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Analysis and Assessment of Whole Structural Fire Safety for Public Buildings

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ABSTRACT: It is a new challenge to the buildings fire safety design and analysis as the quick development of large public buildings with complexity space structure. In this paper, the disadvantage of traditional fire design methods was presented, and the methodology and technology to analyze the mechanical respond of whole structures exposed to a real fire was studied carefully. A newly developed integrated system-BFIRESAS was introduced to analyze the overall fire safety behavior of large space structures under real fire conditions. This system adopts computer integration technology to perform the overall process of structural fire safety analysis and assessment from fire simulation to structural analysis, with the coupling thermal and mechanical effect considered. Some large public buildings, including the gymnasiums for the competition venues of 2008 Beijing Olympic Games, have been studied through the BFIRESAS. The results show that the structural respond and behavior of large space building under fire conditions have the systemic nature of a coherent whole, rather than the local effect. The case demonstrates that the whole structural analysis coupling with fire simulation is a powerful methodology and has high advantage while used to perform fire safety analysis.

1 INTRODUCTION

With the quick development of china economic, it is a new challenge to the buildings fire safety design and analysis as the quick development of large public buildings with complexity space structure. Fire resistance is one of the significant concerns to be taken into account of their safety evaluation. It is extremely important to identify the dangerous members that may highly, probably result in the whole structural collapse from global structure under fire condition, so that fire-resistant systems or equipments against firing can be reasonably prepared and proposed in advance.

To study fire development process for a real buildings in laboratory is difficult and expensive due to time-consuming preparation, high expenditure, and difficult operation of fire experiments [1]. With the development of computer science, especially with the simulation technology, computer simulation now can take the place of experimental research in some aspects, or can reduce experimental workload. The possible solution is to apply some advanced computational simulation software, such as FDS (Fire Dynamics Simulator), CFAST, and FLUENT for the safety evaluation of buildings in fire [2]. While those easily damaged structural components that may highly lead to the structural collapse of their corresponding gymnasiums cannot be predicted by these mentioned software tools alone, some structural analysis software can be contributive to the judgment, such as ANSYS and ABQUS etc.

However, in the traditional fire protection design, ISO834 curve usually was adopted as the time-temperature curve that is different from the temperature curve of real fire condition. Thus, an integration analysis of structure design coupled with real fire simulation need be executed. But, these existing analyzing tools or software are seemingly intended for use only by the field-related experts or professionals (i.e. fire safety or structural analysis) and adopted with different algorithms to model physical features of buildings under varied environmental conditions; hence it probably leads that the data exchange

and information sharing are realized in a great difficulty. Consequently, it is difficult to effectively use a set of disparate tools in a sophisticated integration analysis.

In this paper, a newly proposed and developed integrated analysis system-BFireSAS (Building Fire Simulation and Analysis System) is presented. By the assistance of BFireSAS, several potential fires can be specified and the evolvement process of a specific fire can be simulated. Based on the variable temperature during the fire evolvement process, what components are, in a relatively speaking, easily damaged and hence, in a high possibility, lead to the collapse of the corresponding gymnasium's structure can be estimated and obtained. The simulating process with the analyzed outputs can be displayed graphically. Therefore, as a case study, the BFIREASAS system had been selected to apply as a case study of evaluating the fire safety of Beihang gymnasium, a sports center.

In the following sections, the system architecture, data model, central controller, and a case study are described and discussed in details.

2 THE ARCHITECTURE OF BFIREASAS

BFIREASAS is designed as an integrated analysis system supported by a kernel database, two numerical analysis subsystems, and other several assistant modules. AutoCAD has been adopted for the platform of the system, on top of which two numerical analysis subsystems coupled with other assistant functional modules has been developed for the smooth analysis of computing structural safety of buildings in fire. Furthermore, a core database has been developed to support the data store and exchange of integrated BFIREASAS system and bridge the connection among the different modules.

The numerical analysis section is composed of FDS and ANSYS. FDS is used to simulate a temperature field induced by an artificial designed fire, whereas the software of ANSYS is responsible to analyze different structural impacted and damaged levels under varied designed firing temperatures and load cases.

FDS (Fire Dynamics Simulator), used to simulate a computational fluid dynamics (CFD) model of fire-driven fluid flow, numerically solves a form of the Navier-Stokes equations that are appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. The software is intended to provide a quantitative estimation of certain likely consequences of a fire. The simulated model is subject to a range of verification tests to assess the accuracy of the calculations [3].

ANSYS is a generally purposed finite elemental modeling package for numerically solving a wide variety of mechanical problems. These problems include static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electromagnetic problems. Moreover, ANSYS uses the finite elemental method to solve the underlying governing equations and the associated specific problematic- boundary conditions [4].

The other components of the system such as a user interface, a user model constructor, two model transformers, a central controller and a data manager have been developed for both current and future integrations with different software and professions expert system. These assistant modules are designed to construct and transform building model, manage and deal with data, control the process of program and solve the conflict between the diffident analysis tools, etc.

According to the operational flow of BFIREASAS graphically shown in Fig.1, the system is composed of three major parts, which working flows and responsibilities are described as follows:

(1). **PREPROCESS:** PREPROCESS is composed of User Model Constructor, Transformer 1, Transformer 2, and Fire Designer. It is designed to construct an effective and user-friendly computer model for the structure of a specified gymnasium, and this major part is independent to applications. One of the transformation processes from a user model to FDS model is operated and completed by Transformer 1, while the other transformation process from a user model to ANSYS model is performed by Transformer 2. The last component used to specify a potential fire based on the fire risk analysis is Fire Designer.

(2). **ANALYSER:** The main functions of ANALYSER involve the analysis of temperature field based on a designed fire and structural analysis based on temperature loads. It controls the running process and coordinates with the work sequence of CFD and FEA program associated to the integrated system; hence, one transformation process is necessary to be operated by Transformer 3 in order to transform from fire simulated results to temperature loads adopted by ANSYS.

(3). **VISUAL:** VISUAL is consisted of two visualization types, dynamic visualization and static visualization, for the display of analyzed results, as shown in Fig.3. In the BFIREASAS system, the VISUAL module developed based on OpenGL is programmed. VISUAL can import the static CAD model from AutoCAD, as well as read the output data used as dynamic visualization from FDS and ANSYS so

that users are able to view and observe the analyzed outcomes.

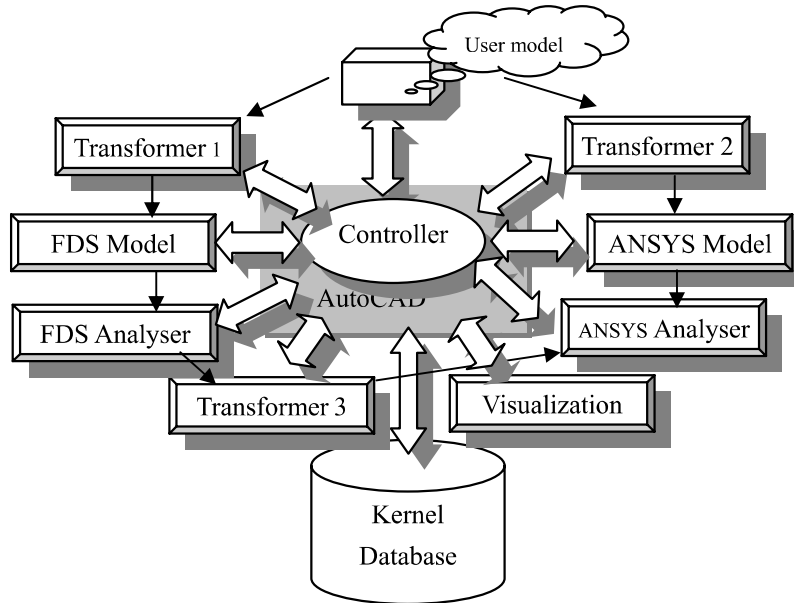


Fig.1 The architecture of BFIREASAS

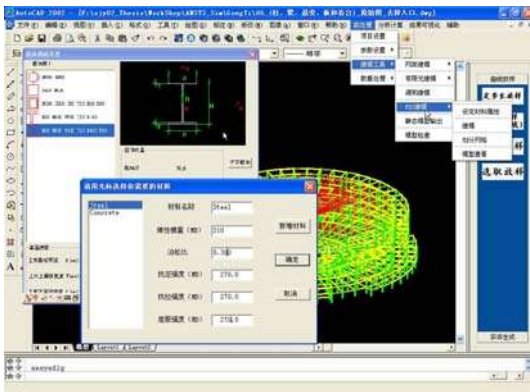


Fig.2 An uniform GUI

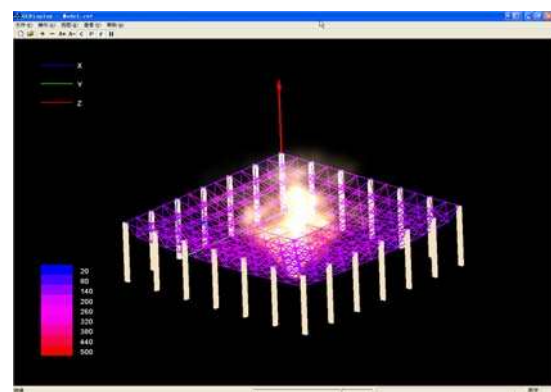


Fig.3 An VISUAL snapshot

The FDS model and ANSYS model are constructed for the computational algorithms. Users need not construct these two models by themselves, since they are automatically derived from the user model with the Transformer 1 or Transformer 2. The consistency and completeness of the data are docked during the creation of the FDS model or ANSYS model by one data mapping mechanism in kernel database. Therefore, when a user modifies the structure by modifying the user model, its related FDS model and ANSYS model are then modified automatically for users' requests of the structural analysis.

The efficiency of a computer system for the fire safety analysis is depended significantly on the structure of itself database. An important part of BFIREASAS system is the kernel database, in which large volume data are disposed and managed. Different subsystems also commute with each other through the kernel database. All data required for fire simulation and structural analysis are stored in the kernel database according to the class of temporal performance, which are associated with their specification in all models, but they can be used momentarily whenever users request a fire simulation or a structural analysis.

3 CASE STUDY

One of the selected gymnasiums for the competition venues of 2008 Beijing Olympic Games has been taken as a case study of BFIREASAS system. The studied building is a steel grid structure with a large span

that covers an area of 33×33 m with an overall height of 11 m from the top to the ground, whilst the center of the roof is a structure of a steel space truss with its steel grid structured left and right sides, supported by concrete columns around the building.

The assumption of the occurrence of a fire had been practiced in the gymnasium hall; thus, with being simulated the developing process of the fire, the temperature field within the gymnasium could be obtained. Since the fire resistant performance of steel structures is worse than that of concrete structures, this case study has mainly focused on the behavior of steel structures.

A fire scenario was designed as the follows:

- (1) Fire location is designed in the centre of the hall. The vertical distance is 11.2m from the fire location to the low chord of the grid structure.
- (2) Fire loads. Based on the analysis of the combustible material, the fire loads were designed as 8MW.
- (3) Fire development curve. The heat release rate is specified as a t2 curve and can be computed by adopting the formula denoted as the follow:

$$Q = \alpha \cdot t^2$$

Where Q denotes the heat release rate, α is the coefficient of fire increasing and t is the burning time.

- (4) The ventilation and active fire control devices are taken into account.

The above-described fire scenario is shown in Fig.4. Based on the fire simulation, the graph of the temperature-time curve is figured out in Fig.5

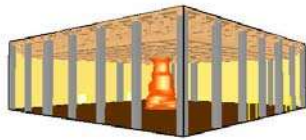


Fig.4 The fire scenario

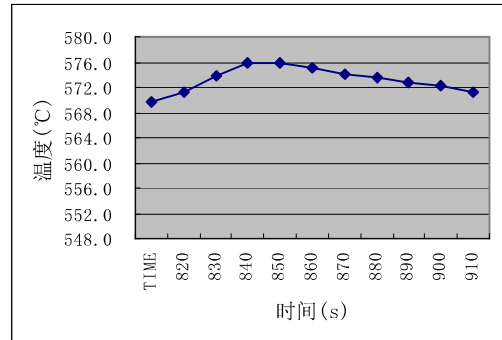


Fig.5 Heat Release Rate-Time curve

From the above figure, the peak of heat release rate occurs approximately at the 859th second and its corresponding highest gas temperature is 576°C at the location of the most dangerous components over the fire origin. Furthermore, the temperature distribution cloud image provides the significant information of the occurrence of varied temperature throughout the simulated building space. The temperature history in each structural member was firstly calculated based on the “true” environment temperature field calculated by the fire simulation described in the previous section. Fig.6 shows the temperature distributions state of steel grid structure affected at the peak time.

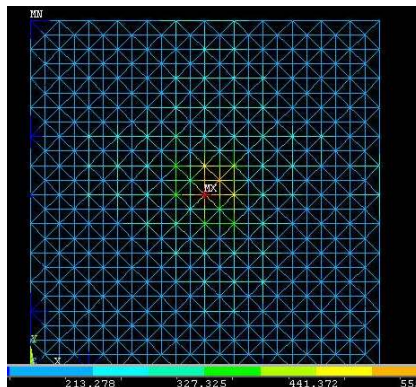


Fig.6 The temperature distributions state of steel grid structure

The structural response analysis was then carried out using 3D link finite-element to model the grid structure. The thermal load effects presently accounted for included the thermal expansion and reduction of

yield stress and modulus of elasticity at elevated temperatures, at which, both the yield stress and modulus of elasticity descended at different rates reflecting the capacity degradation due to the increasing temperature [5]. In addition, the large-deflection effects would happen at higher temperature as the yield strength was reached in the part of steel components. Thus, the geometric non-linearity was also taken into account.

The analysis was firstly carried out on the grid structure affected at the ambient temperature. The structure reached its resisting limit at the load factor, 1.48. At the service load level the midspan beam deflection was 58.4 mm, which is less than span/300's, 110 mm. The structure was well designed to satisfy both the ultimate and limiting serviceability states at the ambient temperature. By further combined thermal-force analysis, the safety status of the steel structure due to the fire was evaluated. Fig.6 shows the displacements of the roof's grid structure due to the thermal loads. From the analyzed results, we can acknowledge that the destruction of the grid structure occurred under the fire service loads. When the time exceeded 375 seconds after the fire was ignited, some members located in the center of the grid structure were broken down. When the time reached 900 seconds, most of the components were destroyed and consequently the grid structure collapsed.

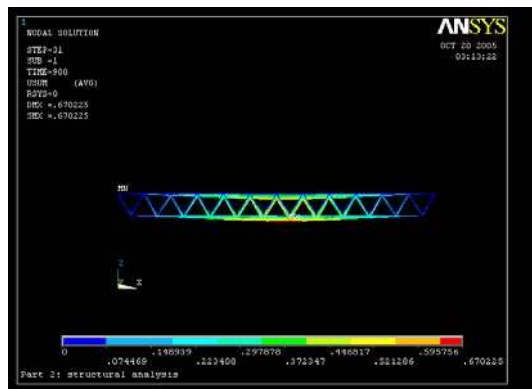


Fig.7 The displacements of grid structure

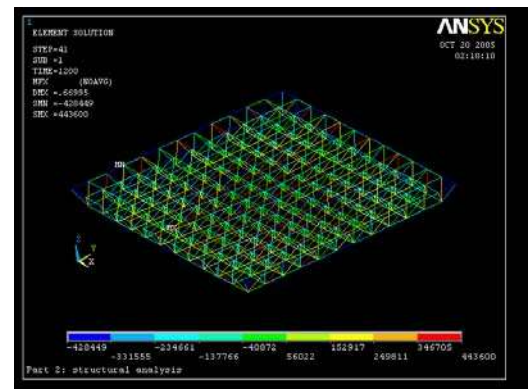


Fig.8 The force of grid structure

4 CONCLUSIONS

The results obtained in this paper show that the development of integrative simulation system of building fire safety offers the performance-based design of fire safety a new way and platform. On the basis of experiences gained in the development of BFIRESAS system, the following conclusions are finalized:

- It is possible to develop an integrated system for the safety evaluation based on the fire simulation and structural analysis;
- The development of a pre-processing module greatly simplifies the modeling and parameter-setting processes and relieves users from the burdens of modeling and inputting parameters. Application of new models transform technology in computer improves significantly the professional level of the system;
- The incorporated overall process of the analysis enables a more realistic and rational simulating process of a structural fire;
- The linkage of fragmented and uncoordinated information and data in the structural fire safety analysis has been implemented by developing an dynamic temporal database; The transfer and share of the information and data by means of an interactive data mapped protocol in central database ensure a smooth progress of the incorporated analysis process.

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