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Research and Application of Construction Technology for Adjacent Structures Foundation Pits

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Abstract: The construction technology for the excavation of the foundation pit of adjacent structures first involves conducting an engineering investigation to determine the key and difficult points of the project as well as potential safety hazards. On the premise of ensuring the elimination or reduction of safety risks, targeted measures are taken to eliminate or reduce the safety hazards, and necessary detection methods are employed to digitally and intuitively represent the safety of the project. Based on the anticipated working conditions as determined through on-site investigation and the actual data reflected by the investigation, effective engineering measures are adopted to ensure the safety of the project construction.

Keywords: Adjacent structures; Foundation pit; Excavation plan; Pile extraction and grouting

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1. Introduction

With the acceleration of the urban capacity renewal process, the development and utilization of urban above-ground and underground spaces have been increasing, and the construction technology of adjacent structures has become an important research topic in the field of construction engineering. This project focuses on the influence mechanism of foundation pit excavation on important adjacent structures, as well as the adaptability of excavation technology under different geological conditions. After studying a series of key factors affecting the safety of foundation pit excavation, and based on this, targeted technical improvement measures were proposed, providing useful references for similar projects. This construction technology research has important theoretical and practical significance for promoting the development of foundation pit excavation technology for adjacent structures, ensuring project safety, improving construction efficiency, and promoting the sustainable development of the civil engineering industry [1].

2. Project overview

This project is the first section of the post-disaster reconstruction of the Jialu River (from Chemical Road to Chenzhuang Bridge) in Zhengzhou. The project is adjacent to the Chemical Road Bridge and the Jialu River, and belongs to the post-disaster reconstruction project. The Chemical Road Bridge is a major transportation road in Zhengzhou, and both sides are filled with water, electricity, gas, heating, etc. pipelines. Due to the severe damage to the slopes on both sides of the Chemical Road Bridge caused by the 7.20 flood, many pipelines were destroyed, and it was necessary to re-arrange the comprehensive pipelines.

The main purpose of this river-crossing pipeline design is to reserve space for the overpass of damaged water-supply, gas, etc. pipelines during the 2021 July 20 flood damage. The overpass pipeline adopts the pipe jacking construction method, and the receiving well and working well are supported by steel sheet piles for excavation. Each single pipe is 115m long, and three DN1000 reinforced concrete pipes are arranged in parallel, with a total length of 345m. The top elevation of the overpass pipe is 99, the bottom elevation of the pipe in the pipe is 97.9, and the elevation of the left and right banks of the construction site is approximately 111.65, the elevation of the overpass section is approximately 101.7, and the maximum burial depth is 12.65m.

3. On-site investigation and scheme design

According to the design drawings and the construction goals of this project, this river-crossing pipeline project mainly focuses on the repair of cross-river pipelines damaged in the 2021 July 20 flood in Zhengzhou. The river-crossing pipeline project of this project is adjacent to the existing bridge, Chemical Road Bridge, and the cross-river section of the pipeline project is 3*115m DN1200 construction. The inspection well of the pipeline is 12.65m deep, and the concrete inspection well with specifications of 9.8*9.4 (m) is cast in place. The well position is adjacent to the north side of the Chemical Road Bridge. The specific engineering environment is shown in **Figure 1**.

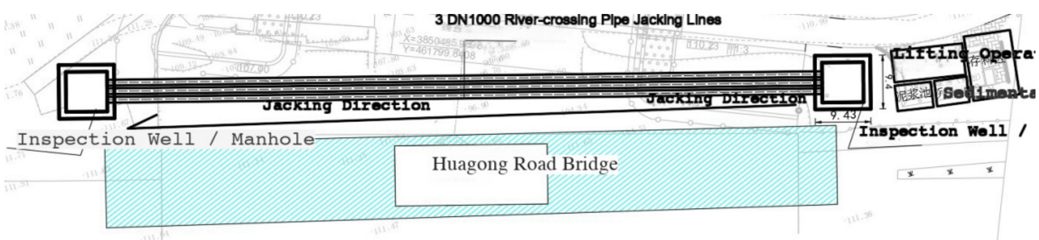

Figure 1. Engineering environment floor plan.

The original design was for static pressure steel sheet pile support + pipeline burial + inspection well sinking construction. Considering the on-site investigation results, the current condition of the project is severely damaged by water erosion. The static pressure steel sheet pile support for the river-crossing pipeline and the direct burial of the pipeline construction take a long time, require a large investment in steel sheet piles, and affect the original river flow surface. Moreover, the pipeline construction in the riverbed has strict requirements for dewatering, and the pipeline construction will affect the 2022 annual river flood control target of the ongoing river. Additionally, the two inspection wells are located in the high backfill areas of the bridge abutments. The original design adopted the cast-in-place sinking well construction scheme. However, due to the long construction period of the cast-in-place sinking well and the use of lowering the surrounding soil friction resistance to achieve sinking, the sinking construction process will disturb the surrounding soil. In the bridge abutment backfill area, the sinking construction of the steel sheet pile causes soil disturbance, and the stability of the bridge pile foundation or the bearing platform and the concrete foundation is prone to negative friction, resulting in a high risk of bridge safe operation and traffic [2].

Considering the urgency of the post-disaster reconstruction construction tasks, the importance of river flood control, and the overall construction interrelation, the project department proposed reasonable suggestions to the design unit. After a joint investigation and detailed discussion among the five responsible entities, a construction scheme consisting of pipe jacking with steel sheet pile-supported foundations and cast-in-place inspection wells was finalized. Based on this, the project department optimized and determined the construction plan for the pipeline project, which adopts pipe jacking engineering to accelerate the construction period, does not affect the river flow surface, and ensures the river flood control target. The inspection wells adopt two layers of support → long-arm excavator excavation → micro-dewatering + bottom sealing → main construction → grouting → full-scale settlement observation. The special construction plan was submitted for review and approval, and was strictly implemented according to the relevant plans to ensure the overall safety and orderly progress of the project.

4. Construction procedures

Figure 2 shows the construction procedures.

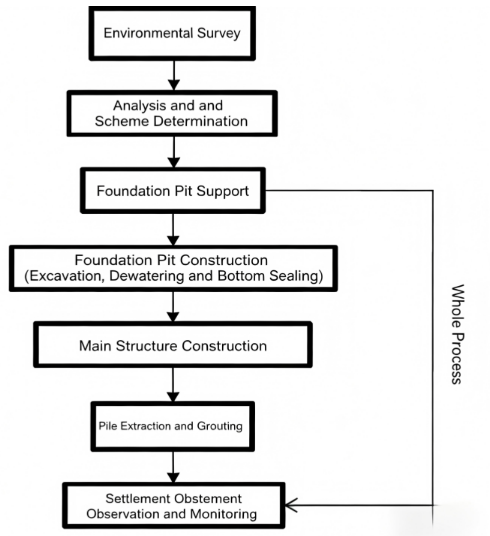

Figure 2. Construction process flow chart.

5. Foundation support for inspection wells

Due to the severe damage caused by the 7.20 flood disaster, the area of the bridge abutment's backfill soil was severely damaged, and the inspection wells at both ends of the bridge head were very close to the bridge abutment, with a vertical distance of only 4.3 meters. To prevent the construction of the inspection well foundation from affecting the stability of the bridge abutment's backfill area and the traffic safety of the chemical road bridge, the project department, in accordance with the design drawings and expert suggestions, determined a construction plan for the foundation support of the inspection wells, which included setting up two layers of supports. The first layer of support was set between the inspection well and the bridge abutment, blocking and weakening the influence on the backfill area of the bridge abutment. It also played a supporting and stabilizing role for the soil of the bridge abutment's backfill area. It could prevent the soil from sliding along the support surface due to the removal of the second layer of support when the river channel was eroded. The second layer of support was set around the inspection well to provide excavation protection. The other two layers of support were arranged in a stepped pattern to avoid the occurrence of cracks at the end of the support steel sheet piles and their development into large cracks.

After the foundation support of the pit was completed, the first layer of support was set between the bridge abutment and the inspection well. The two layers of support were arranged in a stepped pattern. The first layer of support had a deeper burial depth and the top of the second layer of support was 2–3 meters above the ground. The specific layout is shown in **Figures 3** and **4**.

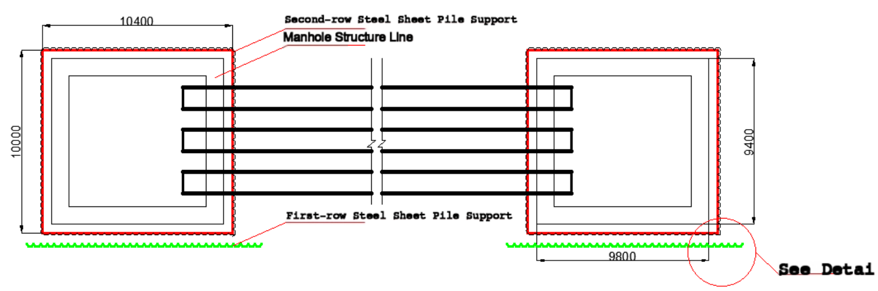

Figure 3. Plan view of the inspection well support at the bridge abutment of the bridge.

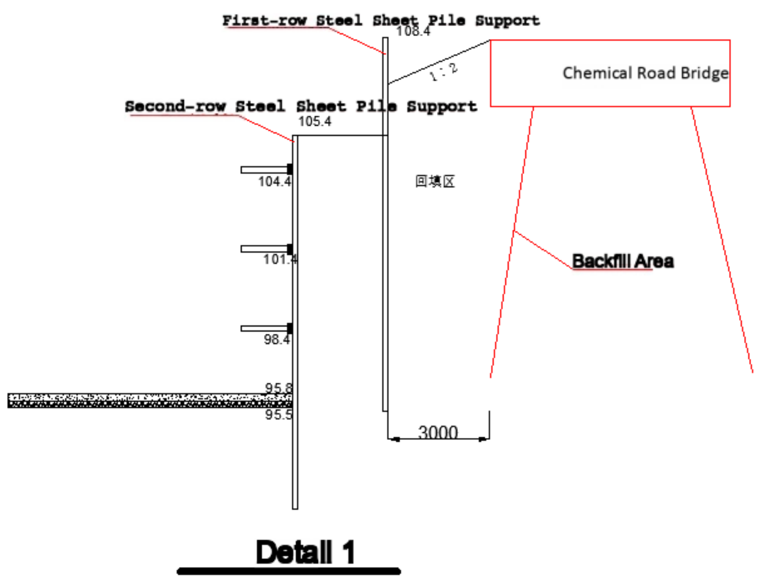

Figure 4. Sectional view of inspection well at the abutment of the bridge.

The retaining structure of the inspection well, which is the second supporting structure, uses 15-meter-long Larson steel plate IV-type steel sheet piles. The top elevation of the foundation pit is 107.45 meters. Before construction, the on-site soil and earthwork were excavated downward by 2 meters to level the site, reducing the site elevation to 105.45 meters. The perimeter of the foundation was excavated with two-step inclined slopes at 2 meters each, with the bottom elevation of the pit being 96.00 meters. Three sets of 45b steel beams were set at the top of the pit, with the first set of support located 1 meter below the top of the steel sheet piles, the second set 3 meters away from the first set, and the third set 4 meters away from the second set. The tie beams all use double-sliced 45b steel beams, and the corner braces are also double-sliced 45b steel beams, forming a 45° angle with the tie beams (**Figures 5** and **6**).

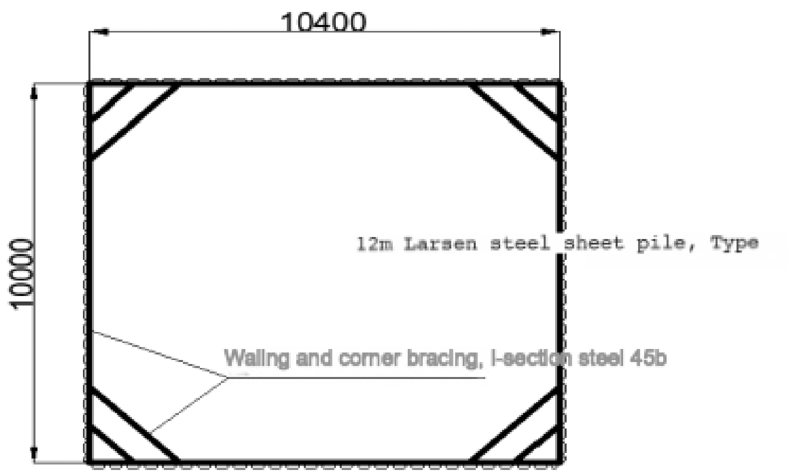

Figure 5. Plan view of inspection well support structure.

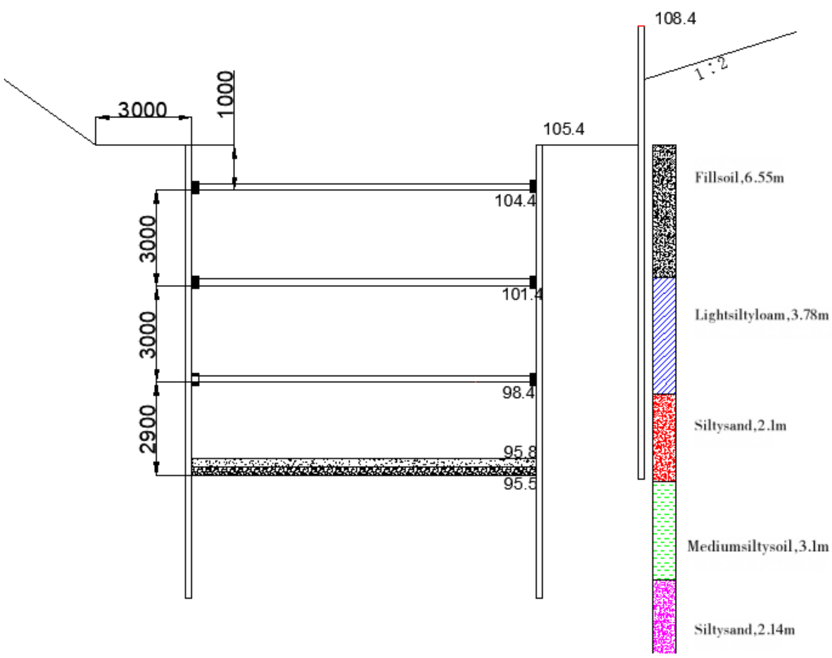

Figure 6. Geological section diagram for inspection and support at abutment area.

5.1. Layout of settlement observation points

After the completion of the two rows of foundation pit supports, settlement monitoring points were installed. Settlement observation points for the bridge were arranged at the pedestrian railing on the north side of the bridge. Observation points for the original soil of the foundation pit were established at locations with exposed large tree roots in the undisturbed green area and at the existing brick-lined inspection well wall within the exposed soil area of the foundation pit. In addition, settlement observation points were arranged for temporary and permanent support quality inspection to monitor soil settlement variations throughout the construction process.

6. Foundation pit construction

6.1. Construction of inspection well dewatering

Based on the depth of the working well in this project and the groundwater level elevation (below the ground surface by 4.42–8.51 meters), the main water affecting the foundation pit is groundwater. Dewatering started 7 days before the foundation pit excavation. The drainage in the foundation pit uses a combination of light well-point dewatering and open drainage. Before the foundation pit is excavated to the design elevation, the water level in the foundation pit should be lowered to no less than 50 cm below the bottom of the pit to reduce the moisture content of the foundation pit soil, facilitate the excavation of the foundation pit and subsequent construction operations, and ensure the stability of the soil in the pit. At the same time, monitoring should be done to minimize the settlement of the surface and the surrounding environment caused by dewatering.

6.1.1. Calculation of foundation pit water inflow

Based on the design data in the drawings and the groundwater level conditions in the geological investigation report, the water inflow will be calculated using a groundwater well. The calculation formula is as follows:

$$Q = \pi k \frac{\left(2H_0 - s_o\right)s_o}{\ln\left(1 + \frac{R}{r_0}\right)}$$

In the formula, Q : the water inflow volume of the foundation pit (m^3/d);

k : the permeability coefficient (m/d), according to the survey report, based on relevant standards and regional construction experience, the permeability coefficient of the sandy silt layer ③ is 1 m/d;

H 0: the thickness of the aquifer (m), take 20 m;

s 0: the water level drop of the foundation pit (m), take 2.3 m;

R : the precipitation influence radius (m); R = 2 s 0; $\sqrt{K^H}$ =20.6m

r_0 : the equivalent radius of the foundation pit (m); The ratio can be expressed as $r_0 = \sqrt{A/\pi}$ =6.55, where A is the area enclosed by the connection line of the precipitation well group.

It is calculated that the water inflow volume Q = 191.5 m^3/d;

The water volume of a single well q = $120\pi rl\sqrt[3]{k}$;

Q: the allowable water discharge capacity of a single well, m^3/d;

K: the permeability coefficient (m/d); take 1 m/d

I: the working length of the filter pipe; take 1.5 m

R: the radius of the filter device's outer edge (m); take 0.25 m

$q = 120 * 3.14 * 0.25 * 1.5 * \sqrt[3]{1} = 141.3\ m^3/d$

The calculation formula for the number of precipitation wells

N = 1.2Q/q = 1.2 * 191 / 141.3 = 2 units. Considering that the inspection well is close to the river and the surrounding area is a sculpture park green irrigation area, the water volume may temporarily increase, so 4 well points are used for precipitation.

6.1.2. Design of rainwater wells

Based on the analysis of various factors such as geological and hydrogeological data from exploration, the surrounding conditions of on-site construction, the situation of underground pipelines, and the influence of existing structures, it is determined that the groundwater in the area where this project is located is approximately 1.3 meters above the base plate. Before the earthwork excavation, a scheme of arranging ring-type light well points inside the foundation pit and one observation well outside the pit is proposed. The layout of the well points is shown in **Figure 7**.

The water extracted from the well points is collected through a main pipeline that connects all the well points and discharged to the sedimentation tank. The water in the sedimentation tank is tested for quality and can be used for construction after passing the test. The observation wells are used to promptly understand the groundwater situation and the implementation effect of the well point system. Based on the observed groundwater level, the pump type and pump capacity are adjusted in a timely manner to ensure a good well point effect. The water level observation wells are sealed after the foundation pit construction is completed.

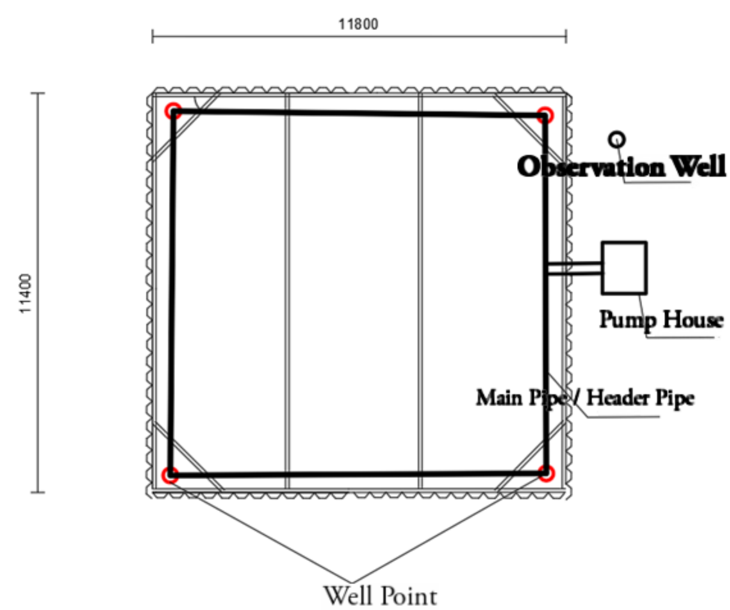

Figure 7. Layout plan of the dewatering system showing the well points arranged around the excavation perimeter, connected to the main/header pipe leading to the pump house, with an observation well provided for groundwater monitoring.

6.2. Excavation

On the side away from the bridge abutment backfill area, an excavator is used to cut and level the high slopes around the inspection well and to provide an operation platform for the long-arm excavator.

According to the requirements of the approval and review plan, when the long-arm excavator digs to a position 1m below the working platform and 50cm below the first horizontal tie beam, the excavation operation stops. The first tie beam and corner brace construction is carried out by the support operation team, and the excavation is continued until the design base level is approximately 20cm above the base of the inspection well.

At the bottom of the inspection well pit, a 400*400 (mm) water collection pit is excavated, avoiding the third tie beam, corner brace and inspection well wall position. The water collection pit is manually excavated to a depth of 75cm below the design base level, and a Φ300 reinforced concrete pipe is placed, with a height 30cm above the design base level. If there is water accumulation in the water collection pit, a self-suction pump is used to drain the water, and the water stability is measured using a measuring rope. The water stability in the water collection pit is basically stable, and the water stability height is basically below 75cm and not higher than the design base level. When the water level drops below 50cm, the drainage speed should be reduced to avoid excessive precipitation and affect the water and soil balance state of the surrounding bridge abutment backfill area.

After the manual excavation and leveling are completed, 15cm of graded crushed stone is laid on the base, and 15cm of C20 concrete slab is poured on the upper part, making the top of the pipe joint with the Φ300 reinforced concrete pipe at the same level. The pipe is filled with the same material as above.

7. Main structure construction

After the sealing of the pipe well is completed, the reinforced concrete works within 2.5m below the inspection well are carried out; when the reinforced concrete works of the inspection well below the base are completed and the strength is up to standard, the pipeline jacking construction across the river is carried out; after the pipeline jacking construction is completed, the layered pouring of the inspection well and the batch removal of the tie beams are carried out; when the part of the inspection well outside the base pit is constructed, the periphery of the well is layered backfilled and compacted layer by layer.

8. Pile extraction and grouting

When extracting the support steel sheet piles around the inspection well, grouting operations are carried out simultaneously. The specific construction is as follows:

For the insertion and extraction of the steel sheet piles in this project, the EP60 hydraulic pile driving machine is mainly used for the steel sheet piles. Due to the limitations of the mechanical extraction machine head, it is clamped at the top of the steel sheet pile, and the vibration is slowed down for 1–2 minutes to loosen the soil around the steel sheet pile. The grouting operation is carried out simultaneously. On the one hand, it strengthens the soil, and on the other hand, the slurry forms a liquid sliding membrane between the steel sheet pile and the soil, reducing the friction resistance of the soil on the steel sheet pile. Then, it is slowly lifted upwards. If there are difficulties in extracting the pile or abnormal situations occur, the extraction should be stopped immediately, and it is observed whether the operation arm of the extraction machine head is perpendicular to the steel sheet pile, whether there is deviation or angle due to human factors, and confirm that there is no error before vibrating for 1–2 minutes or slowly hammering down 0.5m before extracting again.

Before the steel sheet pile extraction construction, the grouting pipeline is buried. Along the circumference of the inspection well, 50cm away from the edge of the well wall, a ring-shaped grouting pipe is laid. The pipe spacing is 0.8m. On the side of the bridge abutment backfill area away from the inspection well, an additional grouting pipeline is set 0.8m outside the ring-shaped grouting pipe.

At the design position around the inspection well pit in the drawings, holes are drilled using a drilling machine or hand drill to a design depth, with a diameter of about 75mm. Then, a 50mm diameter grouting pipe is inserted into the hole. At the bottom of the pipe, a grouting hole is set, and a casing is provided outside the grouting pipe. A sand is filled between the grouting pipe and the casing. The gaps on the surface of the grouting platform are filled with 1:3 cement mortar or clay, and then the casing is pulled out.

According to the geological and hydrological report provided by the surveying unit, an appropriate grouting pressure is selected. In sandy soil, it should be 0.2MPa to 0.5MPa, and in cohesive soil, it should be 0.2MPa to 0.3MPa. For dense grouting, the slump of the cement mortar slurry should be 25mm to 75mm, and the grouting pressure should be 1.0MPa to 7.0MPa. Grouting reinforcement construction is carried out in combination with the geological conditions, settlement observation conditions and the extraction conditions of the steel sheet piles, and the pressure is adjusted slightly [3].

9. Conclusion

By analyzing each construction process such as foundation support, dewatering, excavation, settlement observation, and grouting reinforcement, as well as conducting research on the force balance of soil and water, two sets of support methods were adopted to ensure the traffic safety of the adjacent chemical road and bridge. During the excavation construction of the inspection well foundation project, through micro-dewatering + settlement observation + grouting reinforcement, the disturbance impact of the foundation excavation on the existing structures and the surrounding soil was reduced. While ensuring the normal traffic of the chemical road and the stability of the abutment backfill soil, the rapid construction of the pipeline across the Jialu River and the inspection well project was guaranteed. This promoted the successful completion of the post-disaster reconstruction project of the Jialu River, significantly saving the construction period and reducing the management cost. It has achieved remarkable economic benefits.

Disclosure statement

The author declares no conflict of interest.

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