Validation of aircraft FE model for impact analyses

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1 ABSTRACT

The paper deals with the comparison of calculation based on Riera model and calculation of aircraft impact through FEM interaction of two bodies (aircraft and building). Because it is not possible to create detail and accurate FE model of aircraft due to necessary simplification of the model as well as unavailability of the detail plane structure documentation, the check of adequacy of aircraft model is important. Riera model was chosen because this model is general accepted and has been validated by tests.

2 INTRODUCTION

After tragic experience with terrorist attacks in USA, in which large passenger aircraft have been used, safety of sensitive targets (and therefore also safety of nuclear devices and buildings) has become more important. Request for evaluation of this risk caused incorporation of large aircraft impact into design analyses. The loads caused by aircraft crash can be introduced into the calculation of response of impacted building in several ways. In case of perpendicular hits to relatively rigid structures the published loading curves can be often used, which are determined based on experimental tests or based on simple computing models, e.g. Riera (1968). When the hit structure is not rigid or has articulated surface, the forces acting between structure and aircraft will differ. In such case it is necessary to use an adequate computing model of aircraft and the task need to be resolved for each case individually as interaction of both bodies.

Structure of a large aircraft represents a complex structure compound of many components and thus a reasonable level of the computing model simplification is necessary to be selected. From the viewpoint of an aircraft crash into the building it is not necessary to model the aircraft construction in detail, the FE model doesn’t need to replace the computing plane models used by plane producer. For computation of an impact, the most important task in aircraft modelling is to model adequately the layout of mass and to include in the model rigidity of main components of the aircraft structure. Some simplification is possible by means of construction components substitution (e.g. the aircraft fuselage consists of horizontal and vertical reinforcements and covering) by a relevant macro-element having adequate mass and rigidity, but from the computation process viewpoint it represents simplification. In case of the already mentioned aircraft fuselage, application of shell elements with area mass corresponding to the fuselage together with substitute rigidity corresponding to bending and membrane rigidity of reinforcement and covering seems to be advantageous. In this way it is possible to simplify complicated structure of the aircraft up to relatively simple computing model, which provides a sufficient rate of reality without requirements on computing performance. On the other hand, application of a simplification increases requirements on verification of such computing model accuracy.

Computing model verification is possible by means of comparison of computing model response and the aircraft construction for aircraft structure design loads. This approach to given issue requires close cooperation with the aircraft manufacturer and it is not easy to ask for a helpful cooperation aircraft manufacturers and designers with anybody who establishes any simplified model of their aircraft. With regard to the fact, that for computing of impacts even a very simplified model of aircraft suits, some well known, already published results of air crash computation can be used for assessment of given computing model adequacy. As an appropriate reference solution of aircraft crash impact, Riera approach to
computation of force, affecting a rigid barrier, seems to be well applicable. This computation is generally considered as accurate enough from the given issue viewpoint.

In case of the computing model presented here, the impact of Boeing B747-400 was expected as a result of intended act. This aircraft presents the greatest civil aircraft commonly used today. This aircraft type is a long-range aircraft and consideration of this aircraft type in safety analyses is conservative from the point of view of its mass as well as from the point of view of fuel quantity. The plane velocity of 150 m/sec in instant of hit was determined. This velocity was chosen with regard to relatively small dimensions of NPP buildings thus considering necessity to perform fine-tuned flight corrections in small height; therefore the flight velocity is limited.

3 MODEL DESCRIPTION

Computation of effecting force acc. to Riera approach is based on the distribution of the aircraft construction mass and rigidity alongside its length. By means of analytic solution it is then possible to determine in a simple way the time history of the resulting total force through which the crashed aircraft acts on the solid barrier. The total force is given by sum of a force caused by impact of mass in specific instant and a force arising in the still compact structure of the aircraft due to a braking rate of the remaining part of the plane (this force is limited by the maximum force, which the unbroken part of the aircraft is able to transfer). As an input to Riera computation of loading force it is necessary to define distribution of mass and rigidity within the whole length of the aircraft. Distribution of mass alongside the aircraft length was determined for single sections, in which a constant mass of each running meter of the aircraft length is supposed. These sections were selected in such a way, that in each section the aircraft geometry, aircraft structure rigidity and mass distribution were similar. The course of rigidity alongside the aircraft length was determined similarly, estimation of aircraft structure rigidity was based on distribution of buckling load presented in Riera (1968) adapted to dimensions of evaluated B747 structure.

The FE model calculations were performed by the Abaqus FEM code taking into account non-linear material behaviour and full contact of all parts of model. The explicit dynamic analysis was used and the resistance of the structure was evaluated based on reaching the failure state of material in elements. The model represents a rigid wall and aircraft structure – see Figure 1. The aircraft model covers the main structure parts of aircraft – fuselage with cargo, main and upper decks, front and rear pressure bulkheads and central fuel tank; wings with main beams and engines on pylons and tail surfaces – see Figure 2. Laminated shell elements were used in the model. Material parameters correspond to the aluminum alloys (defined using Abaqus classical metal plasticity material model). The total weight of the aircraft model corresponds to the maximum takeoff weight 397t. The rigid wall is composed from mass less surface (one row of solid elements ensuring contact surface) connected by rigid links to one node, which is supported by spring element. The flexibility of spring element improves numerical stability and smoothness of force history. In Figure 6 there is a comparison of results for two different spring stiffness – stiffness 1x10^6 kNm (maximal displacement up to 0.5m) and 1x10^7 kNm (maximal displacement up to 0.05m). The comparison shows increase of “nois” in force history while the global shape of curves is close.

4 CALCULATION RESULTS

A comparison is performed both for the total force having the aircraft affecting a rigid barrier and for the force effect caused by impacted mass only (aircraft structure rigidity is minimized). A comparison of total force histories calculated by Riera approach and by FE model is in Figure 3. Maximum peak force and area under the curve is similar but there is a difference in initial phase where the force calculated by FE model is higher while time of maximal peak is shorter. Influence of stiffness on total loading force is demonstrated in Figure 4 for Riera approach and in Figure 5 for FE model. In case of Riera approach, the effect of stiffness is small at the beginning and significant influence of stiffness on total force is in time of impact middle, the most solid, part of aircraft. In case of FE model, the effect of stiffness is evident in all history in spite of the fact that the stiffness of aircraft structure was only decreased (not eliminated) due to necessity to retain computation stability. The comparison of influence of stiffness on total loading force in both cases along with comparison total loading forces for both method of calculation shows that it would be advisable to re-evaluate calculation of aircraft structure stiffness in case of Riera approach. The re-evaluation requires to
discuss the effects of material nonlinearity and influence of buckling under rapid dynamic loading with specialists on aircraft structure design.

In general, the comparison of Riera approach and results of FE model demonstrated the applicability of such comparison and possibility to validate complex FE models by comparison with simple analytic approach. In comparison with Riera approach, application of computing FEM model in combination with general contact between mutually interfering elements of the model allows to analyze easy even an impact into a soft barrier, or into a barrier, which is not plane (e.g. broken or curved barrier – containment cylindrical surface). Verification of the whole model by comparison with Riera approach does not provide, however, sufficient information on adequacy of computing model in case of interaction of a part model only with the building. To assess local affects of aircraft rigid components impact (e.g. landing gear, engine), empiric relations defined on tests basis (impacts of projectiles on steel or concrete plates) can be used. Published results of tests can be also applied for the computing model calibration, which consequently allows analyzing of impacts configurations, which do not meet directly presumptions of the experiment. More difficult is finding of a reference solution for impact of two flexible bodies, which are in a partly contact only – e.g. aircraft crash impact on columns of the building, where the aircraft is split into some parts and aircraft components movement is not stopped. In such case the instant force depends more significantly on local structure of the aircraft in area of impact, as well as behaviour of fuel contained in fuel tanks plays greater role. Solution of such cases requires implementation of many presumptions and dependent on them, great variety of results can be obtained.

5 CONCLUSION

Issues related to aircraft crash impact into a building represent a difficult non-linear dynamic task, solution of which requires implementation of many simplifications and choice of appropriate presumption for computing process. Correctness of this problem solution can be checked by comparison with already published solutions or an experiment. Impacts of projectiles into civil structures elements were verified in series of experiments modelling an impact of a relatively small compact projectile into a concrete or steel plates. Such experiment contributed a great deal to establishing a calibration of simplified computing models applicable for analyses of military aircrafts or big airliners engines crash impact. No experimental data are available until now for a large aircraft crash impact. For computing model verification, already published Riera analytic solution can be used.

Necessity to introduce a lot of simplifications into computation results in different solutions of an identical task developed by various authors. Provided a great number of big airliners is taken into consideration (even at presumption of the same mass category), the following question comes into being: would not be wise to standardize load caused by aircraft crash in order to get better conditions for single analyses comparison and at least partly reduction of uncertainties in computations? Standardization, prepared on the basis of big airliners design characteristics generalization, would allow unambiguously definition of load affecting civil structures in case of a crash of an aircraft classified in some established category. The load would be then defined by Riera curves including definition of input parameters for their computation. With regard to possibilities offered by computing systems it is also possible directly to define and establish for single aircraft categories substitute computing models of aircrafts, which enable to solve more accurate general cases of aircraft crash impact on buildings. This is quite common practice in car industry: for analyses of car crash impact into standardized barriers, verified computing models of barriers are available.

REFERENCES

Figure 1. Global view at FE model

Figure 2. Longitudinal cross section of B747-400 aircraft model
Figure 3. Comparison of Riera loading function and FE result

Figure 4. Comparison of Riera loading function considering only mass and mass with stiffness
**Figure 5.** Comparison of FE results considering only mass and mass with stiffness

**Figure 6.** Comparison of FE results for different stiffness of wall support