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Numerical simulation of aircraft crash on large-scale LNG storage tank

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ABSTRACT

The safety of the large-scale LNG (liquid natural gas) storage tank is threatened by the accidental or deliberate aircraft collisions, while the related studies are limited. At present, based on the missile-target interaction method, the dynamic damage and failure of the Chinese Yang Shan pre-stressed LNG storage tank against the impact of the commercial aircraft A320 are assessed numerically. Firstly, the fine FE (finite element) models of LNG storage tank and Airbus A320 aircraft are established with the program HyperMesh, which are validated by comparing with the classic IRIS (Improving the Robustness of Assessment Methodologies for Structures Impacted by Missiles) impact test of deformable missile as well as the modified Riera function, respectively. Then, the whole impact process of A320 aircraft on the LNG storage tank is reproduced with the explicit dynamic analysis program LS-DYNA. The impact force-time history, the deflection of the outer concrete tank, the effective plastic strain of the inner steel tank, et al. are obtained and discussed. Finally, the parametric analyses are performed to study the influences of the impact velocity, angle and position on the dynamic responses of the LNG storage tank. The conclusions are helpful for the design and safety assessment of LNG storage tank subjected to the potential aircraft collision.

1. Introduction

With the rapid economic development, the energy consumption is increasing tremendously in recent years. As a kind of clean and eco-friendly energy resource, the demand for LNG (liquid natural gas) has grown sharply [1,2]. Considering the flammable and combustible properties, LNG is usually stored in tanks (Fig. 1). More than eighty LNG terminals have been built around the world, and fifteen of which have been operated in China. Commonly, each LNG terminal consists of three to six storage tanks, which has the height of 40 m~50 m, diameter of 70 m~80 m and 160 thousand cubic meters stored LNG.

The September 11, 2001, terrorist attacks have raised attention to the research in the field of the disaster prevention and mitigation, especially to the study on the large-scale structure subjected to the collision of commercial aircraft. LNG storage tank is highly visible and easily identified as well as the explosion of the LNG would cause destructive damage, thus it has becoming one of the most valuable and potential target to terrorist attack. Although most of the design specifications and security codes for the LNG tanks are beginning to take into account the external impact effect [4–6], the studies on LNG storage tank subjected to the aircraft impact are relatively limited.

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Fig. 1. LNG storage tank [3]

Comparably, the safety of NPP (nuclear power plant) containment and its auxiliary buildings with storing the radioactive fuel and wastes against the aircraft impact has been drawn much more attention. Since the overall dimensions and structure of LNG storage tank are comparative to that of the NPP containment, the aircraft impact studies on the LNG storage tank can refer to the related achievements on the NPP containment.

Determination of the aircraft impact force is essentail and vital to examing the global response and local failure of the impacted target, Riera [7] early developed the function of aircraft impact force based on a one-dimensional rigid-perfectly plastic model, which is comprised by the crushing and inertia forces of the aircraft. In order to verify the accuracy of the above impact force function, Sugano et al. [8] performed the test of a prototype F-4 Phantom fighter against a rigid concrete wall. The test results confirmed that the original Riera function with a reduction coefficient 0.9 of inertial term, is a practical way of evaluating the impact force. Recently, by performing the scaled aircraft models impacting on the steel-reinforced concrete plates, Wen et al. [9] futher vertified the applicability of the modified Riera equation, and the variation range of the reduction coefficient should be located within 0.8–1.0.

Considering the huge cost to perform the prototype or large-scale aircraft impacting test, and the rapid development of high-performance computers, the numerical simulation has been becoming an feasible method to study this issue. Generally, there are two main numerical approaches to study the dynamic responses of structures under aircraft impact: (i) the loading-time history method (decoupled simulation): applying the loading-time history curve on the structure derectly [10–14] (ii) the missile-target interaction method (coupled simulation): establishing the FE models of aircraft and structure to reproduce the whole collision process [15–20]. Zhang et al. and Siefert et al. [15,21] vertified that the dynamic responses of the target in the coupled simulation are more serious than that in the decoupled simulation, and using the decoupled method is prone to dangerous for the practical structure design. Therefore, the missile-target interaction method is adopted in the following analyses.

In this aspect, Zhang et al. [15] established the FE models of NPP containment and A320 aircraft to study the protective performance of containment against the aircraft impact, and performed the parameter influencial analyses of impact condition and containment structural configuration. Lu et al. [16] built three Boeing-767 FE models with different fidelities to evaluate the influences of model fidelity on the impact force-time history curves and containment damage. It indicated that the over-simplified aircraft models would underestimate the impact forces, and the detailed model considering the internal structures was recommended in the coupled simulation. For the safety assessment of large-scale structure against aircraft impact, Kostov et al. [17] assessed the structural safety of A92 reactor building under aircraft collision, and it was derived that the external protective structures provided enough strength and ductility to prevent penetration. Thai et al. [18] examined the global, local and vibration safety by establishing both the FE models of the NPP containment and the surrounding auxiliary building, and it showed that the safety of the containment, excepting vibration safety, are ensured in all aircraft impact scenarios. Lee [19] developed the numerical models of a prestressed NPP containment and a B747 aircraft to study the global responses of containment under aircraft impact. It indicated that, the global responses differ significantly at different aircraft impact velocities and angles, while the tendon prestress and impact position affect the global response slightly. Thai et al. [20] estabished the FE models of a nuclear building and B767-400 aircraft to analyse the influences of the rebar ratio and arrangement on the structural behavior of nuclear buildings, it was obtained that the rebar ratio has significant effect on resisting aircraft impact and reducing the local damage.

Generally, the existing studies mainly focus on NPP containment subjected to aircraft impact, and the dynamic damage and failure of the LNG storage tank against the impact of commercial aircraft are assessed at present. Firstly, in Section 2 and 3, the fine FE models of Chinese Yang Shan LNG storage tank and Airbus A320 aircraft are established, which are validated by the prototype impact test [22] and the modified Riera function [8], respectively. Then, in Section 4, based on the missile-target interaction method, the nonlinear dynamic analyses of LNG storage tank subjected to the commercial aircraft impact are performed. Furthermore, aiming to provide some beneficial instructions for the design and assessment of LNG storage tank, the influences of various impact conditions (impact angle, position, velocity) are evaluated numerically.

2. Modeling and validation of LNG storage tank

In this section, the FE model of Yang Shan LNG storage tank located in Shanghai, China is established by using the modeling