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Research Article

Dynamic Response of the Single-Layer Kiewitt-8 Reticulated Dome Subjected to the Airplane Crash

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Abstract: Aiming to investigate the dynamic response of the single-layer Kiewitt-8 reticulated dome subjected to the airplane crash, events of aircraft impact to the single-layer kiewitt-8 reticulated dome were simulated by using the 3D ANSYS/LS-DYNA. Impact loadings were carried out respectively by the Riera force history method and by modeling a real plane similar to Bombardier Challenger 850. Simulation results indicated that the impact by modeling a real plane directly is more reasonable than the method by Riera force history. Furthermore, a series of different impact events were added to investigate the effect of impact position and the flight attitude of the airplane. It was found that at a certain initial condition, the impact position and the flight attitude can change the damage mode of the dome structure.

Keywords: Finite element model of a small airplane, riera force history, single-layer kiewitt-8 reticulated dome

INTRODUCTION

Shock dynamics mechanics of large space structure subject to the airplane crash has gained researchers more attention since the occurrence of the 9/11 incident in Fig. 1. Large space structures are usually such symbolic buildings of social and economic importance. It is very necessary and beneficial to investigate the dynamic behavior of large space structures.

In fact, study of airplane crash to the building structures as a subject of academic research and practical interest had been approached since the 70's. At the beginning, this study was mainly focused on the nuclear facilities against the airplane impact (Abbas *et al*., 1996; ASCE, 1980; Chelapati and Kennedy, 1972). And crashworthiness evaluation was ascertained mainly by a combination of tests and analytical methods. But due to the complexity of the airplane crash, tests and analytical methods is not feasible to evaluate the detailed information and the tests are at the expense of great wealth

Alternatively, with the arrival of faster computers and more efficient explicit finite element codes, the detailed crashworthiness studies gained the advanced development. Until now, for the numerical simulation method of the airplane crash, there exists be two methods, as described in the following:

- **Riera force history method:** Idealized "smooth" force curve versus loading recorded from the plane model impacting rigid target in Fig. 2. The impact load is carried out by the Riera force history method (Jorge, 1968, 1980).

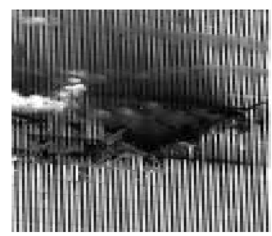

Fig. 1: A 'clean' cut driven by the wings of a boeing 767 into the facade of the north tower

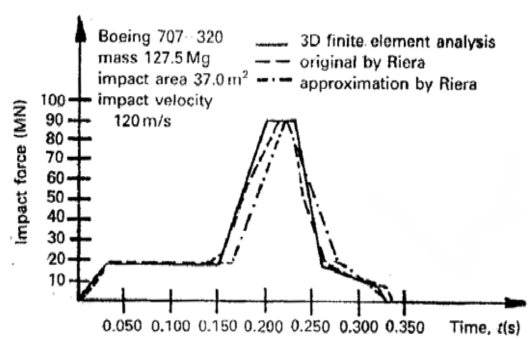

Fig. 2: Comparison results of riera (Arros and Doumbalski, 2007)

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- **The real modeling method:** The impact process is conduct by modeling a real airplane impacting the target (Omika and Eiji, 2005; Arros and Doumbalski, 2007).

On the other hand, under accidental impact, lots of previous studies and investigations concentrated mainly on the frames and high-rise buildings and nuclear facilities, typical researches could be found in several works (Bonder and Symonds, 1979; Zhou *et al*., 1989; Samuel, 2003; Lynn and Isobe, 2007). Yet, the work on the reticulated domes is relatively few. In this study, the case with the airplane impact to the single-layer Kiewitt-8 reticulated domes was investigated by a series of 3D simulations. The impact process was carried out by the Riera force history method and the real modeling method respectively. And further, the factors including the impact position and the flight attitude of the airplane were analyzed by the real modeling method, where the Bombardier Challenger 850 was adopted.

MATERIALS AND METHODS

Airplane crash by riera force history curve: In this section, using the Riera force history curve, the dynamic response of the single-layered kiewitt-8 reticulated dome was investigated. The Riera force history curve is shown in Fig. 3, which was based on the event that Boeing 707 impacts the rigid target (Jorge, 1968, 1980). The airplane mass is 127.5 T, the impacting velocity is 120 m/s.

Horizontal loading and normal loading were conduct, which were labeled with A and B, as shown in Fig. 4. Single node impacting and dual nodes impacting styles were analyzed considering with the airplane size.

Final damage was shown in Fig. 5. Based on the analytical results of the reference (Fan *et al*., 2008, 2010), it was found that for horizontal loading the dome mainly happens to the global damage, part members are broken. The affect zone of dual nodes impacting is slightly larger than that of single node impacting. However, for the normal loading, a different damage mode is found. The damage zone becomes larger. Especially, for the dual points impacting, a global damage mode is found as shown in Fig. 5d.

As discussed above, the damage mode exhibits a difference between horizontal loading and normal loading. For adopting Riera loading history curve to simulate the dynamic response of the airplane crash, there are mainly the following factors constraining the application of this method:

- Irregulary of the airplane geometry contributes to increase the error of the analyzed results.
- The Riera loading history curve was gained by studying the airplane impacting the rigid wall, which is different to that of the airplane impacting the real structure.

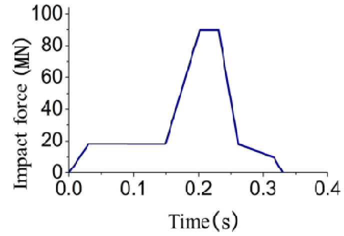


Fig. 3: Riera force history

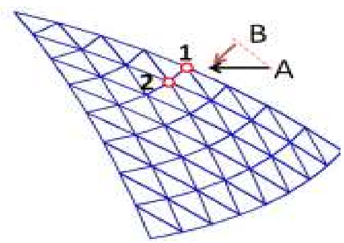
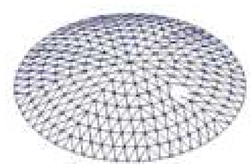
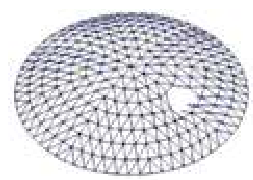


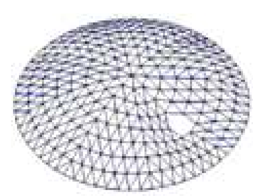
Fig. 4: Sketch of impacting points and impacting attitude



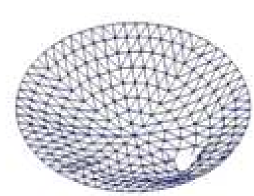
(a) Horizontal loading for point A



(b) Horizontal loading for point A and B together



(c) Normal loading for point A



(d) Normal loading for point A and B together

Fig. 5: Final deformation results by using the riera force history curve

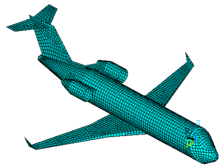
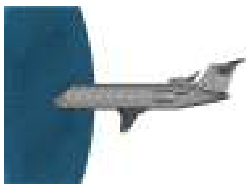
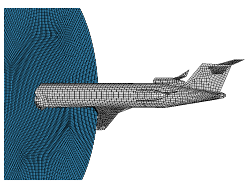


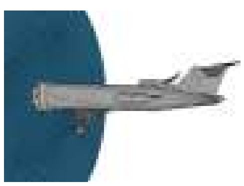
Fig. 6: Finite element model of bombardier challenger 850



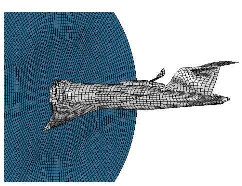
(a) 0 s



(b) 0.02 s



(c) 0.05 s



(d) 0.1 s

Fig. 7: The deformation process with impacting the rigid wall

- At the impact progress, the airplane itself happens to the deformation.

Thus, aiming to gain the more accurate analytical result, it is very necessary to simulate the real airplane. In the following section, the real airplane will be simulated to study the dynamic response of the airplane impacting the single-layer kiewitt-8 reticulated dome.

AIRPLANE CRASH BY MODELING THE REAL AIRPLANE

Generally, it is difficult to find the detailed parameters of an airplane. Thus, considering the dome

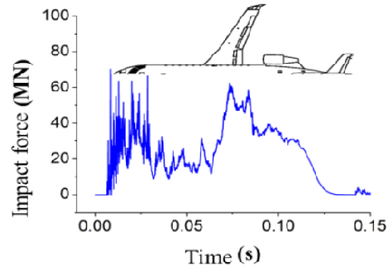


Fig. 8: Time history curve of average impact force with impacting the rigid wall

size and the key factors including mainly the mass distribution and the overall shape, the Bombardier Challenger 850 was chosen as the analytical target. The finite element model is given in Fig. 6. The airplane total length is 27 m, the wingspan is 21 m and a maximum gross take-off weight is approximately 24.5 T.

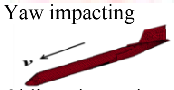
Analysis of “taylor” impact: Aiming to validate the relatively reasonability of the finite element model, the event with the airplane impacting rigid wall was firstly conduct. The deformation process of the airplane is given in Fig. 7. It is found that there is a liked folded deformation in the front part of the airplane, which is very similar to the analytical results of Rieta. And for this small airplane, the power engine is at the end of the airplane and the fuel tank is positioned in the airplane. This indicates that the mass center is closed to the back of the airplane and the mass distribution is relatively uniform in the front part of the airplane. Corresponding to the history curve of the average shock force (Fig. 8), it makes sense that the shock force peak is located in the back part of the curve. Further, in light of the variation trend of the average shock force with time, there is a certain similarity with the Riera force history. Thus, based on the deformation and shock force feature of the airplane, it could be concluded that using the finite element model of Bombardier Challenger 850 above given to investigate the dynamic response of the single-layer Kiewitt-8 reticulated dome is feasible.

Analysis of airplane crash: Based on the dome model descripted in the above section, the event that the small airplane of Bombardier Challenger 850 impacting the single-layer Kiewitt-8 reticulated dome was analyzed in this section, where the impact velocity with 100 m/s was involved.

It is necessary to point out that the damp effect was considered by applying the Rayleigh damp, where the mass proportional damp is set to 0.765 and the stiffness proportional damp is 5.197×10^{-5}.

In the study, three kinds of impacting styles were involved, which are the horizontal impact, the yaw impact and the oblique impact, as given in Table 1. For

Table 1: Impacting positions and impacting attitudes

Series no.	Impacting styles	Impact velocity (m/s)
Impact 1	 Horizontal impacting	Horizontal: 100 Vertical: 0
Impact 2	 Yaw impacting	Horizontal: 98.0 Vertical: 20
Impact 3	 Oblique impacting	Horizontal: 86.6 Vertical: 50

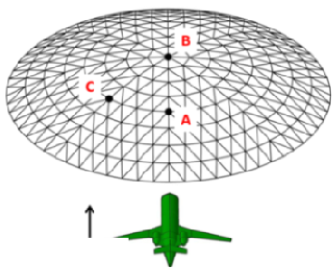
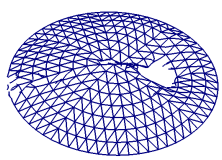
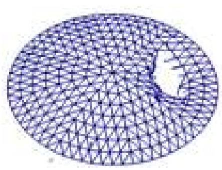


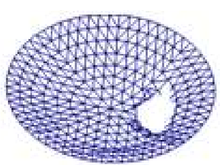
Fig. 9: Sketch of the impact positions



(a) Impact 1



(b) Impact 2

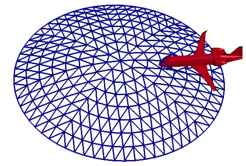


(c) Impact 3

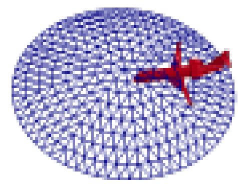
Fig. 10: Final damage results of three impacting styles for point A

an airplane crash, the airplane is generally under and forward of the impacted dome before the impact in Fig. 9, this demonstrates that probability of impacting point A is maximum, which is the key case investigated. Meanwhile, for the yaw impacting, Point B and C will be analyzed.

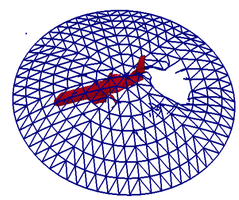
Point A: Firstly, the results with three impacting styles impacting Point A respectively were given in Fig. 10.



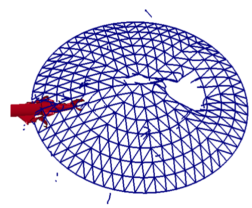
(a) 0.1 s



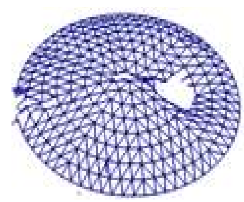
(b) 0.2 s



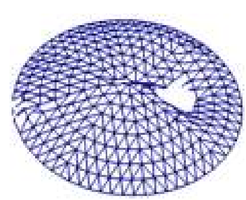
(c) 0.5 s



(d) 0.9 s



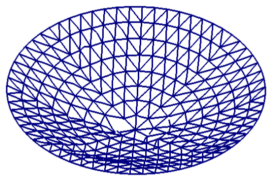
(f) 1.5 s



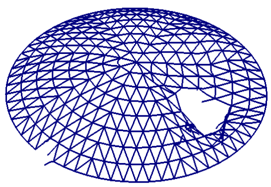
(g) 10 s

Fig. 11: A typical deformation process: Impact 1 for point A

Clearly, the dynamic response among three impacting styles is different. According to the study of Fan *et al*.



(a) Point B



(b) Point C

Fig. 12: The final damage results of the cases with the yaw impact to the point B and C, respectively

(2008) and Fan *et al*. (2010), the damage mode resulting from the horizontal impact and the yaw impact belong to the local damage. Reversely, the oblique impact happens to the global damage. A typical deformation process is given in Fig. 11.

Point B and C: In order to investigate the effect of impact points to the dome damage, for the yaw impact, two additional points (Point B and C) were considered, as shown in Fig. 8. The analytical results were given in Fig. 12. From the final deformation of the dome structure, it could be concluded that the case with Point B happens to the global damage without the airplane perforation, but for the case with Point C the damage is local with the airplane perforation.

Thus, the analytical results above given indicates that the flight attitude of the airplane before the impacting and the impact positions have a large influence to the damage mode of the dome structures. It is necessary to point out that in the present study, the influence is only investigated and analyzed qualitatively, more detailed study will be approached in the future study.

CONCLUSION

Aiming to investigate the dynamic response of the single-layer Kiewitt-8 reticulated dome subjected to the airplane crash, a series of 3D numerical simulations by LS-DYNA software were conduct. In the present study, impact loading of the airplane crash was reached by two methods, one was that the Riera force history curve was applied, the other was that the impact was carried out by modeling a real plane similar to Bombardier Challenger 850. The analytical results demonstrated that the second method is superior to that of the first method and it was found that the flight attitude of the airplane before impacting and the impact position are the key factors to the final damage of the dome structure. The results gained in the present study are very beneficial to control the damage level for the airplane captain.

ACKNOWLEDGMENT

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