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Experimental research on impact loading characteristics by full-scale airplane impacting on concrete target

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A R T I C L E I N F O

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A B S T R A C T

To investigate the impact loading characteristic during an airplane impacting process, an experiment of a full-scale airplane impacting on a movable concrete target was carried out, using a rocket slid propulsion facility. In the experiment, an on-off signal measurement system was used to monitor the airplane's impacting velocity; the total impacting process as well as the fragment dispersion of the airplane's wreckage were recorded by a high-speed photography system. Moreover, five accelerometers were installed on the reverse side of the target to measure its acceleration, from which the impact force-time history can be obtained. Moreover, two storage airborne accelerometers were placed on the airplane's tail to measure the acceleration history of the airplane, from which both the crushing force-time history and the crushing force distribution along the fuselage can be obtained. It is found that the measured impact force-time history is in good agreement with that calculated using the modified Riera impact loading model. This verifies the reliability of using the modified Riera model to predict the impact force acting on the target during the airplane impacting process, and the value of the correction coefficient α in the Riera model can also be determined. In addition, it is observed that, except at the initial moment, the ratio of the crushing impulse to the impacting one remains roughly a constant, which makes it possible to further simplify the Riera model by getting rid of the crushing force distribution curve.

1. Introduction

Since the three major nuclear accidents (i.e., the Three Mile Island-2 in 1979, the Chernobyl disaster in 1986 and the Fukushima accident in 2011.) and the “9.11” attack, researchers have been carrying out extensive studies on the safety and security of nuclear power plant containments under malicious impact of large airplanes (Hua and Mi, 2014). Historically, to determine the impacting force acting on the impact surface of a nuclear plant containment during an airplane impacting process, Riera (1968, 1980) proposed at first a theoretical model to predict the impact force history. In the Riera model, during the total impacting process, the airplane is assumed to be separated into the crushed and the uncrushed portions, and the airplane crushing occurs only on the impacting interface between the airplane and the target. Moreover, on the impacting interface, a buckling force decelerates the uncrushed portion as a rigid body, and the material behaviors of the fuselage and the concrete target are assumed to be of rigid-perfectly plastic and rigid, respectively. Later, taking into account the fragments dispersion characteristics of the destroyed airplane, the influence of debris flight angle and fuselage material characteristics, Wolf et al. (1978), Bahar and Rice (1978), Drittler and Gruner (1976) and Hornyik (1977) further verified and revised the Riera model and developed a so-called modified Riera model. Under the assumption that the length of the crushed portion is zero, Bahar and Rice (1978) suggested that the value of the correction coefficient α should be equal to 0.5. Experimentally, Sugano et al. (1993a–c) performed a full-size airplane impact test, the only one up to now, using the F-4 Phantom, and the impact force-time history was obtained. It verified the reliability of the modified Riera model and suggested that the value of the correction coefficient α in the modified Riera model is about 0.9. In addition, many numerical simulations for large airplanes such as the Boeing and Airbus impacting on nuclear power plant containments were carried out to analyze the global or the local structural response of the concrete containments. The impact force-time histories were also obtained via the simulations, based on which some schemes for strengthening the safety and security of nuclear containments are proposed (Arros and Doumbalski, 2007; Frano and Forasassi, 2011; Frano and Stefanini, 2016; Itoh et al., 2005; Jeon et al., 2012; Kostov et al., 2014; Kukreja,

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2003).

As is well known, a precondition for calculating the impact force-time history using the Riera model is to predetermine the crushing force distribution along the fuselage. To estimate the crushing force distribution of a complicated structure, Gerard (2012) proposed the following approach: one can separate the complicated structure into typical sub-structures (such as the angle-shape, the plate, the square tube, the T-shape, the cruciform, the I-shape, etc.), then the total crushing force of the complicated structure can be obtained by appropriately combining that of the sub-structures. However, it is difficult to determine a reasonable segmentation for an airplane because of its extremely complicated structure. Although much aforementioned research has been done to investigate the impact loading characteristic of a large airplane impacting upon a concrete target, most of them are based on numerical simulations or the experimental data measured from small airplane's models. Therefore, it is necessary to obtain more experimental data for a full-sized airplane in order to verify the reliability of the impact loading models. In this paper, a full-scale airplane impact test is designed and carried out to provide more reliable experimental data for the nuclear safety research. Based on that, the impact loading characteristic is investigated and further implications are discussed.

2. Test set-up

Using a rocket propulsion facility, a test system for a full-scale J-6 airplane impacting on a movable concrete target at the striking velocity of 200 m/s is carried out to investigate the impact-force characteristic. An on-off signal measuring system and a high-speed photography system are used to measure the airplane's velocity at the initial moment. The total impacting process and fragment dispersion of the airplane's wreckage are recorded also by the high-speed photography system. Moreover, five accelerometers were installed on the reverse side of the target to measure the motion of the target, that is supported on a roller-bearing sliding track, to get the impact force-time curve, and two airborne storage accelerometers are placed on the airplane's tail to measure the accelerations time history. The layout diagram of the test system is shown in Fig. 1.

A full-scale J-6 airplane (Fig. 2) with the empty weight of 5.28 t (including fuselage, ejection seat, main wings, engines, empennage and swept-back tail, but with the pitot tube and the undercarriage removed) is supported on a second-stage rocked sled for feasible propulsion. The length, wingspan, and height of the airplane are 12.54 m, 9.00 m and 3.89 m, respectively. Moreover, both the attached product sled and the

Fig. 2. Full-scale J-6 airplane.

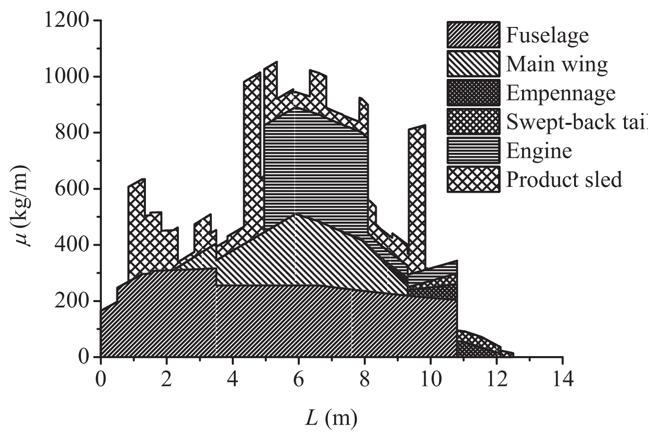

Fig. 3. Mass distribution of the J-6 airplane in the test.

airborne storage accelerometers installed on the airplane's tail will not be separated from the fuselage during the impacting process, and the total weight of the airplane under the test condition is 6.71 t. In addition, the airplane's mass distribution along its longitudinal direction is shown in Fig. 3.

The C40-concrete target used in the test measures 7.0 m wide, 5.5 m high and 1.8 m thick (Fig. 4). The average density and the practical measured compressive strength are 2.61×10^3 kg/m^3 and 44.3 MPa, respectively, where the specimen used to measure the concrete's strength is a cube of 20 × 20 × 20 cm. Because of the small ratio of the thickness to the height of the target, two rear supporting structures are used to prevent the target from toppling after impact, and the size of each rear supporting structure is 3.0 × 1.2 × 0.4 m. Moreover, to reduce the moving frictional resistance of the target to meet requirements of the test measurement, a roller-bearing sliding system (Fig. 5) is

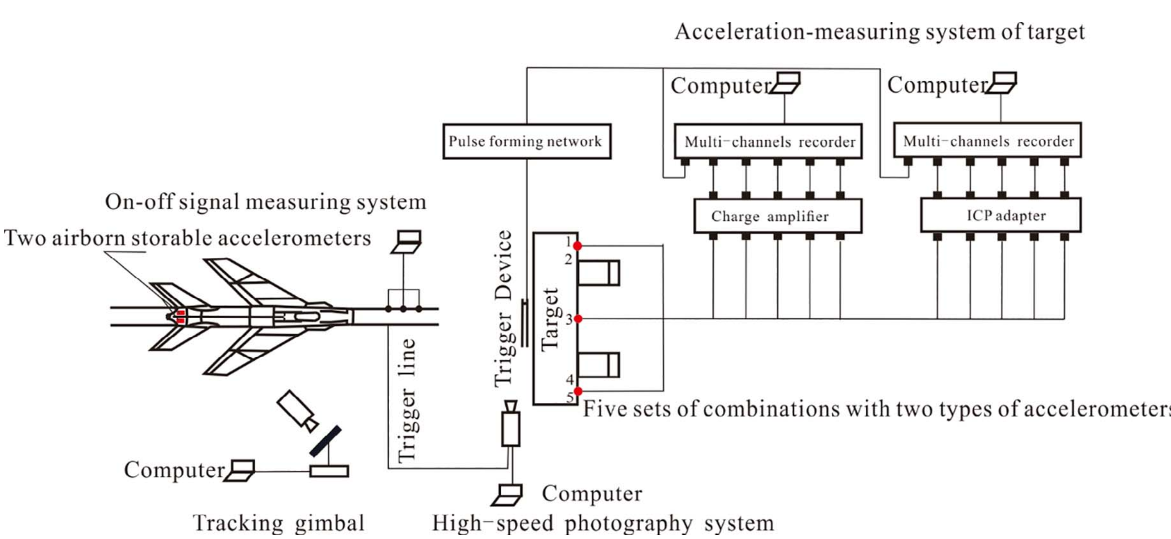

Fig. 1. Layout diagram of the test system.