Research and development of comprehensive safety management system for super-tall buildings in Shanghai

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Abstract. In order to meet the requirements of comprehensive safety management of super-tall buildings, a set of integrated safety management system is developed, which can be popularized and demonstrated, including three subsystems of structure, enclosure and firefighting. Interfaces are reserved for water supply and drainage, facilities and equipment, strong and weak electricity and other building safety management subsystems, which can realize the functions of comprehensive safety assessment, safety early warning, Internet of things safety monitoring and data analysis of super-tall buildings. Through the demonstration application in Shanghai Center, it is eventually proved that the system is feasible and effective.

1 Introduction

With the development of society, the increase of urban population, the decrease of building land and the progress of building science and technology, more and more high-rise and super-tall buildings appear. Super-tall buildings are called vertical cities which differ from 100-meter defining height of high-rise buildings, over 100 meters are supertalls [1]. According to statistics, about 25% of the 100 tallest buildings around the world are located in China; 54% of the supertalls built over 200 meters are in China.

2 General situation of super-tall buildings in Shanghai

Since the late 1970s, a large number of high-rise buildings have been built in Shanghai. The number of high-rise buildings has rapidly developed from 121 in 1980 to 40,822 in 2015, with a construction area of 396.52 million square meters, of which 1,569 buildings with 30 stories or more covering a construction area of 44.81 million square meters, and are increasing annually [2]. According to statistics, from 1995 to 2000, 2,045 new high-rise buildings were built in Shanghai; from 2000 to 2003, 2,194 new high-rise buildings were built, with a new construction area of 30.16 million square meters. Facing the rapid increase of high-rise buildings, in 2003 the Shanghai Municipal Government issued a "height limit" plan, stipulating that "double increase" were required in Shanghai urban planning -- increase public green space and activity space, and "double decrease"-- reduce building capacity and high-rise buildings. The introduction of this policy has largely curbed the rapid progress of high-rise buildings. Since then, although the total supply of high-rise buildings has continued to rise, the growth rate has slowed.

Not only the number of super-tall buildings in Shanghai is increasing year by year, but also the record of building height has been repeatedly broken. The Shanghai Jinmao Tower, which was started in 1994 and completed in 1998, has 88 floors above ground, with 93 floors plus minarets, with a total height of 420.5 meters. The Shanghai World Financial Center was built on August 29, 2008, with 101 stories above ground and a total height of 492 meters. The construction of the pile foundation of the main building of the Shanghai Central Building was carried out on November 29th, 2008, the structure was capped on August 3, 2014, the main body of the building has a total height of 632m, a structural height of 580m and a construction area of 433,954 square meters.

3 Overview on comprehensive safety management of super-tall buildings

Super-tall buildings generally have comprehensive functions with huge amount of investment. The construction cycle generally is over 5 years, consuming lots of manpower, material and financial resources. Meanwhile, with the number of super-tall buildings increases, the cost of operation and maintenance increases, and with the sharp increase of building height and scale, there are many problems in construction technology and management of super-tall buildings. The super-tall is a typical large-scale and complex project, which has particularity. The deficiency of traditional project management method in dealing with super-tall buildings is becoming more and more obvious. It is precisely because the characteristics of super-tall buildings are different from ordinary ones that once problems occur, including fire, falling of exterior wall finishes, self-

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explosion of glass curtain wall, aging of materials, damage of facilities and equipment, gas explosion and so on, it will cause serious consequences. Therefore, super-tall buildings need special technical and management methods.

At present, the attention to the safety of super-tall buildings at home and abroad is basically to monitor the new buildings of especial importance, and there is no research on the comprehensive safety management of super-tall buildings. For example, to monitor the settlement and deformation in the construction stage, or to monitor the structural dynamic response parameters in the operation stage, or to monitor some loads that affect structure safety, such as earthquake, wind speed and etc.. Except that the monitoring results of some individual parameters may play an early warning role, most of the monitoring data are only used for analysis and research. These monitoring are actually discrete, sporadic and incomplete. According to these monitoring results, we can not evaluate the overall safety of the structure or the super-tall buildings. The super-tall building is a complex system, including structural system, enclosure system, fire protection system, heating and ventilation system, strong and weak electricity system, vertical traffic system and so on. Only paying attention to the safety of the building structure can not guarantee the overall safety of the super-tall building. Instead, we should carry out comprehensive safety management, that is, comprehensively consider the safety of the whole life cycle of the building, the safety, usability, durability and overall management of all subsystems. It is of great practical significance and long-term economic value to check the safety status of super-tall buildings, find various risks in time, predict the impact of disasters on buildings, and evaluate the safety, durability, applicability and reliability of buildings.

Therefore, it is necessary to study the comprehensive safety management technology of super-tall buildings, comprehensively considering the whole life cycle of super-tall buildings, considering all the factors affecting their safety, and considering the safety, usability and durability of the buildings. Make real-time and regular check and assessment of the safety of super high-rise buildings, so as to carry out management and decision-making. This has important practical significance for timely understanding of the overall performance of the building, timely early warning of potential dangers, reducing the incidence of safety accidents, improving the ability of building disaster prevention and management efficiency, and has become a new demand for the safety management of super high-rise buildings.

4 Research and development of comprehensive safety management system for super-tall buildings

According to the characteristics, operation of super-tall building, an extensible structure of integrated safety management system is designed. The system includes structural subsystem, enclosure subsystem and fire protection subsystem of super-tall building, and has interfaces for safety management subsystems such as water supply and drainage, facilities and equipment, strong and weak electricity, etc.. In addition to the basic data of the whole life cycle of super high-rise buildings, the data sources of the system also take into account the data of real-time monitoring, daily inspection and regular inspection. After integrating the data of each subsystem, the functions of each subsystem are integrated to form system functions such as comprehensive safety assessment, safety early warning, Internet of things safety monitoring, data analysis and so on.

4.1 Research on overall structure and function design of systems

As a comprehensive management information platform for super high-rise buildings in Shanghai, the system construction mode based on integrated management service platform is considered in the system design. As a safety management of a complex system, the system focuses on developing structure subsystem, enclosure subsystem and fire protection subsystem. The specific safety management functions are as follows:

(1) Information management: namely the local data management module, mainly as the data support system of each subsystem, completes the work of data archiving, query, storage, maintenance and printout, and displays all kinds of information of super high-rise buildings simultaneously, including information about building structure, construction structure equipment, construction, inspection and identification, repair and renovation, safety and evaluation, safety early warning and so on. The management of the basic data of super high-rise buildings in the city includes information input, modification, arrangement, backup, browsing, retrieval, extraction, output, data update, system maintenance and management, etc.

(2) Information maintenance: Maintain and operate the attribute information of super high-rise buildings.

(3) Data analysis: Realize two-way query and retrieval of graphics and attributes, generation of statistical reports and thematic maps for super high-rise buildings in the city, for example:

1) Basic data: statistical analysis such as scale, distribution, height etc.

2) Real-time monitoring data analysis;

3) Data analysis of safety check;

4) Data analysis of safety inspection;

(4) Safety warning: Monitor every super high-rise building in the city, and realize the early warning and related treatment based on safety early warning models such as safety inspection cycle, safety repair cycle and influence range of underground projects;

(5) Safety monitoring of Internet of things: through the setting of sensors, the remote real-time monitoring of super high-rise buildings is realized, and the monitoring results are monitored on the virtual simulation model, including:

1) automatic data acquisition module: mainly responsible for signal acquisition, transmission, processing and analysis control;

2) remote data management module: mainly carry out remote real-time monitoring and warning, data statistics

analysis, comprehensive safety assessment, data management and query functions integration.

(6) Based on the data of safety monitoring and inspection, the systematic safety assessment of structure, fire protection and enclosure is carried out for each super high-rise building before final results come out. Meanwhile, the safety assessment results are displayed on the virtual simulation model, and report is output.

(7) Input and display of demonstration project: While completing the comprehensive safety management system of super high-rise buildings, the data of two super high-rise buildings, Shanghai Center and Shanghai International Financial Center is entered into the system, and the functions such as data analysis, Internet of things monitoring, comprehensive safety assessment and safety early warning are verified and demonstrated.

4.2 Research on key Technologies of functional Module of Comprehensive Safety Assessment

Integrated Safety Assessment Module is one of important functional modules in comprehensive safety management system of super-tall buildings. Integrated Safety Assessment of super-tall buildings is based on real-time monitoring data, daily inspection data and periodic test data which includes structural system, fire protection system and enclosure system etc.. The safety status of each subsystem is obtained after taking into account the indicators in each subsystem that affect the safety of building, and finally the comprehensive safety assessment results of super high-rise buildings come out. Finally, comprehensive safety assessment results of super-tall buildings are obtained finally. In this module, various parts related to safety assessment processes are designed, including comprehensive safety assessment index system of whole super high-rise buildings and data input of assessment indexes of each layer (including text, digital, chart and reporting formats etc.), index weight input, preservation and output of final assessment result, corresponding countermeasures, import and review of historical assessment results, Modeling steps and assessment processes, assessment methods, decision-making suggestion and key technologies of functional modules design.

4.3 Research on key technologies of safety early warning function module

The aim of safety early warning of super high-rise buildings is to perceive potential risk factors beforehand and dispose timely to ensure the safety of buildings. Therefore, it includes two stages: Firstly, timely early warning and forecast of potential risk and unsafe conditions in super high-rise buildings, and provide support for timely disposal of risk; Secondly, the disposal of the early warning and forecast information also affects the building safety condition, that is, the building risk factors, the severity of the unsafe state and the disposal jointly affect the early warning level. With reference to the early warning of meteorological disasters, four levels are set up, with red, orange, yellow and blue corresponding to level I to IV, and level I is the highest.

Table1. Early warning Index and type of safety management

No.	Type of early warning	Warning parameter
1	Warning over length of use	Duration of use
2	Warning beyond detection cycle	Detection cycle.
3	Warning beyond repair cycle	Repair cycle
4	Early warning of Comprehensive Safety Grade C and Grade D	Comprehensive Safety Assessment Grade of building
5	Warning of damage behavior	Damage behavior.
6	Early warning of adjacent Engineering Construction	Influence scope of adjacent Engineering Construction
7	Natural disaster warning	Grade of natural disasters

Table2. Safety warning rating and explanation

Grade	Sign	Early Warning Instruction
Level I	Red	There are serious safety risks in the building, or the building is suspected to be dangerous, which is in urgent need of inspection and disposal.
Level II	Orange	There are serious safety risks in the building, or the building is suspected to be seriously damaged. Inspection and disposal is necessary.
Level III	Yellow	There is a hidden danger in the building, or there is a high probability of damage affected by external factors, so it is necessary to check and confirm the damage.
Level IV	Blue	There is a large probability that the building has a hidden danger of safety, or the building is affected by external factors, but the probability of damage is small, so it is necessary to check and confirm the damage of the building.

4.4 System display

The home page of the system are shown in figure 1 .

Fig 1. System Home Page

As the comprehensive safety management platform for super high-rise buildings in the city, the system displays the functions given by the corresponding permissions according to the different roles of users. On the home page, users can get the comprehensive safety situation of super high-rise buildings in the city clearly. The base map of the system is based on the sky map uniformly issued by Shanghai Surveying and Mapping Institute. In the center of the home page, the corresponding positions of the super high-rise buildings on the map are indicated, and the comprehensive safety levels A, B, C and D of the building are represented by green, blue, orange and red respectively. The left side of homepage shows high ranking of all super-tall buildings in the city. Clicking on corresponding building can connect with its attribute information. The upper right corner of homepage shows the percentage of comprehensive safety status of super-tall buildings in the city by circular diagram, and in the right middle of the homepage, it shows the distribution of safety warning of buildings by bar chart. At the bottom of the homepage it shows the safety levels of structure system, fire protection system and enclosure system respectively and makes real-time rolling announcement about the information on safety warning.

The database contains basic building information about structure, equipment, BIM (figure 2, left), construction, previous inspection and identification, previous repair and renovation, previous daily maintenance, termite control, demolition, previous comprehensive safety assessment and subsystem safety assessment (figure 3), previous safety early warning (figure 2, right) and etc..

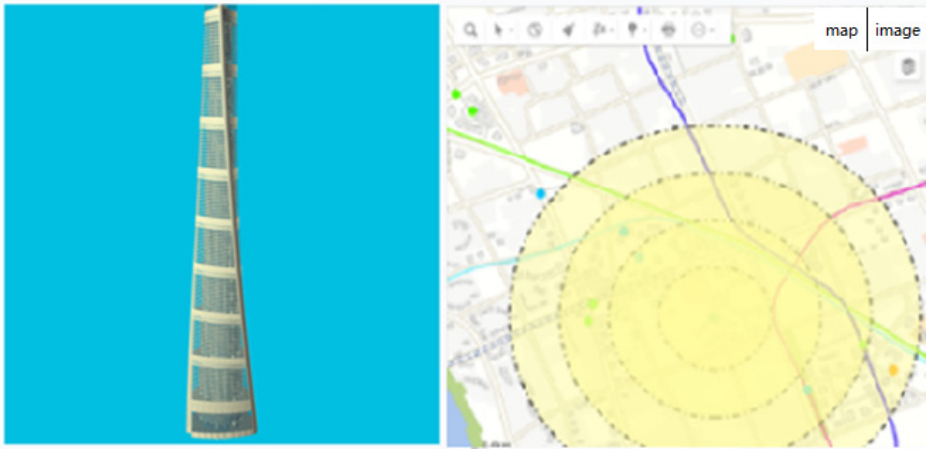

Fig 2. Combining with BIM model to check the structure, equipment Information of super high-rise buildings (left part) and previous safety early warning Information (right part)

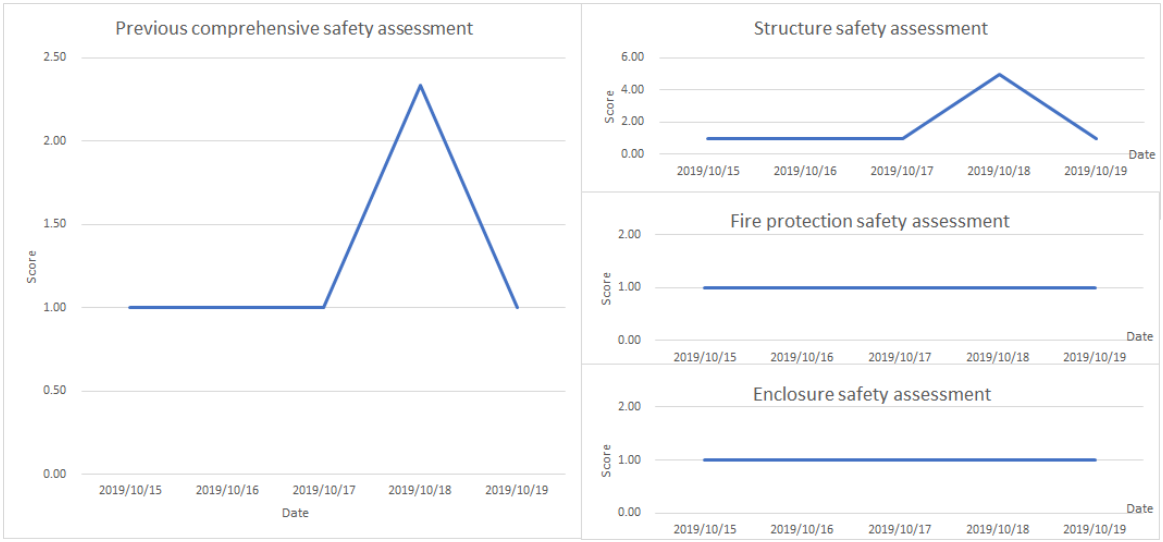

Fig 3. Previous comprehensive safety assessment and safety assessment Information of each subsystem (structure, fire protection, enclosure)

5 Conclusion

In view of each super high-rise building, using "one net" to cover all the problems that may occur in the building, the comprehensive safety assessment is completed through the expert system with the available visual display. At the city level, a super high-rise building comprehensive safety management platform can be set up as the control center, and the mechanism of "finding problems-solving them in time" is established, so as to realize the fine management of a super-large city, which can be replicated and promoted across the country. On the one hand, on the basis of considering the characteristics of each stage in the whole life cycle of super high-rise building, the daily inspection, regular inspection and real-time monitoring of structure, enclosure, fire protection and other subsystems are integrated, combined with safety, usability and durability, a comprehensive safety assessment model for super high-rise buildings is established. On the other hand, the research and development of a safety management system that meets the comprehensive support needs of super high-rise buildings can not only establish digital archives in the whole life of buildings, but also provide scientific and intelligent management means such as comprehensive safety assessment, remote real-time monitoring and safety early warning for super high-rise buildings to realize the safe and orderly management of super high-rise buildings in the whole life cycle and provide technical support for its comprehensive, overall and comprehensive safety management.

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