Parametric Studies for Reactor Building Raft

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1 INTRODUCTION

The base Raft of Reactor Building (RB) for 500 MWe PHWR, is 62.0 meter in diameter, founded on good rock 20 meters below the finished grade level. Double containments and the internal structures, transmit all vertical and horizontal loads to the base Raft. Raft is generally analysed as a plate on elastic foundation simulating foundation rock as equivalent rock springs applied at the nodes (Refer Fig.3). This being a sub-structure analysis, modelling of geometry and all other parameters viz. effect of super-structure/adjacent rock interface etc. play an important role.

This paper explains studies conducted to establish simplistic procedures to account for various complex parameters which influence the design of the raft.

2 OBJECTIVES

Embedment Effect

RB-RAFT is concreted against excavated rock surface (Refer Fig.1). Peripheral interface between the raft and rock offers resistance against lift-off during seismic condition.

Para 3 describes a methodology for estimation of this resistance and its use in the static analysis of the raft.

Effect of change in centreline

Raft is provided with variable thickness depending upon the design requirements of uncracked condition. As the raft is analysed as a thin plate on elastic foundation, effect of change of centre-line can not be considered in the analysis. In order to assess the extent of inaccuracy involved, a 3-D shell model consisting of raft and part of containment walls is used. Para 4 describes these studies in detail.

Tension Bond Between Rock & Raft Interface

While analysing the raft as a plate on elastic foundation, it is usual procedure to cut off the rock springs at bottom of Raft, which are likely to undergo tension. However, in reality some kind of tension bond is expected to be present between the rock and the raft interface. Para 5.0 describes an experimental setup for estimation of tension bond under the actual site conditions.

Stiffening Effect of Containment Walls

Cylindrical containment walls have a large stiffness as compared to the raft in a direction tangential to the walls, and very low stiffness in the direction normal to the walls. Para 6.0 describes a mathematical formulation for simulating the stiffening effect of the containment walls in plate bending analysis.

3 EMBEDMENT EFFECT ON RAFT

The embedment effect of the rock side surface on the raft can be studied by idealising the raft and the adjacent rock in an elastic half space model. However, the present study is limited to estimate the peripheral rock-concrete interface resistance in the vertical direction by inplane analysis of the vertical cross-section of the rock profile under unit loads so as to find out its equivalent vertical side springs which can be used in a conventional plate bending analysis. As the inplane problem under consideration cannot be categorised as a plane stress or plane strain problem, analysis is performed for both these conditions and an average value is adopted. In the finite element model, rock profile having a width and depth of two times the diameter of the raft is considered. Appropriate elastic properties of the rock at various depths are accounted for in the analysis. The equivalent springs so calculated work out to be 51,000 Tonnes per m of vertical displacement per m of circumferential length measured at the rock-raft interface. Fig.4 shows two displacement graphs, one in which the above mentioned vertical spring has been applied along the circumferance (curve B)and the other in which the springs are absent (curve A).

4 EFFECT OF CHANGE OF CENTRELINE

Raft is provided with 5.0 m thickness in the peripheral zone and 3.0 m in the central zone. As the plate bending finite element model can not account for change of centre line, a 3-D model using thin flat shell element is prepared and 2 sets of analysis are done, one in which actual change of centre line is accounted for and the second in which a common centre line is assumed. The resuts of these analysis are shown in Fig.5.

5 METHODOLOGY FOR ESTIMATION OF TENSION BOND

Casting of Concrete Test Blocks & Test Arrangement

Tests for evaluation of Tension Bond were carried out for a 235 MWe nuclear power plant site, on the exposed rock, at the bottom of RB Raft foundation level.

Three locations were identified by visual inspection and no special surface preparation methods like wire brushing were used except that these locations were cleaned by a jet of water. Concrete blocks of 1.2 m diameter and 1.0 m height were cast on each of the 3 locations using M20 concrete (cube crushing strength = 20 N/mm2) using 40 mm down graded aggregates. A Structural Steel beam with built up box section was placed above the test block (Refer Fig.2). Three dial gauges having 0.01 mm accuracy were set, two near the jacks and one at the centre of the beam. Two jacks of 100 tonnes capacity each placed suitably below the box girder. Both the jacks were connected to the same plenum to ensure equal load application. After initial jacking equivalent to the weight of the concrete block, anchor bolts and box girder readings were recorded after every 5 tonnes increment in load. Adequate safety precautions were taken against sudden failure of tension bond.

Test Results

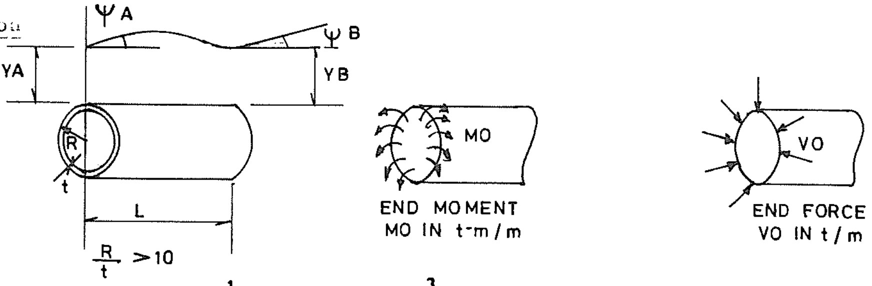
	Location-1	Location-2	Location-3
Area of interface in sq.m	1.13	1.13	1.13
Failure Load in Tonnes	29.5	39.5	3.98**
Intensity of load in tension t/sq.m	26.08	34.92	3.52

** Location of shear zone

Note : Mode of failure in all the three tests indicated weakness of exposed surface rock to take tension.

6 MATHEMATICAL FORMULATION OF STIFFENING EFFECT OF CONTAINMENT SHELLS

Derivation



$$\lambda = \left[\frac{3(1-\nu^2)}{R^2 t^2}\right]^{\frac{1}{4}}$$

7-a

$$D = \frac{E\,t^3}{12(1-\nu^2)}$$

7-b

E = modulus of Elasticity

7-c

Consider a cylinder as shown in Fig 7-a Ref. (1).
Let us consider it as a long shell i.e. $\lambda L > 6$ with Ref. to Fig. 7-b & 7-C
Rotation $\Psi A1 = -Mo/(D\lambda)$ and Deflection $YA1 = Mo/(2D\lambda^2)$
Rotation $\Psi A2 = Vo/(2D\lambda^2)$ & deflection $YA2 = -Vo/(2D\lambda^3)$
As the Raft restrains any end displacement of the containment shell.
$YA1 + YA2 = 0$ i.e. $Vo = Mo \cdot \lambda$
& total rotation $\Psi A = \Psi A1 + \Psi A2 = -Mo/(2D\lambda)$

∴ Rotational stiftness at A $= Mo/\Psi A = 2D\lambda$

For ICW $R = 25.36$ m $t = 0.61$ m $\nu = 0.15$, $\lambda = 0.3327$

i.e. if $L > 18.03$ m it will be a long shell. As the height of ICW is greater than 18.0 m, boundary conditions beyond this height will not affect the results at the raft level. For Inner Containment Wall (ICW) and Outer Containment Wall (OCW) rotational stiffness works out to be 38627 and 36782 t-m/radian respectively. As the stiffness parallel to the wall is very high, a value equivalent to about five times of the above value is used. These stiffness values are to be applied appropriately at the location of containment walls in a plate bending analysis of Raft.

Results

In order to assess the effectiveness of the above formulation 3 different analyses are carried out and the Vertical displacement plot along the line of symmetry of the raft have been presented in fig.6.

i. Plate bending analysis without using rotational stiffness of the containment walls (curve A).

ii. Same as above but considering rotational stiffness of the containment walls (curve B).

iii. A 3-D model consisting of Raft and 20 m height of both the containment walls, with a free boundary condition at top (curve C).

7 CONCLUSION

Side rock resistance when considered, minimises lift-off substantially.

Effect of change of centre line is negligible and as such plate bending analysis can be performed instead of 3-D shell analysis.

For a specific site where testing was done, no advantage can be derived due to jointed nature of rock. However, for a site where good tension bond resistance can be obtained, a safe value using appropriate factor of safety can be considered. Thus the criteria for cutting the rock springs in tension can be modified as 'cut those springs in tension where tensile stress exceeds permissible rock-concrete interface bond'. This will help in minimising the lift-off there by reducing moments in the raft.

Stiffening effect of shell using equivalent rotational springs matches well with actual 3-D shel analysis.

8 REFERENCE

i. Roark R J & Young W C - Formulas for Stress and Strain.

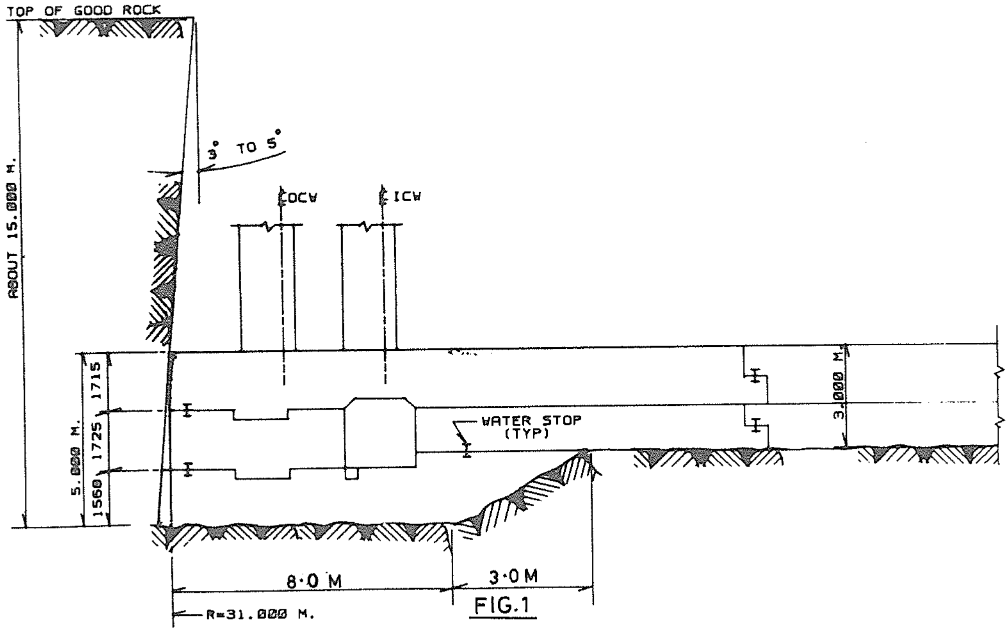


FIG.1

9 ACKNOWLEDGEMENTS

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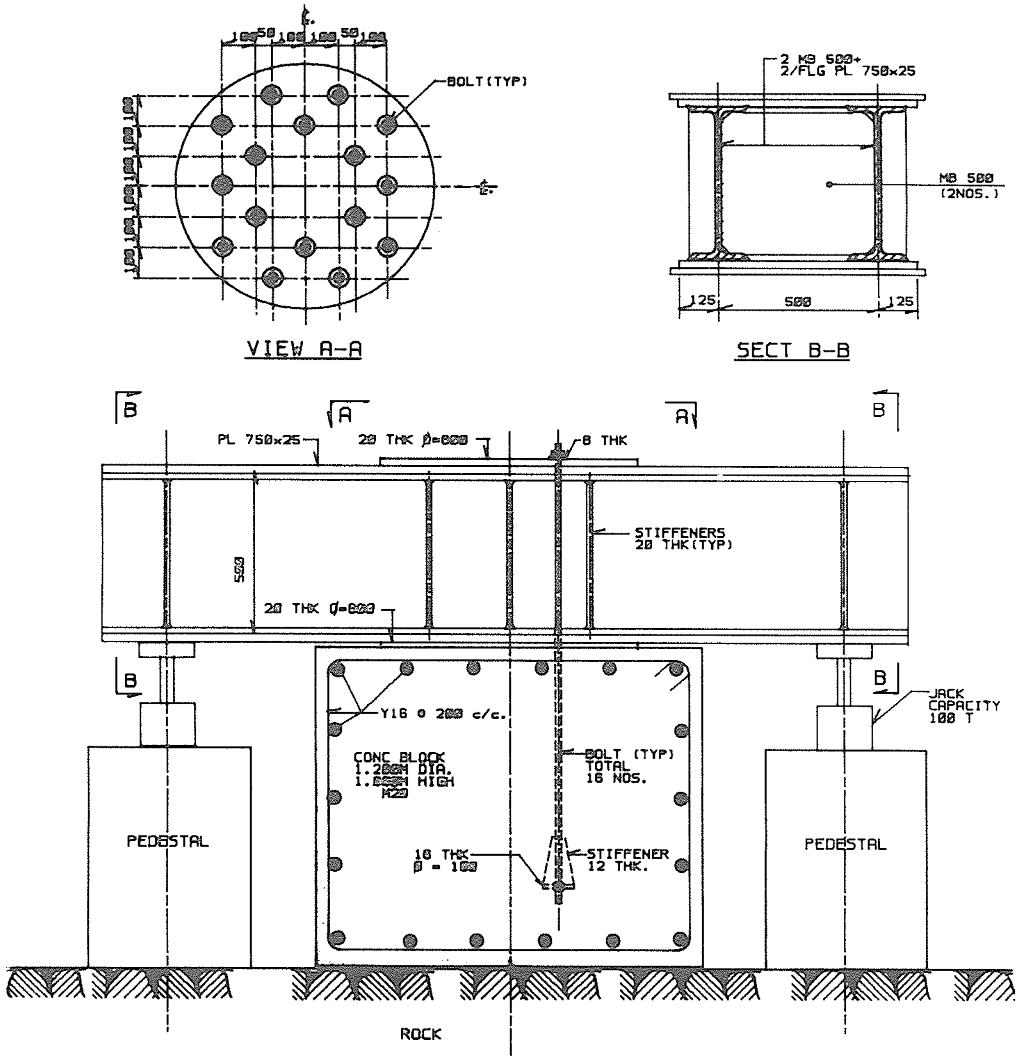

FIG-2

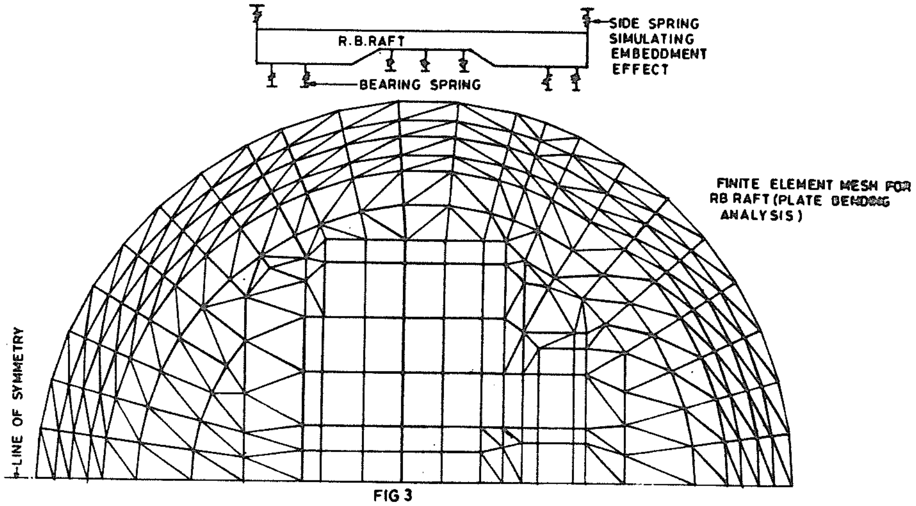

FIG 3

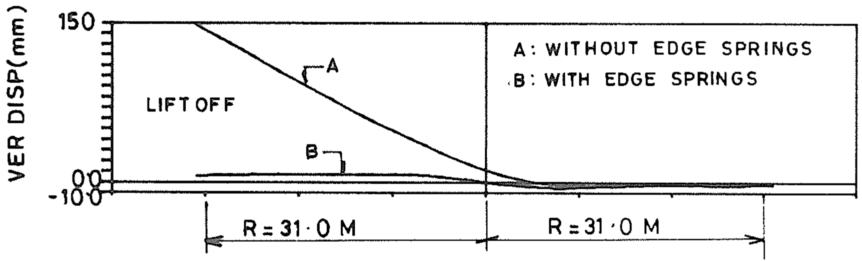

FIG.4

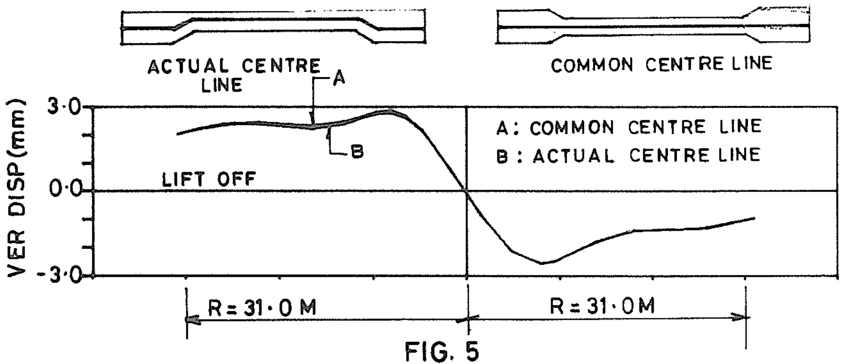

FIG. 5

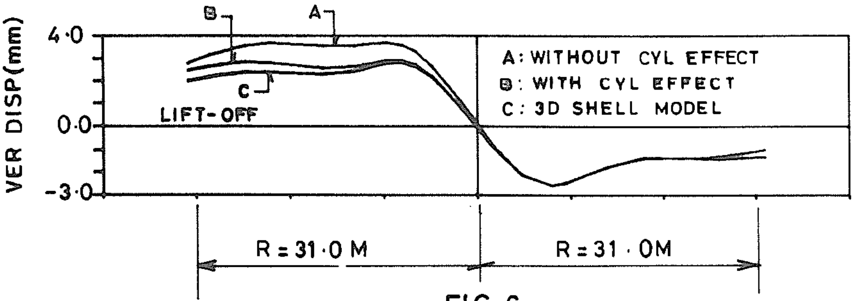

FIG.6