EXPERIMENTAL SEISMIC QUALIFICATION OF DIVERSE SAFETY ROD AND ITS DRIVE MECHANISM OF PROTOTYPE FAST BREEDER REACTOR

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Abstract. Prototype Fast Breeder Reactor (PFBR) at Kalpakkam, India, has two independent and diverse fast acting shutdown systems. The absorber rod of the first system is called Control & Safety Rod (CSR). The mechanisms that handle Control & Safety Rods (CSR) are called Control and Safety Rod Drive Mechanism (CSRDM). CSRDM & CSR are for start up, control of reactor power, controlled as well as emergency shutdown of the reactor. The absorber rod of the second system is called Diverse Safety Rod (DSR). The mechanisms that handle Diverse Safety Rods are called Diverse Safety Rod Drive Mechanism (DSRDM). DSR serves to shutdown the reactor on demand and are in fully raised position during normal reactor operation. Each system consists of independent sets of sensors connected to two reactor protection logics of different designs. The output of either of the reactor protection logic system is capable of ordering safety actions through SCRAM signal by de-energizing electromagnet of CSRDM & DSRDM. Full scale DSRDM along with DSR has been extensively tested at room temperature in water for Operation Base Earthquake (OBE) and Safe Shutdown Earthquake (SSE). The results of the extensive testing are presented. Full insertion of DSR within the stipulated time and healthy functioning of DSRDM during and after seismic testing have been demonstrated.

Key Words: Seismic qualification, shutdown system, drive mechanism, drop time.

1. Introduction

The assessment of control rod insertability within stipulated time during seismic events is one of the most important design tasks for ensuring safety of nuclear power plants. This paper presents the experimental verification of performance of PFBR Diverse safety rod & its drive mechanism under seismic conditions.

Prototype Fast Breeder Reactor (PFBR) at Kalpakkam, India, has two independent and diverse fast acting shutdown systems. The absorber rod of the first system is called Control & Safety Rod (CSR). The mechanisms that handle Control & Safety Rods (CSR) are called Control and Safety Rod Drive Mechanism (CSRDM). CSRDM & CSR are for start up, control of reactor power, controlled as well as emergency shutdown and of the reactor. The absorber rod of the second system is called Diverse Safety Rod (DSR). The mechanisms that handle Diverse Safety Rods are called Diverse Safety Rod Drive Mechanism (DSRDM). DSR serves to shutdown the reactor on demand and are in fully raised position during normal reactor operation. Each system consists of independent sets of sensors connected to two reactor protection logics of different designs. The output of either of the reactor protection logic system is capable of ordering safety actions through SCRAM signal by de-energizing electromagnet of CSRDM & DSRDM.

Full scale prototypes of DSRDM & Diverse safety Rod were manufactured and extensively tested for their performance and endurance in air and in sodium at IGCAR simulating reactor conditions [1]. These tests had qualified them for normal operation in reactor. In order to ensure satisfactory performance during and after seismic events, testing of DSRDM along with DSR under simulated seismic conditions in water at room temperature was carried out.

2. Description of DSR and DSRDM

Three Diverse Safety Rods (DSR) and their Drive Mechanisms (DSRDM) form a part of the second shutdown system in the reactor. The DSR is housed inside DSR subassembly as shown in Fig.1. The DSR subassembly consists of hexagonal sheath, dashpot cylinder, and geometrical feature to orient and support the subassembly on grid plate. The height of DSR subassembly is 4.46. The DSR moves inside the hexagonal sheath of DSR subassembly and there is a minimum radial gap of ~ 4.5 mm between them.

The DSR consists of a circular sheath in which an absorber pin bundle containing 19 absorber pins is housed. Each pin contains B4C pellets enriched in B-10 (65%). At the foot of DSR, dashpot piston made up of ferritic steel is attached. At the top of DSR, there is an armature. The armature and DSR body is connected through two swivel joints which allow rotational degree of freedom about two horizontal axis. There is an electromagnet (EM) at the bottom of DSRDM. The DSR and DSRDM are coupled through armature and electromagnet. During normal operation DSR & DSRDM is coupled and DSR is parked above the active core. On receiving the scram signal, the EM is de-energised and the DSR is released to fall under gravity. At the end of free fall travel of 825 mm, the DSR is decelerated by a sodium dashpot-piston arrangement in the DSR subassembly & DSR for the remaining 250 mm travel.

FIG.1. Schematic of DSR subassembly & DSR

DSRDM is housed in control plug. The lower part of DSRDM is partially immersed in hot pool sodium and the upper part is in the environment of mechanism box of the control plug. Overall length of DSRDM is about 12 m and maximum diameter is 330 mm. Fig.2 shows the schematic of DSR and DSRDM. The mobile assembly of DSRDM consists of translation tube and electromagnet. The mobile assembly is coupled with the nut of the roller screw-nut mechanism. Motor drive sub-assembly rotates the screw in either direction to raise or lower the mobile assembly. The mobile assembly slides over two guide columns fixed to support tube. The mobile assembly is also guided by three bushes at different levels. Weight of the mobile assembly is continuously monitored using inbuilt load cells in DSRDM. When the mobile assembly is lowered and the electromagnet touches the armature of DSR, the torque limiter in the driveline slips, which is sensed and further lowering of the mobile assembly is stopped. Because of the load applied on the armature, it swivels and gets aligned with the lifting face of the electromagnet. Then the electromagnet is energised and the DSR is held with the electromagnet.

When the mobile assembly is translated with the DSR, the swivel joint provides the required flexibility for the translation. However it may be noted that the design provisions allow only limited flexibility to absorb expected misalignment during normal operations. Misalignment beyond certain limit will try to separate the armature - EM and may lead to release of DSR to fall under gravity.

3. **Experimental Test Setup**

A facility for conducting the seismic testing of tall and slim mechanisms like Absorber Rod Drive Mechanisms (ARDMs) has been erected at the Dynamic Research Laboratory of Structural engineering Research Center (SERC), Chennai. The facility is mainly a concrete structure having 14 m height. 6 m of the structure is below the ground level and 8 m above the ground level. Above the ground level, it is open on one side and closed on the other three sides. Below the ground level it is having walls on all four sides. Through holes are provided on the reaction walls to facilitate the fixing of the required support structures at regular intervals.

3.1 Simulation of Boundary conditions

The reaction walls of 14 m height x .5 m width were used as a rigid support. In reactor, DSRDM is supported at control plug top level. DSR subassembly is supported at grid plate level and radial movement of subassembly is constrained at button level. The same boundary conditions have been simulated during experiment. Three rigid support structures for simulating the following excitation points were designed, fabricated and erected.

1. Grid plate level
2. Button level of hexagonal subassembly and
3. Control plug top level

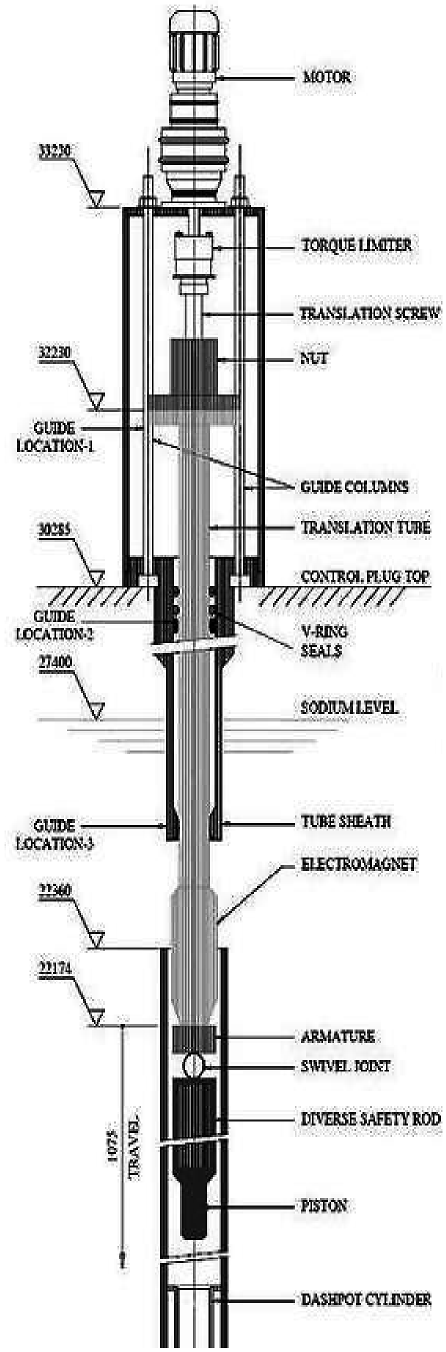


FIG.2. Schematic of DSRDM

These structures act as a rigid interface between reaction wall and DSRDM assembly. Fig.3. shows the experimental setup. hydraulic actuators were used to for simulating seismic excitation. The added mass and damping effect due to sodium was approximately simulated using water in the experimental condition.

4 **Measurements.**

The most important safety parameter measured was the drop time of the DSR & EM response time during seismic activity. Apart from this strain, acceleration and displacement at critical locations were also measured.

FIG.3. Experimental set up

5 Drop time of DSR

The drop time is the most important parameter as the negative reactivity added during this travel of DSR ensures shutdown of the reactor. The drop time is defined as time elapsed between start of DSR fall and DSR entering dashpot. An electronic circuit was used to measure the EM response time, the same signal was used to mark the start of freefall travel. An alternative measurement of start of freefall was done using DSRDM load cell. The end of free fall was measured using dynamic pressure transducer mounted on the dashpot in DSR subassembly. The time for damped travel was also measured, this ensures the healthy functioning of dashpot. Together drop time and damped travel time ensures that reactor is safely shutdown with sufficient margin.

5.1 EM response

On receiving SCRAM signal, the detachment of armature from EM takes place after a characteristic delay time. One of the major parameters affecting EM response time is EM current. When current is higher, holding force is higher but EM response also will be higher. If EM current value is set low, it may lead to spurious dropping of DSR. Hence set value of EM current is carefully selected based on measured value of minimum current to hold DSR and adequate margin required during normal operations.

5.2 Drop time measured

The measured values of drop time of DSR are listed below in Table.1. The drop tests were conducted in stagnant water and also in flowing water which conservatively simulates drag & buoyancy forces on DSR due to flowing sodium in reactor. The results show that increase in drop time due to drag & buoyancy is 235 ms max.

TABLE.1 DROP TIME OF DSR UNDER DIFFERENT CONDITION

S.No.	Condition	Drop time (ms)
1	Normal drop in stagnant water [1]	565
2	Normal drop in flowing water [1]	800

6. Natural frequency

Experiments to find out natural frequency of individual components and in coupled conditions were performed. Resonance search by impedance and resonance search using base excitation with random signals was used. Estimated and measured natural frequency of DSRDM, DSR subassembly and coupled system are tabulated below.

TABLE.2 NATURAL FREQUENCY

Sl. No.	Component	Measured natural frequency (Hz)
1	DSRDM	1.25
2	DSR subassembly with DSR	12.6
3	DSRDM coupled with DSR SA	4.1

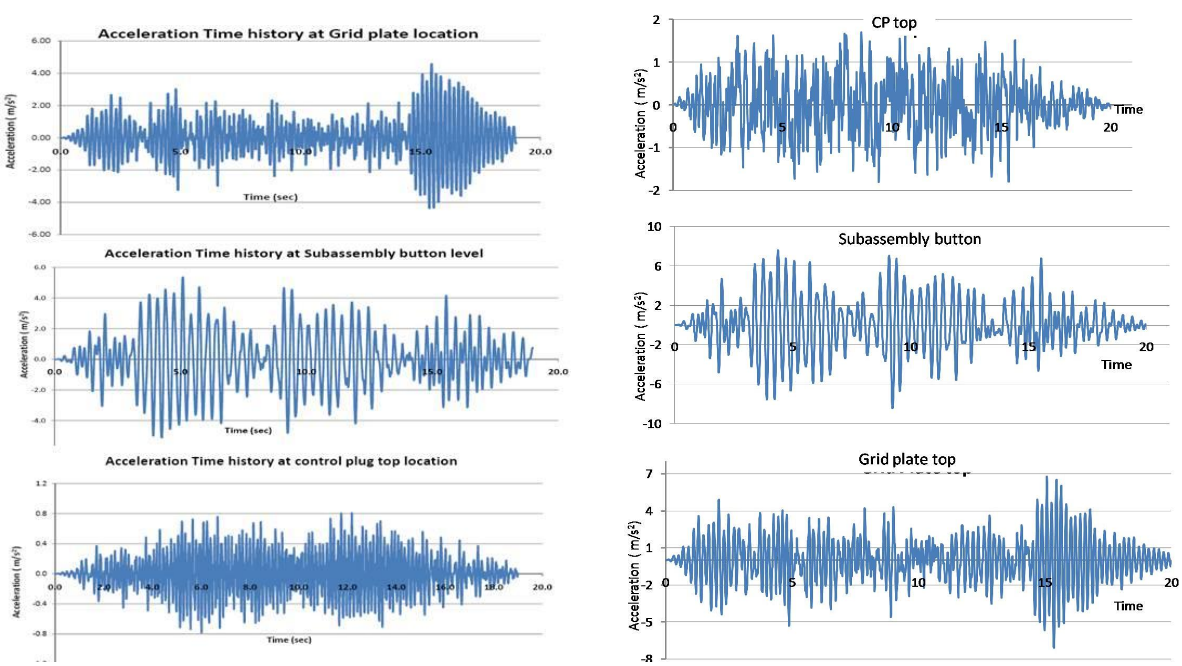
7. Assumptions & Approximations

Vertical excitation gets transmitted to DSR subassembly at the grid plate level and to the DSRDM at control plug top level. Once the drop is initiated, the DSR is detached from electromagnet and it falls under gravity. There is only negligible transmission of vertical components to the falling mass. Considering above facts, only horizontal excitations were simulated.

The experiments were conducted at room temperature in water. Water was used to approximately simulate the dynamic aspects of sodium in actual conditions. It is assumed that increase in temperature will not significantly alter the dynamic behaviour of the system. It is also assumed that the drag force due to flow of liquid is not affected by seismic excitation. Hence the experiments were conducted in stagnant water. Increase in drop time due to drag force (caused by flow) was added separately with measured drop time under seismic condition to arrive at total drop time.

8. Experimental Simulation

Full scale prototypes of DSRDM and DSR were subjected to seismic excitations at room temperature. Fig.4. shows the acceleration time history imposed in all the supports. Initial



OBE SSE

FIG.4. Acceleration time history

condition of DSR decides the dropping path and interaction between stationary and mobile parts and hence the drop time. So testing with de-energisation of EM at different instances from the instance of initiation of seismic excitation was done.

8.1 Operation Base Earthquake (OBE) in water

The DSRDM & DSR were subjected to OBE excitation at all three supports. The targeted and achieved response spectrum is given in Fig. 5. During initial testing, it was observed that the DSR fell automatically without pressing SCRAM switch during testing. The observed phenomenon helps to passively shutdown the reactor during seismic activity. In subsequent testing the EM current was set double the nominal value. This is to study the drop characteristics of DSR when it is dropped at different delays from the start of excitation. Even after increasing the EM current, DSR dropped automatically half of the times. The maximum freefall time was recorded when EM was de-energised during strong motion. The experiments were repeated many folds higher than the mandatory requirement of 5 OBE tests. The maximum drop time measured was 755 ms. The maximum increase in drop time with respect to a drop without seismic excitation was 180 ms. The stress measured during experiments were found to be less than that of allowable limit.

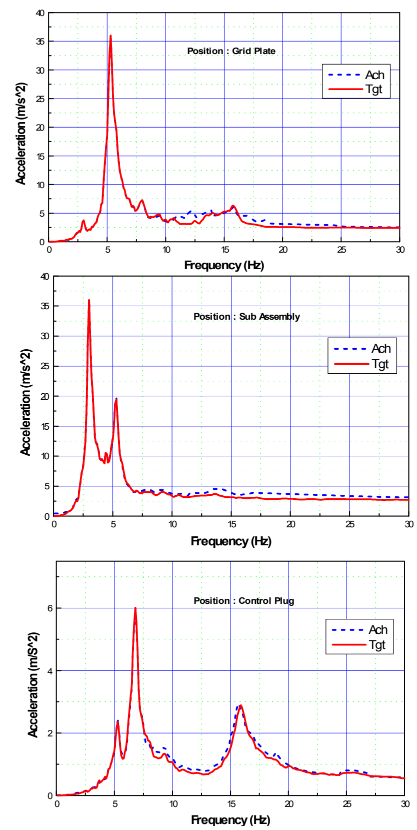


Fig.5. Targeted and achieved response spectrum

8.2 Safe Shutdown Earthquake (SSE) in water

The DSRDM & DSR were subjected to SSE excitation. During testing, DSR dropped automatically every time. However the instant at which DSR dropped automatically, varied for each drop. Most of the times, DSR dropped automatically at the beginning of excitation itself. The experiments were repeated many times with the higher holding current to measure the increase in drop time when DSR is dropped during strong motion. The maximum drop time measured was 780 ms. the maximum increase in drop time during SSE with respect to a drop without seismic excitation was 205 ms. The stress measured during experiments were found to be less than that of allowable limit.

9. Conclusion.

Extensive seismic testing of DSRDM along with DSR at room temperature in water was carried out. Full insertion of DSR within the stipulated time and healthy functioning of DSRDM during and after testing have been demonstrated. Drop time of DSR with different instants of dropping from the instant of start of seismic excitation have been done It was observed that DSR automatically drops during OBE & SSE which acts as a passive feature to shutdown the reactor during seismic events. Strain values during seismic testing at crucial locations were measured and were well within the allowable limits. The healthy functioning of the system after OBE & SSE shows the robustness of design.

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Appendix 1: References:

[1] R. Vijayashree et.al." Design, Development, Testing and Qualification of Diverse Safety Rod and Its Drive Mechanism for a Prototype Fast Breeder Reactor", Journal of Engineering for Gas Turbines and Power, Volume 132, Issue 10, July 2010.