Mechanism and Protective Measures of Local Scouring of Pier

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Abstract

Pier scour is a key link in the process of bridge design, this paper introduces the concept of local scour piers and its mechanism, system summarizes the relevant protection measures and the research status of bridge local scour, should reasonably select the most appropriate for a specific project, the most economical protective measures.The research new protective measures should be strengthened.

Keywords

Piers, Partial scouring, Protective measures, Summary.

1. Pier Local Scour Mechanism

1.1 The Concept of Local Scour Piers

Bridge is completed, in addition to riverbed of natural evolution, and due to the interference caused by water flow and sediment movement of piers bed scour, they interweave together simultaneously, flushing process is very complicated.To facilitate the research and calculation, and often the maximum scour depth of bridge pier is divided into separate three parts: natural evolution caused by scouring, general scour and local scour, and assume that they have happened.Due to the effects of the water and eddy current bridge pier choked flow, isolate the three dimensional boundary layer around the bridge pier, resulting in a high turbulence and the characteristics of the high velocity and local flow, vortex and to spread and development of downstream, produce very big bed surface shear force, formed around the bridge pier local deformation of riverbed is called bridge pier local scour.

1.2 Bridge Pier Local Scour Mechanism

Around piers will change the flow condition, and produce hydraulic phenomenon, the sediment transport capacity increase around piers, led to the near bed scour below.Its main mechanism related to block water formation of vortex piers, including the front of the drop flow, block bottom horseshoe vortex and trailing vortex trick about [1-4].Arise at the pier to meet the water flow by blocking piers stagnation point, and the formation of block before harmony water phenomenon, stagnation point of the water pressure increasing, into stagnation pressure, and descending down, cause bridge incident flow surface pressure gradient change, thus forming a vertical drop water, drop water flow is considered to be the cause of the flushing process.Falling water flow bed surface in front of the pier, before the pier scour, and interact with each other and near the bed surface water flow, form a transverse circular vortex band separation, known as the horseshoe vortex.Horseshoe vortex, in front of the pier pier along the edges to the downstream, bed surface in the process of conveying silt up and downstream direction, is the main factor of bridge pier local scour [5, 6].Pier caused not only a drop water flow stagnation point before, but also lead to the bridge on both sides of the turbulence of the lateral acceleration, flow in the downstream separation piers small wake vortex instability, disorder, and the bed surface near the horseshoe vortex interaction, sediment by vortex disturbance carried out of the bed surface, form after pier scour phenomenon.

Water scouring ability decreases gradually with the enlargement of the scour pit deepening, and at the same time scour pit sand bed coarsening, eventually scour pit sand bed scour resistance equal to water erosion ability, achieve a relative balance of local scour, erosion will tend to be stopped, at this time between the lowest part of the pit and the edge of the pit height difference is called the biggest local scour depth.

1.3 The Influence Factors of Bridge Pier Local Scour

Near the bridge pier local scour of many factors, including water depth, flow velocity, flow, type of riverbed sediment, dry density, particle size, size distribution, etc, also involving the pier size, shape, etc.Factors that affect the bridge pier local scour depth include the following several aspects: characteristics of bridge pier, fluid characteristics, bed material characteristics and flow characteristics of the factors.

1.3.1 Pier width, the length of the bridge pier L B or the diameter of the bridge pier R the impact on the local scour depth

The main cause of bridge pier scour is the existence of the bridge pier compression channel flow caused by the increase of discharge per unit width, resulting in local scour.So the bridge pier length L (or diameter) piers or aspect ratio LAB is a factor affecting scour.Generally speaking, the longer the bridge pier, the wider the piers, the local scour at the pier head will be deeper, because B, L (or diameter piers R) reflects the structure of the compression degree of the water, the greater the compression, blocking the flow structure directly cause changes in the structure of water flow, the greater the strong vortices around the pier head and the greater the role of sediment in river channel, thus cause the greater the scour depth.

1.3.2 Marched near the velocity V is the impact on the local scour depth

(1) when the line near the velocity is less than the impact velocity of bed sand, bed surface sediment motionless, local scour around bridge pier is not happen.

(2) when $\upsilon_0^{'} \le \upsilon \le \upsilon_0$ (starting velocity is bed sand), around the bridge pier due to flow around an increased local velocity, bed material to move to the downstream, the scour pit.Scour pit no sediment from upstream supply, referred to as the clear water flushing.

(3) the velocity increases to or exceed the bed load starting speed, that is, the bed surface sediment of starting, get scour pit to sand, scour depth with the increase of flow velocity and changes greatly abate, the scour called moving bed scour.Due to frostbite and sediment supply, scour rate can infer when velocity reaches a certain value, does not increase the local scour depth.

1.3.3 Marched near the depth of the water, the impact on the local scour depth

(1) marched near water depth change on local deep influence, it is generally believed line near water depth is small, local use deep increase with the increase of the depth of the water, and when the water depth increases further, local use a deep and water depth has little to do.Sediment particles under riprap stone pore was scour.

(2) spats and caisson impingement: set up around the bridge pier spats and caisson, prevent the down stream and horseshoe vortex sediment particles directly, make its ability to tow in the water and sediment is weakened, so as to achieve the goal of the scour protection.

(3) slotted impingement: slotted anti scour protection is to make the water turned to leave the bed or reduce the impact and flow on the impact of the riverbed, slit width, length and position are the important parameters.Such as the location of the slit near the river and near the surface of the water two kinds of circumstances, the two position of slit flow is different.When the slit and spats, can further reduce the scour depth.

2. Pier Local Scour Protection Measures

2.1 Riprap Protection

Riprap protection is one of the main bridge pier protective engineering measures, its working principle is a rubble-mound for bed protection, increase the flow velocity for the bed load starting or young still.The second is the ripped-rock can increase near the bridge pier local roughness, to reduce the velocity near the piers also played a positive role.

In recent years, many scholars on characteristic parameters that affect the effect of riprap protection, such as stone particle size d_{50} , the setting height h, riprap thickness t, stroke range c and the ripped-rock grading σ_g , etc were studied.

At home and abroad about the research achievements of riprap grain size a lot [7-9], one of the most representative is Richardson, etc. [10] for the highway administration recommended the median particle size of stone, stone:

$$\frac{U_0^2}{(\rho_g - 1)gd_{50}} = \frac{2.890}{K} \tag{1}$$

Type: d_{50} for stone, particle size, m; U_0 As the line near the velocity, m/s ; ρ As the sediment density, kg/m^3 ;G is acceleration of gravity;K for the pier shape coefficient, round head rectangular column pier by 1.5, rectangular pier by 1.70.

Bigger influence on the protective effect of riprap protection range, because around the bridge pier dynamic water pressure on the surface of the bed than not affected by disturbance flow of dynamic water pressure to several times.The choice riprap protection scope of the general rule is that at least than do not take any protective measures when the scope of the pit.Richardson of [10], such as riprap protection range should be at least 2 times the pier width, the width from the surface of the bridge pier.Limb [11] of the experimental results show that with the increase of setting range, riprap layer protection is almost linear increase.

Riprap level matching the protective effect of riprap layer has important influence.Because grading better stone, can guarantee the stability of riprap layer structure, and can prevent the protective layer of fine grained sediment from riprap stone between porosity loss.Riprap protection effect level of the study is less, the general rule is relatively smooth riprap, the particle size distribution curve is used to grading of poor riprap stone, can also pass in riprap layer filter layer arranged between the bed surface and methods to improve the effect of protection.However, should be used as much as possible grading better riprap, because in some cases, setting filter layer is rather difficult.And for those who lay in riprap layer under the river bed surface, without setting filter layer [10, 12].

Riprap protection is still large and medium-sized bridge pier is the most widely used form of protection, it is conveniently, simple construction and can adapt itself to the changing terrain.Poor but the wholeness of riprap protection, maintenance and workload is bigger in the process of using, especially when the flow rate for the critical friction velocity of 2. 5 times above, river bed surface has a bigger bed form appears, riprap will be embedded into the depths of the pit, biggest result in riprap layer protection completely lost

2.2 Enlarge Pier Foundation Protection

Expand the pier foundation protection refers to the buried steel cofferdam construction stage to bed scale the following certain depth, then lower pile foundation construction, foundation construction in the reserve a certain height above the bed surface after the completion of caps, and then placed on the top of piers protection engineering.The main working principle of the protection method is used to expand at the top of the pier foundation of xiaosha pier before falling water scour.

In recent years, studies have shown that, the main factors influencing the expansion of pier foundation protective effect on the basis of height is placed on the surface of the top and expand pier base head upstream reach.

Laursen etc. [13] and Parola etc. [14] according to the protective effect of the difference between the top of the pier foundation position is divided into three categories: the first is when expanding at the top of the pier foundation stands above the bed surface, the exposed parts caused greater scour depth;The second is when expanding at the top of the pier foundation is located in the scour pit, expand the pier foundation of kill some of the top face downward flow and horseshoe vortex scouring force, then cut the scour depth around bridge pier, especially when enlarge the surface of the bridge pier foundation is right at the river bed surface, reduce impact effect is most obvious, after that with the increase of buried depth, top face protection;The third kind is enlarged at the top of the pier foundation under the maximum scour depth around piers, its protective effect. Parola, etc. [14] think, expand the pier foundation to upstream part tend to protection of river bed surface from horseshoe vortex flush, thus reducing the depth of the scour pit. Domestic many scholars put forward the design to expand the calculation method of bridge pier local ran deep and the relationship between the top buried depth and width, and think that expand the pier foundation top surface below the bed surface, the more, the smaller the width should be buried in it is advisable to bed scale the following 1 ~ 2 m, width should be compatible with width of horseshoe vortex activities, generally should not be less than 15 to 18.

Despite a large number of studies have demonstrated that when the upstream reach 2 times for the enlargement of pier diameter at the top of the pier foundation and leveled, river bed face protection effect is obvious, however, Breusers etc. [19] does not recommend the use of such protective form, unless it can accurately predict the change of river bed elevation. Because during the flood, at the bridge site, contraction scour of general erosion and river channel transverse swing, under the joint action of river bed surface usually incised to a certain height, the expansion of pier foundation top above the river bed surface, expanding the pier foundation of exposed usually cause larger flush, and this kind of pier, base combined with more than pier scour depth alone to cause the depth of the pit.

2.3 The Mold Bag Concrete and Concrete Hinge Line Protection

Mold bag concrete is the use of high strength fiber materials woven double bag body and can control a certain distance.Mold bag concrete protection refers to the internal filling mold bag concrete (or mortar) to form a rigid plate bumper block, and can adapt itself to the changing terrain and close to the bank or the riverbed and the function of anti-scouring concrete protection technology. Concrete hinge hinge line is to use connect concrete plate and form protection entity.

Fothorby [20], such as an application example of concrete hinge line and the mold bag concrete pier local scour protection of flume experiment showed that the mold bag concrete soft template effect, concrete, through the pressure on land reclamation to compacted molding, has high strength, strong integrity, scour prevention performance is good, fast construction speed, casting is flexible and can be some advantages, such as underwater construction, moderate cost, especially in the case of stone material scarcity, is a good replacement .However, the method of construction is relatively complex, when underwater terrain is steep protective effect is not very good, especially when the water depth is larger, the water flow is urgent, underwater construction is difficult, after construction to adapt to the riverbed deformation ability is poorer, vulnerable to scour the lower edge. Concrete hinge line of bank protection have good integrity and can easy materials, factory production, mechanical construction, and quality advantages of easy control, but the cost is higher, and broke down to prevent damage.

2.4 Four Feet Concrete Protection

Four feet of concrete block (Ctetrapods) is used for coast protection at first. In 1993, Bertoldi [21] about four feet of concrete block has carried on the bridge pier local scour protection feasibility study.Found that pier itself unique connection makes and riprap stone size and quality is four feet of concrete block stability is better, better protective effect. But, with four concrete protection to replace the traditional riprap protection has certain difficulty, on the one hand, because of four feet concrete block construction cost is much higher than riprap protection; Four feet, on the other hand, concrete blocks need a precise arrangement around the bridge pier, the construction is difficult.

2.5 Protective Ring Protection

Generally speaking, the slowdown is not impact protection method is more economical and practical, especially near the bridge site there is no enough stone mining. Retainer protective method is typical of deceleration not blunt protective method, it is through the use of top of the retainer block and kill drop water, minimize the principle of protection of the horseshoe vortex strength.

Most of the research results show that the main factors influencing the retainer protective effect for the placement of retainer height, the size of the retainer and the form of a retainer. Dargahi [22] studies suggest that the retainer the flow field around piers is divided into three regions, respectively for the retainer above the region, the retainer under flow of water area and water area on the surface of the river bed. Three areas are horseshoe vortex system. However, the location of the boundary layer separation in the first and second retainer edge parts of the region. When circular retainer in bed more than 0. 25 times the depth of the water, the bed near the vortex intensity has not been effectively reduced. When circular retainer in bed surface above 0. OS times the depth of the water, the bed near the vortex intensity becomes weaker. Piers vertical symmetrical equilibrium scour depth on the surface of the measured results show that when the retainer is placed in the bed surface below 0. 015 times of water depths, the depth of the pit reduced the most obvious, protective effect is best. Scour depth at this time when there is no retainer protection relative to the maximum scour depth reduction is 50% 70%.

All in all, retainer protection method can play the role of protective bed surface from scouring around piers, especially under the condition of clear water scouring the retainer arrangement with the location of the river bed surface flush, protective effect is more obvious. But, under the condition of fixed bed scouring, the emergence and spread of riverbed form may make a bridge piers at the bottom of the retainer exposed to water, causing retainer fails, or perhaps because of bridge site in general erosion and caused by the contraction scour binding retainer above the bed surface caused by the retainer.

2.6 Slotted Pier Protective

Pier YingShui before the drop flow and formed in the leading edge of the pit around the bridge pier on both sides of the flow downstream of the horseshoe vortex interaction leads to a bed surface sediment eroded around bridge pier, so a way to control and reduce erosion is cut down and the strength of the horseshoe vortex flow, or completely prevent the formation of the two kinds of flow structure. Can bridge piers slotted blunt the horseshoe vortex and the function of the intensity of falling water, is one of the good way to bridge pier local scour protection.

But, in the process of practical application, the slit on the bridge piers are likely to be floater or ice floe congestion, lead to slit the failure. Due to factors such as river swing bridge pier on nearly in the direction of flow of change makes the slit in the direction of flow is not consistent, can also lead to lose protection slotted.

2.7 Protective Pier in Front of the Pile

Upstream protection refers to the block in front of the pile pier of a certain number of pile group arranged according to certain rules and when bridge pier in pile group of drafting zone, used for bridge pier local scour protection pile itself will be washed by water, so it can make the block in front of the high speed deviation in the direction of flow, and can in the back of the form a wake region, effectively reduce turbulence intensity of vortex system around the bridge pier, so as to effectively curb the local scour around bridge piers.

Normally, pile protective effect depends on the number of row pile in the pile, pile relative to the size of the bridge pier, the height of the pile out of the water (i.e., partially exposed or completely submerged), the construction situation of pile group, and pile group and the relative position of the piers. The construction form of pile group of varied, but the best layout form is triangle layout, including the acute Angle of the triangle vertices to the upstream. When the flow deviation from the axis of the bridge pier, protective effect of pile is reduced, or even disappear completely. Melville [23], such as adopting the best layout form of pile protection test showed that when the increase in the number of piles, the greater the construction scope of pile group, pile group of the greater the wake region, so the protection for such protection can reduce about 50% of the largest pile of scour depth. In addition, when each root pile pile is placed on the upstream wake zone, will make the whole pile group of drafting area bigger, so the protection effect is improved. Their research also found that the closer from pile piers, protective effect is better;Don't pile out of the water of the protective effect is better than when out of the water.

2.8 Around the Tetrahedron Permeable Frame Group of Stroke Protection

Existing pier local scour protection engineering measures there are some shortcomings and the insufficiency, under certain conditions, these shortcomings and the insufficiency and even cause collapse of the entire protection engineering, safe operation, in turn, affects the stability of the bridge piers and Bridges. Hohai university, therefore, water environment comprehensive treatment experiment hall around the bridge pier is put forward the tetrahedron permeable frame group of stroke protection method. Pier group around the tetrahedron permeable frame protection method is a perfect combination of speed and the real resistance to impact and not protection feature in the integration of new protection engineering measures, its working principle is to use the framework of reduction of energy dissipation function make around the bridge pier turbulence intensity of flow is reduced, the sediment silting, into the purpose of protective pier weeks on the surface of the bed.

Model test results show that [24] : when the tetrahedron permeable frame group layout density satisfies the requirement of bridge pier local scour the overall protection, pier front near the pier scouring pit in a crescent shape, therefore, on the premise of guarantee the overall protective effect, should minimize the tetrahedron permeable frame group overall layout density, increase the crescent framework of layout density within the scope of the pit; When using the protective range greater than without any protective measures, the range of scour pit in along with the rising of the scope of protection, protective effect is better ;Framework of the rectangular layout form a round head rectangular layout forms of protective effect is good. Further research shows that under the condition of same framework of the protective effect of also depends on the mound on nearly velocity, water depth and density of framework of the overall layout.Depth of the pit with the line near the velocity and water depth increases, but when the respective reaches a certain value, the depth of the pit with the change of the water depth is not obvious;Scour pit depth decreases with the increase of density of framework of the overall layout, when setting density tends to be a great value, the depth of the pit tends to minimum, best protective effect, but at the moment, with the increase of cropping density and depth of the pit, the reduction is not very big.

3. Conclusion

This paper introduces the concept and mechanism of bridge pier local scour system summarized its protective measures and related research status quo, in order to give a reference for the researchers and engineers. For different specific circumstances should be fully demonstrate select the most appropriate protective measures, so as to achieve efficient and economic protection.

In recent years, almost all in the design of the bridge foundation is to use the bridge pier directly embedded into the depth of bedrock surface under permanent, but this kind of design method of engineering cost is very high, the bridge construction of the overall cost performance is reduced, and the scour depth around bridge pier is bigger, the pit water structure had a great influence on the overall stability of the piers and it is difficult to predict, say in some complex geological conditions, permanent bedrock surface is not easy to determine. In addition, the pier foundation construction process, construction cofferdam will occur around the flushing, the scour phenomenon similar to scour near the pier. So the study the characteristics of the bridge pier local scour protection engineering protection is still very necessary. Because of the complexity of the bridge pier local scour phenomenon and intrinsic to the limitations of traditional protective engineering measures, yet it is not a sufficient theoretical basis and the method was proved to be fully effective, therefore, the new type of bridge pier local scour protection engineering measures and its combination with traditional protection engineering measures of protection research has very important practical significance.

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