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Damage assessment of nuclear containment against aircraft crash

Mohd. Ashraf Iqbal*, Md. Rehan Sadique, Pradeep Bhargava, N.M. Bhandari

Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee 247667, Uttarakhand, India

HIGHLIGHTS

- Damage assessment of nuclear containment is studied against aircraft crash.
- Four impact locations have been identified at the outer containment shell.
- The mid of the total height has been found to be most vulnerable location.
- The crown of dome has been found to be the strongest location.
- Phantom F4 caused more localized and severe damage compared to other aircrafts.

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ABSTRACT

The behavior of nuclear containment structure has been studied against aircraft crash with an emphasis on the influence of strike location. The impact locations identified on the BWR Mark III type nuclear containment structure are mid-height, junction of dome and cylinder, crown of dome and arc of dome. The containment at each of the above locations has been impacted normally by Phantom F-4, Boeing 707-320 and Airbus A320 aircrafts. The loading of the aircraft has been assigned through the corresponding reaction-time response curve. ABAQUS/Explicit finite element code has been used to carry out the three-dimensional numerical simulations. The concrete damaged plasticity model was used to simulate the behavior of concrete while the behavior of steel reinforcement was incorporated using the Johnson–Cook elasto-viscoplastic material model. The mid-height of containment has been found to experience most severe deformation against each aircraft. Phantom F4 has been found to be most disastrous at each location. The results have been compared with those of the available studies with respect to the containment deformation.

1. Introduction

The air traffic in the last two decades has increased many folds imposing increased risk of accidents. An accidental or deliberate hit of aircraft may lead to local or global failure of critical structures. Particularly the nuclear containment structures are highly vulnerable to such attacks due to the immediate and long-term aftereffects associated to their failure (Abbas, 1992). Hence, the damage assessment of the existing nuclear containment structures needs a careful investigation against such unpredictable events.

The nature of problem is highly complex as a matter of fact that the two interacting bodies demonstrate different mechanical behavior and damage response due to their distinct stiffness and material properties. In order to avoid these complexities Riera (1968) uncoupled the problem by obtaining the reaction time response curve of Boeing 707-320 aircraft against a flat rigid target assuming conservation of momentum. The subject was further extended by Riera (1980) through the incorporation of target flexibility and oblique incidence in the reaction time response curve. Abbas et al. (1996) also concluded that the containment thickness of 1.2 m will be sufficient to resist the horizontal crash of Boeing 707-320. However, the dome of the containment will not remain safe if the thickness is reduced to 0.6 m (Paul et al., 1993). The strike of Boeing 707-320 near the junction of dome and cylinder has been found to damage the containment locally but no significant deformation was noticed at the crown and at the region 180° azimuth from the position of impact (Kukreja et al., 2003; Kukreja, 2005).

The studies in the literature led to the conclusion that a fair estimate of the response of containment can be obtained with the help of reaction-time response as the loading criterion. Further, the junction of dome and cylinder has been significantly studied as a location of impact. However, the other locations at the dome

* Corresponding author. Tel.: +91 1332 285866/9897379426.
E-mail addresses: iqbal_ashraf@rediffmail.com, iqbalfce@iitr.ac.in (Mohd.A. Iqbal), rehan.sadique@gmail.com, mrsaddce@iitr.ac.in (Md.R. Sadique), bhpdpfce@iitr.ac.in (P. Bhargava), nmbcefce@iitr.ac.in (N.M. Bhandari).

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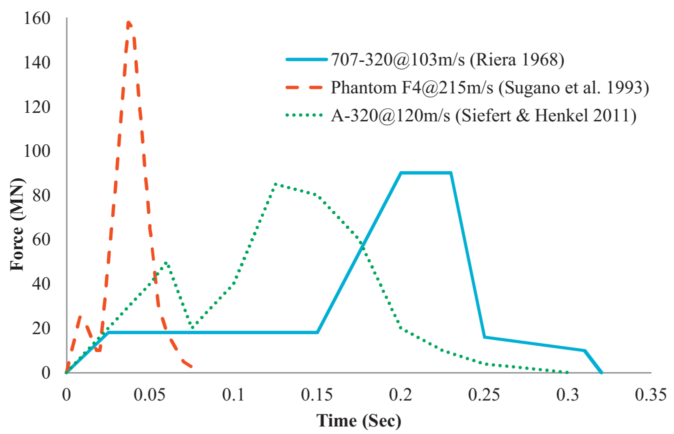

Fig. 1. Reaction time response of the aircrafts.

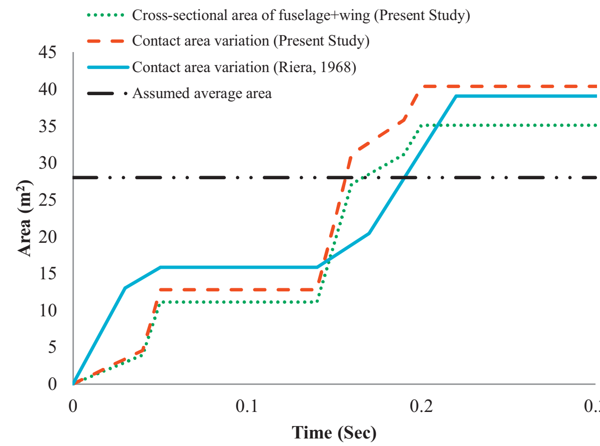

Fig. 2. Variation in area of impact for Boeing 707-320.

and cylinder of the containment have rarely been explored in the open literature. In the present study four different locations of aircraft strike have been identified including the junction of dome and cylinder. At each impact location the global and local damage of the containment has been estimated against three different aircrafts and the results thus obtained have been compared and discussed. The following strike locations have been identified:

(i) Center of overall height.
(ii) Junction of dome and cylinder.
(iii) Arc of dome.
(iv) Crown of dome.

2. Impact loading

Impact analysis of aircraft crash on containment structure through Riera's approach has been accepted widely in literature. The reaction-time response provides the reaction obtained from the flat rigid surface against the crushing aircraft with respect to time. The reaction time response can be determined through analytical expression with the help of the crushing strength and mass per unit length of the aircraft (Riera, 1968; Abbas et al., 1995). It can also be derived through numerical simulations performed on available finite element codes (Siefert and Henkel, 2011). A full length experimental test has been performed by Sugano et al. (1993) wherein the Phantom F4 aircraft was hit on 3.6 m thick reinforced concrete wall to obtain its response. The reaction time response obtained through this experimental study confirmed the existing "Riera approach". The same methodology has been adopted in the present study to define the aircraft loading on the containment, see Fig. 1.

The loading of aircraft was assigned to the containment at a given constant area equivalent to the average of total cross-sectional area of fuselage and wings. In general the contact area during the interaction of a projectile and target depends on the target curvature incidence angle and velocity of projectile. The contact area during an aircraft crash varies in size and shape with respect to time. Initially it is circular until the strike of wings, and thereafter bird shaped. As such the cross-section of fuselage reduces near the tail, however, it is seen that the tail generally does not come in contact. The objective of the analysis decides the precision to which the contact area is calculated. If the objective is to study the local damage caused by the different parts of the aircraft then the precision in the determination of contact area is very important. However, when the purpose is to evaluate the global response of the containment, simplifications can be made for the determination of contact area keeping in view the degree of complexity involved in the problem. The maximum fuselage diameter for Phantom F4, Boeing 707-320 and Airbus A320 is 2.8 m, 3.76 m and 3.7 m respectively. The wing span is 12 m, 45 m and 34 m respectively. Riera (1968) calculated the probable interface between a Boeing 707-320 aircraft crashing normally on a spherical surface 33.5 m in radius. Thus an average contact area was proposed to be 37.16 m^2 for flat surface and 20.44 m^2 for a curved surface. For Phantom F4 the same was considered to be 7 m^2 against a flat surface, Riera (1980). For the same aircraft however, Sugano et al. (1993) experimentally obtained an average contact area of 10 m^2 against a flat concrete surface neglecting the contribution of wings. However, Abbas et al. (1995, 1996), assumed an average contact area of impact 28 m^2 for Boeing 707-320, Phantom F4 and FB 111 against a BWR nuclear containment of 42 m diameter. Gomathinayagam et al. (1994) and Kukreja (2005) later assumed same contact area (28 m^2) for different aircrafts considered in their studies.

To resolve the uncertainty of impact area, a fresh calculation has been performed in the present study. The detailed dimensional drawings of Boeing 707-320 provide the description of net cross-sectional area at any point along the length of the aircraft (Boeing Commercial Airplanes). Abbas (1992) plotted the variation of impact load for Boeing 707-320 with respect to both time and distance from the nose of aircraft. With the help of this data an effective cross-sectional area verses time graph of Boeing 707-320 is plotted for an incidence velocity 103 m/s, Fig. 2. However, it has been reported by Yang and Godfrey (1970) that the contact area between the aircraft and target increases by 10–15% as compared to actual cross-sectional area of aircraft. Therefore the cross-sectional area calculated above was increased by 15% to obtain the contact area for Boeing 707-320 aircraft. The contact area versus-time curve thus obtained has been found to have close correlation with that of the curve proposed by Riera (1968), Fig. 2. The average area calculated from Riera (1968) approach is 28.25 m^2 while that obtained from the present investigation is 28.8 m^2, Fig. 3. As the maximum diameter of fuselage for Airbus A320, Boeing 707-320 and Phantom F4 is nearly equivalent (3.7 m, 3.0 m and 2.8 m respectively) hence the average contact area has been considered to be same (28.8 m^2) for each aircraft with diameter ⌀ 6 m. The reaction force was converted to pressure, by dividing with the contact area (28 m^2), and assigned to its respective location, see Fig. 3. The contact area (28 m^2) was the area corresponding to the full containment. However, in order to economize the problem half of the containment has been modeled and thus the symmetry has been duly incorporated in the application of the load.

In the present study four impact locations have been identified to study the behavior of the nuclear containment building. "Location A" is at containment wall 33.5 m above the foundation level.