Design and Implementation of Realtime Scour Monitoring of Hangzhou Bay Sea-Crossing Bridge Pier Based on Dual-Axis Scanning Sonar

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Abstract. This paper introduces the design and implementation of the realtime scour monitoring system for piers of Hangzhou Bay Sea-Crossing Bridge, including the construction of the monitoring system for the scour of the piers and the key technologies of the monitoring system. Through integration of dual axis scanning sonar technology and monitoring software, real-time seabed topography observation, data processing, analysis and data release based on the Internet is realized, qualitative, quantitative and locational decision support for management departments is provided.

1. Introduction
Scour surrounding bridge pier is one of the main causes of bridge damage. Scour monitoring of seabed around the pier can provide calculation parameters and result verification for further research revealing the evolution law of pier scour by means of mathematical model and physical model. Hangzhou Bay sea-crossing bridge is located in the southeast coastal estuary, the seabed sediment erosion and deposition is complex and variable. Previous study shows that most of the piers of the bridge are partially scoured from north to south, and the impact of local scour on the safety of piers has attracted the attention of relevant management departments [1-2].

However, most of the existing scour monitoring techniques can only be carried out on a regular temporal basis, it can not reflect scour changes in time. Or installing FBG sensor in some selected location to obtain the terrain change data of designated points, this way can not fully represent scour in the area around the pier. Dual-Axis Scanning Sonar System (DAS System for short) is an acoustic measurement equipment specially used for scour monitoring [3]. Through mechanical rotating device, seabed terrain around the transducer can be swept surveyed, and the data can be sent to software system in real time, real-time scour condition around the pier can be accurately tracked by cost effective means, and long-term monitoring of scour and sediment transport is realized.

2. System architecture
Streamline of realtime scour monitoring system for piers is as shown in Fig 1, firstly, multibeam echosounder system is used to measure underwater terrain background of the pier area in the scale of 1:1000. Secondly, DAS equipment and its accessory equipment are deployed, of these equipment, real-time attitude compensation of the sonar sensor is provided by the dual-axis inclinometer, and real-time sound velocity correction of the measured water depth data is provided by the sonar. After output
data of the above equipment is transferred from the serial communication to the network, it is transmitted to the scour monitoring software system remotely by 4G DTU for preprocessing, analysis and calculation, and the analysis results are published through the Internet.

3. Deployment of equipment

3.1. Equipment installation

In order to obtain typical scour of the bridge, the target monitoring piers are determined according to the underwater topographic survey, the design data of piers and the previous scour research. Because bridge pier itself blocks part of DAS sonar’s acoustic signal, a set of DAS sonar equipment is installed at the upstream and downstream of the selected monitoring bridge pier respectively, so as to achieve full coverage monitoring of the bridge pier seabed as shown in Fig 2. According to the characteristics of bridge pier’s cylindrical structure, the equipment is installed in form of hoop. Before the equipment is deployed, a special support bracket is designed to fix the DAS and the dual axis inclinometer together, indoor test is carried out to obtain the attitude difference between them. During the installation, it is necessary to firmly fix the mechanical support through welding, hoop, cable and other methods, in order to ensure that the transducer can be fixed in the whole survey, and can withstand the challenges of severe environment such as strong typhoon and storm surge, and always collect data at the same position and attitude to ensure the consistency of data. During the installation of the underwater equipment, the attitude data of the dual axis inclinometer is read in real time, and the attitude of the installed DAS is adjusted to ensure that the installed DAS is horizontal[4].

3.2. Equipment calibration

After installation of the DAS system, geographical coordinate of the center of DAS transducer is accurately obtained by total station and steel ruler according to known control points. Attitude of
transducer is an important parameter to transform the data in local transducer coordinate frame into geographic coordinate frame. Based on the data of multibeam echosounder background survey, the attitude correction parameters in three directions (Heading, Pitch, Roll) are calculated by least square method to achieve accurate attitude correction.

3.3. Data collect&transmission
Before data acquisition, firstly, according to the installation position of the equipment and its relative relationship with, water depth, etc., parameters such as horizontal opening angle, vertical opening angle, scanning angle interval, measurement range, display mode, is tuned finely to obtain reasonable and distinct seabed terrain data.

A robust power supply and data transmission scheme is designed to ensure uninterrupted data acquisition and transmission during the long-term unattended survey. In terms of power supply, the bridge's municipal power supply is used as main power supply. At the same time, solar panel power supply is used as the standby power supply. In the aspect of data transmission, due to the slow scanning speed of DAS system and the small amount of data generated per second, the upstream bandwidth of 4G network can fully meet the data communication bandwidth requirements of DAS system, so stable and reliable data transmission with low cost and long distance is realized through 4G network technology.

4. Realtime scour monitoring software system
A realtime scour monitoring software system base on Brower-Server architecture is developed (as shown in Fig 3), which receives real-time monitoring data sent remotely, and automatically performs data preprocessing, analysis and calculation. Based on WebGL technology, combined with LOD (Level of Detail) display, data slicing and network service strategy, the 3D visualization display of point cloud and digital terrain model is realized on browser client. Analysis and calculation results can be obtained by the management department conveniently through internet browser, which provides important support for maintenance of the bridge.

Figure 3. Realtime Scour Monitoring Software System Developed Based On DAS System
According to hierarchical architecture design, supported by the industrial technology specifications and safety and security system, the system is divided into four layers, which are support layer, data layer, function integration layer and business application layer.
(1) Support layer: provide software environment support for software operation, including wireless network, network environment of external network, hardware environment of server and network equipment, software support environment composed of operating system and database system.

(2) Data layer: using the combination of discrete file storage and relational database storage to organize and manage the real-time monitoring data and business operation process data.

(3) Basic function layer: provide the functional details required for business operation, including data preprocessing functions such as sound velocity correction, coordinate projection conversion, hierarchical scheduling mechanism, point cloud LOD processing, terrain halo processing, temporal processing, etc..

(4) Business application layer: for business application, it provides the background data preprocessor of C/S mode and the scour monitoring system of B/S mode.

The real-time monitoring business execution process can be streamlined as shown in Fig 4.

**Figure 4.** Data Streamline in Scour Monitoring Software System

**Data Preprocess.** Raw data of DAS system needs to be preprocessed by sound velocity correction, coordinate transformation and DEM construction to obtain the basic data with high precision and geographical registration suitable for further data analysis [5].

Due to DAS system is based on the acoustic signal, its raw data needs to be corrected according to the real-time sound velocity profile transmitted back to eliminate the sound velocity error. Considering the bending of sound ray caused by the refraction of acoustic signals when they pass through different sound velocity layers, layered sound velocity correction method based Snell's law formula is adopted to meet the accuracy requirement of scour monitoring as shown in Fig 5.

**Figure 5.** Layered Fine Sound Velocity Correction Base on Snell Law Formula

Coordinate transformation. In order to improve the applicability of the data, it is necessary to convert each sampling point from polar coordinate system centered at transducer to the geographical coordinate, combined with the installation position and attitude calibration parameters of the equipment as shown in Fig 6. Assuming that the geographical coordinate of equipment installation is XYZ, and the attitude parameter of transducer obtained through calibration is HPR, the coordinate can be transformed into absolute geographical coordinate according to the affine transformation. After the transformation, the data of two DAS systems on the same pier, and the data of different phases are unified in the same reference system, which is the spatial basis for comparative analysis.
Digital Elevation Model (DEM) building. After geographical registration, complete point cloud data of seabed topography is obtained. In order to facilitate the calculation of scour distribution and scour volume, DEM is built, normalized grid data is obtained, and discrete digital representation of topography is realized [6] as shown in Fig 7. First, Triangulated irregular network (TIN) is established, then DEM is built by bilinear interpolation on the basis of TIN. In order to accurately depict the terrain around the pier, the system uses a spatial resolution of 0.25m.

Data Organization and Management. Basic geographic information data, pier scour monitoring data, hydrological observation data and business process data are organized and managed according to time in the form of file storage and relational database storage. On the one hand, it stores and indexes the text format raw data, binary format preprocessing data results, tidal current, tide level weather and other data of real-time monitoring, on the other hand, it adopts the form of relational database to ensure the data organization logic is clear, and the compatibility of the later multiple pier real-time monitoring, data mining and analysis and other business expansion is ensured at the system design level.

Data Analysis. After preprocessing, any two DEM data can be analyzed and calculated to obtain scour distribution map and scour volume. In addition, time series animation is generated based on continuous DEM data, which can vividly show the evolution of terrain around the pier along time. Users can also get selected DEM data’s profile change map through man-machine interactive as shown in Fig 8. In this way, qualitative, quantitative and locational analysis of the scour condition around the pier is provided to manager department.
5. Conclusion
The scour monitoring system based on DAS system is successfully applied in Hangzhou bay sea-crossing bridge, especially the unintended operation mode, accurate calculation mode and vivid data display are proved to be a great assistance for the sea-crossing bridge’s maintenance. Further study to integrate more elements, including mathematical model, physical model, etc., is continuing in order to provide more practical and more elaborate decision support for the bridge’s maintenance.

6. References
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Acknowledgments
This work was supported by Fundamental Research Fund Project for Central Public Welfare Research Institutes “Research on real-time monitoring technology of local scour based on dual axis scanning sonar” (No. TKS20200302), “The underwater monitoring system for the foundation leveling of the subsea tunnel in Shenzhen-Zhongshan Bridge”(No. TKS180212) and project of National Key R&D Program of China “Intelligent monitoring, early warning and information service of inland waterway facilities” (No. 2018 YFB 1600400).