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Research Article

Testing the Key Performance of Mobile Flood Protection System

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Mobile flood protection systems provide a standardized flood protection method with high reliability. A comprehensive test site for mobile flood wall was established with the support of real applications, which provided opportunities to perform various tests. The anchor plate installation, seepage characteristics, and stress behavior of mobile flood protection systems were investigated through a process test, a water impounding test, and a post loading/unloading test. Test results indicated that installing anchor plates either by direct fixing or by preopened slots and eyes satisfy the construction and normal work requirements. However, the former is preferable over the latter. The mobile flood protection wall leaks when filled with water, and the leakage changes exponentially with the level. The leakage accelerates when the water level exceeds 1.5 m, thus registering 300 L/h at the 1.7 m level. In the post loading test (0–100 kN), concrete plastic deformation was first observed. Then, residual displacement was developed in the posts. The stressing process indicated that the failure process in the post, anchor plate, and base concrete system propagates from the concrete on both sides of the anchor plates toward the water side.

1. Introduction

Today, there are more than 400 cities worldwide with one million or more population [1]. More than half of the world's population lives in cities which provide job opportunities and quality life. Historically, major cities are located along rivers and coastal areas. This makes them and their populations vulnerable to natural disasters such as flood. Furthermore, natural disasters and weather-related disasters have been occurring at an increased frequency during the last decade [2].

This upward trend in losses has been mainly attributed to socioeconomic developments, such as economic and population growth in disaster-prone areas, which have increased the exposure of properties that can be damaged by natural hazards over time [3, 4]. Moreover, future natural disaster losses are expected to increase in many regions around the world [5, 6].

The high-level urban flood control system is the basic guarantee for the sustainable development of modern cities, and the beautiful water environment and river landscape are the important symbols of modern cities. The need of protection is increasing with rising population density and concentration of valuables in low-lying coastal and river areas in the last decades [7]. Nevertheless, a fact frequently overlooked is that small local events cause approximately 50% of total flood damage [8]. For example, the flooding caused by the hurricane can be assumed as the flooding with the highest economical losses for more than $81 billions at the US coast [9]. Tropical Storm Irene and spring flooding in 2011 exposed the vulnerabilities of mobile home parks in Vermont when 154 mobile homes in parks were destroyed [10].

Beneath dykes and floodwalls, mobile constructions are a solution for flood protection especially in densely populated areas where no space for permanent structures is available. In addition, permanent structures may obstruct heavily the view onto the water body. In these cases, mobile flood protection measures may be a solution to fit both requirements: protection in case of flooding and open access to the floodplain over the remaining time. Furthermore, mobile protective systems can be used as an emergency tool against flooding in unprotected low-lying areas and for heightening of permanent flood protection structures in extreme events [11].

Greening flood protection (GFP) is increasingly recognized as an adaptive and flexible approach to water management that is well suited to addressing uncertain futures associated with climate change. In the last decade, GFP knowledge and policies have developed rapidly, but implementation has been less successful and has run into numerous barriers [12].

Therefore, the demand for technical protection measures is growing. It means that the construction of flood control projects should not only meet the requirements of urban construction, but also meet the requirements of water and shore two-way landscape viewing and residents' and tourists' visiting [13]. Recently, more and more mobile protection schemes are on the market promising to fit both requirements: protection in case of flooding and open access to the floodplain in the remaining time. With the severe situation of urban flood protection in China [14], mobile flood protection systems can satisfy the different quality of life and safety requirements for the urban residents. The mobile flood protection method has been successfully applied in many American and European countries [15]. For example, in 1984, Cologne City, first installed the mobile flood protection baffle to protect against river flood. In 2005, Czech built a 17.2 km long and 6.0 m high mobile flood protection system, which is one of the largest urban flood protection systems in the world. After the flood protection exercise, 310 fire protection volunteers completed the installation of the entire system in 11 hours. Grein City in Austria also introduced flood protection equipment which successfully resisted the maximum rainfall record in the area in June, 2013. In recent years, mobile flood protection systems have been implemented by important flood protection cities in Heilongjiang province and Zhejiang province in China. However, these flood protection systems have not met the flood.

Mobile floodwalls can be installed at river dams, large-size port piers, railway tunnel portals, culvert openings of expressways, openings of civil air defense structures, and urban large-scale communities to prevent flood disasters. Compared with the traditional flood protection method, mobile floodwalls have the advantages of low-labor intensity, high-work efficiency, and small seepage over traditional flood protection methods [15]. Mobile floodwalls improve the standard of urban flood protection and can effectively prevent flood disasters under the requirement of preserving the urban landscape [16]. Mobile floodwalls usually comprise posts (including center post and end posts), dam beams, ground seal, bolts, pressing tool, and anchor plate [17–19]. For mobile floodwalls, reinforced concrete plinths embedded with anchor plates are constructed in advance at the site of floodwalls. The posts should be installed on the anchor plates before flooding occurs, and the dam beams and ground seal should be installed among the posts to form a closed wall to prevent flooding. When flooding occurs, water enters the vacuum dam beams through the contact parts of the dam beams and the vertical posts. Then, the self-weight and stability of floodwalls are improved. After the flood recedes, all components are reversely removed and orderly stored in a warehouse.

During a flood, several causes of failure may occur related to the flood protection system. Failure types can be distinguished into five general situations: (1) sliding/rolling, (2) seepage, (3) leakage, (4) tilting, and (5) collapse. Every flood protection system has the possibility of failure. Therefore, it is important to design the system in a way that minimizes the possibility to meet one or several failure types. Wind, floating elements, bad design, vandalism, and human failure are all factors that may cause failure of the flood protection system [16]. Obviously, it is important to try avoiding the mentioned failure types. During the design phase of a flood protection system, the engineers should consider the risk of failure and put it up against properties that the system should hold. For instance, large and heavy systems provide stability and robustness, but on the contrary, they will be more difficult and expensive to produce, store, and transport. Therefore, it is important to consider which strengths the flood protection system should get and which to neglect [20].

Two problems should be considered for such a combined flood protection system. The first one is the installation precision of anchor plates as the key control components for the assembly and force transmission of floodwalls in which the anchor plates are embedded in reinforced concrete plinths for connecting fixed columns. Ensuring the installation precision of anchor plates without deviation during concrete pouring is crucial because the control precision of concrete pouring is in millimeter accuracy, and the installation precision of anchor plates should be controlled in centimeter accuracy. The second problem is the seepage and safety of flood protection systems, which is the primary concern of practical and research [7]. However, the seepage and safety of flood protection systems have not been studied in the literature. Considering the two problems, this study used the mobile flood wall from IBS company through the construction of experimental bases and investigated the installation technology of anchor plates, the leakage characteristics of mobile flood protection systems, and the stress conditions of posts and anchor plate bases to provide a reference for the application and promotion of mobile floodwalls in China.

2. Test Scheme of Mobile Floodwalls

2.1. Product Characteristics. The mobile flood wall used in this study is obtained from IBS Company, Germany, and has been applied in Germany, Austria, UK, and China. The installation effect is shown in Figure 1. The posts (including center posts and end posts) and dam beams of the system are made of aluminum alloy (with a tensile strength of 200 N/mm^2 and yield strength of 165 N/mm^2). The pressure tools and anchor plates are made of stainless steel (with a tensile strength of 500 N/mm^2 and yield strength of

Figure 1: Mobile flood wall.

Table 1: Main structure parts and materials of mobile floodwalls.

Class	Model	Material
Center post	MS100K-T05-1865	Aluminum alloy EN AW 6005
End post	E100K-T01-1865	Aluminum alloy EN AW 6005
Dam beam	DBAL100 × 200–2.5 (width: 3000 mm)	Aluminum alloy EN AW 6063 T66
Ground seal	BD100K (width: 3000 mm)	PE/PU
Pressing tool	VS 100K	Stainless steel SS304
Anchor plate	AP 100K-T05	Stainless steel SS304

190 N/mm^2). The type and materials of their components are shown in Table 1, and the main structure parts are shown in Figure 2. In this research, the single span and the height of maximum water level for the system are 3.0 m and 1.8 m, respectively.

2.2. Test Design. Figure 3 shows the layout of mobile floodwalls at the test site. The test site is divided into three areas: water storage, post damage destructive, and standby areas. The test site is 10.4 m long and 10.0 m wide. Three spans, two end posts, two center posts with an anchor plate, and three-span dam beams (27 dam beams) were designed for the floodwalls in the prototype test area. The destructive test area comprises a center post and its anchor plates.

The base plate in the test site was 30 cm thick, and a layer of Φ18 reinforcing mesh with a spacing of 20 cm was installed inside. The reservoir wall was a standard reinforced concrete U-shaped shear wall, which was 250 mm thick and 2.4 m high. The base of the anchor plates for the center posts was 10.4 m (length) × 1.2 m (width) × 1.0 m (height), and the reinforced concrete posts of the anchor plates for the end posts were 0.8 m (length) × 0.8 m (width) × 1.8 m (height). When water is impounded to the designed height of 1.8 m, the volume of the impounding reservoir is 55.341 m^3.

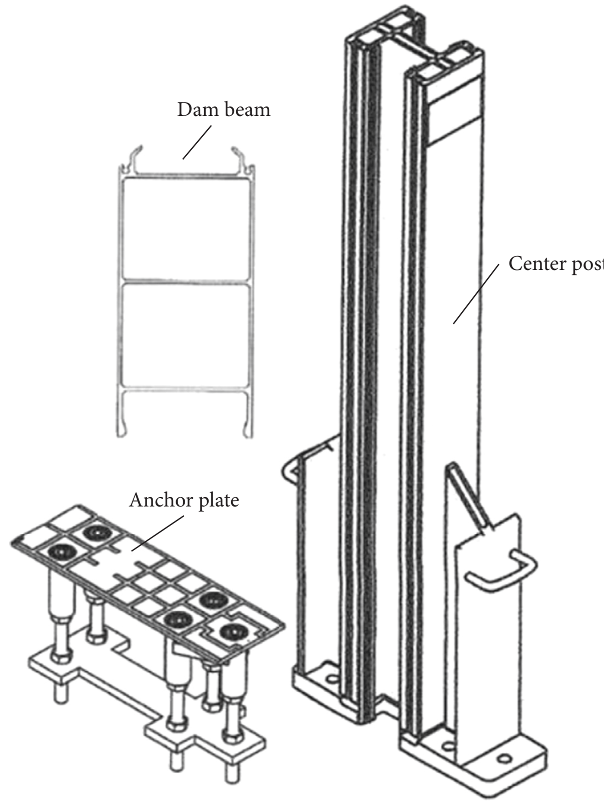

Figure 2: Structure of main parts.

The test site was built using C25 reinforced concrete and completed in two layers. The first layer comprised the base plate and the base of the anchor plates, and the second layer comprised the reservoir walls.

2.3. Test Procedures and Method. After the test site is conducted according to the design, the following are performed:

(1) The installation methods for the test of anchor plates: two methods are adopted for the installation of anchor plates. The first one is the direct installation method; that is, the anchor plates are installed and fixed. Then, concrete is poured after the steel bars are assembled. The second one is the reserved slot method; that is, the anchor plates are installed, and slots are reserved on the base after the poured concrete reaches a certain age.

(2) After the anchor plates are installed, the steel bar meters and the strain meters are arranged as shown in Figure 4. R1–R5 are steel bar meter number, and S1–S3 are strain gauge number. The steel bar and strain meters are obtained from Geokon Instruments Co., Ltd. Full-automatic wireless collection devices are used for real-time collection, and they recorded data once every 3 mins.

(3) Concrete is poured and cured for 28 d. Subsequently, reaction frames, the waterproof impounding reservoir, water inlet and outlet pipelines, and the ceiling are installed and erected. Then, the construction of

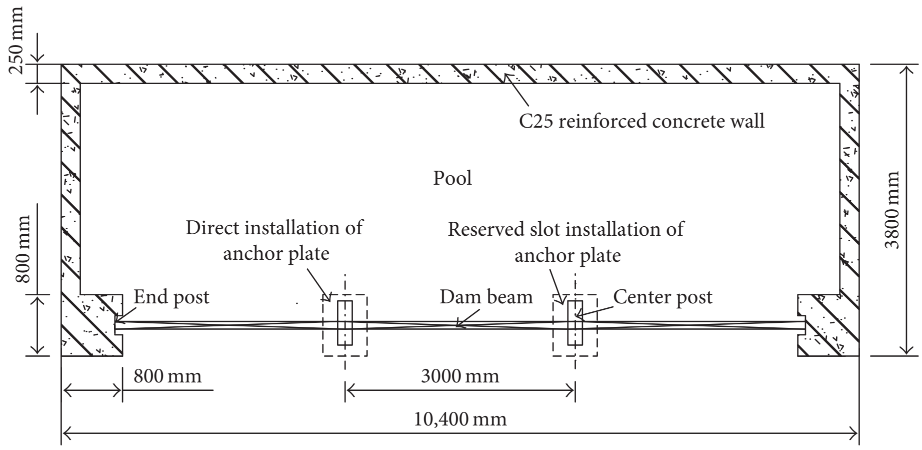

FIGURE 3: Test site layout.

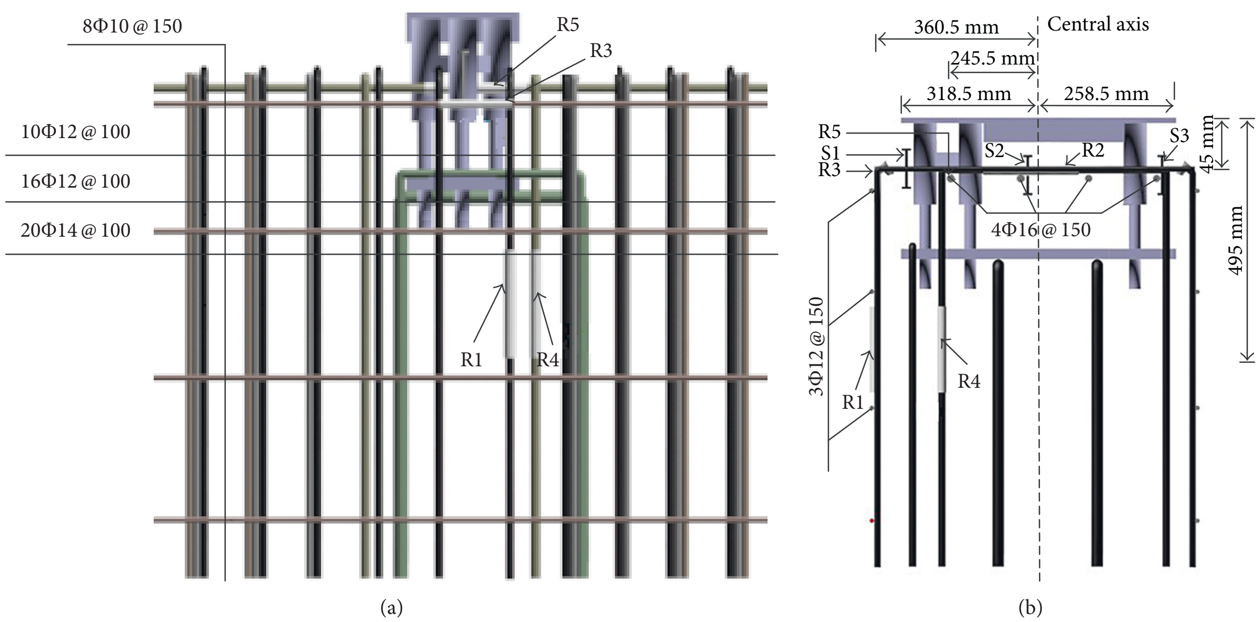

FIGURE 4: Layout of reinforcing steel bars, steel bar meters, and strain meters. R1–R5 are steel bar meter number, and S1–S3 are strain gauge number. The same as in Figure 4(b). 3Φ12 @ 150 refers to three steel bars with diameter 12 mm and spacing 150 mm, the same as in Figure 4(a).

the test site is completed such that the ceiling can prevent the influence of sunlight or rainfall during the leakage test.

(4) Water storage and post loading tests are performed.

3. Installation Technology of Anchor Plates

3.1. Installation Precision of Anchor Plates. The precision of anchor plates' installation depends on the designed water level. Considering the water retaining height of 1.8 m as an example, the tolerances of all directions are shown in Figure 5. The control tolerances in the axis direction of the anchor plates are ±5 mm and ±10 mm in the vertical direction, ≤3° of the horizontal angle, 0.15% of the vertical angle, ±3 mm of the interval errors for the contiguous anchor plates, and ±5 mm interval errors for the interval anchor plates, perspective.

3.2. Installation Technology of Anchor Plates. Two installation methods, namely, the direct installation method and reserved slot method, are used for anchor plate's installation for this test. For the direct installation method, U-shaped steel bars are arranged firstly at the installation position (Figure 6), and the anchor plates and U-shaped steel bars are welded. The foundation steel bars are assembled, and concrete is poured all at once. The advantage of the direct installation method is the integrity of the anchor plates, steel bars, and base concrete. However, the installation precision of anchor plates cannot be easily controlled because the anchor plates easily deviate when concrete is poured. And their surrounding concrete cannot be easily vibrated and compacted.

For the reserved slot method, concrete should be poured one time at the lifting elevation of the foundation and slots should be reserved in the concrete foundation according to

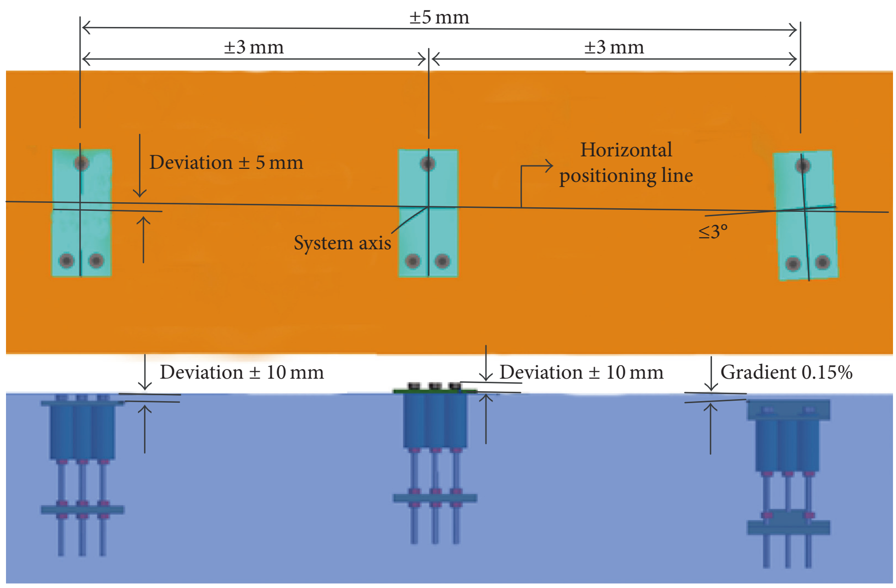

Figure 5: Installation tolerances of anchor plates.

(a) (b)

Figure 6: Direct installation method. (a) Anchor plate fixation. (b) Reinforced bar assembly.

the requirement and water level of the flood period during construction. The steel bars around the anchor plates cannot be arranged in advance. However, U-shaped steel bars are welded with the anchor plates completely in advance (Figure 7(a)). Then, the second-stage concrete is poured after the anchor plates are fixed by an adjusting device (Figure 7(b)). In the reserved slot method, the base concrete can be constructed firstly, and thus, the installation is convenient and precision can be easily controlled. However, the periphery of slots is processed as construction joints, and leakage channels can be easily formed at the joints.

The two methods have been applied on-site for this research.

4. Analysis of Test Results

4.1. Water Storage Test. After civil engineering is completed, the mobile floodwalls are installed for the water storage test, as shown in Figure 8. The measured values of steel bar meters of the two installation methods are shown in Table 2. The strain gauge measured values of two installing methods are shown in Table 3. The layout of the steel bar and strain meters of the base is shown in Figure 4.

The stresses on all parts are changed after water storage with water pressure, water weight, and deadweight of the flood protection system. The stress condition of the direct installation method is as follows: maximum tensile stress appears at R1 and R4 positions where a tensile stress of 0.9 MPa was recorded; moreover, R3 and R5 positions are compressed, reaching a compression stress of 5.8 MPa. Compared with the direct installation method, the stress characteristics of R1, R3, and R4 positions are consistent. At the same time, the stress features of concrete under the two installation methods are consistent, but the strain generated by the latter is higher; for instance, S2 generates tension strains 5.45 $\mu\varepsilon$ (direct installation method) and 1.39 $\mu\varepsilon$ (reserved slot method). The analysis indicates that the integrity of anchor plates installed via the reserved slot

(a) (b)

Figure 7: Reserved slot installation method. (a) Reinforced bar arrangement. (b) Adjusting device and anchor plate fixation.

(a) (b) (c)

Figure 8: Water storage testing of mobile flood wall storage. (a) Overall view. (b) Pool (not storage). (c) Pool (stored water at 1.8 m).

Table 2: Measured values of steel bar meters of the two installation methods (unit: MPa).

Number of steel bar meter	Time of measurement	Direct installation method		Reserved slot method	
		Actual measured value	Variation value	Actual measured value	Variation value
R1 (Φ14)	Before storage	4.32	0.90	−2.83	1.04
	Storage to 1.8 m	5.22		−1.79	
R2 (Φ12)	Before storage	−15.96	0.49	—	—
	Storage to 1.8 m	−15.47		—	
R3 (Φ12)	Before storage	14.35	−5.71	22.93	−5.64
	Storage to 1.8 m	8.64		17.29	
R4 (Φ16)	Before storage	3.44	0.87	6.25	1.39
	Storage to 1.8 m	4.31		7.64	
R5 (Φ16)	Before storage	22.87	−5.92	6.38	0.82
	Storage to 1.8 m	16.95		7.20	

method is low, which just like anchor plates and slot concrete form a member that is embedded into the base. Then, the stress state of the reserved slot method is clearly different from the direct installation method. So, the direct installation method is apparently safer than the reserved slot method. The actual stress values of impounding of the two installation methods are lower than the allowable values of reinforced concrete plinths.

4.2. Leakage Test. The seepage test was performed when the level of stored water reached 1.78 m. After 3 h, the water level

Table 3: Strain gauge measured values of two installing methods (unit: $\mu\varepsilon$).

Number of steel bar meter	Time of measurement	Direct installation method		Reserved slot method	
		Actual measured value	Variation value	Actual measured value	Variation value
S1	Before storage	41.31	8.68	—	—
	Storage to 1.8 m	49.99		—	
S2	Before storage	79.97	5.45	4.75	11.95
	Storage to 1.8 m	85.42		16.70	
S3	Before storage	63.32	−25.84	12.33	−26.32
	Storage to 1.8 m	37.48		−13.90	

decreased to 1.75 m. Given 1.75 m as time 0, the observation frequency was measured every 6–2 h, until 150 h was reached. Then, the water level was 1.37 m at 300 h. The observation times and corresponding observation levels are shown in Tables 2 and 3. The variation in the actual measured level with time did not exhibit a linear correlation. The following regression formula was obtained by origin regression analysis:

$$H = 0.202e^{-t/18.79} + 0.217e^{-t/182.02} + 1.327, \quad (1)$$

where H is the water level (m) and t is the time (h), when $t = 0$ and $H = 1.75$ m.

Fitting testing was conducted via (1). The correlation coefficient was 0.995, and the fitting effect was good. Forward and backward predictions were performed to verify the accuracy of the relation formula. The calculation results indicated that the H value was 1.784 m (the actual measured value was 1.78 m) when the time was moved back by 3 h ($t = -3$ h in the calculation), and the calculation value was 1.369 m (the actual measured value was 1.37 m) when the time was moved forward to 300 h. Thus, the consistency of the result was good. The decrease of water level is caused by the leakage in the mobile floodwalls, and the critical water level is 1.327 m.

The seepage rule for mobile floodwalls has not been from the literature. Generally, seepage only occurs at contact positions, which are the positions between dam beams and posts, the positions between the bottom dam beams and the foundation, and the positions among dam beams. Considering the current test condition, the leakage amount of all parts cannot be obtained through the test. Under the requirement of ignoring the influence of water evaporation at the reservoir surface, the leakage amount of mobile floodwalls is calculated according to the following formula:

$$q = -1000\ Av = -1000\ A\frac{dH}{dt}, \quad (2)$$

where q is the leakage amount (L/h) and A is the reservoir area (m^2). For the test conducted, $A = 30.745\ m^2$ and v is the seepage velocity (m/h), $v = dH/dt$.

After the derivation of (1), the seepage velocity is obtained. The variation rule for the average leakage amount at different water levels is obtained after substitution in (2). Then, the average leakage amounts are compared with the average leakage amount after the conversion of the actual measured water level (Figure 10). Figures 9 and 10 show that the range of water level variation becomes fast and the seepage rate becomes large,

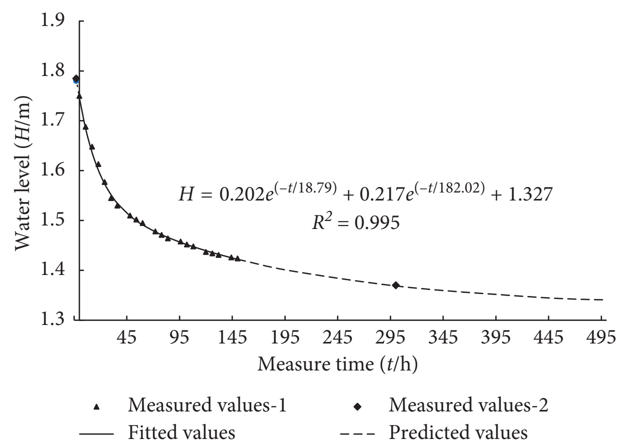

Figure 9: Variation rule of water level with time.

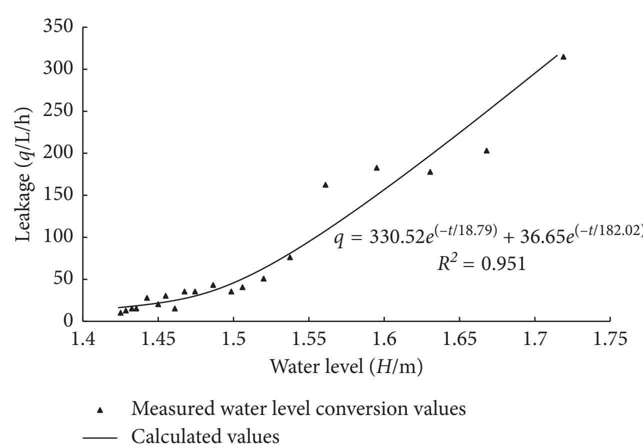

Figure 10: Leakage variation rule with the change of water level.

which is more than 50 L/h, when the water level exceeds 1.7 m, and the seepage rate can exceed 300 L/h when the water level exceeds 1.5 m. Seepage quantity is an important aspect to consider when floodwalls increase the flood protection height.

4.3. Post Loading Test. Section 4.2 indicates that under the normal hydrostatic pressure, the base of the mobile flood wall is slightly stressed and generally cannot damage the concrete. However, the hydrodynamic action or the impact of foreign objects should be considered during the process of flood resistance. At this time, the post, anchor plate, and base system ensure the safety of flood protection.

Figure 11: Post loading test.

The post loading test site, layout of its loading devices, displacement meters, and strain plates are shown in Figures 11 and 12. And the layout of the base steel bar and strain meters is shown in Figure 4. In Figure 12, strain meters C1 and C2 are arranged at the side of the posts, which is 1.02 m away from the base surface, to observe the self-deformation of the posts. Displacement meters A1, A2, and A3 are arranged at the downstream surface of the posts, which are 0.25, 1.02, and 1.57 m away from the base surface, respectively, to measure the overall displacement of the posts. The steel bar and strain meters are arranged in the same way as that in Section 4.1. The test adopted the hydraulic jack continuous loading mode, the set load limit was 100 kN, and all measurement equipment was measured once at 0, 25, 50, 75, and 97 kN. The loading and unloading process lines of all monitoring devices are shown in Figures 13–16.

The oblique strains (C1 and C2) of the post show a linear variation with the load during the loading process. The loading and unloading curves are basically consistent, and the directions and values of C1 and C2 are opposite and similar, respectively. Under loading of 50 and 97 kN, the strain values are approximately 500 and 1000 $\mu\varepsilon$, respectively, which indicate that the posts are consistently in the elastic phase during the loading process. The overall radial displacement of the posts shows that one of the upper parts is higher than that of the lower part, and the maximum value appears at the upper parts of the posts. For instance, the displacement meter A3 is 9.8 mm when the load is 50 kN, and displacement meter A3 is 17.1 mm when it is 97 kN. The radial displacement of the posts shows a nonlinear variation with the load variation, and the actual measured residual displacements of A1, A2, and A3 are 0.17, 0.36, and 0.50 mm, respectively, after unloading. The values are in linear relationship with the heights where the displacement meters are located (as showing in Figure 17); that is, the posts are also at the elastic stage. Thus, residual displacement shall be generated by the reinforced concrete plinth of the anchor plates.

Considering the concrete load-strain curve, concrete enters the plastic stage from the elastic stage when the load is approximately 25 kN. For example, S1 and S2 reach 97.34 and −389.47 $\mu\varepsilon$ when loaded to 7 kN. At this time, S1 is close to the ultimate tensile deformation value of concrete, and the residual strains are 6.50 and −26.39 $\mu\varepsilon$, respectively, after unloading. This condition can also be observed from the load-stress curve of steel bar meters. Stress shows a linear variation with the load when the load does not exceed 25 kN, which indicates that the steel bars and concrete are in the elastic stage of coordinative deformation at this time. Stress shows a nonlinear variation with the load when it is loaded continuously, and residual stresses are found, which are 0.39 MPa (R1), 0.20 MPa (R2), 0.16 MPa (R3), and 0.10 MPa (R4), after unloading. Unfortunately, R5 was broken, so the record cannot be gotten. The stress of the loaded steel bar is lower than the yield condition because the test uses HRB335 steel bars. Thus, the residual stresses displayed by steel bar meters are caused by the plastic deformation of concrete. In addition, the strain rule of steel bar meters is R2 > R1 > R4 > R3. For example, when the loading is up to 97 kN, the actual maximum measured stress values of R1 to R4 are 8.50, 12.50, 2.70, and 3.63 MPa, respectively, which indicates that the side surface of the anchor plates is in maximum stress. Thus, crack starts from the two sides of the anchor plates and then develops to the positive side of the water gradually if damage occurs.

5. Conclusions

Mobile floodwalls can be installed at river dams, large-size port piers, railway tunnel portals, culvert openings of expressways, openings of civil air defense structures, and urban large-scale communities to prevent flood disasters. Mobile floodwalls improve the standard of urban flood protection and can effectively prevent flood disasters under the requirement of preserving the urban landscape. In order to investigate the safety of mobile flood wall, the anchor plate installation, seepage characteristics, and stress behavior of mobile flood protection systems were investigated through a process test, a water impounding test, and a post loading/unloading test. Test results indicated the following:

(1) The installation precision of anchor plates ensures the rapid assembly and normal operation of mobile flood protection systems. Combined with engineering characteristics, the technologies of the direct installation and reserved slot methods are studied. The two methods are assumed capable of satisfying the construction requirements after technical testing. However, the integrity of the former is better than the latter. The impounding test also proved that the two methods can satisfy the requirements of normal operation. However, the stress condition of the direct installation method is better than that of the reserved slot method. So, direct installation method is recommended for the actual project.

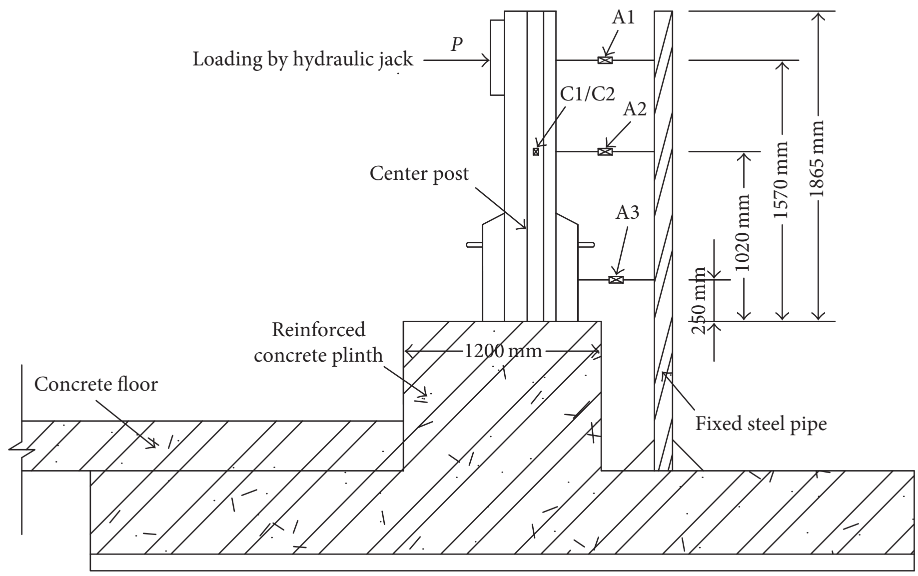

Figure 12: Layout of displacement meter, strain meter, and loading.

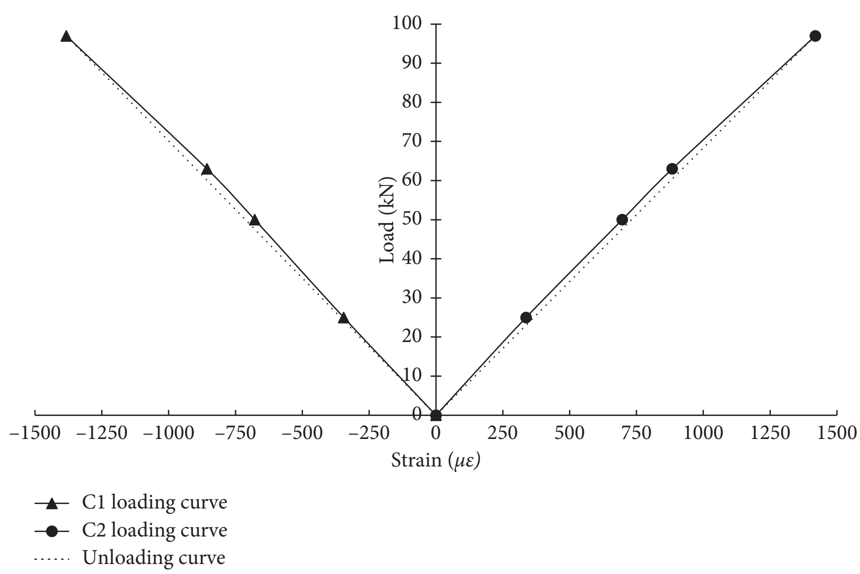

Figure 13: Relationship between post oblique strain and load.

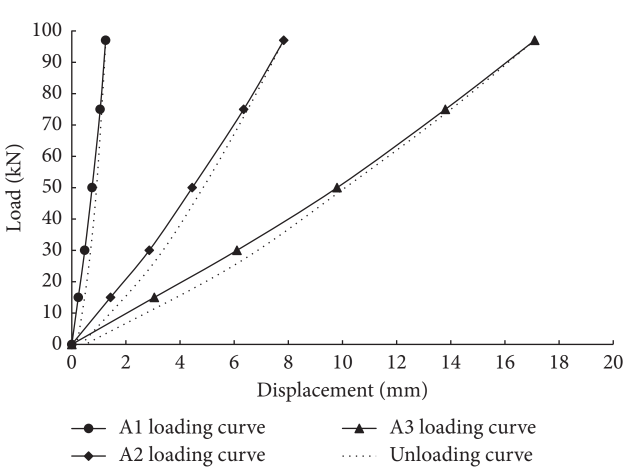

Figure 14: Relationship between displacement and load.

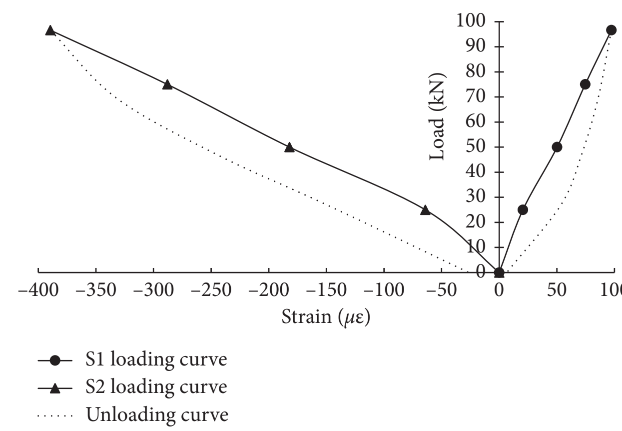

Figure 15: Relationship between concrete strain and load.

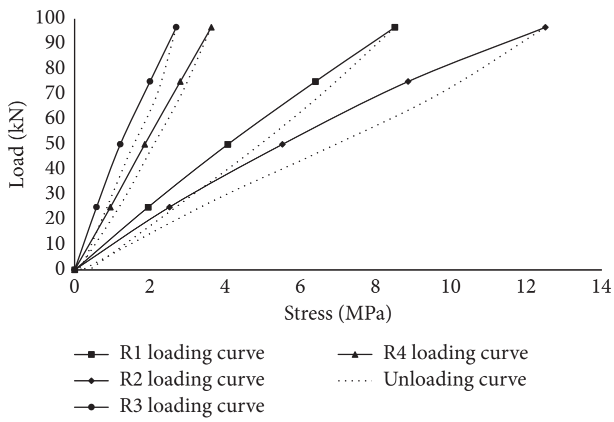

Figure 16: Relationship between steel bar stress and load.

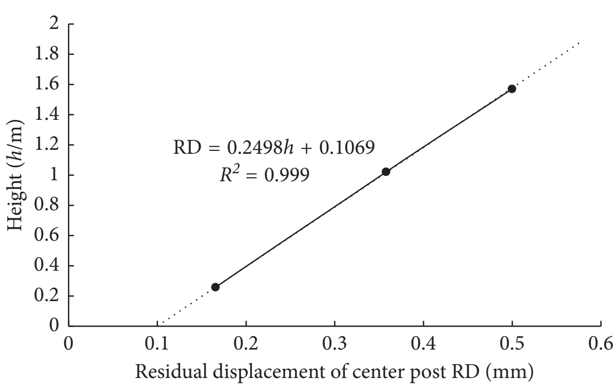

Figure 17: Relationship between residual displacement and height of the post.

(2) The leakage characteristic of the mobile flood protection system should be considered during flood prevention. The impounding test for the reservoir of three-span mobile flood protection system indicated the actual measured water level and time, and the leakage amount and water level are in the index variation relationship. The leakage amount, which is higher than 50 L/h, will rapidly increase when the water level is higher than 1.5 m. For example, the leakage amount can be 300 L/h when water level is 1.7 m, which indicates that the leakage should be solved when the water retaining height of the mobile flood protection system increases.

(3) In the entire mobile flood protection system, the post-anchor plate-reinforced concrete plinth system ensures the safety of flood protection. The post loading and unloading tests (the limited load is 100 kN at this time) indicate that the plastic deformation of concrete around the anchor plates occurs when the load is up to 25 kN. When the load is reaching 97 kN, the concrete would be close to ultimate tensile deformation. However, the posts and steel bars are all in the elastic stage during the entire loading process. The actual measured residual displacements of posts and residual stress of steel bars are caused by the plastic deformation of concrete after unloading. In addition, the stress analysis of the loading and unloading processes shows that the damage of the post-anchor plate-foundation system will start from the concrete around the anchor plate and gradually develop toward the surface of the water surface until the whole is destroyed. Therefore, the mobile flood control system engineering should pay full attention to the construction quality of concrete around the anchor plate.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] T. Brinkhoff, "The principal agglomerations of the world," 2010, http://www.citypopulation.de.

[2] W. Uddin, ""Natural disasters occurring more globally?"," 2011, http://infrastructureglobal.com.

[3] L. M. Bouwer, "Have disaster losses increased due to anthropogenic climate change," *Bulletin of the American Meteorological Society*, vol. 92, no. 1, pp. 39–46, 2011.

[4] T. Haer, W. J. W. Botzen, J. Zavala-Hidalgo et al., "Economic evaluation of climate risk adaptation strategies: cost-benefit analysis of flood protection in Tabasco, Mexico," *Atmosfera*, vol. 30, no. 2, pp. 101–120, 2017.

[5] J. Hinkel and R. J. T. Klein, "Integrating knowledge to assess coastal vulnerability to sea-level rise: the development of the DIVA tool," *Global Environmental Change*, vol. 19, no. 3, pp. 384–395, 2009.

[6] Y. Hirabayashi, R. Mahendran, S. Koirala et al., "Global flood risk under climate change," *Nature Climate Change*, vol. 3, no. 9, pp. 816–821, 2013.

[7] M. Diakakis, G. Deligiannakis, K. Katsetsiadou et al., "Mapping and classification of direct flood impacts in the complex conditions of an urban environment. The case study of the 2014 flood in Athens, Greece," *Urban Water Journal*, vol. 14, no. 10, pp. 1065–1074, 2017.

[8] B. Merz, F. Elmer, and A. H. Thieken, "Significance of "high probability/low damage" versus "low probability/high damage" flood events," *Natural Hazards & Earth System Sciences*, vol. 9, no. 3, pp. 1033–1046, 2009.

[9] E. S. Blake, E. N. Rappaport, C. W. Landsea et al., "The deadliest, costliest, and most intense United States tropical cyclones from 1851 to 2006 (and other frequently requested hurricane facts)," *Hurricanes Preparedness Facing the Reality of More & Bigger Storms*, vol. 2812, pp. 75–104, 2007.

[10] D. Baker, S. D. Hamshaw, and K. A. Hamshaw, "Rapid flood exposure assessment of Vermont mobile home parks

following tropical storm Irene," *Natural Hazards Review*, vol. 15, no. 1, pp. 27–37, 2014.

[11] B. Koppe and B. Brinkmann, "Development and testing of water-filled tube systems for flood protection measures," in *Proceedings of the International Conference on Textile Composites and Inflatable Structures, Structural Membranes (CIMNE)*, Barcelona, Spain, October 2011.

[12] S. K. H. Janssen, J. P. M. V. Tatenhove, A. P. J. Mol et al., "Greening flood protection through knowledge processes: lessons from the Markermeer dikes project in the Netherlands," *Regional Environmental Change*, vol. 17, no. 2, pp. 1–13, 2016.

[13] R. Liem and J. Köngeter, "Mobile flood protection walls: experiments and reflections on the risk of flood waves caused by a failure," in *Proceedings of the 29th Annual Water Resources Planning and Management Conference*, Tempe, AZ, USA, June 1999.

[14] Y. Y. Li, J. Q. Li, H. F. Shi et al., "Strategic thinking on major issues in China flood control," *Advances in Water Science*, vol. 21, no. 3, pp. 490–495, 2010.

[15] I. Kádár, "Mobile flood protection walls," *Pollack Periodica*, vol. 10, no. 1, pp. 133–142, 2015.

[16] B. Koppe and B. Brinkmann, "Opportunities and drawbacks of mobile flood protection systems," in *Proceedings of the International Coastal Engineering Conference (ICCE)*, Shanghai, China, June-July 2010.

[17] Z. P. Li, J. W. Yue, and S. J. Hong, "The rapid assembly mobile flood control wall," Patent CN104499460A, 2015.

[18] C. H. Xu, "Mobile flood wall," Patent CN103306237A, 2013.

[19] R. S. Adler and R. A. Ellman, "Removable floodwall system, components and method of installation," Patent US20150147120, 2015.

[20] S. Strømsnes, "Concept development of all-new flood protection system," Master's Thesis, Norwegian University of Science and Technology, Trondheim, Norway, 2015.