High arch dam cable transport efficiency and safety analysis based on real-time monitoring technology

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Abstract. Arch dams are often built in deep and narrow canyons. The way of concrete transported is limited by the complex and limited space. Cable is the most common and main concrete vertical transportation equipment for arch dam. The operating efficiency of the cable is of great significance to the construction progress, construction period and cost control of the arch dam and the guarantee of construction quality. For the traditional management of concrete transportation process is often based on manual methods, lacking the detailed management of the key information of the cable operation process, which leads to the problem of the lack of effective control over the real-time operation efficiency of the cable and the safety status of the cable group, so a real-time monitoring and analysis method based on the Internet of Things is proposed to analyze the efficiency of each link of the cable operation, and to judge the safety distance of the cable group in real time. The analysis of engineering examples shows that this method can effectively analyze the operating efficiency of the cable and master the safe running distance of the cable group, which provides an effective technical management method for ensuring the safe and efficient operation of the cable group.

1. Introduction

High arch dam construction technology requirements are high. Most of those dams are located in the deep and narrow canyon area. The terrain and geological conditions of the dam sites is complex, and the construction site is narrow. The construction of the project is restricted by topography, geology, hydrology and meteorology [1]. The cable is the main vertical transportation equipment in the arch dam concrete construction. It can guarantee the dam to be completed on time and create benefits by making the cable safe and efficient to meet the needs of concrete pouring strength. Traditional measures to improve the efficiency of cables are usually to analyze the factors affecting the efficiency of the cable to divide the concrete pouring process into several links, and develop measures from technical support and management in the perspective of qualitative. Due to the lack of real-time operational data of the cable, it lacks of quantitative and reasonable improvement targets based on the actual operation of the cable [2]. For the problem of the management of traditional concrete transportation processes often based on manual methods, and lacking fine management of key information in the operation process of cable s, Zhong Guiliang et al. proposed the intelligent control technology of high arch dam concrete transportation process, designed the intelligent control structure of transportation process, and verified...
the feasibility of intelligent control technology \[3\]. In addition, Chen Wantao et al. proposed a transportation monitoring method in concrete construction, and designed the vertical transportation monitoring method in monitoring hardware and analysis method \[4, 5\]. With the fine management of engineering construction, the existing methods don’t meet the needs of cable operation management. Therefore, this paper proposes a cable group operation efficiency and safety analysis method based on real-time monitoring to analyze the efficiency of all aspects of cable operation and judge the safety distance of the cable group in real-time at the same time.

2. Research Framework

The research framework of this paper includes two parts: the operating efficiency of the cable based on real-time and safety analysis method and engineering application monitoring, as shown in Figure 1. The operating efficiency and safety analysis method of the cable based on real-time monitoring includes two parts: data collection and mathematical model. The data acquisition as the input information is the time-space coordinates of the cable operation through real-time monitoring technology; the mathematical model includes two parts: the cable running state transfer equation and the safety decision function. Finally, the operating efficiency and safety analysis method based on real-time monitoring is applied to specific projects, and the parameters such as the operating efficiency of each link of the cable, the real-time distances of the cable group and the real-time running speed are analyzed to provide data support for the safe and efficient operation of the cable group.

3. The analysis method of cable operating efficiency and safety based on real-time monitoring

3.1 Mathematical model

In order to analyze the operation efficiency and safety of all aspects of the cable group, the following mathematical model is established:

the cable running state transfer equation: \[\Delta T = t_2(p_i(x,y,z)) - t_1(p_i(x,y,z))\]

the safety decision function: \[D_{ij} = \min(\text{Dis}(p_i(x,y,z), p_j(x,y,z)))\]

\[v_i = \frac{\text{Dis}(p_i, p_{i+\Delta t})}{\Delta t}\]

Where \(\Delta T\)-the time cable using in certain part; \(t_1\)-the start time of a certain part of the cable operation; \(t_2\)-the end time of the certain part of the cable operation; \(p_i(x,y,z)\)-the characteristic position at the start time of the certain part of the cable operation; \(p_j(x,y,z)\)-the characteristic position at the end time of the certain part of the cable operation; \(D_{ij}\)-the minimum distance of the cables at a certain time, \(\text{Dis}\)-calculate the spatial projection distance of the cable group \((i,j)\)(\(i\neq j\)); \(v_i\)-the average running speed of a cable at a certain time, divided into horizontal rate and vertical rate; \(\Delta t\)-the time span of average speed, such as 5s; \(p_i\)-the spatial position of a cable at time \(t\); \(p_{i+\Delta t}\)-the spatial position of the cable at time \(t+\Delta t\).
3.2 Analysis Method
In order to accurately analyze the concrete transportation process by the cable, the single whole operation process of the cable is divided into the following links according to the characteristic position.

The loading stage refers to the length of time during which the cable arrives at the feeding platform and hangs tank to leave the feeding platform during the single concrete transportation cycle. The lifting stage refers to the length of time during which the cable transports the concrete from the hanging tank away from the feeding platform to a few meters above the upper surface of the warehouse (20m set in this research). The alignment phase refers to the length of time during which the cable transports from the upper part of the warehouse to the upper position of the discharge of the surface (5m set in this research) during the single transportation of concrete. The unloading stage refers to the length of time during which the cable arrivals at the unloading position and loads the concrete completely to leave. The return phase refers to the length of time that the cable leaves the warehouse surface and return to the feeding platform.

In the analysis of the operation safety of the cable group, the distance and running rate between the cable groups are calculated in real time, and compared with the minimum safety distance $D_t$ and the maximum operating speed $V$. And request:

$$D_{ij} > D, \quad v_t < V$$

3.3 Real-time monitoring technology based on Internet of Things
Satellite positioning technology has been fully utilized in water resources and hydropower engineering [6]. Using satellite positioning technology to monitor the operation status of construction machinery all-weather provides a powerful measure to improve the construction level. The cable operation monitoring technology based on real-time monitoring is shown in Figure 2. The positioning accuracy of the cable is improved by constructing a positioning differential base station; the integrated object monitoring terminal is installed at the hook beam of the cable to monitor the running state of the cable in real time, including the three-dimensional coordinates and operating speed of the cable hook; at the same time, the monitored data is transmitted to the server for storage and analysis via the communication base station.

Figure 2. The cable operation monitoring technology based on real-time monitoring

4. Case Study

4.1 Project Overview
The A hydropower project is located in the lower reaches of the Jinsha River. The barrage is a concrete double curvature arch dam. The dam crest elevation is 834m, the maximum dam height is 289m, the arch crown dam thickness is 14.00m, the arch dam bottom thickness is 63.50m, and the dam concrete construction volume is 803 million m$^3$. The vertical transportation of dam concrete is carried out by cable.
4.2 Cable operation process monitoring
By installing an integrated IoT terminal at each hook beam of the cable, it is guaranteed to monitor the cable group in real time and all weather, as shown in Figure 3.

![Figure 3. Diagram of cable maintenance equipment maintenance and operation](image)

4.3 All links efficiency analysis of cable operation

4.3.1 All links efficiency analysis of cable operation
In order to improve the pertinence of the analysis of the operation of the cable, the pouring process of a whiteboard warehouse at the left bank in the middle section of the arch dam was selected as the research object. During the pouring period, a total of 6 cables were put into use, and the operating efficiency of each cable is shown in Table 1.

| Cable | Loading (unit: minute) | Lifting | Alignment | Unloading | Return | Single cycle (unit: minute) |
|-------|------------------------|---------|-----------|-----------|--------|-----------------------------|
| 1#    | 2.31                   | 1.70    | 0.62      | 0.66      | 1.92   | 7.22                        |
| 2#    | 2.44                   | 1.70    | 0.74      | 0.79      | 1.69   | 7.35                        |
| 3#    | 2.45                   | 1.92    | 1.29      | 0.90      | 1.99   | 8.54                        |
| 4#    | 2.79                   | 1.52    | 0.57      | 0.63      | 1.59   | 7.10                        |
| 5#    | 2.85                   | 1.71    | 0.6       | 0.65      | 1.79   | 7.59                        |
| 6#    | 2.94                   | 1.79    | 0.78      | 0.80      | 1.80   | 8.12                        |

Table 1. The operating efficiency of each cable

The operating efficiency of 4# cable is the highest in terms of single cycle time. From the monitoring data of the warehouse, the single cycle time of each cable is slightly different. The highest is 8.54 minutes/can, and the lowest is 7.10 minutes/can. In the case where the transportation distance is basically the same, it can be seen that the operating level (proficiency, operating habit) of the cable operator has a significant impact on the operating efficiency, such as only in the lifting and return phase process 3# is more than 0.8 minutes longer than 4#; The 3# and 6# cables near the downstream side are slightly less efficient; the average alignment and unloading time of the 3# cable is longer, which is related to the construction organization level of the warehouse surface. It is necessary to strengthen the information communication between the warehouse command and the cable operator. The curve of the efficiency of each phase of 1# cable is shown in Figure 4.
4.3.2 Concrete placement analysis

The placement during this warehouse pouring period is shown in Figure 5. Due to the suspend production of concrete mixing storey, the pouring efficiency of the entire warehouse surface is greatly affected from 7:00 am to 8:00 am and 18:00 to 19:00 pm. Meanwhile, from 1 am to 3 am, from 12:00 to 14:00 pm, it is the two time periods that the cable is in low efficiency. It is recommended to strengthen the production schedule during this time period. Through comparison and analysis of each period, it can be seen that the single cycle time-consuming peak is basically consistent with the loading time and the peak shape of the unloading, indicating that most of the time-consuming cycles are basically restricted by the loading time and unloading time; and the management of these two link should be strengthened.

4.4 Cable group safety operation analysis

By analyzing the real-time monitoring space data of the cable s, the real-time plane distance and the running average speed among the analysis cable group can be calculated in real time. Table 2 shows the spatial position coordinates of each cable at a certain time (10:39:36); Then, the actual plane distance D of the cable group at that time can be calculated.

| cable | x(m)     | y(m)     | z(m)     |
|-------|----------|----------|----------|
| 1#    | 4150.987 | 5694.657 | 770.989  |
| 2#    | 4170.905 | 5720.782 | 838.189  |
| 3#    | 4089.346 | 5719.823 | 838.315  |
Where $D_{ij}$ is the distance between cable $i$ and $j$. Then $D_t = \min(D) = 7.58$ m. Compared with the minimum safety distance set as 8 m of the A engineering cable group, the running distance of the 1# and 5# cable is less than the minimum safety distance, therefore there is safe risk, and the construction management personnel should be reminded to adjust.

Meanwhile the running speed of the cable can be analyzed in real time, and the running data during a certain period of time of the 2# cable is selected. The analysis results are shown in Table 3 (negative value indicates that the cable is pulling up).

### Table 3. 2# cable running data during a certain period of time

| cable | x(m)   | y(m)   | z(m)   | time          | horizontal rate ($\text{ms}^{-1}$) | vertical rate ($\text{ms}^{-1}$) |
|-------|--------|--------|--------|---------------|-----------------------------------|-------------------------------|
| 2#    | 4267.997 | 5742.396 | 818.41 | 10:39:15      | 2.86                              | -3.41                         |
| 2#    | 4272.009 | 5743.403 | 815.261| 10:39:14      | 2.23                              | -3.41                         |
| 2#    | 4275.255 | 5744.246 | 811.442| 10:39:13      | 1.73                              | -3.35                         |
| 2#    | 4278.035 | 5745.000 | 807.632| 10:39:12      | 1.24                              | -3.35                         |
| 2#    | 4280.287 | 5745.59  | 804.350| 10:39:11      | /                                 | /                             |
| 2#    | 4281.831 | 5746.005 | 801.364| 10:39:10      | /                                 | /                             |
| 2#    | 4282.799 | 5746.270 | 798.196| 10:39:09      | /                                 | /                             |
| 2#    | 4283.630 | 5746.445 | 794.679| 10:39:08      | /                                 | /                             |
| 2#    | 4284.056 | 5746.499 | 790.897| 10:39:07      | /                                 | /                             |

According to the limit of the traversing speed For A project of the trolley 7.5 m/s and the raising / falling of the empty / full load 3.5 m/s, the horizontal and vertical speed of the 2# cable are less than the speed limit, which meets the requirements of safe operation.

### 5. Conclusion

Based on the integrated satellite positioning and other IoT technologies, this paper proposes a high-arch dam cable operating efficiency and safety analysis method based on real-time monitoring. By analyzing the indicators of the efficiency of each link $\Delta T$, the minimum distance of the cable group $D_t$, the operating speed $v_t$, it is possible comprehensively to analyze the operation of the cable, find the weak link of efficiency management, and prompt the operation safety risk. The feasibility of the operation efficiency and safety analysis method of high arch dam based on real-time monitoring is verified by engineering case. This method may judge the efficiency of each link of the cable and the running distance among the cable group in real time, which enriches the operation efficiency and safety analysis method of the cable group and provides a scientific technical management means for engineering construction.

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