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Seismic Test of Bottom-mounted Second Shutdown Drive Mechanism

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1. Introduction

KiJang Research Reactor (KJRR) is under construction and it is equipped with a bottom-mounted second shutdown drive mechanism (SSDM) newly developed by KAERI as shown in Fig. 1 [1]. During the normal operation of the reactor, the second shutdown rod (SSR) is raised to the top of the core by the hydraulic force induced by the pumping water of the hydraulic system. When reactor trip is required by the reactor protection system or alternative protection system, the SSR drops by gravity into the core by de-energizing the valves in the hydraulic system. Therefore, the drop of the SSR within a proper time is the most important safety function for the SSDM which shall be verified during the earthquake events.

In this paper, the setup, requirements, procedure and results of the seismic test for the SSDM will be presented.

2. Test Setup

The seismic test of the SSDM has been done by seismic simulation test center (SESTEC) which is a certified organization for seismic tests.

2.1 Modified SSDM

It is very difficult to simulate the seismic conditions with the full scale test rig due to the length of SSDM. Therefore, a modified SSDM which employs a shortened extension shaft instead of the original one will be used for the test as shown in Fig. 2. Therefore, the structural integrity of moving parts which consists of the SSR, FFA, extension shaft and piston shall be verified through another analysis. The dummy FFA was designed to compensate the omitted mass due to the shortened extension shaft.

2.2 Seismic test rig

The seismic test rig consists of test rig #2 and two adapter plates and is installed on a tri-axial shaker table as shown in Fig. 3. Furthermore, test rig #2 is mainly divided into two parts as shown in Fig. 4. The first one is the bottom structure assembly which simulates the reactivity control mechanism (RCM) room and the second one is the simulated reactor structure assembly

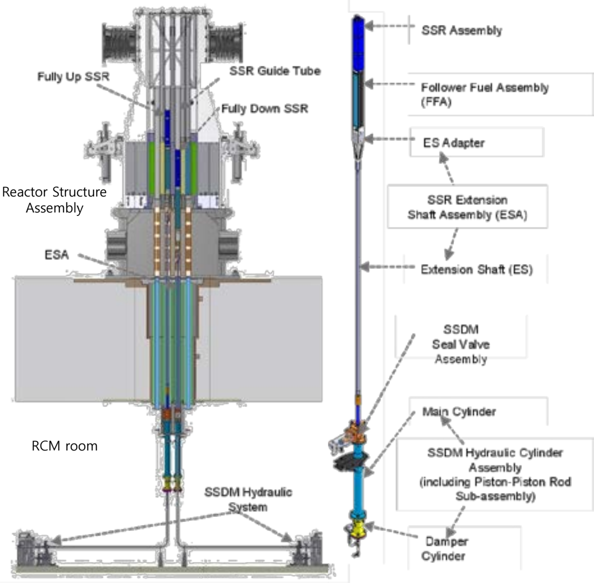

Fig. 1. Configuration of SSDM and its installation in the reactor.

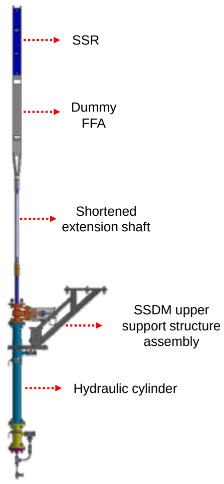

Fig. 2. Modified SSDM with a shortened extension shaft.

(RSA) which substitutes for the reactor structure assembly.

Therefore, the design requirements of the test rig #2 are listed as below.

a) The bottom structure is rigid enough below the cutoff frequency of the ZPA.

b) The natural frequencies of the simulated RSA are similar to those of the real RSA within 10% tolerance
c) The mode shapes of the simulated RSA are similar to those of the real RSA.

Those requirements were verified through resonant tests before the seismic tests.

Two adapter plates provides the identical bolt holes for installation of the hydraulic system at the same locations as the real site.

2.3 Measurement

A high speed camera is installed on the simulated RSA so that the motion of the shortened extension shaft on which a ruler is attached can be recorded as shown in Fig. 5.

Nine tri-axial accelerometers are installed on appropriate locations for measurement of floor response spectrum (FRS) and mode shapes of the test rig. Moreover, two uniaxial accelerometers are installed inside the simulated RSA which is full filled with water in order to measure the accelerations of the SSR guide tube.

The photograph of the seismic test rig on the shaker table is shown in Fig. 6.

3. Requirements

3.1 Function

There are two safety functions to be proven in the test. The first one is the maintenance of its structural integrity. The second one is that the SSR shall drop into the core within a proper time which is represented as the equation below;

$$T_s = T_n + DT_s \leq T_l \quad (1)$$

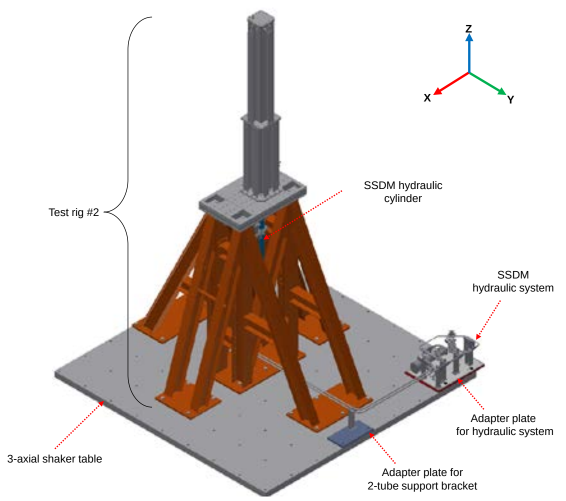

Fig. 3. Configuration of the seismic test rig on a tri-axial shaker table.

where, T_s denotes the drop time during the seismic excitations and T_n means drop time in normal operation. DT_s expresses delay time caused by the seismic excitations and T_l indicates a time limitation.

In a normal operation, there is the coolant flow which is not simulated in the seismic test rig. Therefore, T_n is measured in another test rig and the only delay time due to the seismic excitations is measured in the test. Consequently, the summation of the drop time in normal operation (T_n) and the delay time measured (DT_s) shall be smaller than the time limitation (T_l).

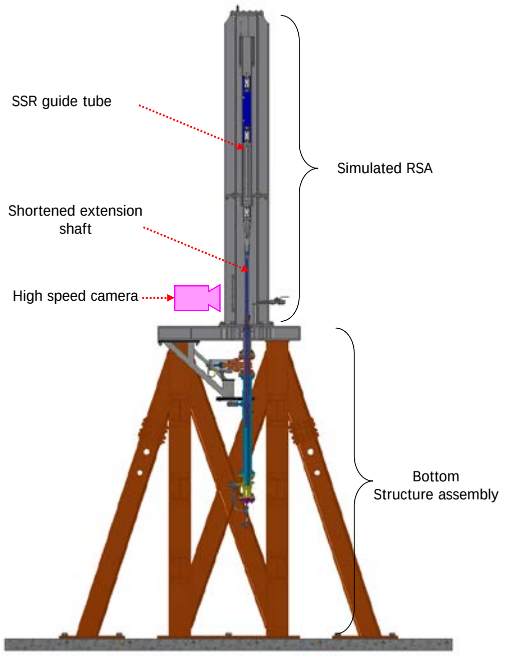

Fig. 4 Section view of test rig #2 equipped with SSDM.

Fig. 5. Photograph of high speed camera installed on test rig #2.


Fig. 6. The photograph of the seismic test rig equipped with SSDM on a tri-axial shaker table.

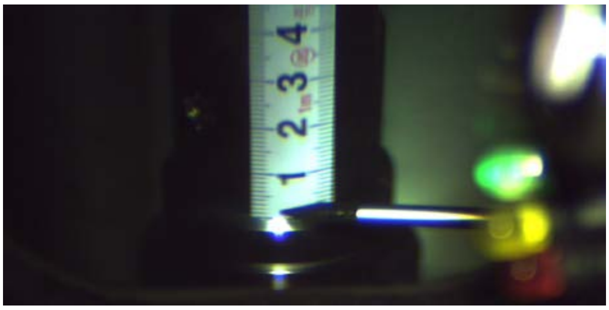
Fig. 7. Photograph of shortened extension shaft before drop.

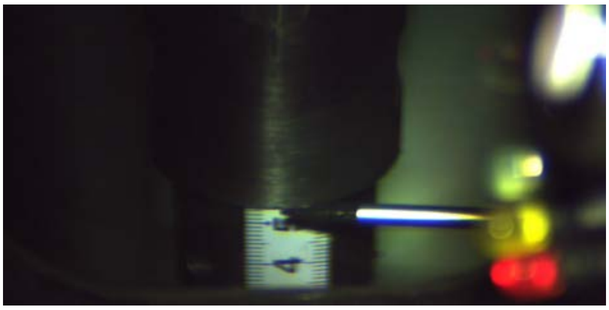
Fig. 8. Photograph of shortened extension shaft after drop.

3.2 Excitation

The test response spectrum (TRS) at the bottom of the bottom structure assembly and the simulated RSA shall respectively envelop the floor response spectrum (FRS) on the RCM room and reactor pool bottom,

The test object shall be excited in three orthogonal directions simultaneously and the excitation signals in three directions shall be independent to each other. The duration of the strong motion is longer than 20 seconds and the drop test shall be done during the strong motion.

The test shall comply with IEEE-344 [2].

4. Procedure

The test has been performed in the order as listed below;

1) Initial inspection before assembly
2) Specimen setup
3) Sensor installation
4) Functional and resonant test
5) OBE test (5 times)
6) Inspection and resonant test
7) SSE test (1 time)
8) Functional and resonant test
9) Post inspection after disassembly

The functional test means the drop test without excitations and the drop tests are also done during every OBE and SSE tests. Resonant frequencies of the test object and the test rig are measured in between steps for detection of any structural damages. As the last step of the test, a post inspection was performed after disassembly of all components.

5. Results and conclusion

The test was done complying with the requirements and procedures described in section 3 and 4, respectively [3].

The drop times were calculated by analysis of the photographs taken by the high speed camera during the test. The samples of the photographs are shown in Fig. 7 and 8 which are ones before and after drop of SSR.

It was verified through the test that the structural integrity of SSDM is maintained and the SSR drops into the core within the limited time during and after the seismic excitations.

Acknowledgement

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