Safety Tests of Concrete Storage Cask for Spent Nuclear Fuel

Sanghoon Lee [a*], Sang-Soon Cho [a], Kyung-Sik Bang [a], Ki-Seog Seo [a]
[a]*Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: shlee1222@kaeri.re.kr*

1. Introduction

In preparation for the timely installation of interim storage facility for spent nuclear fuel (SF), KORAD is developing domestic models of SF storage systems and the concrete storage cask is one of them. A concrete cask consists of a metallic canister which confines SF with welded closure and a concrete overpack which provides radiation shielding and physical protection to the canister. The safety requirements for a SF storage cask is well established in US and summarized in regulatory guides such as NUREG-1536. KAERI has been performing tests of the concrete cask to demonstrate its safety and compliance to the regulatory requirements with high priority stipulated in NUREG-1536. The test program includes the structural performance tests under tip-over and earthquake and decay heat removal test under normal, off-normal and accident conditions. In this paper, brief introduction to the structural tests and their results are provided.

2. KORAD21C Storage Cask

The concrete storage cask (Fig. 1), tentatively named as KORAD21C stores 21 PWR SF of 45,000 GWd/MTU. Detailed specification is given in Table 1.

Table 1: Specification of KORAD21C

Capacity	21 PWR F/A(WH & CE)
Design basis fuel	- Burn-up : 45,000 MWD/MTU - Enrichment : 4.5wt.% U235 - Cooling time : 10 yrs - Decay heat : 16.8 kW/ canister
Dimension	- Overpack: O.D. 3,266 mm X 6,030 mm L - Canister: O.D. 1,686 mm X 4,880 mm L
Weight	- 143.8 t (with loaded canister of 33.0 t)
Material	- Canister : Stainless steel, BORAL(B_4C+Al) or METAMIC - Overpack: carbon steel, concrete
Cooling	Natural convection (4 inlets, 4 outlets)

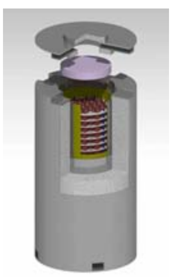


Fig. 1. KORAD21C

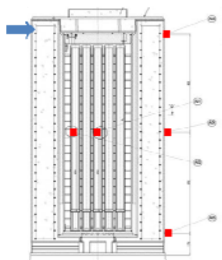


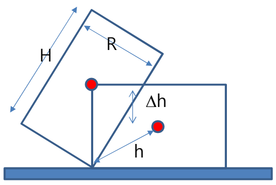
Fig. 2. Tip-over test model

3. KORAD21C Tip-Over Test

3.1 Tip-Over test model and test condition

The tip-over of a concrete cask during handling is one of important accident scenarios which should be considered for structural safety assessment. In our work, a one-third scale model of KORAD21C was designed and fabricated for tip-over test (Fig 2).

Since the tip-over phenomena does not follow a scaling law as can be seen in Fig. 3, the tip-over test is replaced by a horizontal drop with equivalent impact energy as a bounding drop case. The drop height thus determined is 1.84 m.



$$mg\Delta h = \frac{1}{2} I\omega^2 \quad \therefore \omega^2 = \frac{2mg\Delta h}{I}$$

$$I = I_{COG} + mh^2 \quad I_{COG} = \frac{m}{12}\left(3R^2 + H^2\right)$$

$$\therefore \omega^2 = \frac{2mg\Delta h}{\frac{m}{12}\left(3R^2 + H^2\right) + mh^2}, \quad v = \omega d$$

Fig. 3. Scaling analysis for tip-over event

To monitor structural response at important parts of KORAD21C, 5 accelerometers and 32 strain gauges were installed on the test model. Among them, 2 accelerometers and 12 strain gauges were located within the welded canister. The locations of accelerometers are marked as red block in Fig. 2. The measure of safety in this test was the He leak rate of canister before and after the test.

3.2 Tip-Over test results

The test was performed on January 20, 2014 in the transportation package test facility of KAERI. The pre-test leak rate of the canister was 2.4E-5 atm.cc/sec. After the test the leak rate was 3.4E-5 atm.cc/sec which was the values of background He detecting rate. Thus, no significant increase of leak rate of canister was observed after the test, which means that the containment integrity of the canister was maintained.

The maximum acceleration measured on the cask body was 275g after a low-pass filter with cut-off frequency of 500 Hz while that measured on the dummy fuel assembly inside the canister was 454g. The higher value in the dummy fuel seems due to the higher flexibility of internal structures. Since the dummy fuel has different dynamic characteristics with the actual spent fuel, it cannot be concluded that the fuel assembly experiences higher deceleration during tip over.

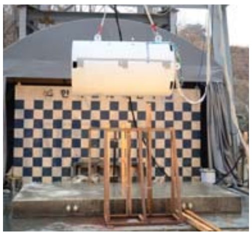


Fig. 4. Drop test from tip-over condition

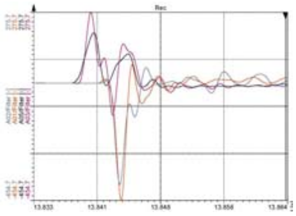


Fig. 5. Acceleration history during drop test

To provide verification data for tip-over simulation, a tip-over test was also performed with the same scale model. In this subsidiary test, the acceleration measured at the top point of cask overpack was 167 g while that measure from the dummy fuel was 272 g. It can be seen that the tip-over induce much less impact force than the horizontal drop with equivalent impact energy with tip-over.

4. KORAD21C Seismic Test

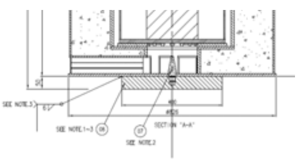
4.1 Seismic test model and test settings

The structural behavior during a probable earthquake is an important measure to be considered in the structural assessment of a storage cask. A one-fourth scale model was designed and fabricated for the earthquake test of KORAD21C.

The tests were performed in 4 different setting. One type of test model has a round disc attached at the bottom to simulate the tip-over due to earthquake while the other does not. To analyze the seismic behavior under different supporting condition, two types of pad were tried. One type of supporting structure was a concrete pad and the other was a metallic plate. For the seismic wave, the ATH and SRTH were considered. The test matrix is given in Table 2. Fig. 7 shows the seismic inputs considered in the test.

Table 2: Settings for seismic test of KORAD21C

Model	Direction	Magnitude (g)
w/ Disc	Pre-test	0.1, 0.2, 0.3
w/o Disc	Vertical	ATH 0.1, 0.3
		SRTH 0.1, 0.3, 0.4
27*4=108	Horizontal (N-S)	ATH 0.1, 0.3
		SRTH 0.1,0.3,0.4,0.8,1.0
	Horizontal (E-W)	SRTH 0.1,0.3,0.4,0.8,1.0
	Vertical + Horizontal (N-S)	SRTH 0.1,0.3,0.4,0.8,1.0
	Vertical + Horizontal (E-W)	SRTH 0.1,0.3,0.4,0.8,1.0

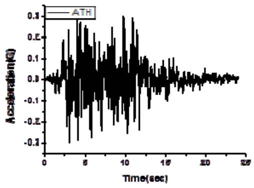


$$\varphi_L^2 = \varphi_m = \left(\frac{1}{4}\right)^3 = \frac{1}{64}$$

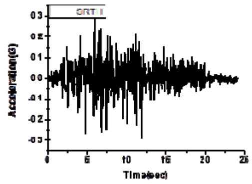
$$\varphi_L = \sqrt{\frac{1}{64}} = \frac{1}{8}$$

$$D = \frac{0.3216}{8} = 0.402m$$

Fig. 6 Seismic test model to simulate tip-over



(a) ATH



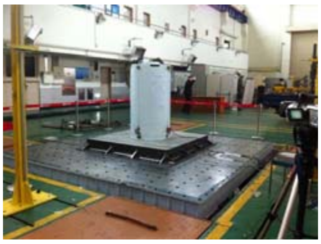
(b) SRTH

Fig. 7 Seismic waves considered in the tests

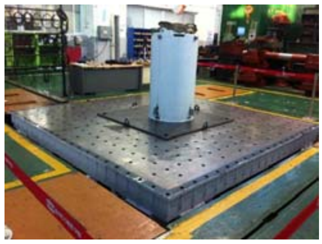
To analyze the seismic response of the test model, accelerometers, laser displacement sensors, potentiometers, and tilt sensors are installed.

4.2 Seismic test results

The tests were performed in structural test facility of KIMM from January 13 to January 17, 2014. The shaker table of capacity 10 t was utilized and to simulate the seismic input to the scale test, the ATH and SRTH profile were compressed in time domain with scale factor of 2.



(a) On concrete pad



(b) On steel plate

Fig. 8 Seismic test of KORAD21C

During the test without the disc for tip-over simulation, no significant rocking motion was observed in any case listed in Table 2. With the disc attached to the model, it was observed that the model tipped over at 1.0 g on concrete pad while no tipping over occurred when the model was on steel plate. Since 0.3 g is the threshold value considered in other countries, it was shown that KORAD21C is very safe under seismic input of considerable severity. For seismic input under 0.3 g, sliding and rocking motion were also very limited. The test results are being compared with seismic simulation results now.

5. Conclusions

Safety tests to demonstrate the safety of KORAD21C concrete storage cask were successfully performed. The structural integrity during tip-over and earthquake were demonstrated with scale model tests and the results are analyzed in comparison with safety analysis results.

REFERENCES

[1] NUREG-1536, Standard Review Plan for Dry Cask Storage Systems, Revision 1A, US NRC, 2009