Experimental Study on Effect of Protection for Local Scour at Piers with Tetrahedron Frame

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Abstract: The merit and shortcoming of the protection method adopted now in China for the scour at piers have been analyzed. The principle of the local scour at piers has been described in the paper. By a series of model experiments, the effect of the clean dumped tetrahedron frame fill has been studied. Furthermore, it proves that the clean dumped tetrahedron frame fill has some engineering value for protecting local scour at piers.

Key words: tetrahedron frame ;protection method， scour

1. Introduction

Building the large-scale bridge in a river makes the local flow suddenly change, which forces the flow sharply to go around the pier. The velocity and direction of flow rapidly change, and a horse-shoe vortex is formed at both sides of the scour hole. Being blocked by the pier, the smooth and straight flow originally is heaped in front of the pier, which gives rise to the vertical flow and the extremely strong downward force of scour for the riverbed around the pier. Thus the scope of the scour hole becomes bigger gradually, which will become a threat to the use of bridge and the integrity of the pier. Owing to the fact that the pier lies in the area of the deepwater and torrent, no matter what we apply to resist the water (the pier applies steel caisson or steel cofferdam), the acute scour can be caused before the construction of the pier. In order to gain the good protection effect and ensure that the pier is safe and stable, it is necessary to protect the riverbed around the pier when the pier is constructed, which can restrain the formation and development of the scour hole.

At present there is mainly two kinds of measurements for the protection of pier, cofferdam and bank: the clean dumped rock fill protection method and the soft sink raft. Between them, the clean dumped rock fill needs the higher technology. To throw smoothly stones on the sandy riverbed, the stable slope should meet three conditions: ⑴.It is not smaller than the stable slope of the saturated riverbed soil. ⑵. It is not smaller than the critical inactive angle of the stone in the flow. ⑶. Pledging that few stones on the slope is washed away by the flow. There exist some problems for the clean dumped rock fill protection method: the quality as a whole is weak, and the expense and working load for maintenance are great on practice. The soft sink raft protection method is used more and more, because it is able to be better to adapt the topography and has the good quality as a whole to resist the scour. But the shortcoming of this method is that the construction procedure is comparatively complicated. When the topography under water is very steep, the effect of the clean dumped rock fill is not very good [1,2, 3, 4].

Because of the shortcoming of the above protection methods, it is important to study a new, effective and economical protection method to substitute for the traditional protective engineering measures. The clean dumped tetrahedron frames fill is a new type of protection method in the protective engineering measures that can protect the roads and bridges against being destroyed by flow. The clean dumped tetrahedron frames fill is developed for the protection of bank. The protection method has been tried out successfully at the island head of the south bank of the Yangtze River of Jiangxi province and appraised by the Science and Technology Developing Center of Water Conservancy Ministry of China. The experimental results show that the tetrahedron frame is more practical and economical than the traditional substantial material and can be fixed up and moved according to the needs on the riverbed and can be used repeatedly and can carry out standardized production at the factory. Especially the protection effect at the foot of the foundation is better. Moreover, the tetrahedron frames need little investment. The construction procedure is easy and convenient. The tetrahedron frames are set up to form the protective engineering around the pier. When flow goes through the tetrahedron frame groups, they can reduce the velocity of flow and make the silt deposit on the surface of riverbed [5]. The experimental study on the protection of bank with tetrahedron frame groups has been carried out [6,7,8]. But the study on the effect of protection of piers with tetrahedron frame group is few. By a series of river engineering flume experiments, therefore, this paper carries out the study on the effect of protection for the foot of foundation with the tetrahedron frame groups and gets some valuable conclusions.

2. Flow structure and scour process in the local scour hole around piers

The pier is a structure that can resist the flow. From the construction to the operation of the pier, the local scour and the silt movement around the pier is a comparatively complicated evolution process, which also is continuously a problem that has engineering value very much. The already existent research findings indicate that the flow structure around the pier chiefly includes the downward flow before the pier, the surge on the surface before the pier and the huge vortex system including the horse-shoe vortex at both sides of the scour hole before the pier and the wake vortex that the flow separation causes at both sides of the pier (shown in Fig.1). Two kinds of vortex at both sides of the pier and behind the pier constantly release some small vortexes and go on developing towards the surface. There appears the surge on the surface ahead of the pier and its whirly direction just is contrary to the horse-shoe vortex. Along the vertical and symmetrical axis of the surface ahead of the pier, the approaching velocity of flow is zero and turns into the stand-point pressure. The stand-point pressure intensity is $0.5\rho\, v^2$. The velocity of flow reduces from the surface to the bottom along the perpendicular line. The downward pressure gradient before the pier makes the flow go downward. The downward velocity of flow changes along the water depth .In the recent years some experiments indicate that the downward maximum velocity of flow has appeared at the place where is 0.02 - 0.05 times width of the pier away from the pier front. The stand-point pressure not only makes the flow go downward, but also forces the flow sharply to go around the pier. Thus the acceleration of the flow appears at the both sides of pier. Therefore, the formation of scour hole is caused by the change of the local flow condition [9].

According to the experimental data, the local depth of scour hole has a relation with the approaching flow velocity V ahead of the pier. When the flow velocity V attains a certain value, the silt at both sides of the pier front is firstly rushed away and scour hole begins to appear. The V at this moment is called the scour velocity V_0. When $V_0 > V > V_0'$ (V_0' is the incipient velocity of flow of the sediment), the scour condition is called the clean water scour. When $V > V_0$, the scour condition is called mobile bed scour. When the supply rate of silt is equal to the transport rate of silt inside the scour hole, the scour trends to balance, i.e. the limit of scour [10]. According to the following text, it is known that the tetrahedron frame groups can restrain or reduce the emergence of the whirlpools and change the flow structure near the pier. Thus the purpose of protecting the riverbed against the erosion and urging silt to deposit on the riverbed is achieved.

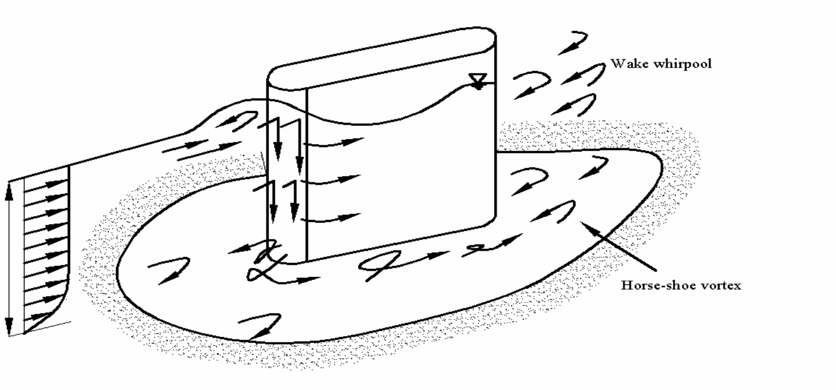

Fig.1 Flow structure around the pier

3.Experimental condition

Owing to the shortcomings and limitations of the clean dumped rock fill and the soft sink raft, we have carried out the experimental study on a kind of new protection method - the clean dumped tetrahedron frame fill. So-called ‘the clean dumped tetrahedron frame fill protection method’ is the method that we imitate the clean dumped rock fill protection method and substitute the stone for the tetrahedron frame that is formed by six roots of concrete pole of the same size to protect the riverbed.

In order to know about the effect of protection with tetrahedron frame, we carried out a series of indoor experiments. The experiment was carried out in a water channel with rectangular cross-section (showed in Fig.2). The length of the water channel is 30m,the width 3m and the depth 1.2m. There is the effective part of the experiment at the 10m of the middle of the water channel. There is the part of entrance and the transitional part at the 10m of the front of the water channel. There are the transitional part, the sand

and gravel trap and the tailwater gate at the last 10m of the water channel. The flow rate is controlled by a weir dam. The water level is controlled by the tailwater gate. The water level is controlled by a water gauge. In front of the model of pier, a flow gauge is installed to measure the approaching velocity of flow.

In the experiment, the wood dust, median diameter is D50=0.63mm, is chosen as the model material. This kind of model material that is treated by a special process can protect against corruption. By a series of experiments, we know about that the closely knit-unit dry weight of the model material γ_s = 1.15T/m3, the unit humid weight of the model material γ_0' = 0.60T/m3 and the unit dry weight of the model material γ' = 0.48T/m3. The model material is paved in the effective part in the model of mobile bed whose length is 10m. The thickness of the model material paved in the effective part is 30cm. The gradation curve of the model material is showed in Fig.3.

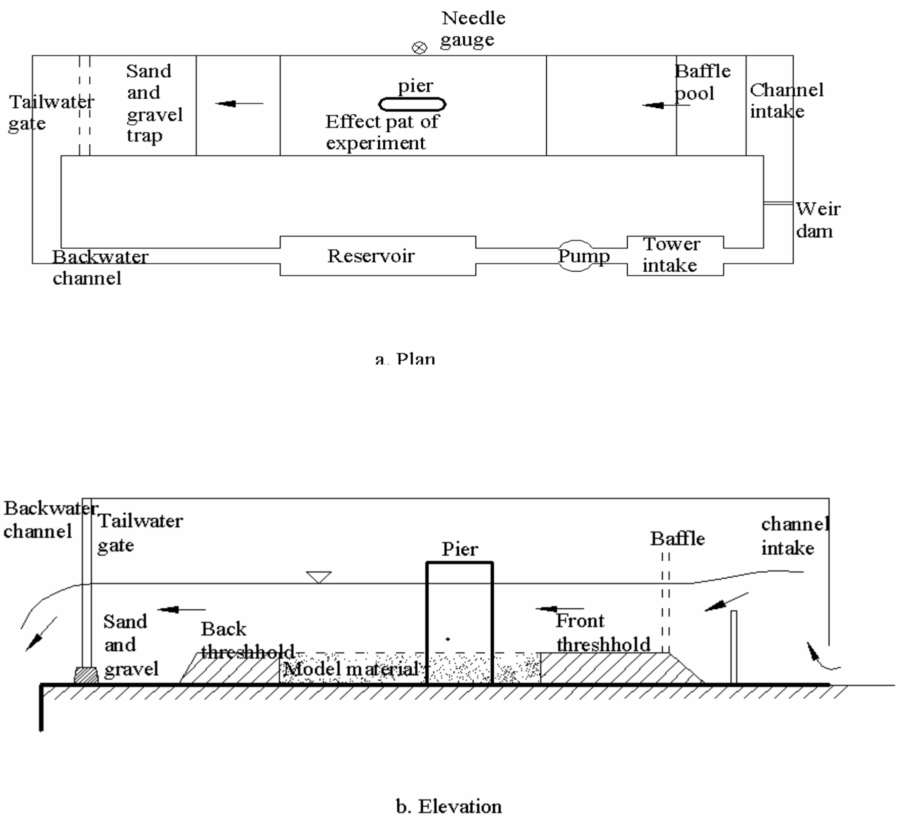

Fig.2 Arrangement of the trial system

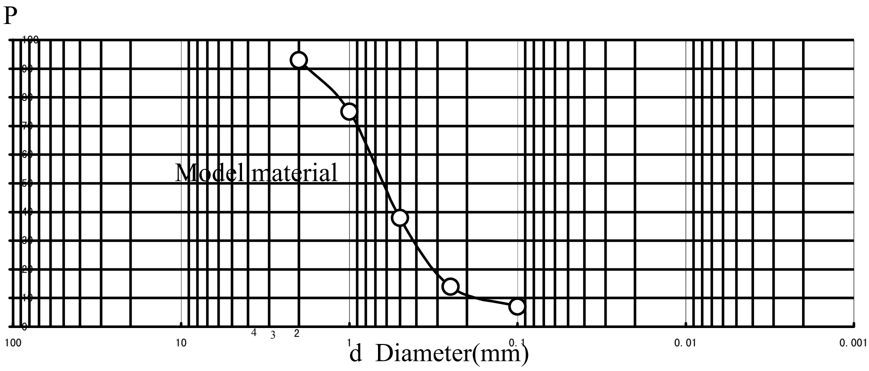

Fig.3 Gradation curve of the model material

We continuously throw the tetrahedron frame in the experiment. The region of clean dumped tetrahedron frame fill is the scour scope of the first experiment in which we don't adopt any protection measures (shown in Fig.4). The altitude of the surface of the riverbed is 0.0m. Scour process achieved the balance after 3 hours. Then topography was surveyed with a level bubble. The water circulation system is adopted in the experiment. The flow rate is controlled by a rectangular weir dam with thin wall. Moreover, the fractional error between the flow rate measured by a rectangular weir dam with thin wall and the one by a water channel with rectangular cross-section is smaller than 3%. The size of rectangular pier with circular heads is shown in Fig.4. The size of single tetrahedron frame is shown in Fig 5.

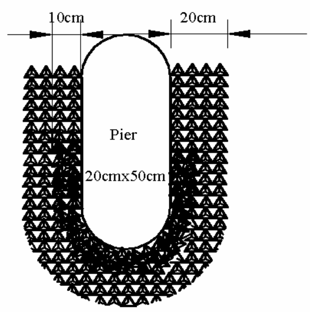

Fig.4 Form of tetrahedron frames fixed up

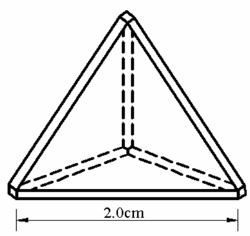

Fig.5 Tetrahedron frame

4. The analysis of experimental results

In order to study the effect of the quantity of the tetrahedron frames, the relative position around the pier and the height of tetrahedron frame groups piled up, we carried out four model experiments after we counted out the incipient velocity of flow

Control Index / Groups	Qantity Of trahedron frames	Approaching flow velocity (cm/s)	Stable depth of water （cm）	Height of the frame groups （cm）	Altitude interval between the biggest depth of scour hole and the riverbed （cm）	The form of scour hole
The first experiment	0	21.9	20.2	0	-23.5	See Fig.6.a
The second experiment	1000	21.9	20.2	1.7	-3.2	See Fig.6.b
The third experiment	1400	21.9	20.2	2.6	2.2	See Fig.6.c
The forth experiment	2000	21.9	20.2	4.5	3.3	See Fig.6.d

V_0'(V_0'=10.35cm/s). The experimental results are showed in the following table1.

Table1 Table of experimental results

4.1*Describing the experimental phenomenon*

In the experiment we observe: ⑴. The depth and scope of the scour hole is the largest without any protection methods and the depth achieves 23.5cm (being showed in Fig.6.a). ⑵. When 1-2 layer of tetrahedron frames are thrown in the 10cm's scope around the pier and 1 layer in the 10-20cm's scope, amounting to 1000 tetrahedron frames, the flow velocity (about 10.1cm/s) in the tetrahedron frames is obviously smaller than the one (about 21.0 - 22.3cm/s) in the main water channel. With time going on, the silt-covered riverbed rises in the zone of the tetrahedron frames. The shoals appear obviously. After 2 hours and 10 minutes, the silt covers the zone of the tetrahedron frame group partly. Thus it can be seen that the silt is quickly deposited on the riverbed because of the influence of the frame group. After the experiment, we observe that quite few frames which lies in front of the pier is washed away, because the flow acts on the tetrahedron frames. Others lie in their original position. The silt deposited on the riverbed plays an important role on fixing the frames. The altitude difference between the biggest depth of scour hole and the riverbed is -3.2cm. Scope of scour hole is reduced (showed in Fig.6.b). When the approaching velocity of flow in front of the pier is gradually added up to 26.7cm/s and trends to be stable, the tetrahedron frame groups are washed away and caved in. ⑶. When 1-2 layer of tetrahedron frames are thrown in the 10cm's scope around the pier and 1 layer inside 10-20cm's scope, amounting to 1400 tetrahedron frames, the flow velocity (about 9.7cm/s) in the tetrahedron frames is obviously smaller than the one (about 21.2～22.5cm/s) in the main water channel. With time going on, the silt-covered riverbed rises in the zone of the tetrahedron frames. The shoals appear obviously. When the flow goes through tetrahedron frame groups, being held back by tetrahedron frames, the flow velocity is reduced obviously. The silt is deposited on the riverbed and forms some sill cuts. With time going on, the silt-covered riverbed rises in the zone of the tetrahedron frames. After 1 hours and 50 minutes, most of tetrahedron frame groups have been covered by the silt. After the experiment, we observe that the tetrahedron frame groups in front of pier are covered completely. The altitude difference between the biggest depth of scour hole and the riverbed is 2.2cm(showed in Fig.6.c). When the approaching flow velocity in front of the pier is gradually added up to 27.9cm/s and trends to be stable, the tetrahedron frame groups are washed away and caved in. ⑷. When 1-2 layer of tetrahedron frames are thrown in the 10cm's scope around the pier and 1 layer in the 10 - 20cm's scope, amounting to 2000 tetrahedron frames, the flow velocity (about 8.3cm/s) in the tetrahedron frames is obviously smaller than the one (about 21.5～22.3cm/s) in the main water channel. After 1 hours and 30 minutes, the silt covers the tetrahedron frames completely. After the experiment, we observe that the scour hole doesn’t appear. At the same time, the quantity of the silt deposited on the riverbed is more than the one of the above. The altitude difference between the biggest depth of scour hole and the riverbed is 3.3cm(showed in fig. 6.d). When the approaching flow velocity in front of the pier is gradually added up to 31.3cm/s and trends to be stable, the tetrahedron frame groups are washed away and caved in.

4.2 *The analysis of experimental results*

The above experimental achievements indicates: ⑴. In the first place, the local scour begins from both sides of the pier front. Then the depth and scope of the scour hole is enlarged gradually. Owing to the emergence of the scour hole, a horse-shoe vortex is formed at both sides of the scour hole front. The separation of the flow at both sides of pier front causes the wake vortex. Because the wake vortex can make the silt deposit at the back of the pier and the quantity of silt deposited on the riverbed is large, the riverbed at the back of the pier is not protected (shown in Fig.4). ⑵. As the depth of the local scour hole relates to the approaching velocity of flow V in front of the pier, reducing the approaching velocity of flow in front of the pier can reduce the depth of the local scour hole. The flow can go through the frame group and the tetrahedron frame group also can hinder the fluid to flow, which depends on the special structure of the single tetrahedron frame. So 40～60％ of the approaching flow velocity is reduced when the flow goes through the frame group. Thus the velocity of flow V can’t reach an enough large value. The flow velocity around the pier is reduced. At the same time, the intensity of the horse-shoe vortex that is formed at both sides of the scour hole front decreases and the size and direction of flow velocity change slowly. Thus the flow condition of the emergence of scour hole is destroyed. ⑶.Tetrahedron frame group forces the originally straight flow not to be heaped in front of the pier because of being blocked by the pier and restrain the emergence of the vertical flow. Tetrahedron frame groups restrain the extremely strong downward force of scour for the riverbed around the pier and make the silt at both sides of the pier front not be rushed away. Thus tetrahedron frame group restrains the emergence of scour hole. ⑷.The gravity center of the tetrahedron frame is low, which makes the single tetrahedron frame having the stability against sliding and tilting. Even though some tetrahedron frames roll and move, the tetrahedron frame groups can keep its own height and not change its whole protection effect and bring its function into full play. Therefore, the maintenance cost is reduced greatly at the end of the protection engineering [11]. ⑸. By three groups of protection trials, we know that the effect of protection with tetrahedron frames also has something to do with their quantity, the scope of protection and the density arranged on the riverbed besides the condition of the flow and silt. The more the quantity of the tetrahedron frames thrown is and the larger the density of the tetrahedron frame group arranged on the riverbed is, the more obvious the effect is. When we throw the tetrahedron frames in the scour scope of the first experiment in which we don't take any protection measures, the protection effect is the most notable.

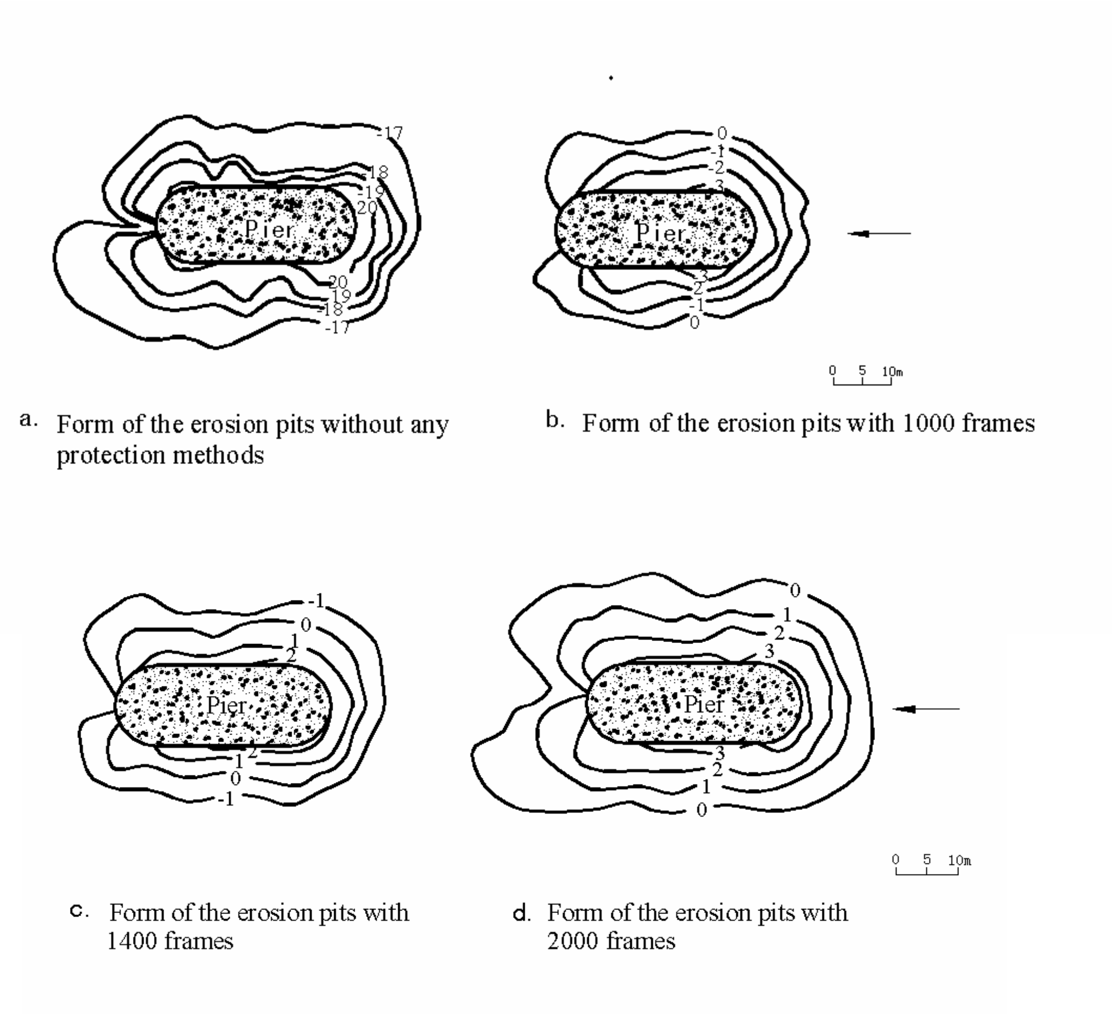

Fig.6 Form of erosion pits

In addition, the tetrahedron frame made of the steel and concrete can be looked on as one kind of new protection measure against the scour. The tetrahedron frame is more practical and economical than the traditional material. The tetrahedron frame doesn't need to excavate the foundation and has the good stability against sliding and tilting. The construction method of the clean dumped tetrahedron frame fill protection is easy and convenient. During the construction, prefabricated components are welded and shipped to the special region. Then the whole tetrahedron frames linked together are ranked on the riverbed with the special equipment. Even though the local tetrahedron frames cave in the silt because of the action of flow, we can go on throwing some tetrahedron frames on them until the collapse is stopped. In practical applications, the geometric size of the tetrahedron frame should depend on the altitude difference between the biggest depth of scour hole and the riverbed. The height of the tetrahedron frame is unanimous to the one of the highest riverbed. We also can overlap the small frames repeatedly to protect the riverbed layer upon layer. These characteristics proved to be useful on practice [11,12]. The tetrahedron frame has the double action that it can change the flow structure and be gone through by the flow, which decides that it can absorb energy and carry the silt and has good functions of speed reduction and sedimentation promotion. So there is a lot of silt deposited on the riverbed and not obvious scour hole in the position where the tetrahedron frames were thrown, which overcomes the shortcoming that there is obvious scour hole at the foot of the stone apron and that the stone rolls into the scour hole and that the desired height of the stone apron is reduced. Moreover, the single tetrahedron frame is an overall structure and its weight is very great. So the single tetrahedron frame cannot be washed away easily by the transversely billowing wave on practice. At the same time, the tetrahedron frame groups can resist the scouring power between the main stream and the riverbed [7]. There is a lot of gap among the tetrahedron frame groups, which makes the energy of the transversely billowing wave dissipate quickly.

5. Conclusion

The factors that influence the local scour around the pier is a lot, which make the appearance of the scour process very complicated. At present what people know about the mechanism of the local scour at piers is a little. By a series of experiments of the effect of tetrahedron frame protection method, it proves that the tetrahedron frame protection method has some engineering value for protecting local scour at piers.

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