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Dynamic Impact Analysis and Test of Concrete Overpack Segment Models

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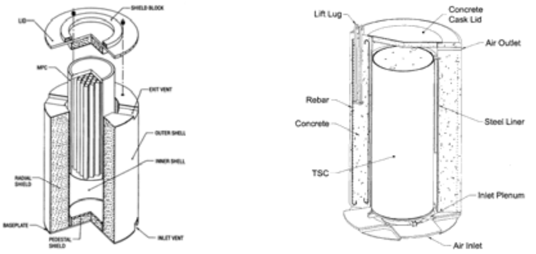
1. Introduction

Concrete cask is an option for spent nuclear fuel interim storage which is used mainly in US. The concrete overpack of the cask provides radiation shielding as well as physical protection for inner canister against external mechanical shock. When the overpack undergoes a severe missile impact which might be caused by tornado or aircraft crash, it should sustain minimal level of structural integrity so that the radiation shielding and the retrievability of canister are maintained. Empirical formulas have been developed for the evaluation of concrete damage but those formulas can be used only for local damage evaluation and not for global damage evaluation. In this research, a series of numerical simulations and tests have been performed to evaluate the damage of two types of concrete overpack segment models under high speed missile impact. It is shown that appropriate modeling of material failure is crucial in this kind of analyses and finding the correct failure parameters may not be straightforward.

2. Concrete Overpack Segment Model

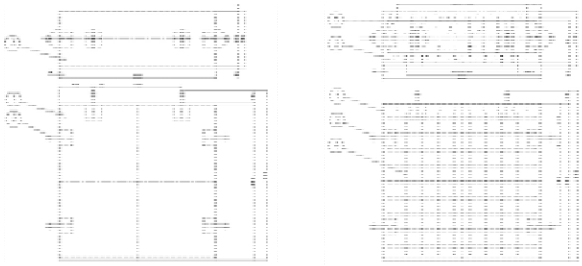
Two types of concrete overpack are considered. One is a steel liner encased concrete overpack without rebar (Type 1, Fig. 1(a)) and the other is an open-type concrete cask with reinforcement (Type 2, Fig. 1(b)). For simplicity, 2 m × 2 m segment models of two types of concrete overpack are designed as in Fig. 3, 4.



(a) Overpack Type 1 (b) Overpack Type 2

Fig. 1. Concrete cask overpack

The material properties and dimensions of the overpack segment models are determined based on the values found in the safety analysis reports (SARs) of commercially available concrete casks. The compressive strength of concrete of Type 1 segment model is 23 MPa and that of Type 2 segment model is 28 MPa. Both are made from the type II Portland cement with designated aggregate sizes in SARs.



(a) Type 1 (b) Type 2

Fig. 2. Segment Models

The material for steel liner is A516 Gr.70 and the rebar is made of A706. In the segment model Type 2, there is no front steel liner and the concrete is exposed.

3. Impact condition and missile

3.1 Missile design

A rigid missile is designed considering the compatibility with the 155 mm cannon which is used to fire the missile with a designated velocity. The missile has a 155 mm diameter with 50 kg weight and the shape is shown in Fig. 3. The material used is high strength steel SCM440.

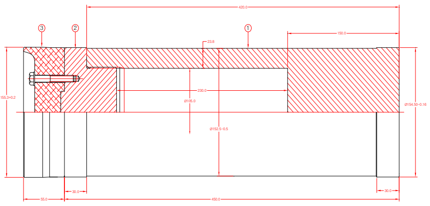


Fig. 3. Design of rigid missile

3.2 Impact condition

The impact scenario considered in this research is the aircraft engine crash with impact velocity 150 m/s. From the modified NDRC formual [1], the penetration depth of a rigid missile with 4.5 t weight and 1.5 m effective diameter into a reinforced concrete wall is 30”. However, Sugano et al. [2] showed that the aircraft engine is more like a deformable missile and the correction factor for the calculation is 0.5. Thus, the penetration depth of an aircraft engine with 4.5 t weight and 1.5 m diameter is 15”. The specifications for the engine correspond to the GE CF6-80C2 engine used in Boeing 747. To produce the same penetration depth with the missile described in section 3.1, the impact velocity is calculated as 314 m/s. In this calculation, the correction factor is not applied because the missile is very close to a rigid missile. The velocity 150 m/s comes from NEI report [3].

4. Numerical Simulation

4.1 Modeling

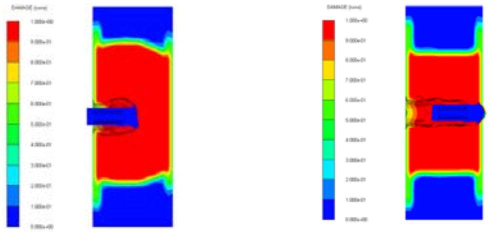
The AUDODYN is used for the numerical simulation of the missile impact into the concrete overpack segment models. The concrete in the overpack is modeled by RHT-Concrete in AUTODYN material library. Hydrostatic pressure is adopted as a measure of material failure in this research. For element erosion, geometric strain is used for erosion criteria. Two sets of failure and erosion parameters are tested as in Table 1. Case 1 is the most commonly used setting for the failure parameters in literature.

Table 1: Parameter settings

	Failure	Erosion
Case 1	0.1	200 %
Case 2	0.08	100%

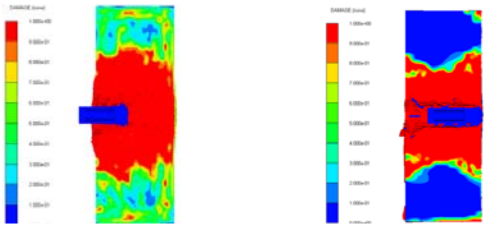
4.2 Results

Fig. 4 and 5 show the analysis results. For both models, case 1 and case 2 shows very different results. Case 1 produces smaller penetration depth than case 2, but the larger deformation in front and backside of segment model is predicted than case 2. The penetration depths in model 1 and model 2 for the same parameter setting are calculated almost the same.



(a) Case 1 (b) Case 2

Fig. 4. Analysis results of Type 1 model (damage plot)



(a) Case 1 (b) Case 2

Fig. 5. Analysis results of Type 2 model (damage plot)

5. Test

The tests were performed in testing site of Agency for Defense Development (ADD). The missile velocities were measured using high speed camera. The measured velocities were 309 m/s for Type 1 segment model and 329 for Type 2 segment model. Test results show that Type 1 model is much stronger against the missile impact in terms of the penetration depth. The penetration depth of Type 1 model is about 25 cm and that of Type 2 model is about 70 cm which means that the missile touches the backside steel liner. Both of the models underwent very sever and similar level of deformation in the back side which corresponds to the inner shell of a real overpack model. Thus we can conclude that the two type of model provides similar level of integrity in terms of retrievability of inner canister. The existence of front liner produces a very dramatic difference in the damage mode of the model. It prevents the concrete from bursting out due to impact shock which is shown in the test of Type 2 model and makes the model stronger against penetration. Fig. 6 and 7 show the Type 1 and Type 2 models after the missile impacts.

Fig. 6. After missile impact (Type 1)

Fig. 7. After missile impact (Type 2)

6. Discussion

When comparing the simulation results with the test results, it is shown that neither setting, case 1 and 2 provides results with consistent agreement with test results. That is, case 1 setting is more close to reality in Type 1 model analysis, but for Type 2, case 2 setting provides more close results to the reality. In both the case, not enough deformation is predicted by simulation compared to the tests. Weak failure and eroding criteria give larger penetration depth with insufficient overall damage due to energy loss with element erosion. So, for this kind of analysis, the appropriate choice of failure parameter is crucial but we can see that the proper choice of those parameters is not always straightforward.

REFERENCES

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[3] NEI, "Deterring terrorism: Aircraft crash impact analyses demonstrate nuclear power plant's structural strength," NEI, 2002.