Experimental Study on Levee Failure due to the Damage of Pressure less Culvert Pipe

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Abstract: The contact areas near culvert pipe through levee are prone to contact erosion, esp. contact erosion due to culvert pipe cracks or holes. In order to reveal the development process of soil erosion damage and levee collapse, physical model tests are carried out by using visual test device to study the development process of contact erosion due to the holes of pressure less culvert pipe. Influence mechanism of hole location and its diameter on erosion failure process are discussed by observing and measuring water head, outlet flow, the amount of soil erosion and the size of pit due to soil collapse. The test results show that:(1) The erosion process can be divided into five typical stages: no obvious infiltration failure stage, erosion initiation stage, erosion development stage, erosion intensification stage and comprehensive failure stage. (2) The larger of the hole diameter and its distance to downstream outflow, the lower the critical water head required for erosion intensification and comprehensive failure;(3) The diameter of hole affects the rate of sand erosion and its position determines the length of silted sand in the culvert pipes. Silted sand has inhibitory effect on erosion processes. When the rate of soil erosion equals that of its transport in the culvert pipe, the erosion pprocess will be the most intense until it collapses.

1. Introduction

The culvert pipe through levee is a common structure in the levee engineering. Concentrated seepage or contact erosion along the outer wall of the culvert pipe, and even levee failure can be caused by the aging, cracking or damage of the culvert pipe, as well as the non-compaction and uneven settlement of the culvert pipe in contact with the surrounding soil. Scholars at home and abroad often classify the seepage failure at the junction of the structures and soil and the interface of different soil layers as contact erosion. According to statistics, nearly 30 % of all kinds of levee failtures are related to levee-crossing structures [1]. During the Great Flood of the Yangtze River in 2016, six structures through the Yangtze River levee were in danger of failure, accounting for 12 % of the total [2]. When typhoon “Liqima” landed in 2019, there were four failures occurred in the Mihe River levee in Shandong Province, all of which were caused by the contact erosion of structures through the levee. According to the U. S. Bureau of Reclamation, the probability of seepage failure through the culvert pipe is about $4 \times 10^{-4} \sim 1 \times 10^{-3}$ [3].Li Lei and Xie Jiabi analyzed the dam failure accidents from 1954 to 1980, 2000 and 2006, and pointed out that the proportion of dam failure caused by leakage of culvert pipe through the dam is 4.5%, 4.9% and 5.6% respectively[4,5] .It can be seen that the contact erosion failure occurred in the position of culvert pipe is the main factor affecting the safety of levee.

Case analysis, physical model tests and numerical simulation methods are used by domestic and foreign scholars to carry out relevant research. Scholars from the Netherlands, the United States and other countries have discussed the failure modes and influencing factors of contact erosion, and evaluated the causes of levee failure [6,7]. Sun Dongya and Yao Qiuling summarized four kinds of contact erosion failure modes of dam culvert pipes, namely, internal erosion caused by the loss of soil particles into the pressure less culvert pipes, internal erosion caused by the overflow of water inside the pressure culvert pipes, internal erosion along the soil around the culvert pipes and internal erosion caused by soil cracks near the culvert pipes [8]. According to whole erosion test, the determination method of erosion rate index I_{HET} in erosion piping and its influencing factors were studied by Wan, C.F. and Benaissa [9, 10]. Bonelli used the dimensional analysis method to construct a mathematical model to explain the HET test process under constant pressure [11]. Cividini and Riha used the finite element method to simulate the separation and migration of fine particles under water-soil interaction [12,13]. Based on the renormalization group theory, Kissi modeled and analyzed the non-uniform erosion process at the entrance of the erosion piping [14]. Liu Jie discussed the anti-seepage strength of soil and the anti-seepage problem of contact erosion [15]. Li Na and Yue Xiuli discussed the occurrence and development process of erosion by physical model test, considering the degree of density and the physical properties of soil [16,17]. Wu Zhimin studied the influence of culvert pipe on the seepage field and stress field of soil by analyzing the variation of pore pressure and seepage velocity in the process of seepage failure [18]. Based on the stress analysis of soil particles, Pang Qiong analyzed the occurrence and development process of erosion failure under the condition of internal water seepage, gave the critical conditions, and briefly discussed the sensitivity of culvert whole location and size to the failure process [19].

The problem of contact erosion of culvert pipes through levee is very complex, and the effective prevention measures need to be based on the deep cognition of the failure mechanism of contact erosion. In this paper, the self-designed visual contact erosion physical test model is used to simulate the occurrence and development process of contact erosion induced by concentrated seepage in holes of pressure less culvert pipe, obtain the hydrodynamic parameters of contact erosion damage process, analyze its dynamic variation characteristics, and deeply reveal the mechanism of leeve failure induced by culvert pipe damage.

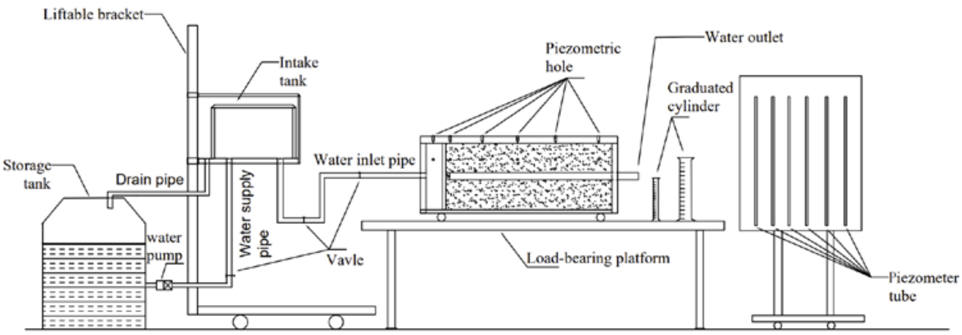
2. Test Overview

2.1 Test device

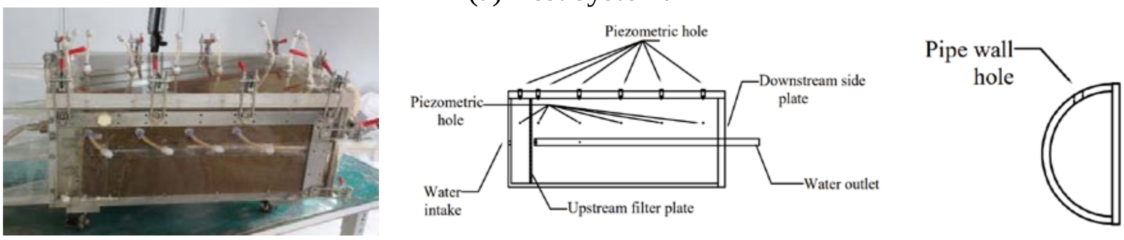
In order to simulate the occurrence and development of erosion and the process of levee failure caused by concentrated seepage of damaged culvert pipe, a visual contact erosion physical test model is designed and constructed, which mainly includes upstream water supply device, main model box, culvert pipe and data and video acquisition system such as piezometer tube and camera (front and top phenomenon record), details show as Fig.1 (a).

The main model box is a cuboid with a size of 500 mm × 300 mm × 200 mm, as shown in Fig.1 (b), made of acrylic transparent plate, with sample length of 450 mm. The top plate and downstream side plate of the model are fixed by screw fastener structure, which can be disassembled for sample preparation. The front part of the model box is equipped with an inlet tank, which is separated from the soil sample by upstream filter plate to ensure uniform water pressure and normal infiltration on the upstream surface of the sample. The filter plate is composed of two layers of perforated steel plate sandwiched with geotextile, fixed in the model box.

The D-type organic glass tube is used to simulate the culvert pipe, which is 55 cm in length, 3 cm in diameter and 2 mm in thickness. According to the test conditions, hole is opened at different position of the pipe wall to simulate the damaged hole of culvert pipe, as shown in Fig. 1 (b). In order to eliminate the impact of contact erosion between the sample and the inner surface of the model pipe, the culvert pipe is the only seepage outlet of the test box. The flat end of the pressure less culvert pipe is fixed on the inner wall of the model in advance by glass adhesive. The upstream end is close to the upstream filter plate, and the downstream end extends out of the model box through the downstream side plate of the main model box. The upstream end of the culvert pipe is blocked. Seepage water and eroded soil enter the culvert pipe through the reserved hole and flow out from the downstream outlet. There is no pressure flow in the pipe. The graduated cylinder and weighing device are used to measure the effluent flow and the amount of eroded soil. The water supply device can provide up to 1.5m stable head for the test soil sample.



(a) Test system.



(b) main model box and culvert pipe.

Fig 1. Test diagram of 1device.

2.2 Test Scheme

Using the above test device, the test conditions are shown in Table 1. The homogeneous sand sample is used for the test to simulate the worst conditions. The content of clay is small. The particle gradation and physical parameters are shown in Fig. 2 and Table 2. The test mainly records the variation of outlet flow and sand deformation in the process of erosion and failure, observes the failure phenomenon and the main characteristics, and analyzes the influencing factors and mechanism of contact erosion failure of pressure less culvert pipe through the levee.

Table 1. Basic test conditions.

The test sample	Hole size *d* /mm	Distance from hole to upstream filter plate *L*/cm	Test number	note
A	2,3,5	9,18,27	A_{ij}	Subscript i represents the hole size;j stands for hole position(1, 2 and 3 respectively from upstream to downstream)
B	2,3,5	9,18,27	B_{ij}	

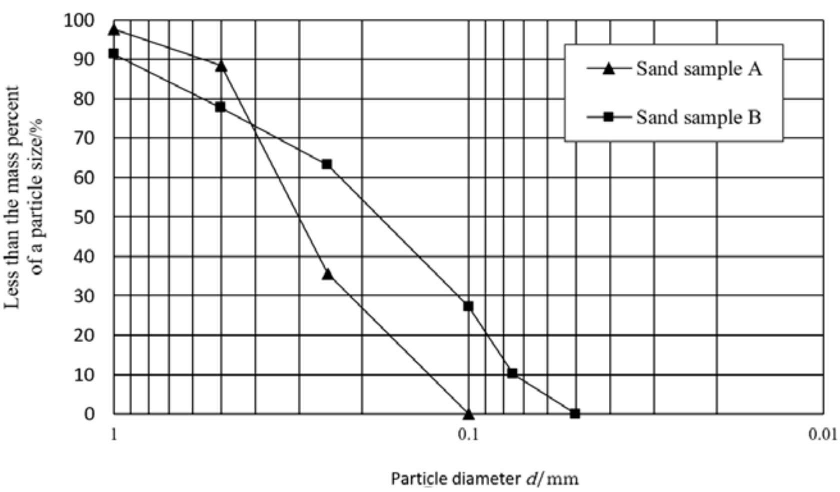


Fig 2. Particle gradation curve of test material.2

Table 2. Basic parameters of test materials.1

Sample	Characteristic parameters d_{10} (mm)	d_{50} (mm)	d_{60} (mm)	d_{60}/d_{10}	Permeability coefficient k /m·s^{-1} (Dr ≈ 85%)	Optimal water content /%	Minimum dry density (g/cm^3)	Maximum dry density (g/cm^3)
Sample A	0.140	0.300	0.350	2.50	5.58 e-2	-	1.4074	1.7804
Sample B	0.075	0.180	0.230	3.06	2.82 e-5	35	-	1.9014

2.3 Test Procedure

The test steps are shown in Fig. 3. In order to ensure the contact density between the test sand and the model box wall to avoid poor contact or even partial void, the sample is prepared by the way of vertical box and throwing fill material in water. The model box is placed horizontally slowly after the soil is saturated and dense. The uniformity of sample preparation is ensured by controlling the overflow flow and filling speed of the model tank, and the influence of natural stratification is prevented by layered filling and manual shaving. The relative density of the sample is controlled by 85 %. After preparation, the actual relative density was calculated according to the volume and quality of sand sample in the model box.

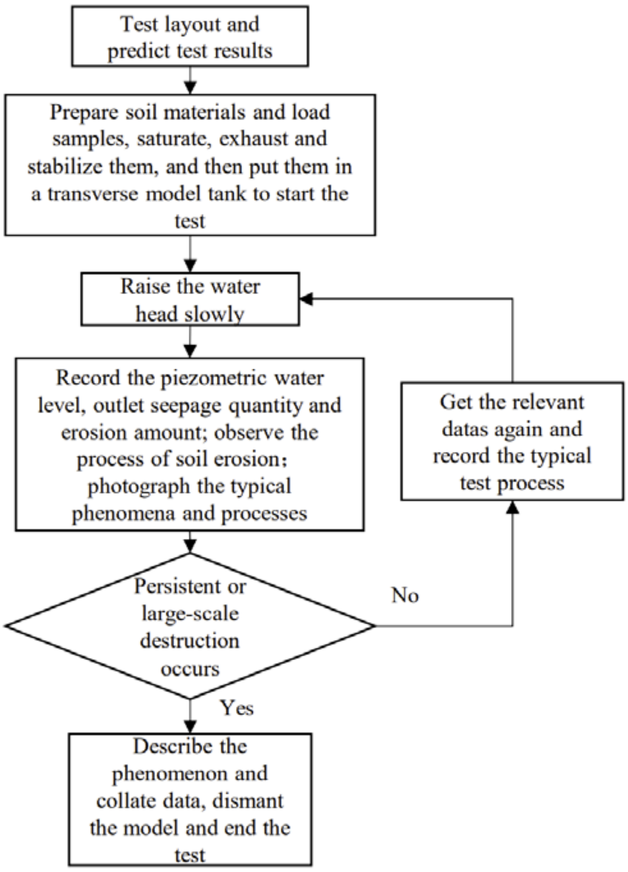


Fig 3. Main steps of the test.3

3. Test results

It was observed in the test that sand particles gradually lost through the hole on the culvert pipe wall under the action of concentrated seepage. The collapse pit formed near the hole, and finally the concentrated erosion piping extended to the upstream surface formed. The erosion process can be divided into five stages according to the occurrence and development process, the outlet flow rate and the change of collapse pit size: no obvious infiltration failure stage, erosion initiation stage, erosion development stage, erosion intensification stage and comprehensive failure stage. The critical water head in different stages are closely related to the particle gradation, the content of fine particles, the size and location of pipe wall hole.

3.1 Contact erosion failure process.

The test process is described in detail in combination with test A52.

The hole diameter of culvert wall pipe in the test is 5mm and 18cm away from the upstream filter plate. When the upstream water head gradually rises to 3cm, a small amount of sand particles begins to lose intermittently, enter the culvert pipe through the pipe wall hole, and the erosion starts. With the gradual rise of water head, the sand particles continue to lose. When the water head reaches 9cm, the sand entering the culvert pipe basically blocks the overflow section of the pipe, and the outflow is mainly seepage. With the increase of water head, under the action of concentrated seepage and gravity, the sand around the hole of culvert pipe wall continues to drain into the culvert pipe, forming a funnel-shaped collapse pit at the top. Due to the blocking effect of sand in culvert pipe, the erosion process is relatively slow. When the inlet head reaches 30cm, the particles in the pipe moves rapidly downstream, intermittent sand laden water flow occurs, the erosion process changes from slow to intense, the top pit is gradually widened and deepened, and the piezometric head near the culvert pipe wall hole drops suddenly. With the further increase of the water head, the piezometer head increases slowly. When the water head reaches 50cm, a small branch shaped erosion piping begins to form along the inner wall of the model box at the upstream side of the collapse pit, resulting in backward erosion piping. When the water head remains unchanged, the erosion piping stops developing. As the water head rises to 55cm, the branch shaped backward erosion piping continues to develop upstream, and finally connects with the upstream inlet. Within a few seconds, the piping develops into concentrated erosion and attain final failure.

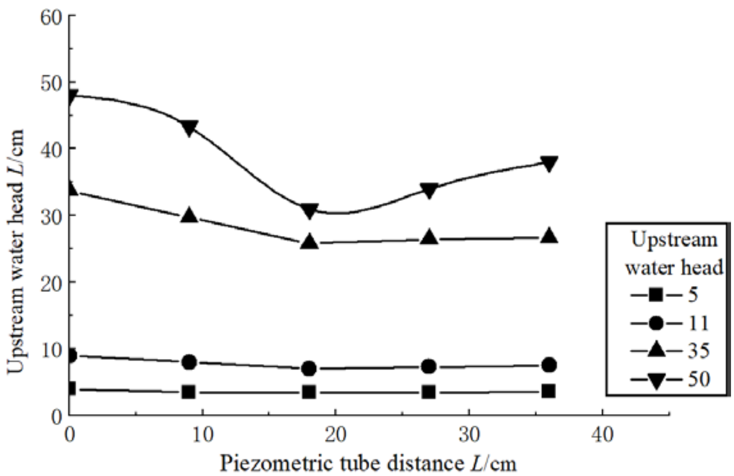


Fig 4. Variation of pressure water head under critical head of test A52.

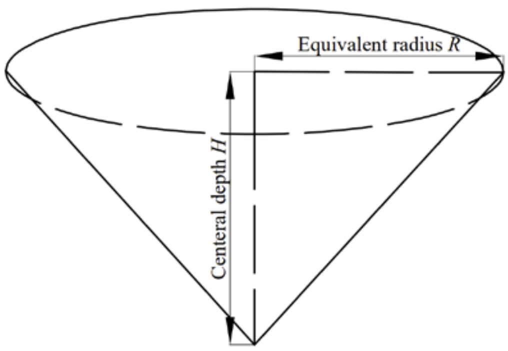
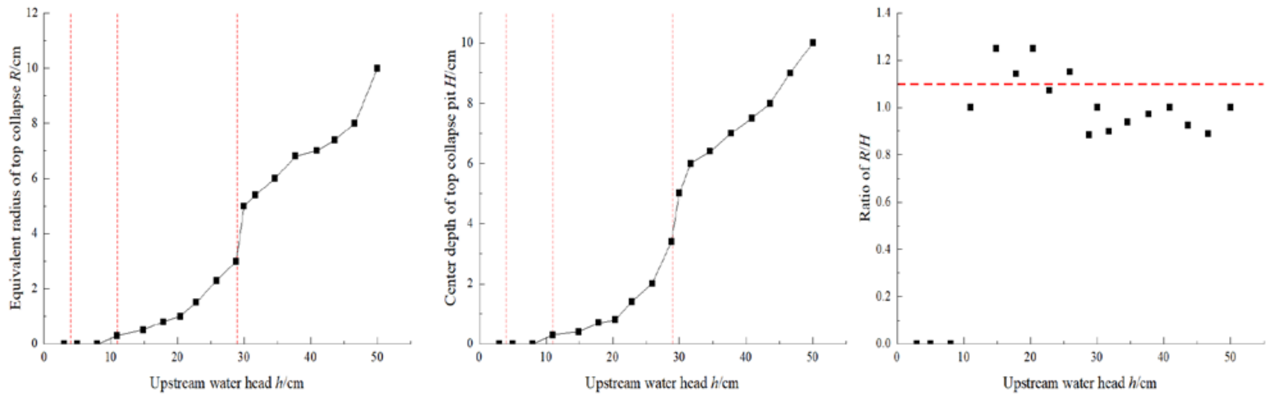


Fig 5. Schematic diagram of erosion pit at the top.

The hole diameter of culvert pipe wall corresponding to test A51 and A53 is 5mm, and the distance from upstream is 9 cm and 27 cm respectively. The simulated scenarios of A51 and A53 tests are basically consistent with the phenomena of test A52. The results of A-type soil and 3mm hole diameter series tests are consistent with 5mm series tests. In the series tests of A-type soil, 2mm hole diameter and B-type soil, the small hole diameter hinders the development of erosion process, or due to the relatively large content of cohesive particles in sand, it is still difficult to form obvious erosion phenomenon and maintain stability when the upstream water head gradually increases, the water head is high and the duration is long.

3.2 Expansion characteristics of soil collapse pit.

If the hole position of the culvert pipe is taken as the axis, the collapse pit is approximately funnel-shaped, which is described by bottom radius *R* and funnel depth *H*, as shown in Fig.5. The collapse profiles at different test stages are shown in Fig. 6, and the variation trends of *R* and *H* are similar. It is obvious that the pit begins to appear in erosion development stage, *R* and *H* ratio is approximately 1. In the early stage of erosion, the growth of *R* is prior to that of *H*, which is manifested as the lateral expansion of the pit first, and then the deepening development. At this stage, the ratio of *R*/*H* is between 1 and 1.2. The abrupt change of *R* and *H* indicates that the erosion enters the stage of intensified development. The *R*/*H* tends to 1 and changes slow down. Finally, the horizontal and vertical synchronous expansion extends to the stage of comprehensive destruction.



(a) *R* varies with the water head (b) *H* varies with the water head (c) *R*/*H* varies with the water head

Fig 6. Change of pit size in test A52.4

3.3 Flow and sand loss rule.

The variation of outlet flow and 15s sand content of test A52 with upstream water head is shown in Fig. 7. At the initial stage of erosion, the outlet flow is small and the flow is clear. At the stage of erosion intensification, the outlet flow carries sand obviously. There are two major changes in the outlet flow during the development process, which are manifested in the intensified erosion process and the comprehensive destruction stage. The corresponding water head conditions of the test are 30 cm and 50 cm.

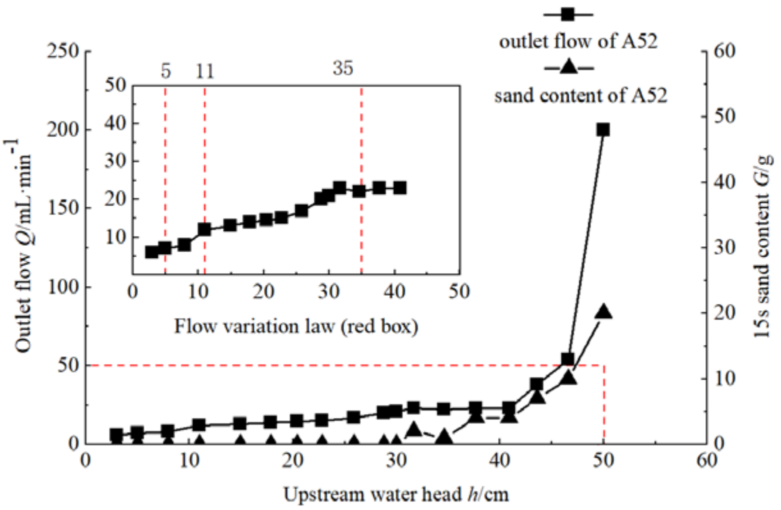


Fig 7. Change of flow rate and sand content at the outlet of test A52.5

4. Analysis of contact erosion process

4.1 Contact erosion process.

Based on the tests of various test conditions, the contact erosion process along the culvert pipe can be divided into five basic stages, as shown in Fig. 8.

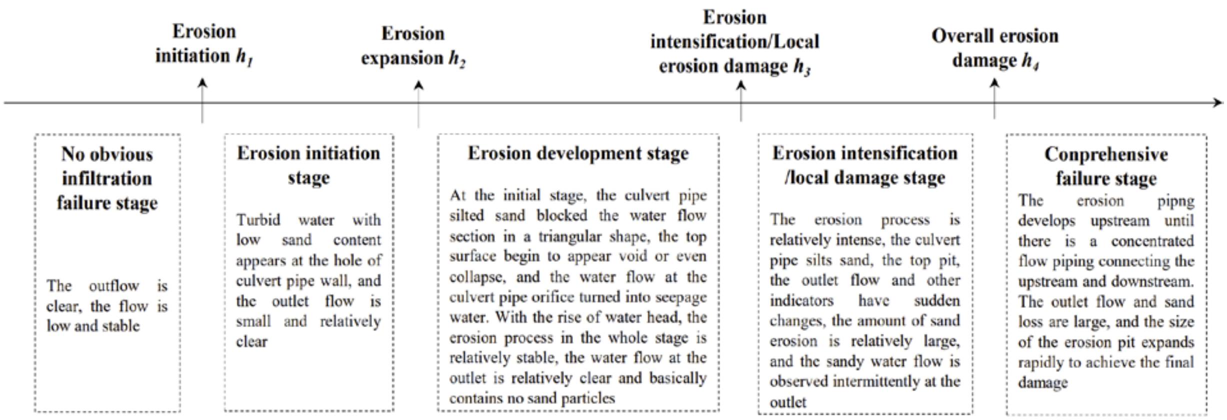


Fig 8. Division and characteristics of contact erosion failure stages.

The erosion failure process of 3mm, 5mm hole diameter and soil type-A is consistent with Fig. 8. Its soil anti-seepage capacity is weak and the culvert hole is relatively large. The erosion development process is related to the head difference between upstream and downstream and sand deposition. The test results of soil type-A with 2mm hole diameter and type-B soil show that: ① The hole of pipe wall is small and the soil has strong impermeability, and the erosion failure process is consistent with Fig. 8; ②Type-B soil "self-healing" and the conditions of hole size increase the critical head required in each stage; ③ The tests of type-B soil with high fine particle content mainly focus on the loss of "particle mass", and most of them form stable internal erosion pits, and its final damage corresponds to the stage of intensified erosion (local failure).

Combined with the observation of experimental phenomena, the evolution process of sand erosion can be shown in Fig. 9, and the total water head distribution of culvert pipe and upper soil is shown in Fig. 10. Due to the seepage concentration caused by the hole of the culvert pipe, the inner and outer wall of the culvert pipe is an unstable area with large hydraulic gradient. In addition, the sand particles have almost no cohesive force. Under the vertical seepage force and the gravity of the sand, the internal erosion holes formed by the loss of sand are mostly directly manifested in the form of top collapse pits. Therefore, under ideal conditions, the contact erosion caused by the leakage of the pressureless culvert pipe also involves the entire length, which changes from “external” erosion to “internal” erosion at the hole of the culvert pipe wall, and the soil inside the culvert is in a state of high permeability and increasing length. The development and final manifestation of erosion damage will be jointly determined by the hydraulic gradients J_1, J_2 and J_3 in the horizontal and vertical directions of the hole.

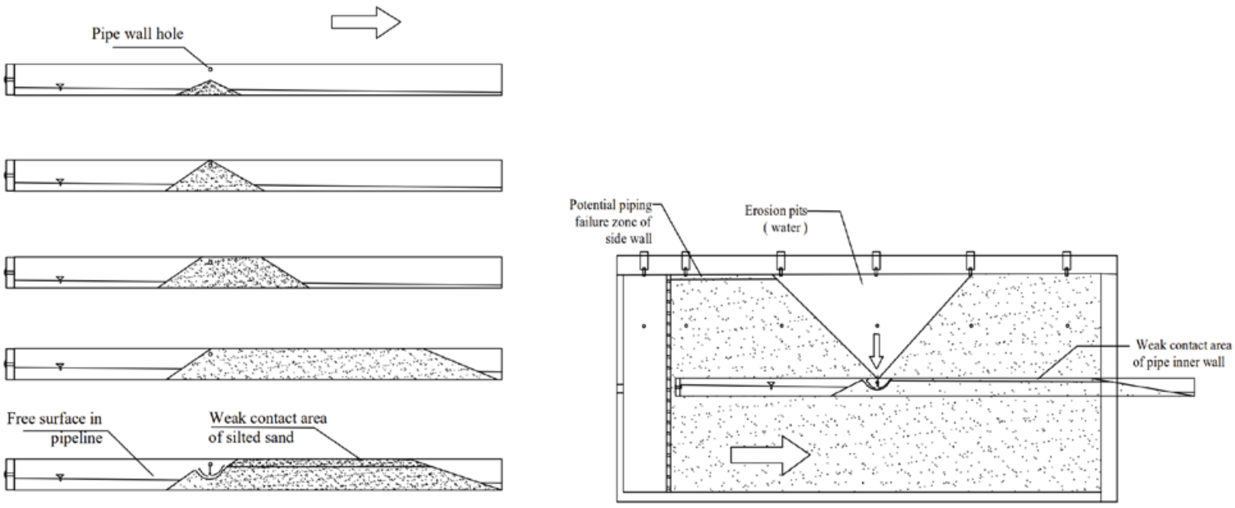


Fig 9. Schematic diagram of sand erosion evolution process.

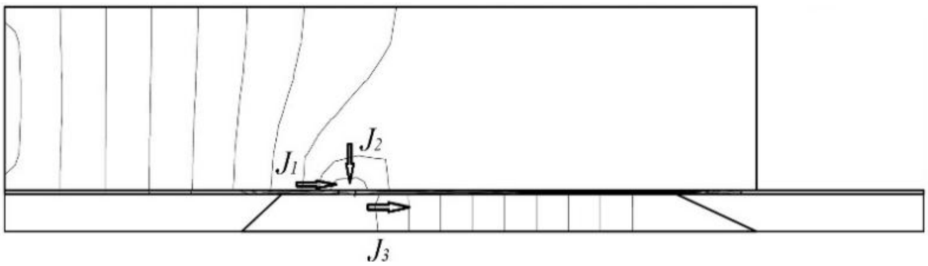


Fig 10. Distribution of contour line of uniform seepage field at upper side of culvert pipe.

4.2 Influence of hole size and position on critical head.

According to the test results, there are mainly four typical critical water heads for erosion damage, as shown in Fig. 11. Each experiment was carried out twice or more. In some experiments, the rise of water head is difficult to make the erosion enter the next stage, and the corresponding critical water head is not measured.

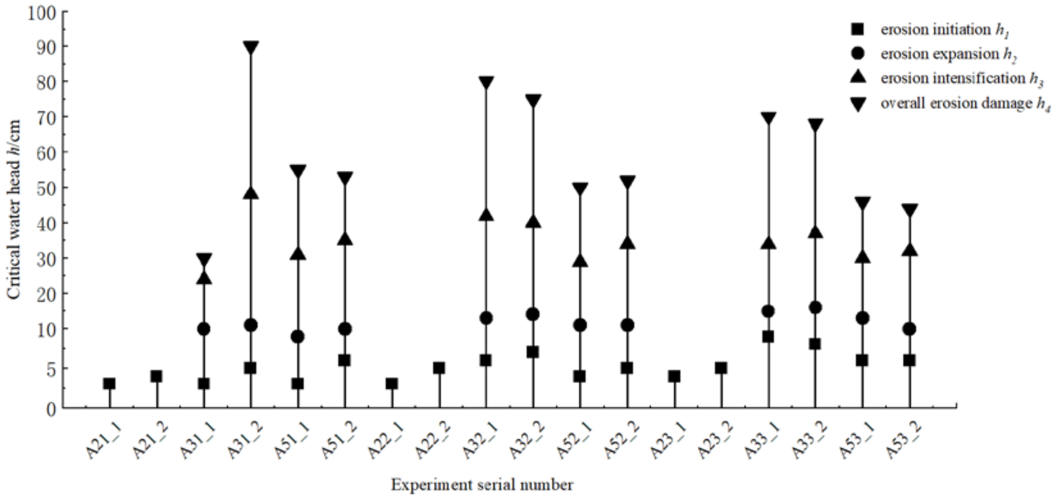


Fig 11. Statistical diagram of critical head of each test.

The average critical head for erosion initiation h_1 and erosion expansion h_2 for each test is shown in Table 3. The test results show that: (1) Under the same hole diameter, the closer the pipe wall hole is to the downstream, the higher the critical water head required for erosion initiation and expansion; (2) The larger the diameter of pipe wall hole at the same position, the lower the critical water head required for the initiation and expansion of erosion; (3) The diameter of pipe wall plays a certain role in limiting the development of erosion. For example, under the 2mm test conditions. There is a minimum diameter, below which erosion is difficult to occur.

The start-up of particles at the seepage outlet needs to break through the limit equilibrium state, and the local hydraulic gradient at the hole plays a major role rather than the overall hydraulic gradient. In the test, the sand has almost no cohesion, and it is easy to reach the starting condition under the action of gravity and permeability, so the difference of h_1 is not obvious. With the increase of upstream water head, it is easier to reach the critical hydraulic gradient required for sand start-up when the hole is located on the upstream side; The larger the hole, the larger the unstable area of sand, the more sand erosion under the same conditions, and the more silted sand is easy to block the culvert section. Therefore, the minimum critical head h_2 required for erosion expansion appears in test A51.

Table 3. Critical head of erosion initiation and erosion expansion.

The critical indicators	Mean critical water head H/cm								
	A21	A22	A23	A31	A32	A33	A51	A52	A53
Erosion initiation h_1	5	6.5	7	4	6.5	8.5	4.5	4.5	6
Erosion expansion h_2	-	-	-	10.5	13.5	15.5	9.5	11	11.5

The average critical water head required for local and overall erosion damage is shown in Table 4. The test results show that the larger the diameter of culvert hole is, the closer it is to the downstream, and the lower the critical water head required for failure is. When the hole is located in the upstream side, the local failure stage of the water head is longer, and the downstream side is relatively short, indicating that the silted sand of the culvert has a significant effect on the resistance to seepage failure.

Taking the 5 mm diameter test group as an example, affected by the blocking effect of culvert sediment, the rise of upstream water head did not directly lead to the loss of sand until it reached the critical water head J_3 required for the start-up of sand in the pipe. The culvert sand moved forward rapidly and the size of collapse pit increased. The water head required for the initiation of the sand at the upstream side of the hole is relatively small. Under the same conditions, the length of the culvert sand is longer than that of the downstream side. Therefore, under the blocking effect, the law of the erosion expansion head is opposite to that of h_2, and the minimum value of h_3 appears in Experiment A53. When the top collapse pit is evenly expanded to a certain range, the weak link will be destroyed by backward erosion piping. Affected by the sampling method, the density of the contact area between the model roof and the sand is low, and the impermeability is weaker than that of the pipeline silted sand. In the later stage of the test with higher upstream water head, the erosion piping will quickly connect with the inlet bin and damage occurs. Therefore, the duration of local failure stage of test A53 is short, and the critical water head h_4 of comprehensive failure is low.

The hole diameter of culvert pipe hole changed from 3mm to 5mm, and the critical head of local failure decreased from upstream to downstream by 32.3%, 24.4% and 18.3% respectively; The critical head of total failure decreased by 40.0%, 34.2% and 33.8% respectively from upstream to downstream. Therefore, the increase of the hole diameter of the pipe wall has a higher impact on h_4 than h_3, that is, the more likely it is to cause erosion damage in the global range.

4.3 Influence of hole size and location on erosion process.

The relation curve of sand siltation length of culvert pipe with whole position and size is shown in Fig. 12. The variation laws of different test are similar, and the inflection point of the curve corresponds to the water head h_4 required for intensified erosion. The test results can be fitted by Logistic model. Taking test A51 as an example, the fitting correlation coefficient is approximately 0.95.

Table 4. Mean critical head of local and total failure.

Texts	Erosion intensification h_3(cm)	Overall erosion damage h_4 (cm)	Local damage sustained head (cm)
A31	48.0	90.0	42.0
A51	32.5	54.0	21.5
decrease of critical head (%)	32.3	40.0	
A32	41.0	77.5	36.5
A52	31.0	51.0	20.0
decrease of critical head (%)	24.4	34.2	
A33	35.5	68.0	32.5
A53	29.0	45.0	16.0
decrease of critical head (%)	18.3	33.8	

It can be seen from Fig 12 that when the whole size is the same, the more its position tends to the downstream, the greater the water head required for sand erosion. Under the same water head, the shorter the sand deposition length, the easier it will enter the erosion intensification stage as the water head rises, and its variation law is consistent with the critical water head. For the same location, the growth law of sand deposition length with different hole sizes is similar, but the 3mm hole has a certain restrictive effect on sand erosion and loss, which increases the corresponding critical water head.

The variation law of outlet flow, sand content and collapse pit size is similar to that of sand siltation length. However, in the stage of intensified erosion, it is difficult to enter a stable state again due to the high upstream head, which is characterized by rapid rise until the end of the test.

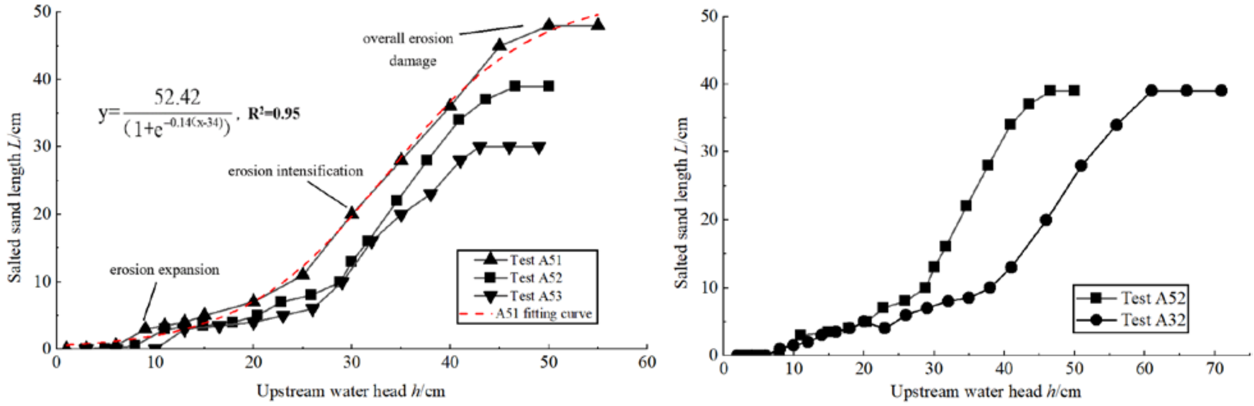


Fig 12. Change of sand siltation length of culvert pipe at the same position.

5. Analysis on the action mechanism of culvert pipe hole

5.1 Influence analysis of hole size

According to the experimental analysis, the hole size directly affects the stability of the natural structure of soil particles at the hole, the seepage field and the occurrence and development of contact erosion. The coarse particle size determines the effective pores provided by the particle skeleton, and affects the start-up, migration and loss of fine particles in the coarse particle skeleton.

The role of different particle sizes in soil is difference. The coarse particles participate in arching and play a supporting role, and d_{90} is used to characterize the coarse particle size that plays a skeleton role in soil. Fine particles mainly determine the permeability of sand body, and d_{10} is widely used to evaluate the impermeability and stability of soil. Sellmeijer of the Netherlands Delta Research Institute studies the boundary particle size d_{70} of sand piping. It is considered that soil particles with particle size less than d_{70} will be washed away in water, and particles with particle size greater than d_{70} will resist water flow. For the test materials in this paper, d_{50} particle size is used as the boundary particle size. When d_{50} is eroded, the soil will suffer large-scale damage [20].

Table 5. Characteristic particle size of soil.

The hole diameter d/mm	Characteristic particle size of type-A soil					
	d_{10}/mm	d_{10}/d	d_{50}/mm	d_{50}/d	d_{90}/mm	d_{90}/d
2	0.14	0.07	0.30	0.15	0.65	0.33
3	0.14	0.05	0.30	0.10	0.65	0.22
5	0.14	0.03	0.30	0.06	0.65	0.13

According to the analysis of the test results in Table 5, the following conclusions can be preliminarily drawn.

(1) When diameter of the pipe wall hole is 2 mm, the soil particles will show weak erosion and loss under the infiltration effect, and the rise of the water head will not cause large-scale erosion damage. It is believed that too small hole size will make large particles form a relatively stable structure and prevent the development of erosion. Therefore, the damage is only manifested as the loss of fine particles and will not expand to a wider range.

(2) When diameter of the pipe wall hole is 3mm, the size of the culvert hole and the interaction of silted sand determine the erosion rate. The larger the hole size is, the more conducive it is to erosion development, but sand deposition inhibits this process. When the sand entering the culvert can be scoured by water and take away from the culvert hole, the inhibition of silted sand on erosion becomes weak and the erosion process develops rapidly, as shown in test A31_1 in Fig. 11.

(3) When diameter of the pipe wall hole is 5 mm, the size of the hole has a weak restriction on the occurrence and development of the erosion, and the erosion is mainly affected by the seepage and the limit equilibrium state of the particles. When the particles reach the critical condition for the initiation, the failure process will develop rapidly and be difficult to control, and the large-scale loss of sand in the culvert pipe will be the main failure form.

5.2 Influence analysis of hole position.

The position of the culvert hole is the concentrated seepage outlet, which directly affects the seepage gradient at the hole position and restricts the initiation and development of erosion. Based on the analysis of the test results in Table 3 and Table 4, the following conclusions can be preliminarily drawn.

(1) The sand entering the culvert pipe through the hole will be silted up due to insufficient flow power. The silt will hinder the flow, increase the water level or water pressure in the culvert, and then reduce the seepage gradient at the hole, which has an inhibitory effect on the subsequent erosion. When the water head is small, the effect is the most obvious. For example, the continuous water head in the erosion development stage of test A51 is longer than that of test A53.

(2) Different positions of pipe wall holes will affect the length of silted sand in culvert pipe. The longer the silt is, the stronger the ability to resist damage is, and the stronger the inhibitory effect on subsequent erosion is. Taking 5mm hole diameter test as an example, the critical water head h_3 of test A53 is 29.0 cm, while that of test A51 is 32.5 cm, and h_3 increases about 12.1 % due to siltation of sand particles in culvert. The critical head h_4 of A53 was 45 cm, while that of A51 was 54 cm, and h_4 increased by about 20 %. Under the anti-seepage effect of culvert sand silt, the test soil can resist the obvious increase of water head, and the effect is the most obvious when the culvert hole is located on the upstream side.

(3) The influence degree of the hole location factor is related to the size of the hole. When the hole is small, the hole inhibits the loss of soil particles, and the sand deposition in the culvert is blocked, so the hole location factor has a strong influence on the erosion process. However, when the diameter of the pipe wall is large, the blocking effect of the silted sand in the culvert is limited, and the influence of the position on the erosion process is weak. Table 4 shows that the critical water head h_3 and h_4 of

test A33 are significantly lower than those of test A31, and compared with A51, the critical indexes h_3 and h_4 of A53 are reduced but the range is small.

6. Conclusion

The physical model test is used to simulate the contact erosion failure process of the levee caused by the hole of the pressure less culvert pipe through the levee. The evolution process, erosion path and morphology of the erosion failure is revealed. The critical water head of the typical stage is determined. The influence of the size and location of the hole on the erosion failure process is explored. The contact erosion process caused by seepage of pressure less culvert pipe can be divided into five basic stages: no obvious seepage failure stage, erosion initiation stage, erosion development stage, erosion intensification stage and comprehensive failure stage. The main erosion phenomena and characteristics in different stages are summarized. At the same time, the size and location of the hole of the pressure less culvert pipe wall determine the development speed and direction of erosion. When the hole of the culvert pipe wall is larger and closer to the downstream, the critical water head required to reach the stage of intensified erosion and comprehensive failure is smaller.

It can be seen from the mechanism of levee failure revealed by the tests that culvert pipe damage has a great influence on the contact erosion of levee. For such buildings, it is necessary to improve the traditional design concept, strengthen the construction quality management, and avoid the fracture and damage of the culvert pipe due to uneven subsidence. At the same time, measures such as downstream filtration should be taken to prevent the contact erosion caused by culvert pipe damage. In this paper, the research on the mechanism of levee failure is mainly carried out for the pressure less culverts crossing the levee. In the future, it is necessary to carry out physical model test and numerical simulation analysis to reveal the mechanism of levee failure in different situations and put forward targeted defense measures for the contact erosion caused by the damage of the pressure culvert pipe and the compaction of the soil around the culvert pipe.

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