Industrial Science
Vol.1,Issue.1/Oct. 2013 ISSN : 2347-5420

Research Papers

AN EVALUATION AND COMPARISON OF SIRJAN'S EMBANKMENT BEHAVIOR WITH INSTRUMENTATION DATA AND SOFTWARE PLAXIS

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Abstract

Permanent control of embankment dam stability during construction, the first impounding and also during utilization of the project, is a significant issue. Instrumentation of such dams which monitor their behavior plays an important role in the dam stability. Regarding that an earth dam is a continuous structure with non-linear behavior, finite element method and appropriate soil modeling could be employed for non linear analysis. In the present research, based on the instrumentation data of sirjan embankment which is located in the North East of Iran, bar dam, a 71 meters high embankment dam, was instrumented in order to monitor internal soil behavior such as settlement and soil stresses. Only typical results of the measurement program are presented here. The results that are given have been selected because they provide Quantitative information about the performance of the instrumentation. Afterward, two soil models including Mohr-Coulomb and Hardening models were selected for stress-strain analysis. PLAXIS 2D, a finite element code was employed to simulate the behavior of dam during the first impounding and for stress-strain deformation. The results specified that Hardening model is more capable of predicting the dam behavior determining the dam stability during construction and afterwards.

KEYWORDS:
embankment, precision instrument, infinite-element, behavior analysis, consolidation

INTRODUCTION

Dams are economically, socially and politically important. Because of their high construction costs and the disastrous consequences of their instability, maintaining and constantly evaluating their stability is of vital importance. Sirjan dam is constructed on Tanguieh river. Its height from the bottom of the foundation is 71 m and its crown is 1100 m long and 14 m wide. Due to proper soil credit resources, such as clay soil mine, fluvial material mine and stone quarry with appropriate haul distances, and the topographical condition and great width of the river; the dam has been designed and constructed as an embankment with clay core.

In order to gather information about the movements and displacements of Sirjan dam side wall, totally 261 precision instruments are installed in the dam and related structures. Precision instruments, including mechanical and electrical, can transfer the data of core water pressure, imposed loads pressure, forces applied to the side walls and foundation of the dam, vertical and horizontal movements and relational displacements from right-hand, left-hand, up and down the dam. Electrical instruments, including 150 total pressure cells, 56 electrical piezometer; and mechanical instruments, including 13 deflectometer pipes and 37 piezometer pipes installed in 5 profiles, report movements of the dam side walls. Four accelographs and seismographs located in different positions in the dam and its related structures, record and report earthquakes. The section of the dam and installment places of the instruments in this section are shown in figure (1).

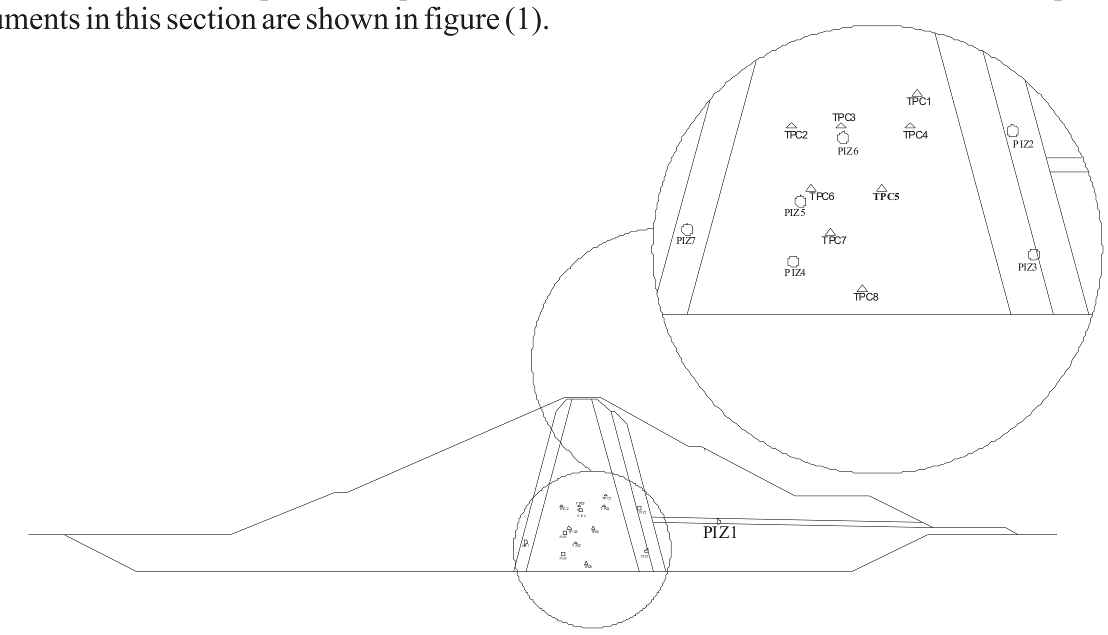

Figure 1- Sirjan dam section and installed and examined precision instruments

Analysis Tools and Methods

Among many different models of materials behavior, in this study, two common models of Mohr-Coulomb and Hardening has been used. In the former, the failure envelope is considered as a line with the following equation:

$$\tau_f = C + \sigma_n \tan\varphi \qquad (1)$$

Where τ and σ are shear stress and normal stress at fracture page; C and φ are cohesion and internal friction angle of the soil. In fact, this equation stated that failure is caused not by maximum normal stress nor minimum shear stress but by a critical combination of both. In Hardening model which is a developed form of Bilinear model; it is assumed that during the materials failure, shear modulus is significantly decreased. Generally in the process of analyzing and designing the embankment, the assumption of constructing the whole structure in a single stage is unreal. So the analysis software used should have the possibility of stage construction where first of all the situation before construction is defined as preliminary condition, then the whole structure is built gradually. In this study the Finite-Element software Plaxis which has the above-mentioned conditions has been used for modeling the construction of the dam in 16 and its impounding in 8 stages. The core of the dam, for more strength and stability, was built in 10 stages to be more realistic. Usually the two-dimensional Finite-Element analysis is used to record the behaviors of a dam. Scientific observations has proved the proper estimation of this modeling and only when the dam is arched or the ratio of the length to the height of the dam is lesser than 6 to 1, the three-dimensional analysis is necessary (which is not the case with this study). In the Finite-Element analysis of dams, the main goal is to find the stresses and strains of the materials and the pressure of the pore water with help of which the places of potential cracks and possible hydraulic cracks can be predicted.

RESULTS AND DISCUSSION

Stressmeter and piezometer were chosen as two main tools for revealing the dam behavior during operation. In figure (2) and (3), the data from precision instruments TPC3 and TPC 8 with those from software modeling (Mohr-Coulomb and Hardening) and also the two behavior models were compared. For the tools in the right side of the core axis where the pressure fall of piezometer water is higher, Mohr-Coulomb model shows higher results than Hardening model. This was predictable, since the former behavior model shows more stress for more deformation than the latter model. But for other tools installed in places where pore water pressure is higher or deformation is lower, Hardening model shows higher results. As shown in figure (3), the rate difference of TPC8 tool from the two modeling is higher than that of other tools used in higher levels of the dam. This difference can be a result of more pressure of pore water on this tool because of complicated changes of water level in the back of the dam and delay of its effects on the precision instruments.

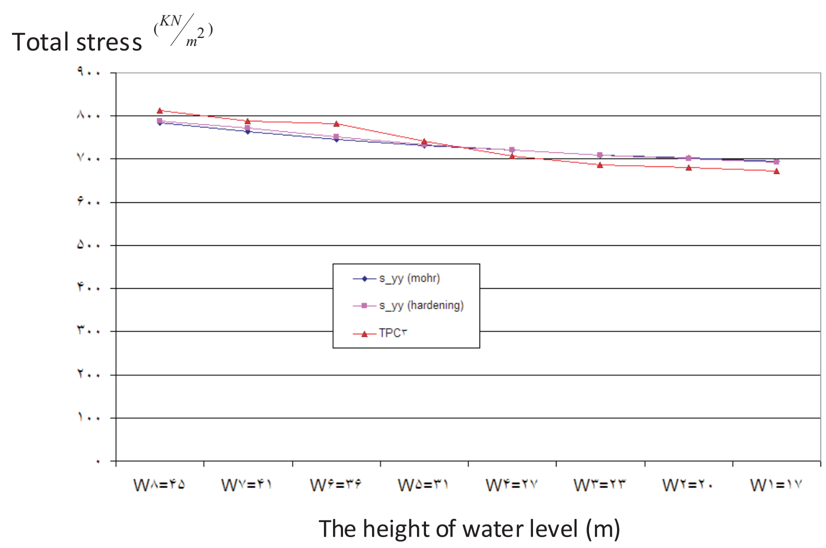

Figure 1- The comparison of TPC3 precision instrument results with those of Mohr-Coulomb and Hardening models for different water levels

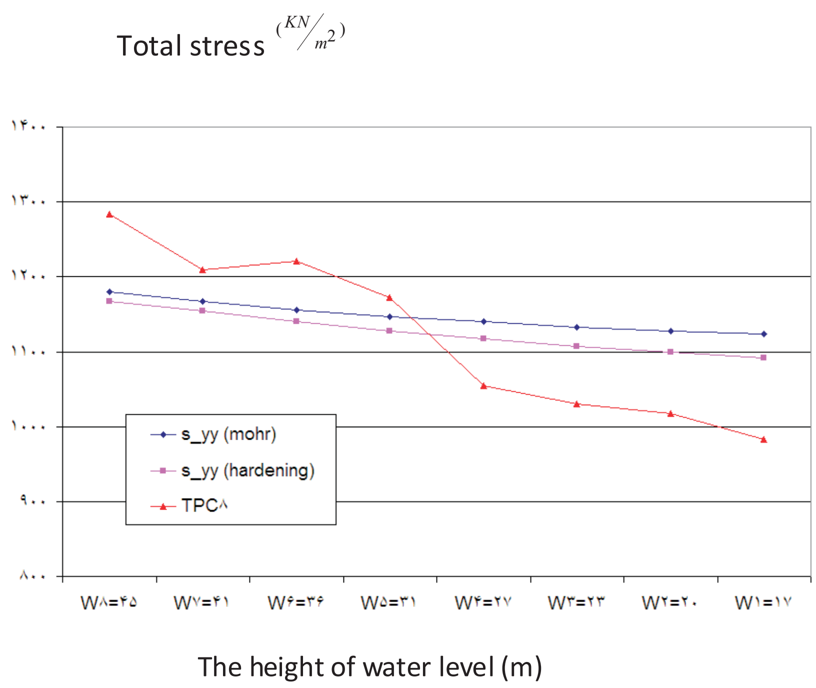

Figure 1- The comparison of TPC8 precision instrument results with those of Mohr-Coulomb and Hardening models for different water levels

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In figures (4) and (5), the results of piezometer tool and software modeling are shown for different water levels. Among 7 piezometers used, the results of piezometers 1 and 2 which have the most differences from the results of precision instruments are presented. These differences are because of the time delays uncontrollability of water level changes effects in analytical modeling. In Piz1 and Piz 2, due to low permeability of the core, some delays may occur which may lead to inaccuracy in modeling.

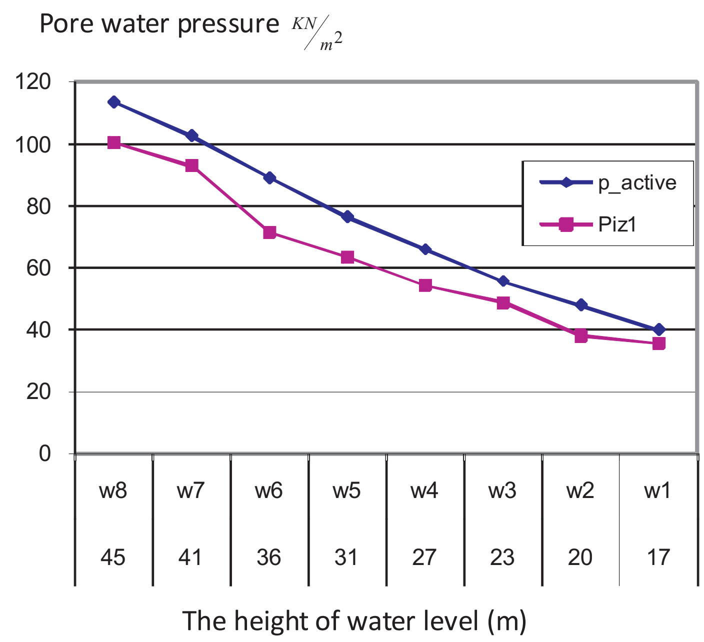


Figure 1- The comparison of PIZ1 piezometer precision instrument results with those software modeling for different water levels

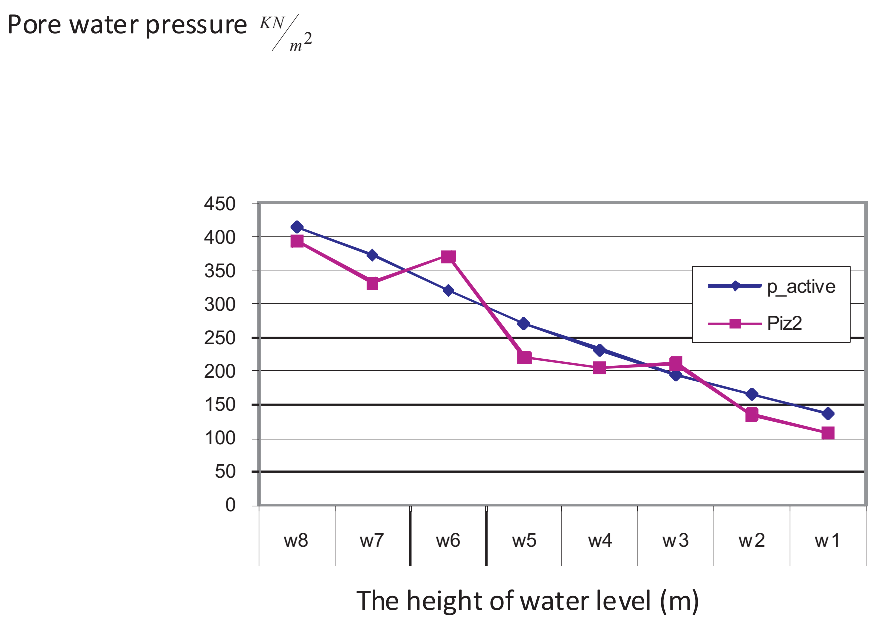
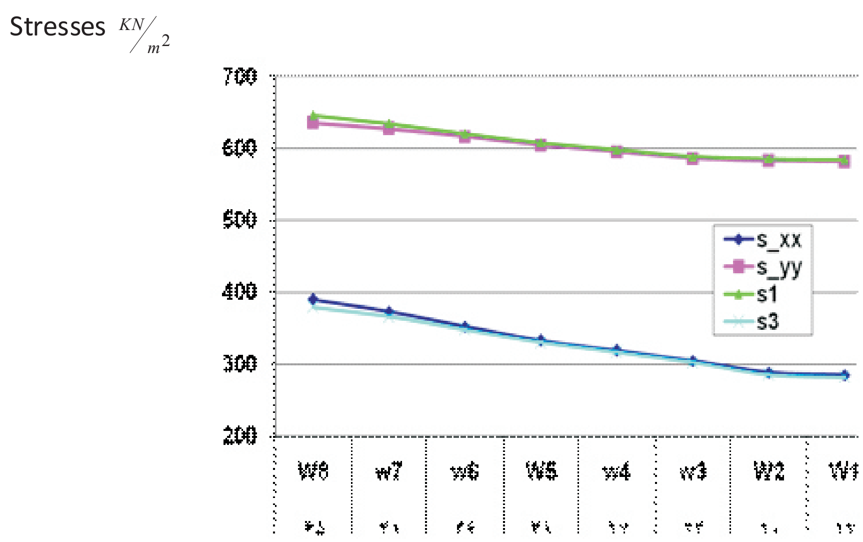


Figure 1- The comparison of PIZ2 piezometer precision instrument results with those software modeling for different water levels

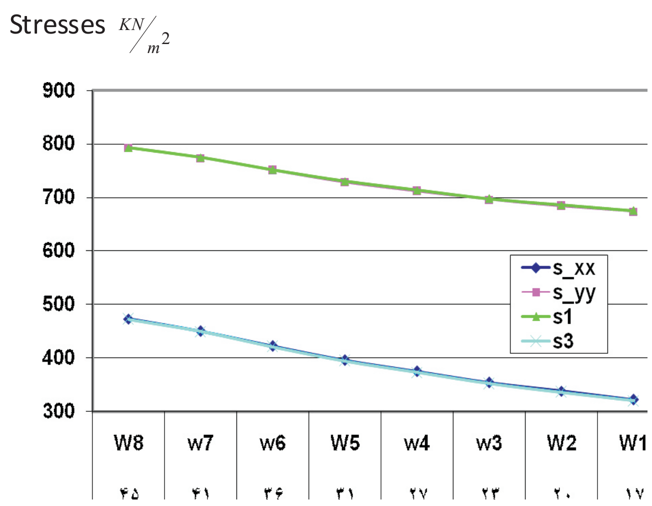
In the above figures, P-active is from the results of software modeling and Piz is from the precision instrument interpretations.

In figures (6) and (7), vertical and horizontal stresses of Sirjan dam resulted from precision instruments TPC1 and TPC2 were compared with main stresses. As shown in the pictures, the difference between the main stress and those related to directions of x and y axes is not noticeable. The difference, which is predictable and a result of pressure of pore water or of the water flow in the dam, rises in higher levels of water. In the following figures, s_xx is the stress in the direction of x, s_yy is the stress in the direction of y, s1 the main stress and s2 in the minimum main stress. The data of the main stresses have been gathered by the model and the stresses in the direction of x and y by readings of the instruments.



The height of water in the back of the dam (m)

Figure - The comparison of the main stresses with vertical and horizontal stresses in TPC1 for different water levels



The height of water in the back of the dam (m)

Figure - The comparison of the main stresses with vertical and horizontal stresses in TPC1 for different water levels

In figure (8), the results of settlement of the construction consolidation is shown. The settlement in the center of the dam is a little more than its margins especially lower layers. This heterogeneousness is because of arching and that the stresses in the margins are more normal. It should be noted that the arching is the hanging of core from the shell of the dam which causes a decrease in vertical pressure in the core. This coefficient is calculated as follows:

$$\text{Arching coefficient} = {}_{v} \big/ \, h \qquad (2)$$

In this equation, $_{v}$ is the total normal stress inside the core, is the specific weight of the core materials and h is the height of backfilling.

Since the core of the dam has been modeled separately; for achieving the results of consolidation of the core, its lateral displacement was impeded in software modeling in order for boundary conditions to be met.

Height of the core (m)

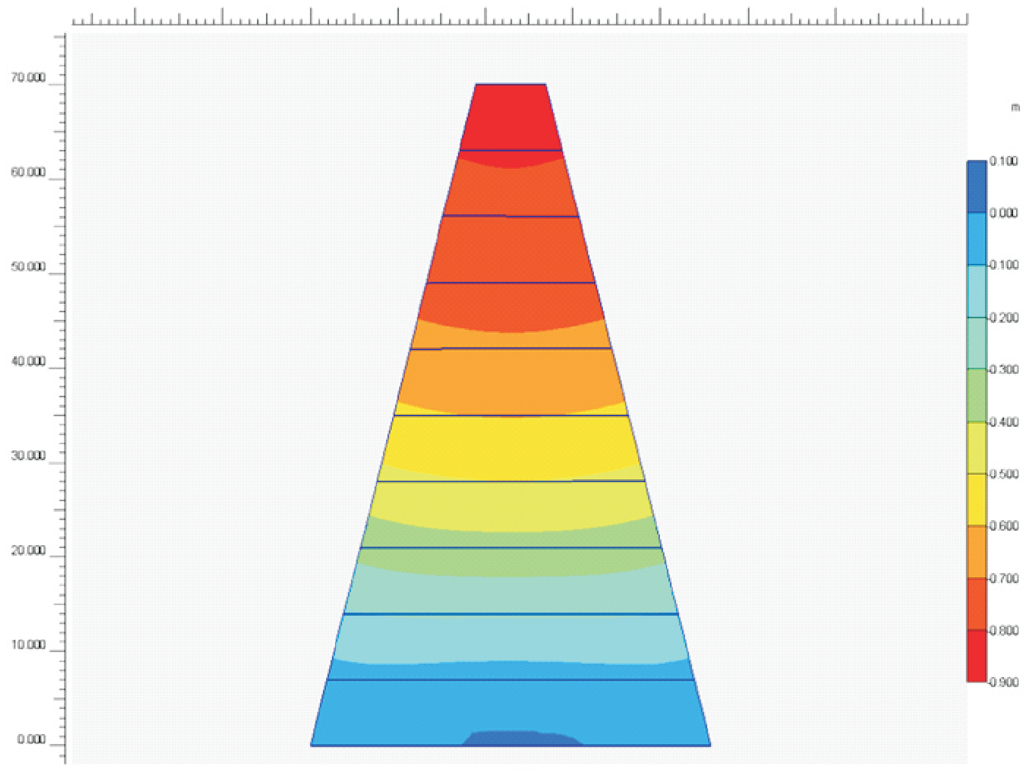


Figure - Vertical displacement resulted from consolidation for construction period (m)

In figure (9), the curve of pore pressure-time changes is drawn. The pore water pressure resulted from consolidation first deceases, then increases in time. The decrease is due to gradual dilatancy of the soil after impregnation and will increase after consolidation.

Pore water pressure $^{KN}/_{m^2}$

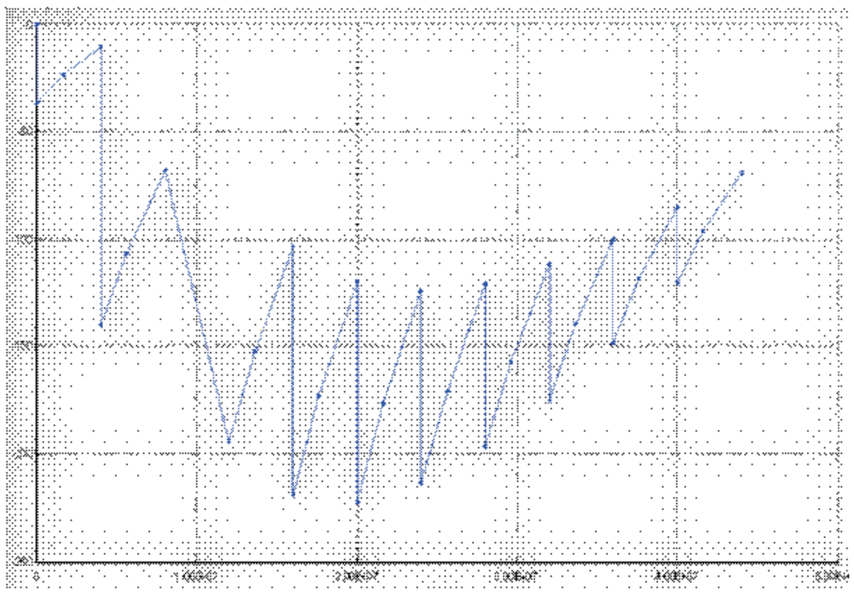


Figure - The curve of core water pressure resulted from consolidation in time during construction period

CONCLUSION

1.Given the fact that the laboratory tests data according to which analytical modeling is carried out and that whatever done in construction and execution processes is always limitedly accurate, instrumentation is still the most important means for investigation of dam's behaviors and ensuring that the designing and execution parameters are accurate. Nevertheless the results of this study reinforces the validity of laboratory and modeling results.

2.The pore pressure remained in the core of the dam can be changed into the Ru ratio of pore pressure to overburdened pressure. This ratio is compared in stability analysis. This comparison shows that safety factor exists in this case. In Sirjan dam Ru=0.22. Having good results from the precision instruments and their compatibility with analytical modeling, we can more confidently speak about the stability of the dam.

3. The arching has a good compatibility with the values predicted during designing and is reasonably similar to arching coefficient of other dams around the world. The arching coefficient of Sirjan dam, at worst when it reached the highest point at the end of construction, is %78. As the dam height increases, the arching coefficient resulted from modeling comes closer to the coefficient from precision instrument readings.

4.As the software PLAXIS and two models (Mohr- Coulomb and Hardening) show; the results of the study, efficiency of the method and the software used for modeling the embankment behavior during construction are acceptable.

5.Mohr- Coulomb model is one of the simplest models of soil behavior; on the other hand, Hardening model has more flexibilities in modeling and involves more parameters in soil modeling. However, in the modeling of this study the two models demonstrated similar and close numbers.

REFRENCE

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