Simulation of local damage to reinforced concrete structures caused by impact of aircraft engine missiles

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1. Introduction

Aircrafts crashing into reinforced concrete structures can produce structural damage including local damage caused by the deformable engines and global damage caused by the entire aircraft. Studies of local damage from aircraft engine impacts are most-often military-centered. Many formulas have been proposed to evaluate this type of damage.

A test program has been performed in the USA and Japan [1,2] to select suitable empirical formulas for predicting the local damage caused by the rigid missile. These studies attempted to account for engine deformation though reduction factors.

This paper focuses on numerical simulation to study the local loading effects of aircraft engine impacts on concrete structures. We compare our results with those from the test programs performed in the USA and Japan [1,2].

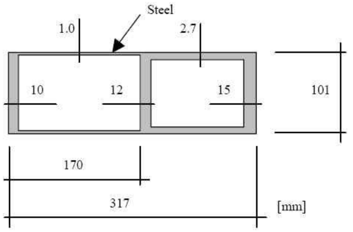
2. Aircraft Crash Simulations

We report on numerical simulations used to predict local damage in concrete slabs impacted by rigid and deformable missiles whose physical characteristics are similar to those of aircraft engines. This work was based on a test program performed in the USA and Japan [1,2].

Numerical simulations have access to energy considerations during impacts. As such, we expect them to shed light on a broad range of issues associated with impact loads and velocities beyond the range of variables probed in the aforementioned test.

Full-scale tests of aircraft engine missiles impacting concrete slabs as well as medium and small-scale tests were performed. Overall, 44 small-scale tests were reported. They employed rigid and deformable missiles at various impact velocities and slabs of different thicknesses and reinforcement ratios. We simulated nine of those tests and address three cases that concern deformable missiles.

Small-scale tests were carried out using a missile launcher that discharged flat-node missiles against concrete slabs. The deformable missile structural characteristics were similar to aircraft engines (Fig. 1). Concrete slab thickness varied from 80 to 350 mm in the tests. For all three simulated cases in this paper, concrete slab thickness was 120 mm.



Weight 3.6kg
Diameter 101 mm
Steel
Yield strength : 411.9 MPa
Ultimate strength : 705.1 MPa
Young's Modulus : 214000 MPa

Figure. 1. Deformable missile used in the small-scale tests. [1]

Numerical simulations were carried out using the axially symmetric model ABAQUS/Explicit (Fig. 2).

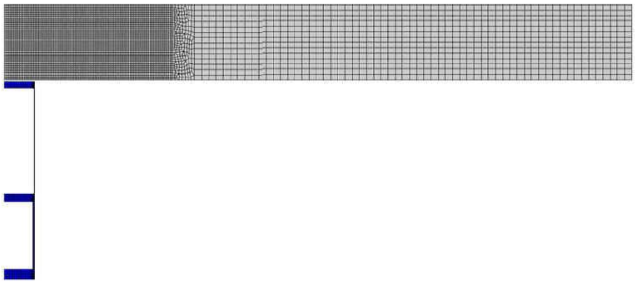


Figure. 2. Axi-symmetrical FE model in simulation.

In the analysis, contact definition between the missile and the concrete slab surface was used to avoid overlapping of finite element meshes.

Nonlinear-plastic material models for steel, using von Mises yield criteria, were used to describe the impacting missile. For the concrete slab, zones can be identified depending on the local behavior of the structure and on the type of failure mode dominating that zone such as compression, tensile or shear failure or a combined failure mode. A von Mises material was used in the zone where compressive stresses were assumed to dominate. The remaining part of the slab was modeled as a brittle cracking material. Material and input data were constant in the analyses; missile velocity varied.

Test and simulation results are summarized in Table 1. In general, local damage to reinforced concrete structures includes spalling and crater formation on the impacted face, scabbing on the rear face, and partial penetration or perforation of the missile through the structure. The governing local damage modes of all simulations of the three cases were evaluated to be coincident with the test results.

Table 1. Small-scale tests simulated in this paper.

No.	Missile velocity (m/s)	Damage to test panel		Missile length after impact in test (mm)	Missile length after impact in simulation (mm)
		Mode [a]	Front depth (mm) [simulation]		
S17	101 m/s	C	4 [3~7]	173	182
S18	128 m/s	S	12 [5~20]	165	171
S19	204 m/s	P	-	88	98

[a] C: penetration mode, S: scabbing mode, P: perforation mode

For case S17, the calculated penetration depth of 3~7 mm (mean value: 5 mm) was close to the 4 mm penetration depth measured in the test. Simulated and measured penetration depth for case S18 are also similar.

Simulated post-impact missile length and damage (buckling mode) were in good agreement with the test data for all the three cases listed in Table 1.

3. Energy consideration

It is a main advantage of the evaluation of local damage to reinforced concrete structures caused by impact of aircraft engine missiles using simulation compared to using empirical formulas that the results from simulation give lots of information of physical phenomena. Induced stresses, strains, forces and displacements of the missile and structures due to impact and energy transformation from a missile to structures, etc. should all be accessible from the simulation.

Energy transformation from missile to structure is a main consideration in the study of impact events. These transformations include kinetic, elastic (recoverable), plastic (irrecoverable), fracture, and thermal energy. Fracture energy is the energy required to create a surface fracture. The total level of energy is the energy required for creating a certain amount of fracture surface. The total level of energy is always constant in an isolated system. If thermal energy is neglected, the kinetic energy of the missile prior to impact has to be absorbed by mechanisms of the concrete and the reinforcement.

Well-defined and accurate material models are very important in studies of this sort because plastic and fracture energy are very sensitive to material properties.

For the aircraft crash simulation studied in this work, we chose conservative material models. Thus, the simulation results were also somewhat conservative compared to the test results.

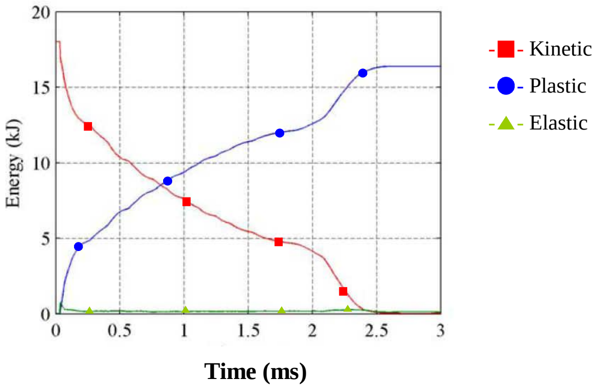


Figure. 3. Kinetic, plastic and elastic energy (S17).

Missile to structure energy transformation for case S17, was calculated automatically by simulation (i.e. ABAQUS/Explicit) (Fig. 3). As shown in that figure, energy transformation from kinetic energy (missile) to other energies of a missile and a structure during the impact can be confirmed reasonably by simulation.

4. Conclusions

Simulation techniques using ABAQUS/Explicit are useful for impact studies, such as those involving local damage to reinforced concrete structures caused by aircraft engine impacts. This is borne out by the good agreement between simulation and measurements as demonstrated in this paper. Note that no adjustments and/or calibrations of input data were needed to fit the experimental results.

In addition, the simulations were able to probe a rich set of dynamics, including induced stresses, strains, forces and displacements of the missile and structures due to impact. Energy transformation from missile to structure, which can be useful for evaluating local damage of structures via impacts, was also accessible thorough numerical analyses.

REFERNCES

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