Durability evaluation software system of concrete structure based on BIM and 4D technology

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Abstract

Based on BIM technology, a 4D structural durability information model is proposed and established which implements the integration of concrete structure durability information used for durability code checking, durability analysis, life prediction and safety evaluation. A BIM-based building information management framework is proposed. Then a software system of structural durability evaluation based on BIM and 4D technologies is developed, which can read, extract and decompose structured IFC model data, define 3D model view, manage and analyze durability information of concrete structures etc. The technologies of BIM architecture and BIM data storage and access are studied. Relative theories and key technologies for the integration are specified. Concrete structure durability evaluation and information integration technologies are applied and the IFC standard is implemented. The achievements of this research have indicated that by applying the BIM-based 4D structural durability information model, sharing and integrated management of building information among different applications and phases in projects can be implemented. This also provides a feasible theory and methodology for the establishment and integrated applications of BIM. Furthermore, this study proposes a new approach for safety and durability assessment by integration of IFC, building information management technology, nonlinear time-dependent safety analysis of concrete structure. The approach lays a foundation for the popularization of further complicated theories and methodologies in these areas.

Keywords: BIM, IFC, 4D technology, durability information model, structural durability

1 Introduction

For appropriate applications of BIM technology in the field of civil engineering, many approaches have been achieved. Renaud Vanlanede et al. presented an extension of the BIM technology to manage information during the entire lifecycle of an AEC project. Zhang Yang et al. developed a BIM Information Integration Platform (BIMIIP), which can read, save, extract, integrate and extend structured IFC model data and understand documents, define partial-model view, manage property set and concept term. However, the above researches focused on the exchanging and sharing platform, without applications in specific areas. Furthermore, Shu Yang et al. attempted to build the structure of evaluation model and intelligent evaluation system on durability of reinforced concrete structures, and have developed intelligent evaluation system on reinforced concrete structures. Hua Shenghe from Canada developed an IFC-based framework to meet the requirements of evaluating building envelope performance by integrating evaluation applications and criteria with IT and IFC. Hu Zhenzhong et al.
developed a BIM-and-4D-based analysis and management system for conflict and safety problems during construction named 4D-GCPSU 2009, which achieves the conflict and safety analysis during construction by integration of construction simulation, construction management and safety analysis. These researches being carried on at present in the world mainly focus on the traditional fields of the civil engineering, such as architecture and structure design, water supply and drainage design, energy saving, cost optimization et. However, IFC-based BIM and 4D technologies have not been used for durability analysis in the maintenance phase of structures which is being paid more and more attention to recently. Consequently, this paper applies the BIM and 4D technology to concrete structure durability analysis, establishes a 4D durability information model and develops a BIM-and-4D based analyzing and managing system for concrete structure durability.

The durability of concrete structure refers to the safety and applicability of a member during its design period. The deterioration of concrete and reinforcement bars behaviour includes both physical and chemical components. Chemical degradation is caused by acids and/or salts aggressive environment where structures located, whereas physical damage is caused by freeze-thaw, external loads and so on. The durability of concrete structure depends mainly on the reduction of structural capacities and stiffness, which is a complicated problem from many factors. The information on those influencing factors comes from each phase of the whole life period of buildings. Moreover, the mathematical model of interference and interrelation among factors is complex, the quantity of building components is great, and the environmental condition and stress condition for the same components at different places are different. Therefore, the workload of manual analysis is huge. Owing to the features of durability analysis and the development of information technology, the application of combining both of them has great potential significance and development prospect.

2 Establishment of 4D durability information model

2.1 Definition of 4D durability information model

The durability of concrete structure depends on two factors, namely the feature of concrete and steel bar and the erosion of the environment under which it’s used. Related factors include concrete cover thickness, cement variety, cement grade, alkali content, cement fineness, alkali reactivity, aggregate particle size gradation, admixture, water-cement ratio, construction quality, dry-wet alternation, freeze-thaw cycles, acid rain, subversive gas, chemical content of the environmental water system, etc. The results of durability analysis research of structure in every aspect are gained under the condition of comprehensively considering multiple influencing factors and by analyzing the interaction of these factors and the influence on durability of each factor. Furthermore, the durability analysis is throughout the whole term of the life period of building. Owing to the random and unpredictable factors influencing the durability, including work environment, load condition, etc., it is necessary to predict the future according to the occurred situations and experiences. With the difference of occurred situations, the result of prediction will vary with the lapse of time, so as to influence the working out of scheme for building maintenance and use. Therefore, 4D technology is applied in this research topic. So the 4D durability information model of concrete structure is proposed in this paper as an information model with comprehensive information including environmental, construction quality, material and structural data, as well as the time variable. This model is used for safety and applicability prediction of the structure in the stage of maintenance.

2.2 Construction of 4D durability information model

This model is composed of four sub-models. There are both sharing and special information among those sub-models, and the inter-access and sharing are realized by means of C++ friend members. The four sub-models are managed by durability information model and they form the durability
information model of structure components jointly. Based on the sub-models referred above, the 4D technology is introduced into the model by adding the time variable $t$ into the durability information model and each sub-model quotes the common time variable $t$ as the fixed value parameter, which has realized the time correlativity of each sub-model data, as shown in Figure 1. The relationship between each parameter and time is encapsulated into a series of $Set()$ member functions of each object; the initialization and alternation of all the parameter values must be realized by calling $Set()$ member functions, which realizes the automatic correlation with time variable.

![Figure 1: 4D durability information model](image)

### 2.3 Loading of 4D durability information model

The process of extracting data from IFC document, loading and initializing the 4D durability information model is shown in Figure 2. The first step is to access the data of environmental action grade, cementing material variety and mineral admixture dosage in the object of durability information model, then judge whether they are in conformity with the requirement according to the table specifying the limitation of cementing material variety and mineral admixture dosage under different environmental conditions in national code (this table has been integrated into the software system); in case of inconformity, the correction is required. In case of conformity, the aerated state of concrete will be extracted, the rationality will be verified according to the table of air content and mean bubble spacing coefficient of air-entraining concrete in the national code, and correction will be carried out. Lastly, the compressive strength of concrete, design service life, component type, water-cement ratio and concrete cover thickness, are accessed and loaded into the model in turn for the use of safety evaluation, life prediction, code checking and durability analysis.
Figure 2. Loading of 4D durability information model

3 Durability evaluation software system

3.1 Software system framework

The durability evaluation software system developed in this paper is composed of six modules: 1. 4D Durability Information Model; 2. Durability Design Code Checking Module; 3. Durability Analyzing Module; 4. Life Prediction Module; 5. Safety Evaluation Module; 6. Data Managing Platform module. The software system framework and the relationship of the modules are shown in Figure 3.

The workflow of the system is as follows: Firstly, the data managing platform realizes the access to IFC document by the IFC Engine toolkit to obtain such basic information on components as entities, attributes and so on. Secondly, checks the absent parameters by means of the parameter integrity checking mechanism, and leads the user to input the absent durability information, perfect the durability data of information model and realizes the initialization of durability information model. Lastly, carries out the durability analysis to the durability information model by loading the durability information model into each function module, so as to gain the result of durability analysis.

3.2 Process of durability design code checking

Figure 4 illustrates the workflow and principle of durability design code checking module in this software system. The code checking function module is achieved by integrating national durability code into this software system to form a series of automatic processes. First of all, the system access the design service life, then enters relevant distinguish sub-module according to the type of component which falls into four common classes, namely wall, slab, beam and column. Next,
according to environmental grade and concrete aerated state, relevant sub-module is called. In the verification phase of compressive strength, two situations of water cement ratio, less than 0.4 and greater than or equal to 0.4 are accepted. The former returns “False” directly, outputs that the design doesn’t conform to code and displays a dialog box to modify the water-cement ratio. The later enters into the verification of concrete cover thickness continuously. After being encapsulated, the above workflow can traverse the components and subcomponents automatically, which makes it convenient to conduct the durability design code checking of all the components of overall structure. Moreover, a friendly user’s operating interface is provided for users to modify the design results.

![Figure 4. Process of durability codes checking](image)

### 3.3 Process of durability analysis

The carbonization depth analysis is the first step of durability analyzing process. Figure 5 shows the working interface of carbonization depth analysis of this software system. The information shown in the figures is the attribute information of selected components. The information on geometrical attribute, topological attribute, etc. of components comes from the opened document in IFC format, such as component name, component ID and IFC sort that the component belongs to. According to the geometrical information from the IFC document, the data managing platform renders the 3D view of the project.

![Figure 5. Snapshot of durability analyzing process with the 4D durability evaluation software system](image)
Other durability information needed to be input from the information interface, such as the absent attribute values of the environmental situation, construction quality, material behaviour and structural property etc. These attribute values are extracted from the 4D durable information model; each attribute value can be modified directly from the window; and these information are completely synchronized with the data in the information model. In the actual durability analysis and the service life prediction of building structure, actual information on building durability, including rest thickness of concrete cover, permeability coefficient, actual corrosion amount of steel bar, etc., can be gained by means of actual measurement and the loading of information can be realized through this interface. Finally, the state of rest bearing capacity of structure can be gained through the application of carbonization depth calculating module, chloride ion penetration depth calculating module and bearing capacity calculating module, the rest service life of structure can be evaluated by means of degradation mathematical-physical model, and the current safety grade of structure can be rated according to the Code for durability design of concrete structures (GB/T 50476-2008) to provide important basic references for formulating scheme on maintenance, reinforcement and use of the buildings.

4 Conclusion

A 4D durability analysis information model for concrete structural durability evaluation is proposed, with the definition, construction and loading mechanism specified in this paper. And a durability evaluation software system based on BIM and 4D technology is developed. Relative technological problems are solved, such as reading and loading of IFC document, integration and programming of durability design code and theories of durability analyzing, service life prediction and safety evaluation. This software system realizes such functions as loading data from document in IFC format, integration of durability information, and conducting durability code checking, durability analysis, service life prediction and safety evaluation by comprehensively applying the above data.

The modules of life prediction and safety evaluation are still being developed. Furthermore, the direct-viewing analysis result in other forms such as diagram, 3D view, etc. is also being developed presently.

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