suitable scale factor. The behavior was compared with responses of flexible unpiled raft, single pile, rigid pile groups. The effect of numbers of piles on the settlement, load improvements ratio and settlement reduction ratio are some of the major parameters presented and discussed.

Keywords: settlement reducing pile, flexible raft, load improvement ratio, settlement reduction ratio

1 Introduction

Raft and pile groups are the two alternative foundation options to support structures with heavy column loads. Raft is normally designed as rigid in order to withstand high moment and differential settlement, which is a function of intensity of load and relative stiffness of raft and soil. In the case of pile groups more number of piles is provided than required to cater the column load and to practically eliminate the settlement, which makes the foundation to be very expensive. The concept of pile raft was conceived and introduced about three decades back to overcome the difficulties stated above as well as for the effective utilization of the pile group. For most piled raft foundation, the primary purpose of the piles is to act as settlement reducers. The proportion of load carried by the piles is considered as a secondary issue in the design. However, it is observed that the design of foundations considering only the pile or raft is not a feasible solution because of the load sharing mechanism of the pile-raft-soil. Therefore, the combination of two separate systems, namely “Piled Raft Foundations” has been developed (Clancy and Randolph (1993)).

2 Experimental work

A series of laboratory tests were performed on models of unpiled raft, single pile and central piled raft to examine the settlement behavior of axially loaded pile-raft foundation system. Tests on 19 mm diameter Aluminum piles with single pile has been carried out for centrally located pile and same thickness of raft. Details of piles configuration and model raft dimensions adopted in present research work is shown in Fig. 1.

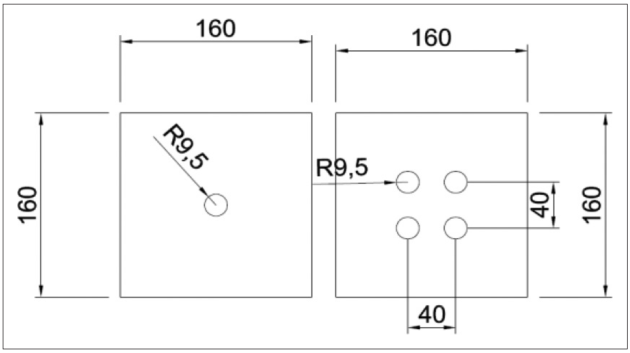

Figure 1 Details of piles arrangement (Dimensions in mm)

2.1 Experimental set-up

Tests were performed in a cylindrical mild steel vessel of 500 mm diameter and height of 500 mm. The mild steel base plate was also provided with four numbers of holes separated at 120° angle and distanced at R/2, R/4, 2R/3 and at center c/c for the drainage purpose. The loading frame consists of four vertical columns (C-Section) of 1 m height, two on each side and two horizontal beams (C-Section). The load was applied through a mechanical jack fixed at center as shown in Fig. 2. Two linear vertical displacement transducers (LVDTs) of 0.01 mm accuracy were located at the middle side of the raft, to measure vertical downward settlement.

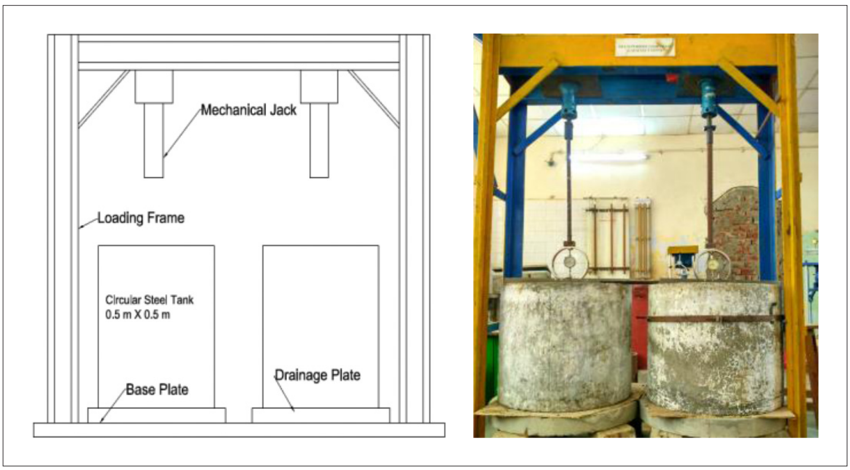

Figure 2 Schematic diagram and actual photograph of model test set-up

2.2 Properties of materials

Marine soft clay is used to prepare soft clay bed. The index properties of soft clay is presented in Table 1.

Table 1 Properties of soft marine clay

Index Property	Values
Specific gravity	2.47
Liquid limit [%]	55
Plastic limit [%]	21.31
Plasticity index [%]	33.69
Shrinkage limit [%]	17.16
Free sweel index [%]	30.77

2.3 Model of raft and piles

Aluminum plates, with fixed thickness, served as model rafts. The dimensions of the raft was 160 mm ×160 mm × 4 mm. The modulus of elasticity and Poisson's ratio of Aluminum plates were 70 GPa and 0.33, respectively. The model piles used in the experiments were Aluminum hollow pipes of 19 mm in outside diameter and 1.5 mm in wall thickness. The modulus of elasticity and Poisson's ratio of the Aluminum pipe were 70 GPa and 0.33, respectively. The embedded pile lengths of 200 mm was used in the experiments. The lengths represent L/D ratios of 10. Top head of each pile was provided with a bolt of 6 mm in diameter with a wooden piece of 20 mm length to connect the pile to the cap through two nuts to ensure a complete fixation between the pile and the cap as shown in Fig. 3.

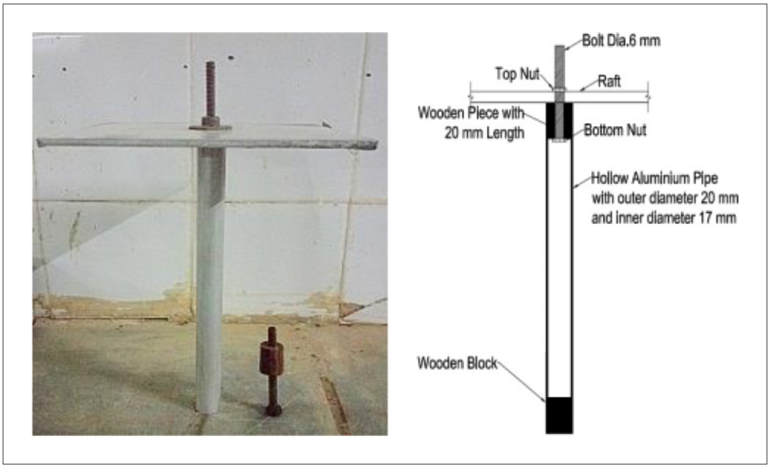

Figure 3 Connection between the pile and the raft

3 Result and discussion

The model tests results obtained from laboratory tests are analysed and discussed in this section. The settlement equal to 10% of pile diameter or raft width is often adopted to define the ultimate load capacity in foundation design (Cerato et al. 2006, Lee et al. 1999, Lee et al.2005). In this model tests, loading was continued till the raft settlement reaches 25 mm and pile settlement reaches 20 mm.

3.1 Effect of raft's thickness

As seen in Fig. 4. the increase in raft's thickness improves load bearing capacity of unpiled raft. The thickness of raft is selected such as the stiffness varrying from very flexible raft to rigid raft. The load carrying capacity of unpiled increases by 6% and 13% at 10 mm settlement going from 2 mm thick raft to 4 mm and 8 mm thick raft respectively. Similarly the increment was 9% and 20% for 4 mm and 8 mm thick raft at 25 mm settlement.

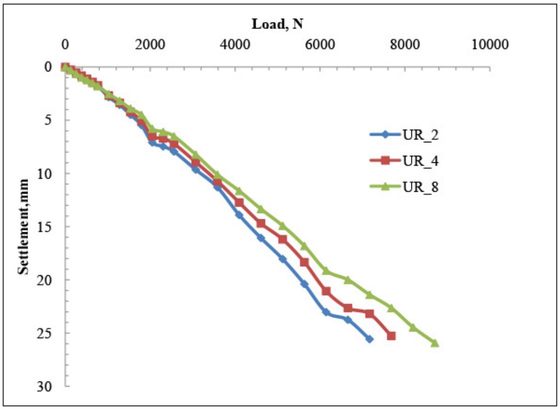

Figure 4 Load vs Settlement for 2 mm, 4 mm and 8 mm thickness of raft

3.2 Effect of number and length of pile in pile group

Figure 5 shows the effect of number of piles in pile group as well as effect of lenght of pile. As seen in the Fig. 5 the load carrying capacity increases as we increase length of pile and it also increases as we increase numbers of pile.The L/D ratio was 10 and 15, number of piles were 1 and 4. It is seen that in case of pile group of L/D=10, increasing pile number from 1 to 4 increases load carrying capacity at 10 mm settlement by 123% and at 20 mm settlement by 120 %. For increased slenderness ratio i.e. L/D=15, increasing pile number from 1 to 4 increases load carrying capacity at 10 mm settlement by 170% and at 20 mm settlement by 117 %. This shows that increasing length of pile is useful for small settlement at higher settlement the load carrying capacity is not increased appreciably.

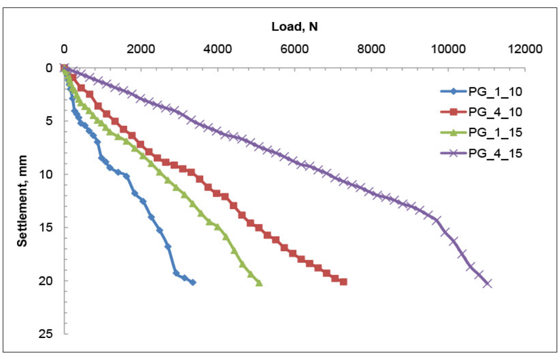

Figure 5 Effect of number of pile with slenderness ratio 10 and 15

3.3 Pile-raft system

Figure 6. shows the comparission of unpiled raft of 2 mm thickness, pile group of L/D=10 and 15 with 1 and 4 number of piles and pile-raft system. It is seen in both Fig.6a) and 6b) as we combine unpiled raft and pile group and form a pile-raft system its load carrying capacity is higher than unpiled raft and pile group. As shown in Fig. 6a) the load carrying capacity of pile-raft for single pile increases by 14% at 10 mm settlement compared to unpiled raft where the increase is 50% at 25 mm settlement. Also the load carrying capacity of pile-raft for four piles increases by 228% at 10 mm settlement compared to unpiled raft where the increase is 306% at 25 mm settlement. Where as in Fig. 6b) the load carrying capacity of pile-raft for single pile increases by 30% at 10 mm settlement compared to unpiled raft where the increase is 111% at 25 mm settlement. Also the load carrying capacity of pile-raft for four piles increases by 396% at 10 mm settlement compared to unpiled raft where the increase is 451% at 25 mm settlement.

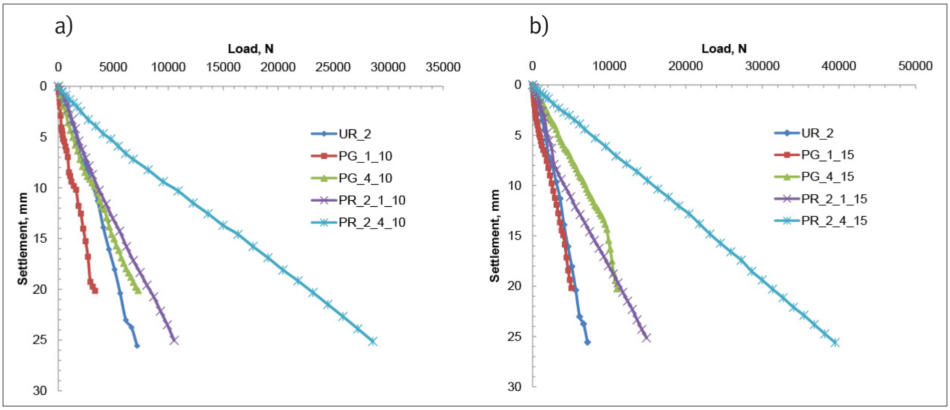

Figure 6 Load vs Settlement for pile-raft system: a) raft thickness 2 mm,L/D=10; b) raft thickness 2 mm,L/D=15

Figure 7. shows the comparission of unpiled raft of 4 mm thickness, pile group of L/D=10 and 15 with 1 and 4 number of piles and pile-raft system. It is seen in both Fig.7a) and 7b) as we combine unpiled raft and pile group and form a pile-raft system its load carrying capacity is higher than unpiled raft and pile group. As shown in Fig. 7a) the load carrying capacity of pile-raft for single pile increases by 69% at 10 mm settlement compared to unpiled raft where the increase is 88% at 25 mm settlement. Also the load carrying capacity of pile-raft for four piles increases by 275% at 10 mm settlement compared to unpiled raft where the increase is 403% at 25 mm settlement. Where as in Fig. 7b) the load carrying capacity of pile-raft for single pile increases by 111% at 10 mm settlement compared to unpiled raft where the increase is 145% at 25 mm settlement. Also the load carrying capacity of pile-raft for four piles increases by 372% at 10 mm settlement compared to unpiled raft where the increase is 519% at 25 mm settlement.

Figure 8a) and 8b) show the variation of the load improvement ratio with the number of piles at 10 mm and 25 mm settlements, respectively. From these figures, it can be observed that for the given raft thickness, the value of load improvement ratio increases as the number of piles and length of piles beneath the raft increases e.g. as show in Fig.8a) at 10 mm settlement, for raft of thickness 2 mm,and pile with L/D=10, the value of load improvement ratio increases by 187%,while installing 4 piles. At 25 mm settlment the increment is 170%. Now for L/D=15; at 10 mm settlement, for raft of thickness 2 mm, the value of load improvement ratio increases by 278%,while installing 4 piles. At 25 mm settlment the increment is 161%.

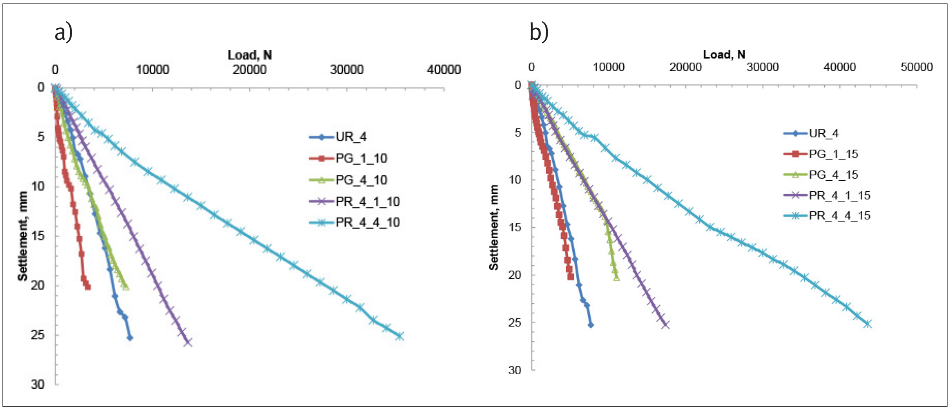

Figure 7 Load vs Settlement for pile-raft system: a) raft thickness 4 mm, L/D=10; b) raft thickness 4 mm, L/D=15

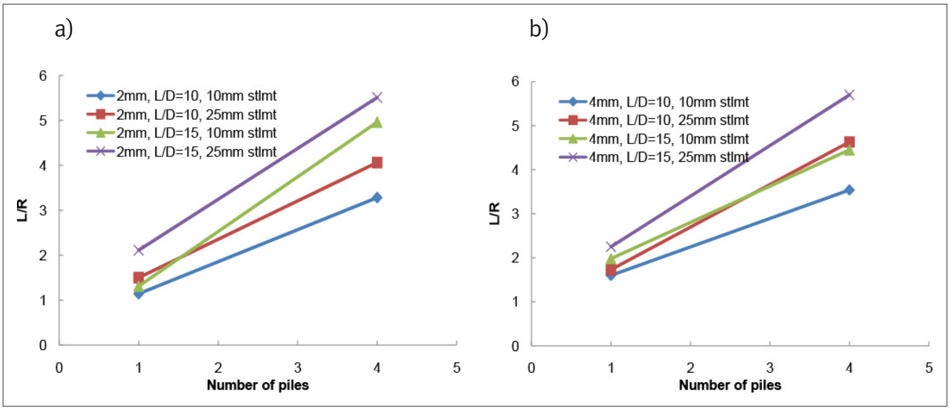

Figure 8 Variation of load improvement ratio with the number of piles at 10 mm and 25 mm settlement: a) 2 mm thick raft; b)4 mm thick raft

As show in Fig. 8b) at 10 mm settlement, for raft of thickness 4 mm,and pile with L/D=10, the value of load improvement ratio increases by 121%,while installing 4 piles. At 25 mm settlment the increment is 167%. Now for L/D=15; at 10 mm settlement, for raft of thickness 4 mm, the value of load improvement ratio increases by 124%,while installing 4 piles. At 25 mm settlment the increment is 153%.
The reduction in settlement of raft due to the presence of piles are represented by a non dimensional factor, called settlement reduction ratio, which was define as defined as the ratio of settlement of piled raft and unpiled raft at a given load.

$$\text{Settlement reduction ratio} = (\delta r - \delta pr) / \delta r \quad (1)$$

where, δr and δpr represents settlement of unpiled raft and piled raft for a given load.

Figure 9 shows the variation of settlement reduction ratio, with the number of piles for rafts with thickness of 2 mm and 4 mm. From these figure, it can be observed that; as the number of piles underneath the raft increases, the settlement reduction ratio increases. The rate of increase of settlement reduction ratio decreases as the thickness of raft increases (e.g. For raft thickness 2 mm, settlement reduction ratio increases by 413%, while installing 1 pile to 4 piles underneath the raft, while for raft thickness 4 mm, settlement reduction ratio increases by 55%, while installing 1 pile to 4 piles underneath the raft).

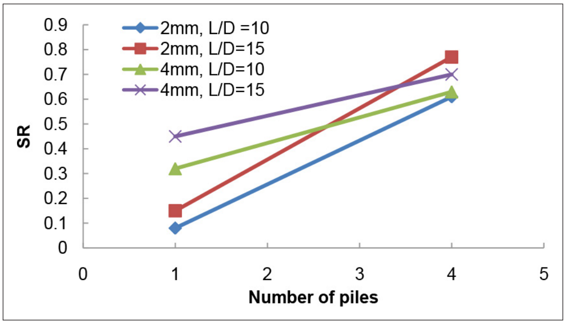

Figure 9 Variation of settlement reduction ratio with number of piles

4 Conclusion

The paper has presented experimental results of load tests on model unpiled raft, pile group, and piled raft embedded in soft clays. The research work focuses on the load-settlement behaviour of pile and raft. From the result of this study following conclusion can be drawn:

- Increase in raft thickness shows higher increment in the load carrying capacity of unpiled raft for large settlment compared to small settlement.
- Increasing the number of piles definitely increases the bearing capacity of pile-raft but increasing the length of pile increases the load carying capacity more effective for smaller settlement.
- In case of integrated pile-raft system the load carrying cappacity of pile-raft increases with increase in number of settlement reducing pile and length of pile.
- The pile-raft system is more effective for higher settlement as adding 4 piles improves the bearing capacity by 3-4 times.
- At 10 mm and 25 mm settlements, L/R, load improvement ratio increases as number of piles increases.
- Its also observed that as the number of piles increases the load shared by raft reduces and load shared by pile increases.
- The rate of increase of settlement reduction ratio decreases as the thickness of raft increases.

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