Application of Digital Technology in Safety Evaluation of Dabeishan Aqueduct

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Abstract: A large number of aqueducts were built in China in the 1950s and 1980s, and there are still quite a few aqueducts still undertaking water delivery tasks. Evaluation of existing aqueducts is an important measure to ensure safe water delivery. In order to cope with problems such as the long construction period of the aqueduct and the lack of original design materials, this paper comprehensively uses digital technologies such as drone aerial photography, BIM, and three-dimensional laser scanning. Take Dabeishan Aqueduct for example, carrying out safety test and evaluation. The adopted methods has enriched the methods of safety evaluation of aqueducts and improved the quality of safety evaluation.

1. Introduction
Since the 1950s in China, a large number of irrigation water supply canals have been built for farmland irrigation, and a large number of structures have been used as aqueducts to transport water across rivers, valleys, depressions, and roads. Due to the long construction period and the low design standards at that time, most of these aqueducts have exceeded the design service life, and various degrees of aging, cracking, deformation and leakage have occurred during operation, which seriously affects the operational safety of the aqueduct. Therefore, it is necessary to conduct a comprehensive inspection and evaluation of the aging and diseased aqueduct structure to determine its safety status and provide a scientific basis for its scrapped reconstruction and danger elimination reinforcement.

According to "Guidelines for Safety Evaluation of Aqueducts" (T/CHES22-2018), "Guidelines for Safety Evaluation of Aqueducts in Zhejiang Irrigation Districts" (for trial implementation) and other relevant standards and regulations, and analysis of relevant engineering examples\textsuperscript{[1~3]}, the main content of aqueduct safety inspection There are appearance quality, concrete structure, deformation, etc. The detection methods mainly rely on conventional methods such as manual observation and measurement, and there are many problems such as low efficiency, poor safety, and high cost. Scholars have realized these problems and tried to use three-dimensional laser scanning technology for geometric shape and deformation detection in the safety inspection of aqueducts\textsuperscript{[4~5]}, but the automatic and information methods for safety inspection of aqueducts are still relatively simple. This article takes the Jiangshan Dabeishan Aqueduct as an engineering example, comprehensively applies BIM, 3D laser scanning, UAV and other information technology to conduct safety inspection and assessment of the aqueduct, and provides references for similar projects.
2. Project Overview
The Dabeishan Aqueduct of the West Main Canal was built in May 1973. The design flow rate of the aqueduct is 10.0 m$^3$/s, the total length is 636m, and there are 53 spans in total. The aqueduct body of Dabeishan aqueduct is a U-shaped steel wire mesh cement thin shell structure, and the supporting structure type is a bent structure. The tank body is a steel mesh cement U-shaped thin shell structure, the wall thickness of the tank is 3.5cm, the inner diameter is 1.4m, and the straight section is 0.8m high. The concrete bent frame maximum height is 15m and the concrete strength is 200#. The bent frame foundation adopts a double-column cup foundation with a length of 5m, a width of 2.2m, and a thickness of 1.0m.

Since its completion, the aqueduct has been operating effectively for more than 40 years. The daily maintenance of the aqueduct includes daily inspections within the protection scope of the aqueduct, inspections during the main flood season and drought-resistant irrigation periods, and daily maintenance work. However, after years of operation, various components have experienced different degrees of aging and damage, and the appearance quality is poor and there are safety hazards. Therefore, it is necessary to carry out safety evaluation of the aqueduct, and carry out safety evaluation of the aqueduct through current situation investigation, on-site inspection, and recheck calculation analysis.

3. Method and Methodology
According to engineering experience and evaluation standards, the items to be tested mainly include: appearance quality of aqueduct, displacement measurement, concrete strength, carbonization depth, thickness of steel protection layer, etc. The test items and methods are shown in the table 1.

| No. | Test items                        | Parts                                                                 | Detection method                                      |
|-----|-----------------------------------|-----------------------------------------------------------------------|-------------------------------------------------------|
| 1   | Appearance quality of aqueduct    | Entry and exit sections, entry and exit troughs, retaining walls,     | Combination of manual observation and drone aerial     |
|     |                                   | trough bodies, expansion joints, cross bars, bent frame columns, bent | photography                                           |
|     |                                   | frame connecting beams, etc.                                           |                                                      |
| 2   | Displacement measurement          | Mainly measure the tilt of the bent frame column and the displacement  | 3D laser scanning                                     |
|     |                                   | of the trough body                                                    |                                                      |
| 3   | Concrete strength                 | Bent column, bent frame connecting beam                               | Rebound method                                        |
| 4   | Carbonization depth               | Bent column, bent frame connecting beam                               | Phenolphthalein solution determination                |
| 5   | Reinforcement protection layer    | Bent column, bent frame connecting beam                               | Electromagnetic induction                             |
|     | thickness                         |                                                                       |                                                      |

In order to improve the quality of engineering safety evaluation, digital technology has been introduced in safety evaluation activities throughout the entire evaluation process. It mainly includes BIM, drone aerial photography, and laser scanning technology.

3.1 BIM method
Building Information Model (BIM) technology is a digital tool applied to engineering design and construction management. In the testing and evaluation of existing projects, BIM technology is mainly used to restore design results. The project was completed for about 40 years, and some drawings were missing. After using BIM technology to restore the design results, use the BIM results to discuss with the operation management unit to ensure the accuracy of the engineering and technical personnel's understanding of the design results. The typical three-dimensional design section of this project is
shown in Figure 1. Also in the test plan planning stage, the BIM model is used to display and communicate the test plan to improve communication efficiency.

3.2 Drone aerial photography
The aqueduct is built between mountains and is a high-rise structure. In the overall investigation phase of the project status, it is impossible to board the aqueduct section by section for investigation, so the drone technology was introduced to collect the project status and its surrounding environment. In view of the partial satisfaction of problems and defects, the project quality inspection is carried out in combination with intuitive and instrumental measurement, appearance quality description, and partial opening methods. From the macro to the mesoscopic, the appearance of the entire structure is investigated and recorded.

UAV aerial photography work is mainly based on the requirements of the technical design of the project to conduct a comprehensive investigation of the aqueduct, and combine videos and photos to sort out various safety hazards. During the flight aerial photography operation, the flight parallel to the aqueduct and data collection. During the flight operation, judge according to the images returned by the high-definition map at any time. After the hidden danger part is approached by the drone, seek a suitable angle, observe and record high-definition photos at close range, and record the hidden danger types, such as leakage, Leakage, displacement, etc., as well as spatial information such as the location of the photo taken. The typical captured images of drones are shown in Figure 2.

3.3 Laser scanning
Displacement measurement of high-rise structures is a difficult point in the implementation of this project. Remember that laser scanning technology measures and evaluates displacement. Use a three-
dimensional laser scanner for laser scanning measurement. The 3D laser scanning system is mainly composed of three parts: scanner, controller and power supply system, as shown in Figure 3.

The laser scanner itself mainly includes a laser ranging system and a laser scanning system. It also integrates CCD and the internal control and calibration system of the instrument. The instrument rotates quickly and orderly through two synchronous mirrors, sweeps the narrow laser pulse emitted by the laser pulse emitter across the measured area in turn, and measures the passage of each laser pulse from the surface of the measured object and back to the instrument. Time (or phase difference) to calculate the distance, while a built-in precision clock controls the encoder to simultaneously measure the horizontal scanning angle observation value $\alpha$ and the vertical scanning angle observation value $\theta$ of each laser pulse, so the three-dimensional coordinates of any measured cloud point $P$ as shown in Figure 4.

4. Test results

4.1. Appearance quality and defects
Observation and analysis the typical captured images of drones, the aqueduct has some defects. For example, leaking at 6th and 7th bent column as shown in Figure 5, displacement at 72th bent column.
as shown in Figure 6. As shown in Figure 7, the concrete of the 57th tank body falls off, and there is white grout on the surface. As shown in Figure 8, the 58th bent beams are severely exposed.

4.2. Compressive strength of concrete
The rebound method was used to randomly check the concrete compressive strength of 22 members of the bent columns and beams of the Dabeishan Aqueduct. The test results are shown in the Figure 9.

![Figure 5. Leaking at 6th and 7th bent column](image1)
![Figure 6. Displacement at 72th bent column](image2)
![Figure 7. The concrete of the tank body falls off, and there is white grout on the surface](image3)
![Figure 8. Bent beams are severely exposed](image4)

![Figure 9. Concrete strength test results](image5)

According to the requirements of the current "Design Code for Hydraulic Concrete Structures (SL191-2008)", the minimum strength level of hydraulic concrete in the open air environment should be C25.
From the results in Figure 9, it can be seen that of the 22 components inspected in the Dabeishan Aqueduct, 8 components have a concrete compressive strength value of less than 25MPa, but meet the design No. 200 (200 #Concrete can be converted into concrete with a strength grade of C18). The requirements of concrete; the remaining 14 components neither meet the requirements of concrete design number 200 nor meet the requirements of the current specifications.

The concrete compressive strength of the inspected components is 100% that does not meet the requirements of the current specifications, and 63.64% do not meet the design requirements, both of which are more than half.

At the same time, the test results mentioned in this program can be entered and viewed on the BIM model. Such as drone photo, test type at the point and test results, as shown in Figure 10.

4.3. Concrete carbonation depth

The influence of carbonation depth on steel corrosion is distinguished according to the ratio $K_c$ of the average value of the concrete carbonization depth in the measurement area to the average value of the measured protective layer thickness, and is evaluated according to Table 2.

| $K_c$       | No effect | Less effected | Effected | Greater effected | Protection layer failure |
|------------|-----------|---------------|----------|------------------|--------------------------|
| $<0.5$     |           |               |          |                  |                          |
| $[0.5,1)$  |           |               |          |                  |                          |
| $[1,1.5)$  |           |               |          |                  |                          |
| $[1.5,2.0)$|           |               |          |                  |                          |
| $\geq2.0$  |           |               |          |                  |                          |

This time, a total of 22 components of the bent columns and beams of the aqueduct were tested for the depth of concrete carbonization. The test results are shown in Figure 11. After analysis, it can be seen that the carbonization depth of the aqueduct has no effect on the corrosion of steel bars and has a small effect, accounting for 63.64% of the inspected components, and the influential and greater impact accounts for 22.73% of the number of inspected components. Therefore, the concrete carbonization depth of the inspected components has little effect on the components. Corrosion of steel bars has little effect.
4.4 Displacement measurement
Trimble TX8 three-dimensional laser scanner is used to perform laser scanning measurement on the aqueduct, and the three-dimensional point cloud data of the aqueduct is processed through software. The point cloud is cropped, and the crop is processed through operations such as rotation, measurement, and plotting, and then the area, length, midpoint, midline and other data information of the fitting area can be obtained.

Take 49# bent column for example, the displacement map is shown in Figure 12. The X axis direction (water flow direction) offset is 3.0cm, the Y axis direction (perpendicular to water flow direction) offset is 3.6cm, the overall horizontal offset is 4.7cm, and the overall tilt is 0.047/10.4=0.0045.

In the interval between 49 and 50 columns, in the direction perpendicular to the flow of water, the upstream column is offset by 1.6 cm, and the downstream column is offset by -1.3 cm. At the bottom of the aqueduct body, the support length of the bent column has also shifted. The distance between the 49th column support and the bent column support is 11cm and 12cm respectively in the upstream and downstream, and the 50th column support is at the upstream and downstream from the bent column support. They are 15cm and 5cm respectively as shown in Figure 13.

Refer to the "Code for Design of Building Foundation" (GB50007-2011) on the overall inclination of multi-storey and high-rise buildings, the allowable value of the inclination of the bent frame may be 0.004; refer to the "Standard for Dangerous Building Appraisal" (JGJ125-2016) for multi-storey buildings According to the regulation of overall tilt, the tilt limit of the bent frame without settlement cracks may be 20%. The inclination of the bent frame column of the aqueduct sampling inspection is greater than the allowable value specified in the "Code for Design of Building Foundation" (GB50007-2011), but does not exceed the limit specified in the " Standard for Dangerous Building Appraisal " (JGJ125-2016).
Figure 13. Tilting situation of No. 49 bent frame column

5. Conclusions
In this paper, the safety assessment of the Dabeishan Aqueduct is carried out by comprehensively using digital means. UAV technology and BIM technology are used to restore the current status and completion status of the aqueduct. On the basis of the digital aqueduct, the engineers carried out work planning and arrangements. And innovatively adopts three-dimensional scanning technology to solve the problem of displacement monitoring of high-rise structures.

Combined with the actual situation of on-site safety inspection, most of the tank body mortar has different degrees of shedding and the steel mesh is exposed; some tank body joints stop water aging and serious leakage; some tank bodies have fine penetration channels; some bent columns and beams Mortar peeling, severely exposed stones, bare steel bars, and cracks; more than half of the concrete compressive strength does not meet the requirements of the design and "Code for Design of Hydraulic Concrete Structures" SL191-2008; more than half of the thickness of the reinforced protective layer does not meet the current specifications and design requirements The requirements have a greater impact on the durability of the structure; the bent columns of the random inspection have a certain degree of inclination, and the trough body has a certain degree of lateral and longitudinal deviation. The quality of the project was assessed as Grade C.

Based on previous engineering experience, it is recommended that the aqueduct replace the water-stop rubber at the joint of the tank body. It is recommended to deal with the cracks of the bent column. And it is recommended to repair the corroded and damaged areas of all components of the aqueduct.

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