CONSTRUCTION MANAGEMENT SYSTEM FOR ROCK-FILLED CONCRETE DAM

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ABSTRACT

Rock-Filled Concrete (RFC) dam is a new type of concrete dam based on the technology of self-compacting concrete (SCC). In China, there have been more than 100 RFC dams completed or under construction till now. To improve the quality control of construction in RFC dam site, a construction information management system for RFC dams (CIM4R) was developed. The function of this infor-mation system include construction quality control and management of personnel, construction ma-terial, and machinery. This software system has two user interfaces. The first is WEB based user interface for PCs, which takes control of the basic project information, the user authorization and data statistical analysis. The second is WeChat (a Chinese-based instant communication software, similar to Facebook) based user interface for mobile phones, which is assigned to users for the work stage control, information collection, message notification, and on-site record. Several modules are increas-ingly developed in this management system, such as inventory and inspection of raw materials, pro-duction control in the mixing plant, testing concrete specimens, quality inspection of unit engineering, management of machine and equipment and so on. AliCloud (a cloud platform run by Alibaba Group) provides a platform for the engineering data storage.

1. INTRODUCTION

1.1 Rock-filled concrete dam

Rock-filled concrete (RFC) was proposed in 2003 as a new type of concrete technology, which adopts self-compacting concrete (SCC) to fill the voids of a rock assembly (Jin et al. 2003, Jin et al. 2005). To construct RFC, an assembly of rock, whose grain size is required as larger than 300 mm, is stacked to a certain thickness, usually 1.5 - 2.0 m, maintaining an open porosity. In RFC terminol-ogy, the assembly of rocks, which are transported and placed by machinery or other means, is called "rockfill". In a recently completed RFC dam, the rockfill was placed up to 3.0 m thick. A high quality SCC, termed High Performance Self-Compacting Concrete (HSCC), is then poured onto the surface of the rockfill.

As shown in Figure 1, The RFC construction process includes preliminary-process, main process and post-process. Pre-process will be working face preparation and formwork installation. The main process can be divided into two main sub-processes: (1) transportation and placing of rocks and (2) production, transportation and placing of HSCC. Curing and protection will be post-process. In the placement of RFC, no vibration or roller compacting needs.

Until the end of 2019, 66 newly built RFC dam have been constructed. 42 newly built RFC dams are under construction and 56 RFC dams are under design and to be built in China. Some RFC dams under construction are listed in Table 1.

RFC has been shown to be able to achieve the goal of simplifying dam construction processes and reduce the consumption of cement, and the use of labor and machinery. Based on extensive en-gineering practice in China, building an RFC dam can reduce construction cost by 10% to 30% when compared to a CVC or RCC under the same condition. Such notable reduction in construction cost is primarily because the RFC technology substantially reduces cement consumption, frees temperature control measures as well as labors over entire construction phases (Huang et al. 2008). In the interna-tional commission on large dams (ICOLD), RFC is evaluated as an environment-friendly damming method, which has the characteristics of rapid construction, simple process, high safety besides the low cost (Jin et al. 2018a). After more than 15 years, RFC damming technology can innovatively form a set of streamlined construction process with supporting theory, structure and machinery (An et al. 2014). However, modern management based on information, computer and network technology is urgently needed for RFC projects (small- or medium-sized hydraulic projects) to improve the construction quality control. Digital engineering is an advocate to implement real-time, online and intel-ligent engineering data for sharing, analysis, and decision-making.

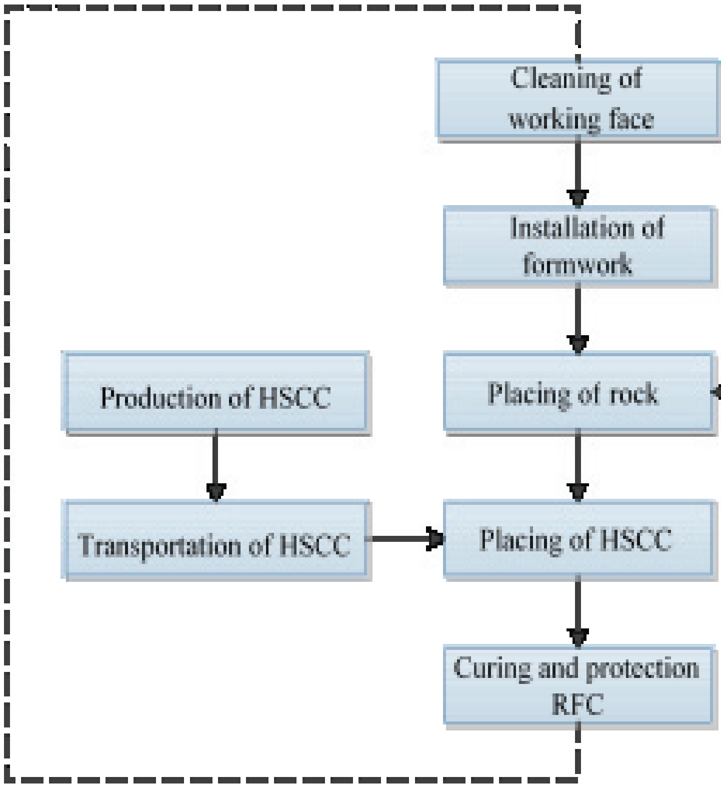


Figure 1 : Construction process of RFC

1.2 Management system of the construction information model

Building Information Modeling (BIM) is the most popular topic in the architecture, engineering, and construction industry in recent years (Azhar 2011). An accurate virtual model of a building is digitally constructed by BIM, focusing on the design stage. BIM has powerful functions, and mean-while it need a powerful development platform and high implementation cost (Czmoch and Pękala 2014). On the other hand, BIM generates a lot of information, which will turn into information gar-bage if there is no supporting application at the later stage. As for the small- and medium-sized hy-draulic projects, information input needs to improve the gold-content of information due to the short-age of IT technicians who is able to analysis the information by big data technology. The construction information collection and analysis are becoming the bottleneck of high level construction quality control for RFC dam projects (Jin et al. 2018b). If there are no adequate unified standards and plat-forms, the surveillance management system at all levels work as information isolated islands and are incompatible with each other. The basic necessary information are studied based upon the analysis of construction quality control data in different stages for RFC dams.

The conventional methods for monitoring construction quality, including supervision engineer patrol and test blocks detection, are low-efficiency and primarily affected by human labor (Zhong et al. 2018). Some completed information systems for dams, e.g. the intelligent temperature control system for Xiluodu dam cooling (Li and Lin 2014), the unmanned rolling compaction system for embankment dams (Zhang et al. 2019), and GIS digital construction management system for Dagang-shan hydropower station (Yu et al. 2013), mainly concentrated on auxiliary engineering construction. Or the information system is too complicated and expensive for owners. In this paper, a construction information management system is developed by the authors to mainly focus on the construction management of Rock-Filled Concrete dams. This system is a combination of construction quality control with personnel, material, and machinery management, and it acts as an information center for data inflow and outflow in engineering projects.

Table 1 : Some RFC dam projects under construction (gravity dam H>60 m; arch dam H>40 m)

No.	Name of project	Province	Height of dam (m)	Volume of RFC constructed (10^3m^3)	Dam type	Commencement time
1	Songlin reservoir	Yunnan	90	300	Gravity dam	2015.11
2	Pingkeng reservoir	Fujian	79	320	Gravity dam	2018.01
3	Xiyuan reservoir	Fujian	77	280	Gravity dam	2017.02
4	Manping reservoir	Qinghai	77	120	Gravity dam	2018.06
5	Houchangjing reservoir	Yunnan	76	180	Gravity dam	2019.05
6	Maliuwan reservoir	Sichuan	75	170	Gravity dam	2019.07
7	Yanggongyan reservoir	Guizhou	65.5	194	Gravity dam	2019.03
8	Wangqianzhuang reservoir	Shandong	64.5	100	Gravity dam	2017.07
9	Shenxihe reservoir	Hubei	63	80	Gravity dam	2017.11
10	Xiandonggou reservoir	Shanxi	61.4	60	Gravity dam	2016.04
11	Shigou reservoir	Shaanxi	61	91.6	Gravity dam	2017.09
12	Longtanhe reservoir	Hunan	60.6	50	Gravity dam	2019.07
13	Fengguang reservoir	Guizhou	48.5	28	Arch dam	2019.03
14	Longdongwan reservoir	Guizhou	48	56	Arch dam	2018.01
15	Xiaoyuanli reservoir	Zhejiang	42	18	Arch dam	2019.04
16	Goujiang reservoir	Guizhou	41	27	Arch dam	2017.02

2. GENERAL FRAMEWORK OF THE SYSTEM

2.1 General framework

The RFC construction management system is divided into two subsystems, i.e. the foreground system: user mobile system embedded in WeChat, and the background system: project management system in PC. The mobile system is a user-oriented design, where different roles are assigned to fill in the on-site construction information based on the different working scenarios. WeChat, which is most popular mobile software in China, provides a convenient platform for information collection, sharing, and notification. The WEB system is mainly used for project information management: the super administrator manages all projects while the project administrator manages a single project. The manager should fill in the basic project information, personnel authorization and upload files in advance. Both the foreground and background system adopt modular design for different engineering needs and personalized settings. There are mainly nine functional modules: personnel management, progress of dam body construction, progress of dam foundation construction, acceptance of project, HSCC and concrete testing, material management, production of mixing plant, machinery and equip-ment, and monitoring instrument (Figure 2).

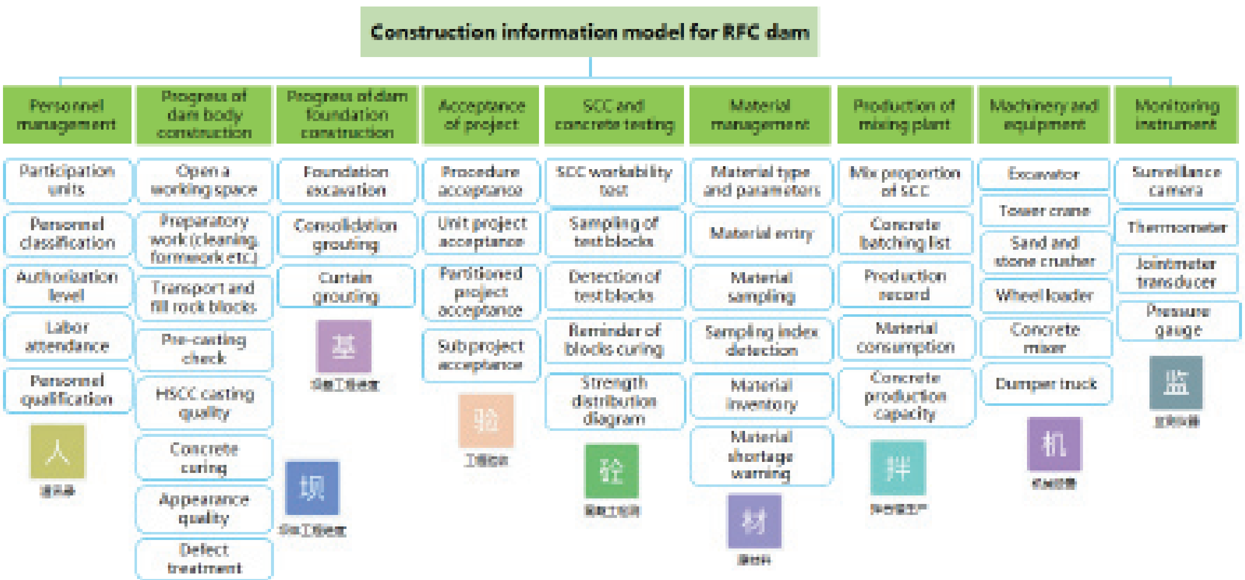


Figure 2 : The general framework of the construction information management system for RFC

2.2 Construction process of Rock-filled dam

Dam construction quality is the top priority of the management system. Based on the whole construction process of RFC technology, the system makes it organized in streamline with raw mate-rial preparing, HSCC production, workplace preparing and placement, and curing (Figure 3).

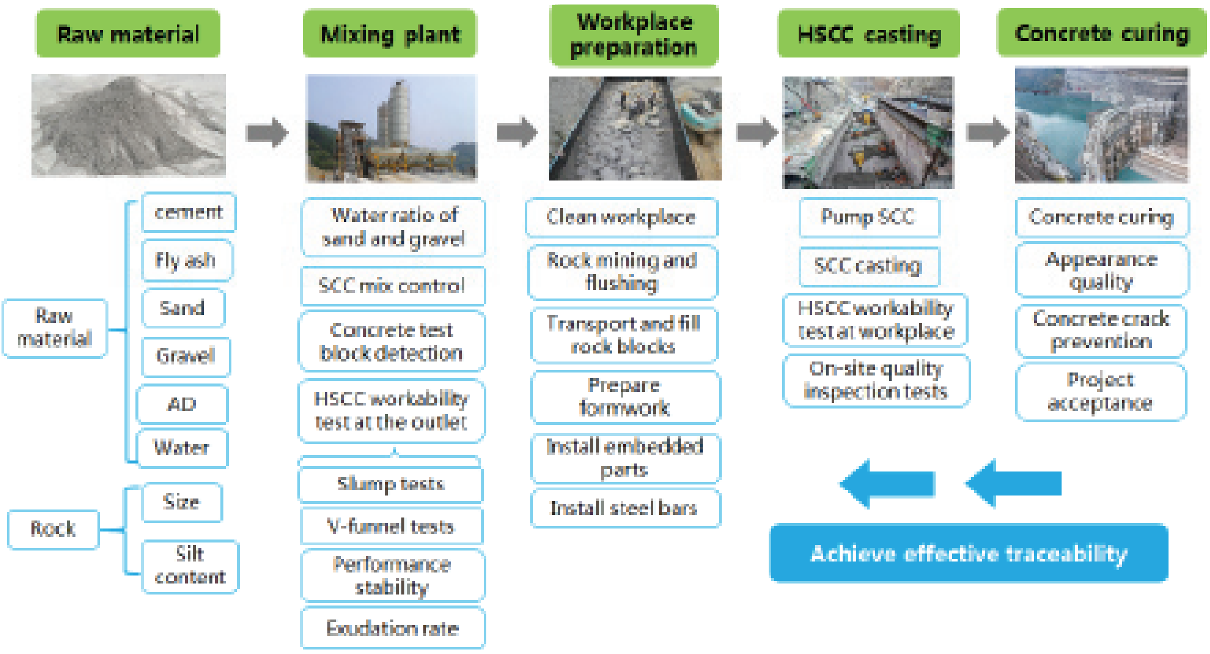


Figure 3 : Achieve effective traceability based on the construction process of RFC dams

Raw materials, including cement, fly ash, aggregates, additive (AD) and large rock, are the basic element of an RFC dam project. The source and quantity of raw material should be checked in entry of the project. The various physical properties (e.g. density, fineness modulus, silt content) of raw materials are monitored by sampling. HSCC is produced at the mixing plant, where mix proportion of HSCC is one of keys for quality control of dam construction. To monitoring the workability and quality of HSCC, technicians have to sample and test HSCC at the mixing plant and the working place in the dam. The quality of the workplace preparing, such as green cutting and cleaning of the working space, transporting and placing of rock blocks, preparing of formworks, installation of em-bedded parts and steel bars, are also monitored. Each construction process should experience at least two challenges of self-inspection and supervision-review. After everything is ready, HSCC casting goes along with frequent on-site flowability tests and quality inspections. Concrete curing will be carefully arranged according to the weather and temperature during concrete harden process. Finally, the appearance quality and crack numbers of the dam directly determine the acceptance of the project. If cracks found, the cracks will be grouted and can be tracked back to the workplace construction, mix proportion, raw material. The causes of cracking will be studied and identified by the data col-lected via the developed management system.

3. SUBMODULES OF THE MANAGEMENT SYSTEM

3.1 Personnel management

During the construction process of an RFC project, there will be kinds of participations, such as owner, designer, contractor, engineer, third-party testing unit and quality supervisory station from local government. In the management system, a contact list with personnel classification is necessary, while each user will be assigned an account with a matched authorization level. The different roles will fill in the data according to the on-site working scenarios, for example a quality inspector is responsible for the construction quality record and a storekeeper for material entry and sampling. The list of personnel allocation in each procedure will be displayed and the leader can temporarily adjust the personnel if someone is off duty, for example, on sick leave etc. Labor attendance and qualifica-tion management of special operations are also involved in the system.

3.2 Project information management

Building a unified database of all RFC projects (Figure 5a) is the primary task for the manage-ment system. Encoding the project information with a designed rule makes the managing and retriev-ing of information expediently, and makes the data sharing and exchanging efficiently. The structure and identifier for the CIM4R system database is developed and will be published. The table name is regulated as CIMR_α_β, in which α is the information type (i.e. PROJ as project information; MAT as material information) and β is the specific content of a table. The identifier of each field name is carefully decided referring to the current information standards of Ministry of Water Recourses, China. As for the project management, the super administrator can create a new project, and get the information updates of all projects. The project administrator can edit the basic information of a pro-ject, and make the process and permission settings. The construction process of RFC dams is divided based on a project unit, which is a casting workplace with the thickness of 2 or 3m. Therefore, the diagram of dam division (Figure 5b), which can display the real-time construction progress, should be initialized by the number of dam monoliths and the elevation of the dam. The acceptance of project is strictly executed from the project unit, partitioned project to sub project, and it can be automatic and convenient to collect continuous engineering data using the developed management system. The module of the construction progress in the dam body is developed and online, but the progress of dam foundation construction is still in coding development, including the foundation excavation, consoli-dation grouting and curtain grouting.

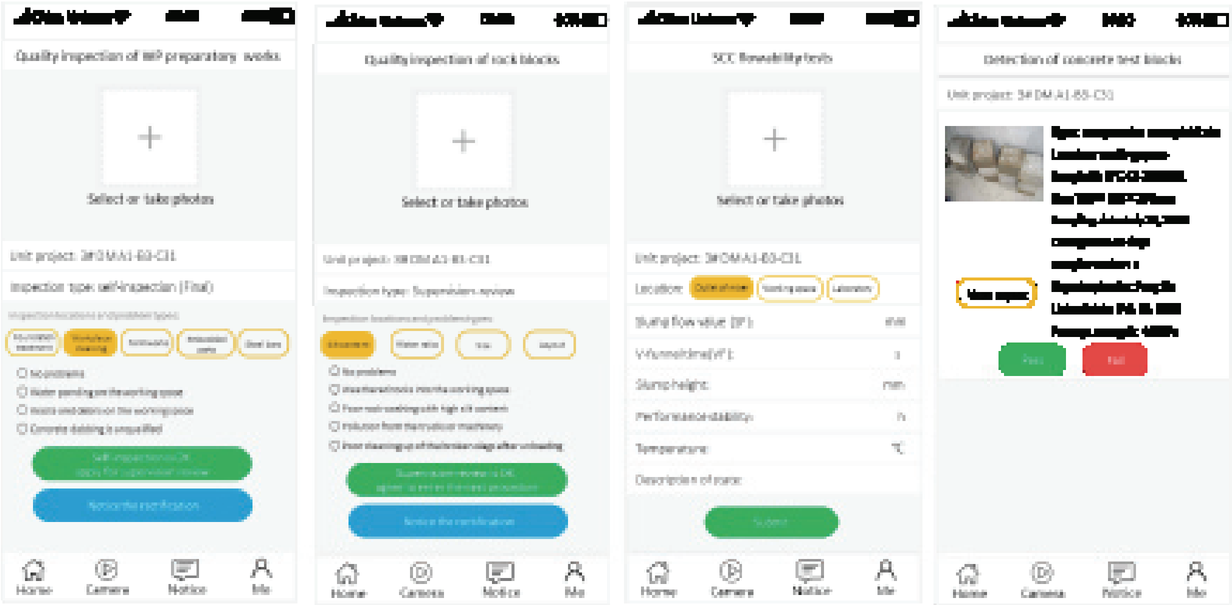
(a) Project list (b) Construction progress (c) Procedure control (d) Concrete production

(Note: DM-dam monolith; WP-working space; MP-mixing plant; CR-concrete curing; CB-concrete blocks)

Figure 4 : Typical interfaces of project management

3.3 Construction Quality Management

Process control runs through the construction quality management of the system (Figure 4c&4d). Starting a working space is the first step of the construction process, and is conducted by the head of production management department of the contactor, who should confirm the personnel allocation, HSCC mix types and the basic parameters of the working space. Preparatory works on the working space will be completed step by step, i.e. cleaning the workplace, preparing formworks, installing embedded parts, transporting and filling rock blocks, and installing steel bars (Figure 5a). Along with the preparatory works, truckloads of rock blocks are transported and filled in the workplace (Figure 5b). The construction quality control pays special attention to the size, dust coating and layout of rock blocks. Pre-casting check involves many roles to confirm a mature preparation. The mixer operator should check the material inventory, the performance of the mixing plant and upload the concrete batching list. The test technician should get the experimental apparatus ready, which are for HSCC flowability tests at the outlet of the mixing plant or the pump outlet on the construction site. The chief supervision engineer approves to start a concrete casting process. The construction quality of concrete production and casting is the core process, with all stuff keeping intensive concentration and working day and night continuously, involving the mixer operator, the test technician and quality inspectors (Figure 5c). When the concrete casting is finished, the on-site construction leader clicks OK to close the working space, which goes into the state of concrete curing. Quality inspection should be followed up on the curing measures and frequency, the appearance quality of dam, and the test result of con-crete blocks (Figure 5d). Acceptance of unit engineering is the last step. On the construction site, the quality inspector of the construction unit does the self-inspection and the supervisor makes the super-vision-review according to the quality evaluate standard of a project unit. Once a routine check is done, the system will make timely notifications to those relevant personnel and a reminder to the next process leader. If there is an engineering problem found, the next procedure will not be unlocked.



(a) Workplace preparation (b) Fill rock blocks (c) HSCC flowability test (d) Concrete block detec-tion

Figure 5 : Typical interfaces of the construction quality control

3.4 Material Management

Cement, fly ash, aggregates, additive, and steel bars are the basic materials, which can be pre-typed into the background system with some common types. The material storekeeper only need to fill in the production lot number, entry date, total weight and photo of the certificates when the mate-rials are trucked in. According to the sampling frequency, the inspector chooses a material batch and records the sample ID, which is the link between the test result of physical properties and the material batch. Usually the storage tanks for a mixing plant is non-transparent, so the residual weight of the cement and fly ash is unknown. In the management system, the increase of materials comes from the entry record while the consumption is calculated from the mixing production of concrete, and the result of their subtraction is the material inventory. If the remaining is less than a preset threshold, the warning message to load raw materials will be automatically sent out.

3.5 Production of mixing plant

The mix proportion design of concrete will determine the dosage of each materials based on the workability, and strength and other performances of concrete the designated age by absolute volume method. All consumption of each raw materials in each batch is adjusted from the theoretical mix design by the moisture content of aggregates in the practical production of the mixing plant. In the background system, the project manager inputs the mix designs in advance. The mixer operators take turns to record the production tray number of chosen mix design, and the system can automatically calculate the concrete casting volume and the material consumption. Regular inspection of the me-chanical system for mixing and pumping should be done and if there is a mechanical breakdown, the operator can record the delay time.

3.6 HSCC and concrete testing

Freshly mixed HSCC and hardened concrete are the two main inspection targets as for the con-struction quality. The HSCC flowability tests involve the slump test, V-funnel test, performance sta-bility, casting temperature and bleeding rate. The test technician should update the real-time data of the HSCC flowability tests on different checking points. Taking samples of SCC cubes or cylinders is the first step for hardened concrete testing, and the samples should be numbered and sent to the lab for curing. The system will automatically send out the reminding messages of the curing time, i.e. 3 days, 7 days, 28 days, and 90 days. The third-party lab can make strength detection and return the result back.

3.7 Dam monitoring management

Monitoring is the primary measures for the smooth construction and operation of a project. Video monitoring with cameras installed at the key construction points is omni-directional and online live in the WeChat management system. IoT (internet of things) technology is a promising method for the unmanned management, and there are thermometer, joint meter transducer, and pressure gauge involved except for surveillance cameras. The system can display the exact position and the real-time monitoring curve of these monitoring instruments on a dam map. Besides, the machinery and equip-ment can be managed in the platform, including the excavator, tower crane, sand and stone crusher, wheel loader, concrete mixer, dumper truck and so on.

4. CONCLUSIONS

This paper presents a construction information management system for RFC dams. The proposed system is comprehensive but practical, providing a combination of construction quality control with personnel, material, and machinery management. Process control is the main line of the management system for construction quality control, aided by the project management, material management, pro-duction of mixing plant, HSCC and concrete testing, and dam monitoring management. If some cracks are found in a dam, the project manager can pick out the problem depending on the effective traceability of the information system. The mobile system embedded in WeChat offers an effective approach to achieve the real-time and online management, and it acts as an information center for data inflow and outflow from different roles of personnel. The future work can be done in terms of Internet of things (IoT) technology integrated into the system, and big data analysis based on the obtained information of RFC dams. As for small or medium-sized projects, the developed system is promising with convenient and portable applications. Up to now, it has been proven correct and effi-cient by many times of practical tests from on-site engineers. In the next year, the construction infor-mation management system will be officially applied to new-built RFC dam projects.

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REFERENCES

An X.H., Wu Q., Jin F., et al. 2014. Rock-filled concrete, the new norm of SCC in hydraulic engineering in China. Cement and Concrete Composites 54: 89-99.

Azhar S. 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering 11(3): 241-252.

Czmoch I. & Pękala A. 2014. Traditional design versus BIM based design. Procedia Engineering 91: 210-215.

Huang M.S., An X.H., Zhou H., & Jin F. 2008. Rock-filled concrete–development, investigations and applications. Int. Water Power Dam Constr. 60(4): 20-24.

Jin F. & An X.H. 2003. Construction method of rock-filled concrete dams. Chinese Patent: 03102674 [in Chinese]

Jin F., An X.H., Shi J.J. & Zhang C.H. 2005. Study on rock-filled concrete dam. Journal of Hydraulic Engineering 36(11): 1347-1352 [in Chinese].

Jin F., Zhou H., & Huang D.R. 2018a. Recent Advances in Rock-filled Concrete Dams and Self-protected Underwater Concrete. 5th international symposium on dam safety, Istanbul, Turkey.

Jin F., Zhou H. & Huang D.R. 2018b. Research on rock-filled concrete dams: A review. Dam Engineering 29(2): 1-12.

Li Q.B. & Lin P. 2014. Demonstration on intelligent dam. Journal of hydroelectric engineering 33(1): 139-146 [in Chinese].

Yu X.N., Wang L. & Rao X.K. 2013. Application of digital construction management system to Dagangshan hydropower station. Journal of Yangtze River Scientific Research Institute 30(4): 99-102 [in Chinese].

Zhang Q.L., Liu T.Y., Zhang Z.S., et al. 2019. Unmanned rolling compaction system for rockfill materials. Automation in Construction 100: 103-117.

Zhong D.H., Li X.C., Cui B., et al. 2018. Technology and application of real-time compaction quality monitoring for earth-rockfill dam construction in deep narrow valley. Automation in Construction 90: 23-38.