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Experimental Evaluation of Integrity of FBR Core under Seismic Events*

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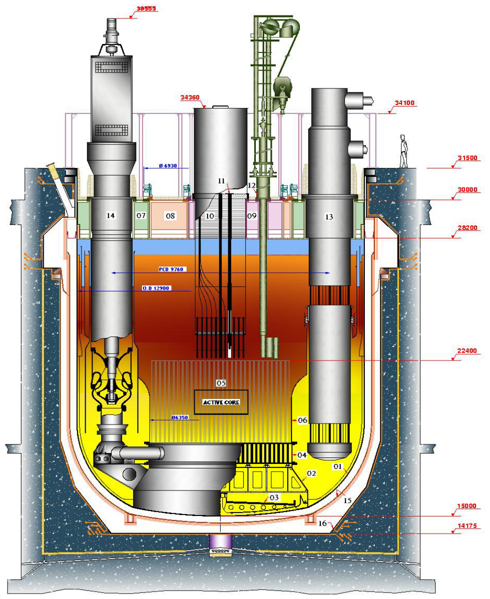
Abstract

The core of Prototype Fast Breeder Reactor (PFBR) is designed to produce 1250 MWt at full power. PFBR is under construction at Kalpakkam, India. In PFBR, the core is of free standing type and one of the major safety criteria for the design of core subassemblies is that the integrity of the core subassemblies should not be impaired and they should not be lifted up from the grid plate even during seismic condition. The net downward force acting on the grid plate is less than the weight of the subassembly due to the hydraulic lifting forces acting on it. Experimental analysis has been carried out to ensure that the subassembly does not get lifted off due to vertical seismic excitation. This paper gives the details of the methodology adopted for the experimental seismic analysis carried out on a core subassembly and the upward displacement of the subassembly under the combined effect of upward fluid force and vertical seismic excitations.

Key words: PFBR, Reactor Core, Hydraulic Lifting Force, Seismic Load Testing, Subassembly

1. Introduction

The core of PFBR consists of the central fuel region enveloped by blanket region. This, in turn, is surrounded by neutron reflectors. Mixed oxide of Pu and depleted U is used as the fuel. Depleted U oxide is used as the blanket. Physically the core is made up of different types of subassemblies (SA). The fuel SAs form the central part and they integrate in them the fuel portion with axial blankets and axial shield. There are 181 fuel SAs arranged in triangular pitch. 12 absorber rods (9 Control & Safety Rods and 3 Diverse Safety Rods) are arranged in two rings within the fuel SA region. Surrounding the fuel SA, there are 120 radial blanket SAs. They are followed by two rings of 132



LEGEND

01. MAIN VESSEL
02. CORE SUPPORT STRUCURE
03. CORE CATCHER
04. GRID PLATE
05. CORE
06. INNER VESSEL
07. ROOF SLAB
08. LARGE ROTATABLE PLUG
09. SMALL ROTATABLE PLUG
10. CONTROL PLUG
11. CONTROL & SAFETY ROD MECHANISM
12. IN-VESSEL TRANSFER MACHINE
13. INTERMEDIATE HEAT EXCHANGER
14. PRIMARY SODIUM PUMP
15. SAFETY VESSEL
16. REACTOR VAULT

Fig. 1: PFBR Reactor Assembly

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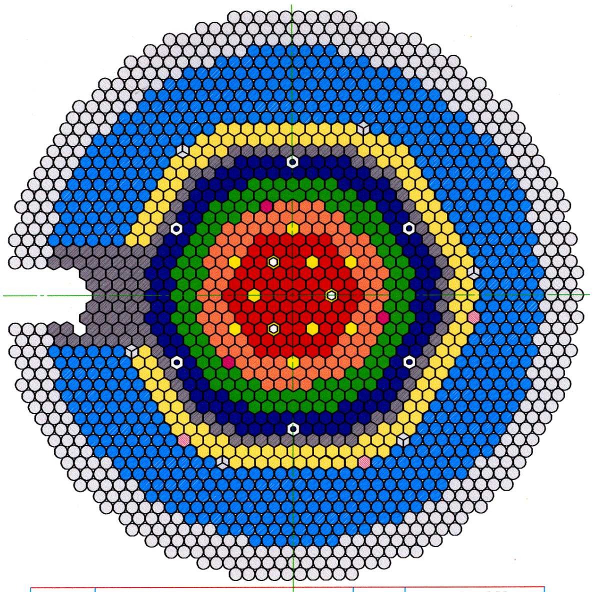
stainless steel reflector SA, one ring of 124 inner B_4C SA and 2 rings of 156 spent fuel storage locations. The rest of the core layout consists of radial shielding SA. Fig. 1 shows the vertical section of reactor assembly of PFBR. All the 1757 SA are located on the grid plate (GP). The arrangement of different SAs on the GP is shown Fig. 2.

The heat generated in the subassemblies (fuel, blanket and absorber rods) is removed by the coolant sodium flowing axially through them. In order to provide the required flow, the pressure of sodium in the GP is maintained at about 0.7 MPa. Under this condition, the fluid pressure develops an upward lift on each of the core subassembly. The maximum hydraulic lifting force equal to 24 % of weight of SA is possible, in case of pump running at 110 % of design flow rate[1]. During normal operating condition of the reactor, the net gravitational acceleration acting on each subassembly (even though it is less than 1 g) is always downward and hence there is no fear of any uplift. However, there exists a concern during seismic events, in particular under vertical excitations. The seismic analysis of reactor assembly indicates that the peak vertical acceleration of GP can be as high as 0.88 g under SSE, which is extracted from Fig. 3.



SYMBOL	TYPE OF SUBASSEMBLY	No.	MASS PER SUBASSY. IN kg
	FUEL (INNER)	85	245
	FUEL (OUTER)	96	245
	CONTROL AND SAFETY ROD	9	200
	DIVERSE SAFETY ROD	3	180
	BLANKET	117	320
	SOURCE	3	200
	STEEL REFLECTOR	132	355
	PURGER	6	355
	B_4C SHIELDING (INNER)	124	181
	STORAGE LOCATION	147	245/320/355
	STORAGE FOR SOURCE	3	200
	FAILED FUEL STORAGE LOCATION	6	245
	STEEL SHIELDING	609	330
	B_4C SHIELDING (OUTER)	417	265
	TOTAL SUBASSEMBLIES	1757	

Fig. 2 : PFBR Core Configuration

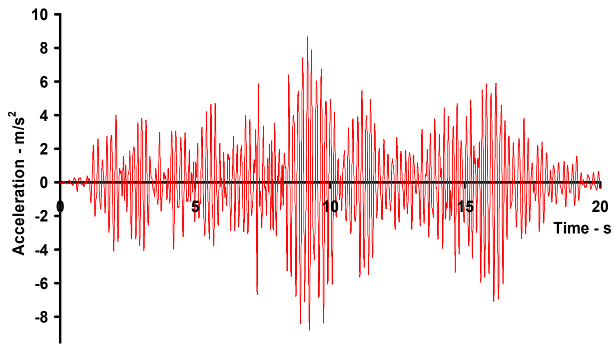


Fig. 3: Vertical acceleration of Grid Plate under SSE

In the present study, upward displacement of a subassembly is quantified under the combined effect of upward fluid force and vertical seismic excitations. One SSE is assumed to occur during the worst situation, viz. beginning of life where each core subassembly is freely standing on the GP without getting any resistance from the adjacent ones and the pumps are running with 110 % of the design flow. The vertical displacements of subassembly are determined through a shake table experiment. This paper gives the experimental evaluation of a core subassembly under seismic condition.

Nomenclature

CSR : Control & Safety Rod
DSR : Diverse Safety Rod
FSA : Fuel Subassembly
g : Acceleration due to gravity
GP : Grid Plate
LVDT : Linear Variable Differential Transformer
PFBR : Prototype Fast Breeder Reactor
SA : Subassembly
SSE : Safe Shutdown Earthquake

2. Details of FSA

The hexagonal shaped FSA contains 217 fuel pins with outer diameter of 6.6 mm and an active fissile length of 1000 mm. Fuel pin has axial blankets on either side (~ 300 mm length on top and bottom end) of the fissile portion. For collecting the fission gases, a plenum of 200 mm at the top and 710 mm at the bottom is provided in the fuel pin. The total length of the fuel pin is 2580 mm. B_4C of 100 mm and steel of 650 mm length are provided at the top portion of the FSA to reduce the fluence on the control plug. The total length of FSA is 4500 mm and its mass is 2403 N. Other geometrical details of the FSA are shown in Fig. 4.

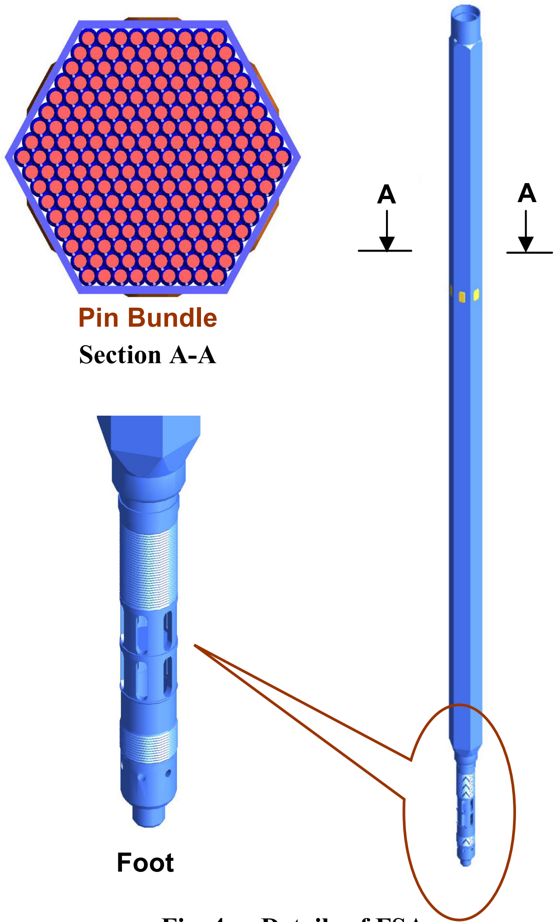


Fig. 4: Details of FSA

3. Loading Condition

3.1 Normal Operation

Under normal operating condition, the loads acting on the FSA are given below:
Downward force = Weight of FSA (2400 N)
Upward force = Buoyant force + Coolant pressure force + Drag force.
The maximum upward force is computed as 0.24 x weight of subassembly.

3.2 Seismic Excitation

Under vertical seismic excitation, the loads acting on the FSA are given below:

Downward force = Weight of FSA (2400 N)

Upward force = Buoyant force + Coolant pressure force + Drag force

Vertical seismic excitation = 0.88 g (Peak value in Fig. 3)

4. Experimental Simulations

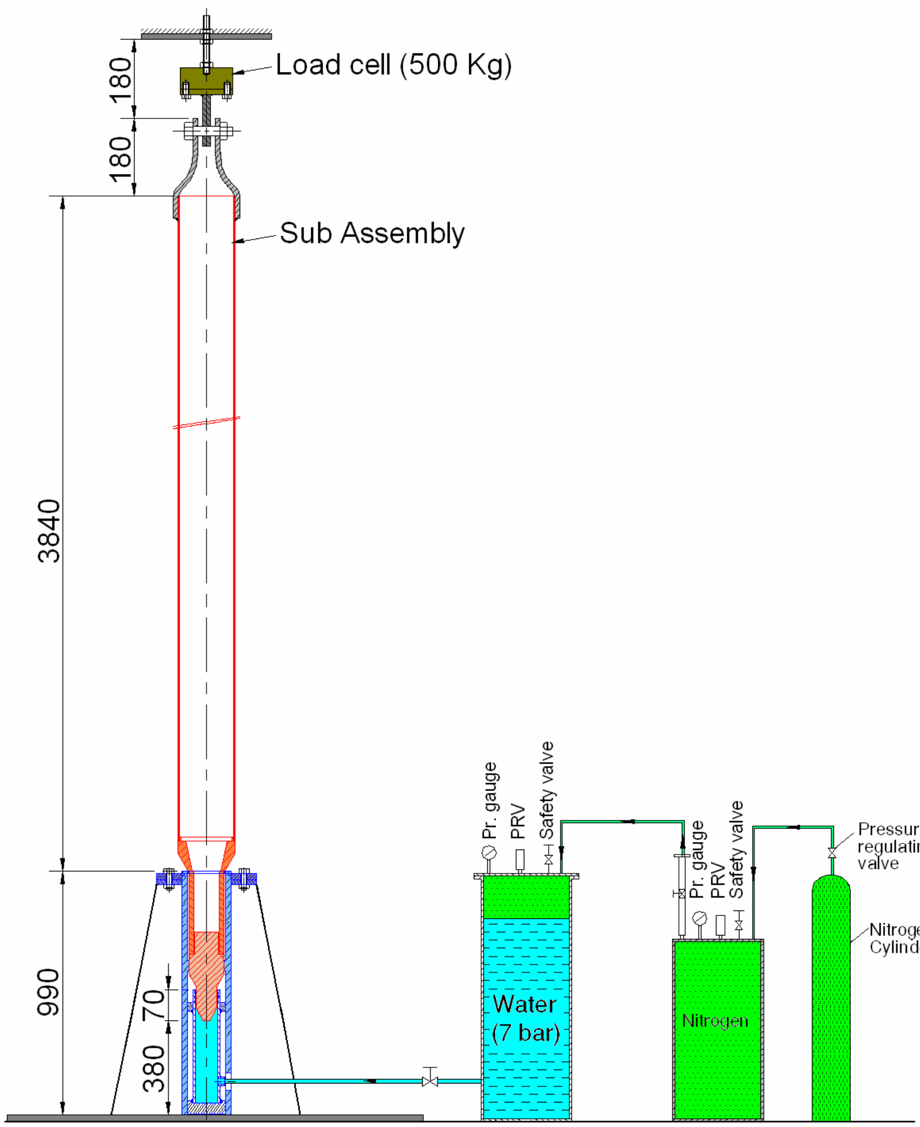


Fig. 5: Test Set-up for the application of Simulated Upward Fluid Force

One free standing FSA is considered for the investigation. This implies that the effects of mechanical interaction with neighbouring subassemblies are ignored to yield conservative results. The test mock-up of subassembly is one of the core subassemblies manufactured for PFBR, except the internals. The main internal, the fuel bundle, is replaced with an equivalent bundle of steel rods of 8 mm diameter, having mass equal to that of prototype. Further, the grid plate sleeve manufactured for the PFBR is used for the test mock-up. Since the test mock-up is geometrically similar, having the same mass and boundary conditions, the stiffness and inertial forces are simulated exactly in the test. The upward fluid force is simulated by applying water under pressure using the setup shown in Fig. 5.

5. Test Procedure

5.1 Establishing Test Pressure

The subassembly is made to freely hang through a load cell so that it can measure the weight of the subassembly accurately. Further, with the O-ring seal between foot and sleeve, it is possible to apply and sustain pressure up to 1 MPa without offering any significant constraint for the vertical motion. The pressure to be applied at the bottom of subassembly to generate the targeted upward lift force equal to 30 % of the weight of SA (an additional

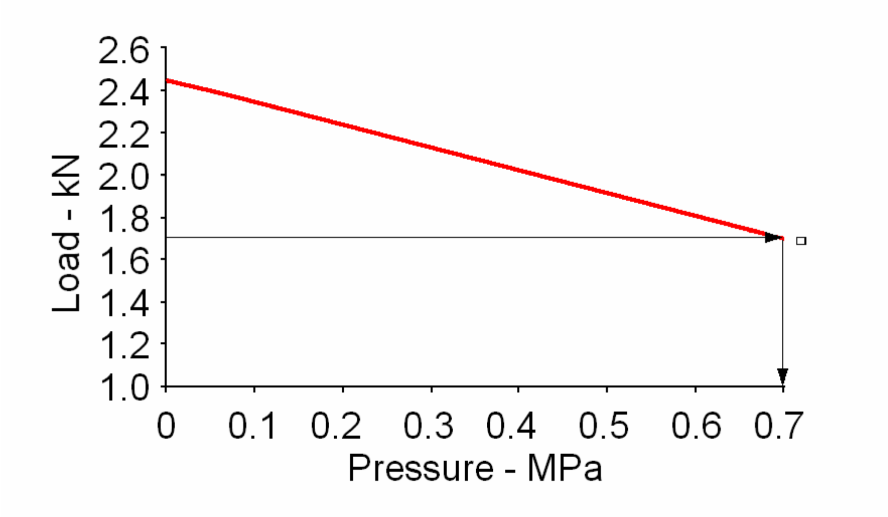


Fig. 6: Weight Measured by Load Cell Vs Pressure applied at Bottom

force equal to 6 % of weight of SA has been considered for accounting the possible uncertainties) is established by measuring the load with the specific pressure applied at the bottom. The graph 'Weight measured by load cell Vs applied pressure at the bottom' is plotted as shown in Fig. 6. The reduction in weight is due to the upward lift provided by the pressure. The pressure to be applied at the bottom is 0.7 MPa

The required pressure of 0.7 MPa is applied by a water pump attached with the test setup through a hose, which provides excellent flexibility during dynamic displacement of test assembly under seismic base excitations after mounting on the shake table.

5.2 Shake Table Tests

Test has been done by using tri-axial shake table of 10 t capacity. Experimental setup is shown in Fig. 7.

A dedicated data acquisition system with 64 channels is used for capturing the structural response under seismic excitation. Three LVDTs are used for measuring the relative displacement of the SA with respect to GP top. Acceleration time history measured by the accelerometer, mounted on the GP support location, ensures that the support structure has sufficient rigidity and hence, the vertical excitations imposed on the table are transmitted to the mock-up without any distortion. The setup is subjected to vertical excitations with the peak accelerations of 0.5 g, 1.0 g & 1.5 g and the accelerations measured at the GP top portion are shown in Fig. 8.

The relative vertical displacement of FSA with respect to GP top surface is measured by using LVDT. All the three LVDT readings along with its average value are given in Fig. 9 - 11 for the peak vertical accelerations of 0.5 g, 1.0 g & 1.5 g respectively.

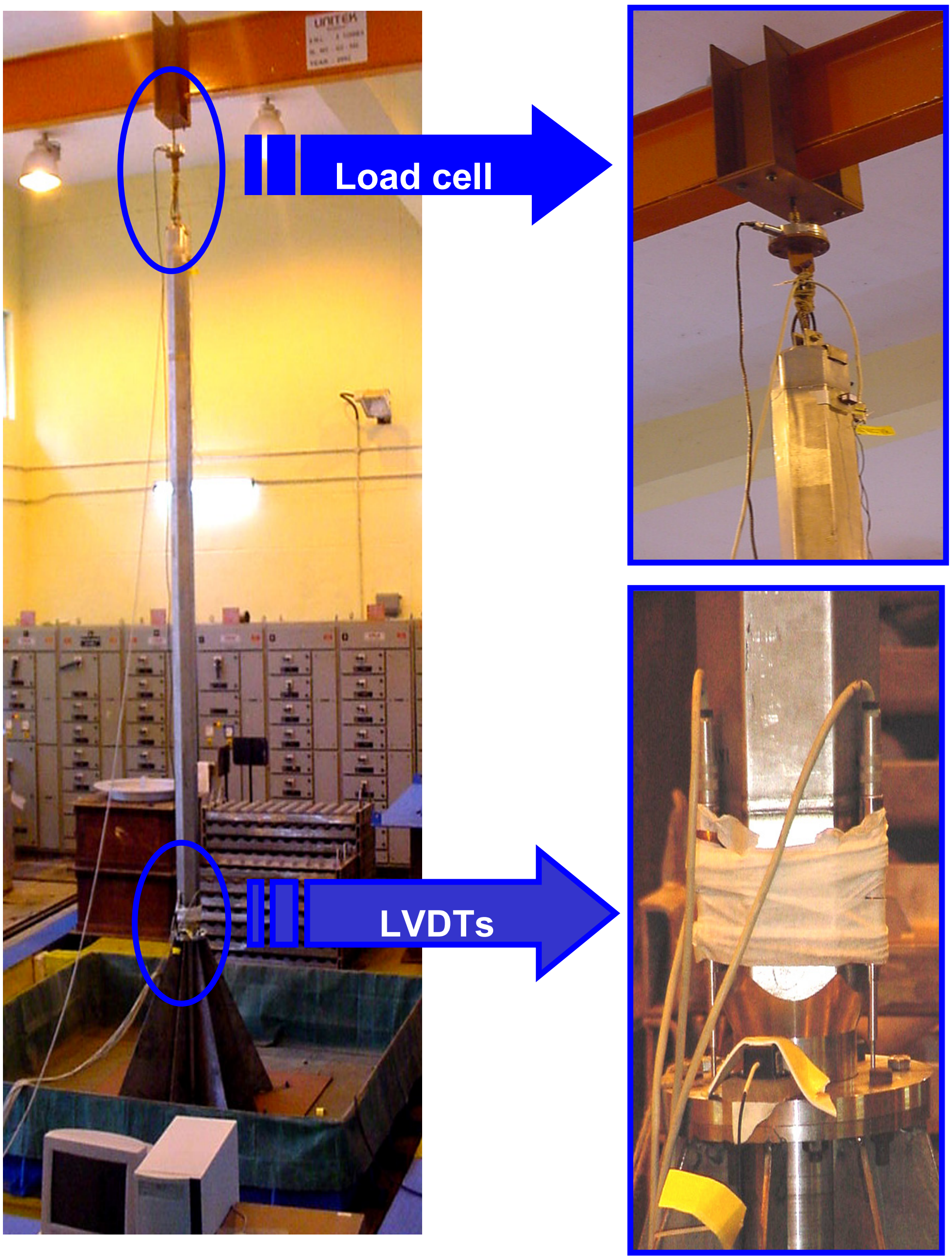


Fig. 7: Test setup mounted on shake table

5.3 Discussion

The results indicate that there is no relative vertical displacement between GP and FSA for the excitations having peak value less than 0.5 g at GP top plane. The displacement histories for the peak accelerations of 1.0 g and 1.5 g indicate that there are multiple impacts. However, the maximum relative vertical displacements are limited to 2.5 mm and 4 mm respectively for the peak accelerations of 1.0 g and 1.5 g. The maximum displacement for the peak acceleration of 0.88 g is computed as 2.2 mm by interpolation.

The foot of the SA is guided with H7/e7 fit over a length of 25 mm. If displacement of FSA exceeds 25 mm, there can be loss of guide and subsequently, there can be unacceptable horizontal displacements due to horizontal component of seismic accelerations. Since the maximum displacements are less than 4 mm for the peak acceleration up to 1.5 g, there is no concern of loss of contact.

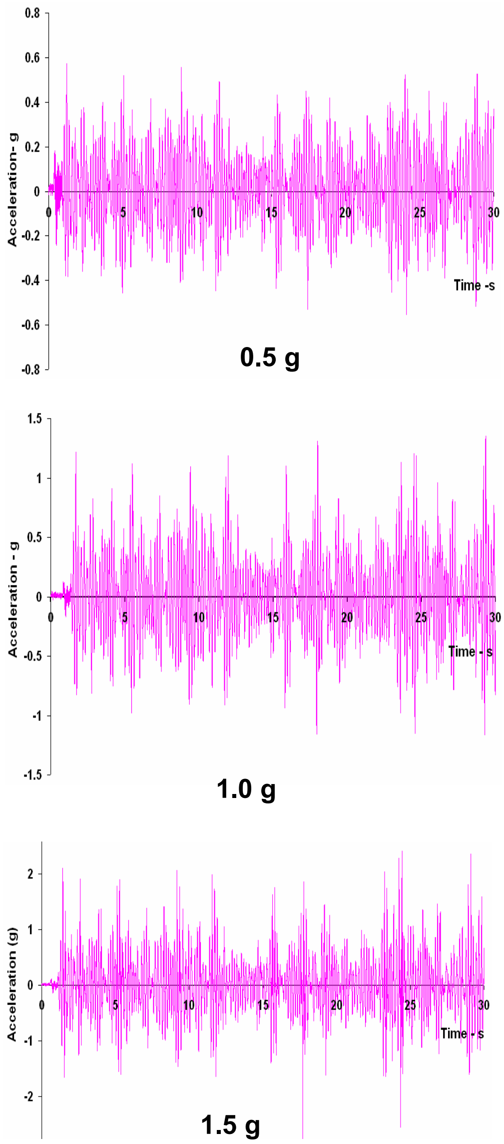


Fig. 8: Accelerations measured at GP Top surface

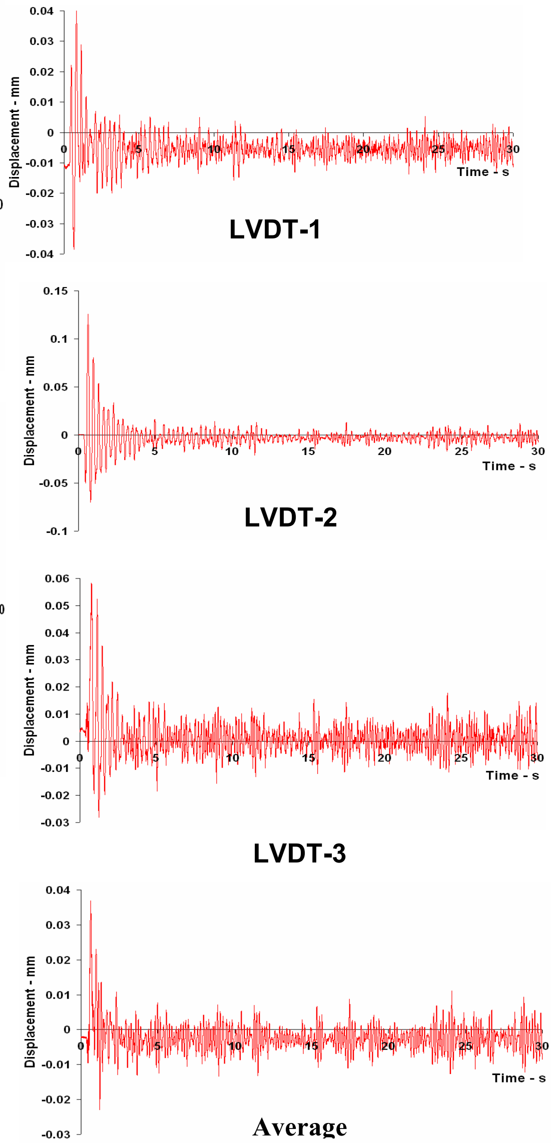


Fig. 9: Relative displacement of SA with respect to grid plate (0.5 g)

6. Conclusion

An experimental seismic analysis was carried out on a core SA and the upward displacement of the SA was quantified under the combined effect of upward fluid force and vertical seismic excitations. The vertical seismic excitations under SSE which cause a peak amplitude of 0.88 g at the GP top can cause a relative vertical displacement of FSA by 2.2 mm with respect to the GP top. Under these displacements, the subassembly would be within the guide span with H7/e7 fit provided at the foot. Hence there is no concern of any unacceptable displacement and loss of integrity of core.

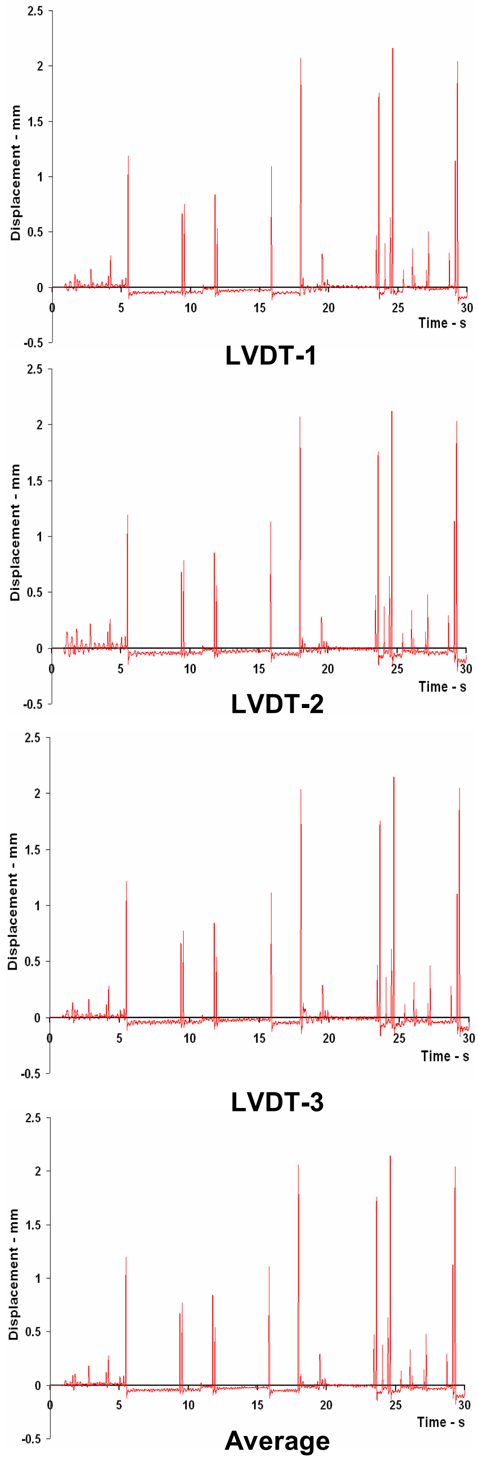


Fig. 10: Relative displacement of SA with respect to grid plate (1.0 g)

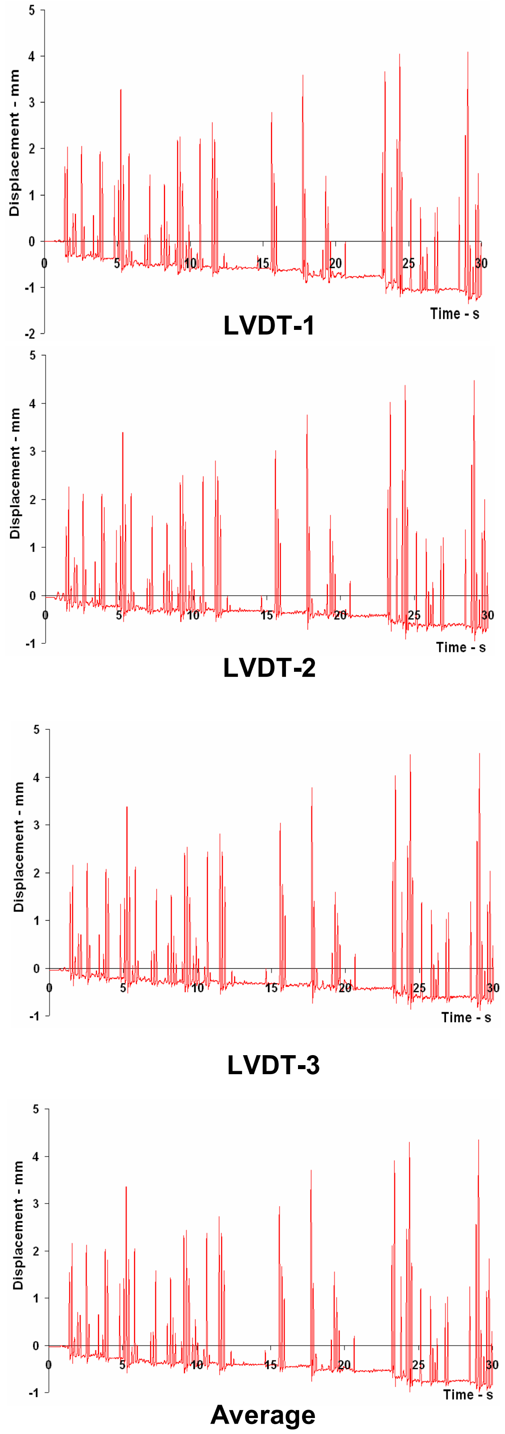


Fig. 11: Relative displacement of SA with respect to grid plate (1.5 g)

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