End Plate Design for 37 Element Fuel Bundle

M. Das, A. G. Chhatre, P. N. Prasad
Nuclear Power Corporation of India Ltd., Bombay, India

INTRODUCTION

The fuel bundle for 500 MWe Indian PHWR (Pressurised Heavy Water Reactor) consists of 37 cylindrical fuel elements of 493 mm length, joined together by welding the elements to the end plates at both ends. The elements are arranged in concentric rings of 1,6,12 and 18 elements in each ring. Each element contains 480 mm long stack of sintered natural UO_2 pellets in a thin zircaloy-4 sheath with end caps welded at both the ends. The elements are separated by spacers attached to the sheaths near the midplane of the bundle. Inter-element spacers are of skewed split spacer type. The bundle weighs about 25 Kgs. Bearing pads are provided on each element of the outer ring to prevent fuel sheath from touching the coolant tube. The bundle weight is transferred through the end plates to the bottom elements whose bearing pads contact the pressure tube. During the process of design of the end plate, two types of end plates designs were evolved from mechanical and hydraulic design considerations. The details of this work are brought out in this paper.

END PLATE DESIGN

The end plate design for 37 element fuel bundle is evolved based on the 19 element fuel bundle end plate design which is used for 235 MWe reactors. The main considerations for end plate design are:

i) Structural strength : must resist the loads imposed by differential expansion of the elements (static and fatigue), fuelling machine loads and impact loads.

ii) Compatibility with the fuelling machine : maximum diameter of the end plate is governed by the penetration of the fuelling machine side stops.

iii) Assembly joint strength : governs the size of the weld.

iv) Minimum resistance to flow : governs the orientation of the spokes with respect to flow subchannels.

v) Minimum zircaloy content.

vi) Cost of manufacturing and limitations.

Based on the above considerations two types of end plate designs have been considered primarily for fuel bundle support. In the first design the spokes connecting the three rings are equally distributed over the circumference and the spokes are placed over the element positions for minimum flow resistance (type 1). The second design is the enhancement of RAPS 19 element fuel bundle end plate with an additional outside ring (to which the outer elements are welded) supported by six spokes aligned with the existing spokes (type 2). The two end plate designs are shown in fig. 1 and 2 respectively.

It was found during the pressure drop experiments [1] that the pressure drop with end plate type 1 is less than that of end plate type 2 and as such the end plate type 1 is a suitable choice from flow considerations. Moreover, the endplates must withstand the loads imposed by differential expansion of the fuel elements. Variations in the thermal neutron flux radially across a bundle due to flux depression causes unequal heat generation in different rings of the fuel bundle resulting in unequal thermal expansion of the fuel elements. This differential expansion in elements in different rings imposes stresses in the fuel elements and the end plate spokes and rings.

Calculations have shown that the differential thermal expansion of elements between the neighbouring rings could be about 0.5 mm. The end plates are also to be designed for these thermal loads as well as the mechanical loads imposed by the fuelling machine rams. The design requirement calls for closer knowledge of the stress distribution in the end plate enabling the designer to foresee the possible failures and take corrective action. As a part of this process, in this work, these two end plates have been analysed by finite element method.

FINITE ELEMENT ANALYSIS

A typical eight noded isoparametric Ahmad's degenerated shell element [2] as shown in fig. 3 has been used for analysis. The nodal parameters for this element are three translations u,v,w of the mid-surface and two rotations α and β of the normal to the mid surface. The end plates have been discritized into 268 elements and 1176 nodes as shown in the fig. 4 and 5. To achieve good accuracy in the solution of the problem, a fine mesh has been considered around the end plate to fuel element weld points. As explained above, at the weld points, the end plate experiences varying deflections firstly due to the different fuel element lengths due to the manufacturing tolerances and secondly as elements in different rings experience different thermal expansion in the reactor during reactor operation. As the maximum differential deflection between two adjacent rings has been considered to be 0.5 mm as design requirement, in the present analysis deflections of 0.5 mm, 1.0 mm and 1.5 mm are applied at the second ring, third ring and the central element, keeping the end plate outer ring element weld locations fixed.

NUMERICAL RESULTS AND DISCUSSION

The stresses obtained at the gauss points of the elements are as shown in fig. 6 and 7 along lines Z1 & Z2 for the two types of the end plates. The maximum stress in the end plate type 1 has been found to be 99.0 Kg/sq.mm on the spoke joining the second and third ring, the maximum stress in the central spoke being 77.7 Kg/sq.mm. The maximum stress in the endplate type 2 has been found to be 83.0 Kg/sq.mm and is in the central spoke. The fact that the applied displacements in the case of end plate type 2 are away from the spokes joining the rings of the end plate, the stress levels are found to be lower than that in the case of the end plate type 1. However, in the central spoke the stress level in both the end plates are of the same order. Using the maximum elastic stress values of 99.0 Kg/sq.mm for endplate type 1 and 83.0 Kg/sq.mm for type 2 respectively and by using the model of Rustagi and Das [3], the maximum number of cycles the end plates can see for the fatigue failure have been calculated to be 268 cycles and 423 cycles respectively. In both cases the number of cycles are more than 200 cycles, which is the maximum number of design cycles the fuel bundle can experience during its stay in the reactor. As such, both the end plates are acceptable from mechanical design considerations. Moreover, it has been seen that the stresses in the end plate type 1 are lower than that in the end plate type 2 when analysed for the axial hydraulic and fuelling machine loads on the endplate. The stress values in both the end plates under these loading conditions are very low. However, as brought out above from the pressure drop consideration end plate type 1 has been finally selected for the 37 element fuel bundle for 500 MWe Indian PHWRs. The recent type tests carried out on the fuel bundles using the end plate type 1 design have shown that the bundle design is capable of withstanding loads upto 2000 kgs [4].

REFERENCE

[1] Pressure Drop Test on 37 Element Fuel Bundle for 500 MWe Indian PHWR - Internal BARC Report.

[2] Ahmad, S., Irons, B.M., Zienkiewicz, O.C., Analysis of Thick and Thin Shell Structures by Curved Finite Elements, I. J. N. M. E, Vol.2, No.3, 1970.

[3] Rustagi R.S., Das. M., Design Considerations for Nuclear Fuel Elements to Suit Reactor Operating in Small Grids - Proc. of 3rd International Conference on Structural Mechanics in Reactor Technology, London, Vol.-C, 1975.

[4] Type Testing of 37 Element Fuel Bundles for 500 MWe Indian PHWR for Side Stop Compatability and Fuelling Machine Load Test. Internal BARC Report.

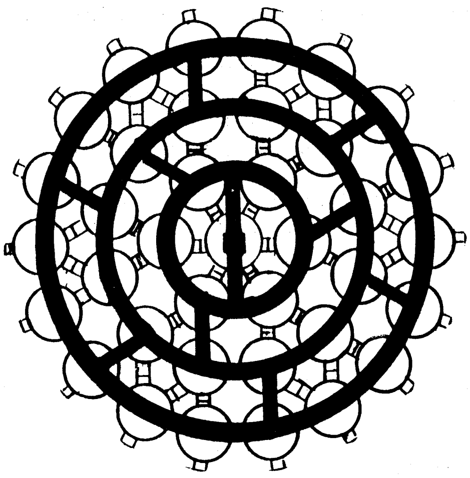

FIG. I END PLATE TYPE-I

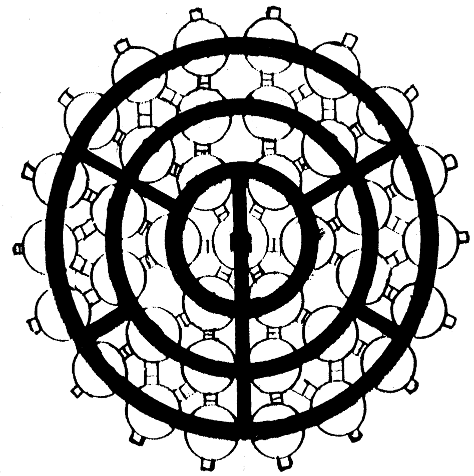

FIG. 2 END PLATE TYPE-II

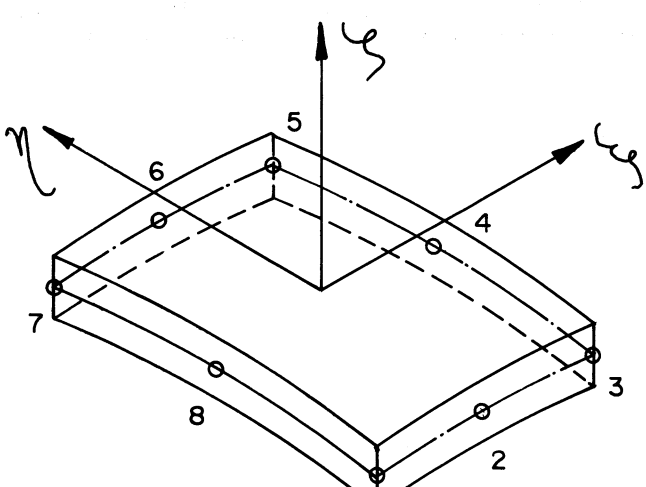

FIG. 3 EIGHT NODED ISOPARAMETRIC SHELL ELEMENT

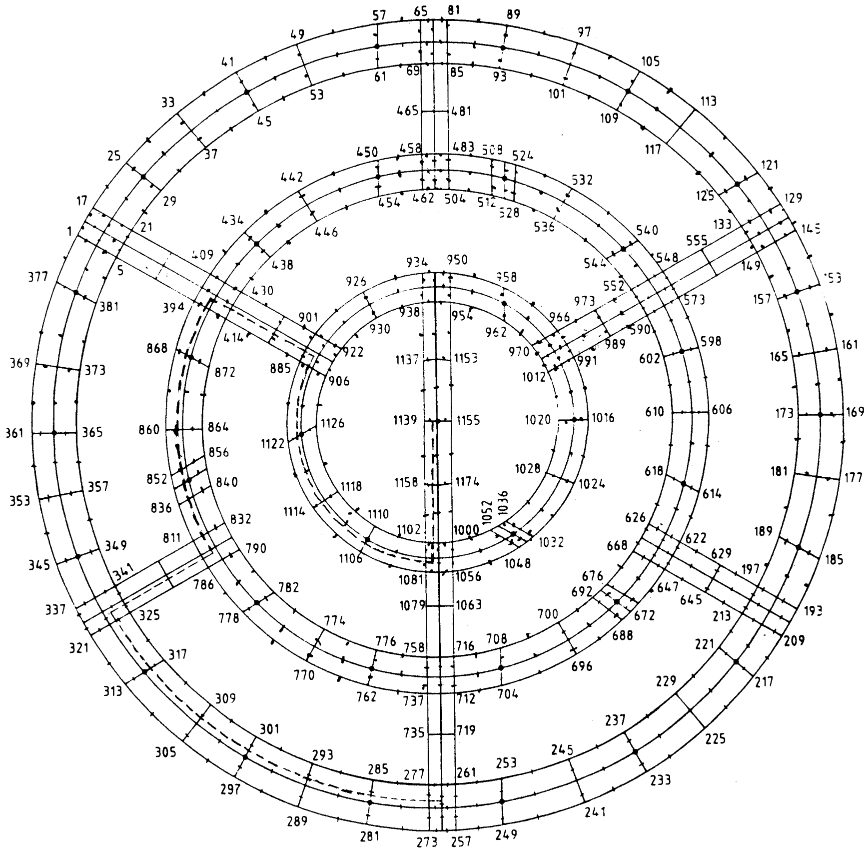

FIG. 5 FINITE ELEMENT IDEALIZATION OF END PLATE (TYPE II)

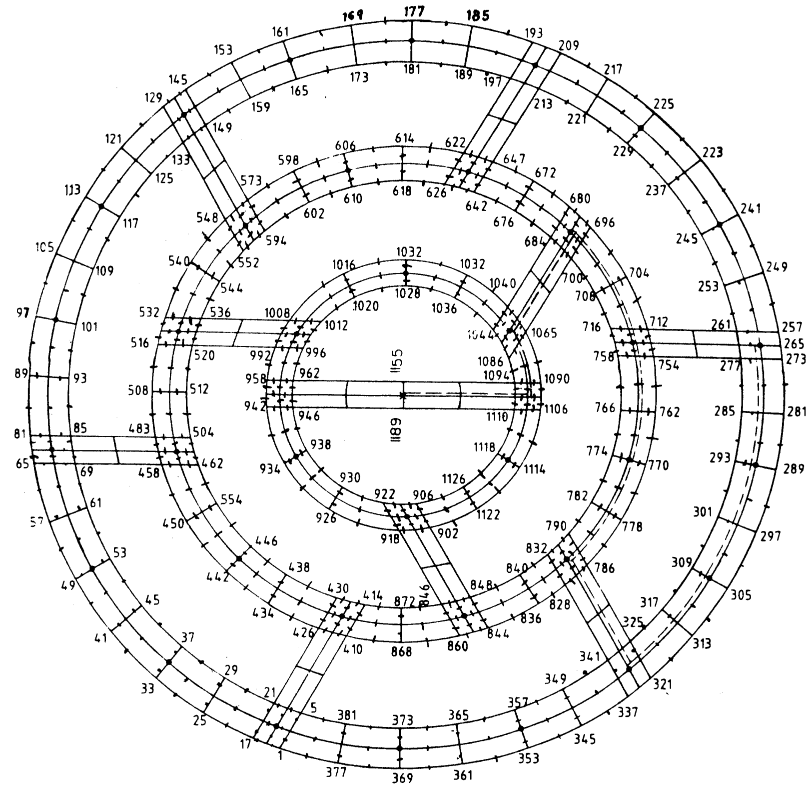

FIG. 4 FINITE ELEMENT IDEALIZATION OF END PLATE (TYPE I)

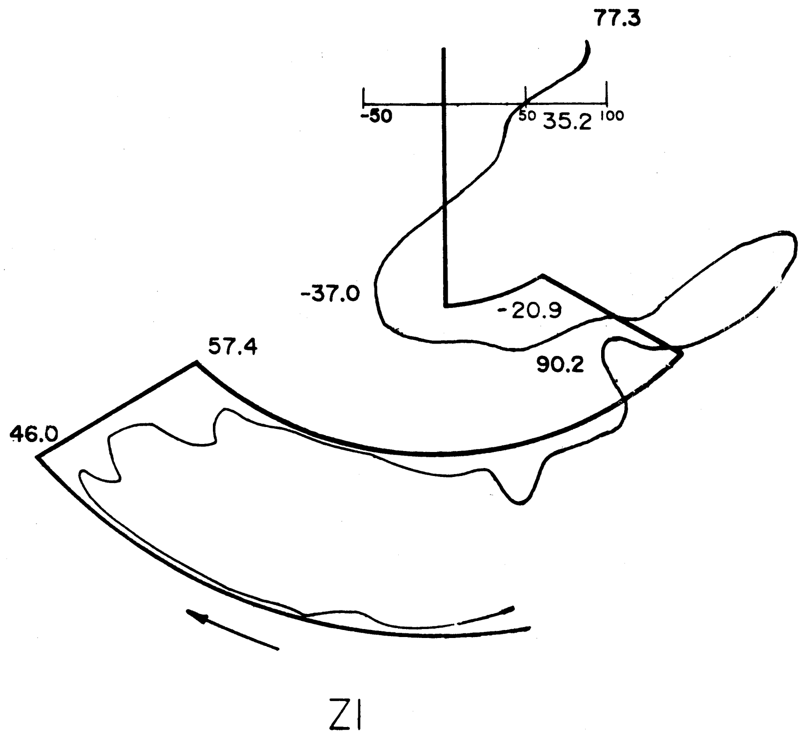

FIG. 6 STRESS VARIATION ALONG LINE Z1 FOR END PLATE TYPE-1

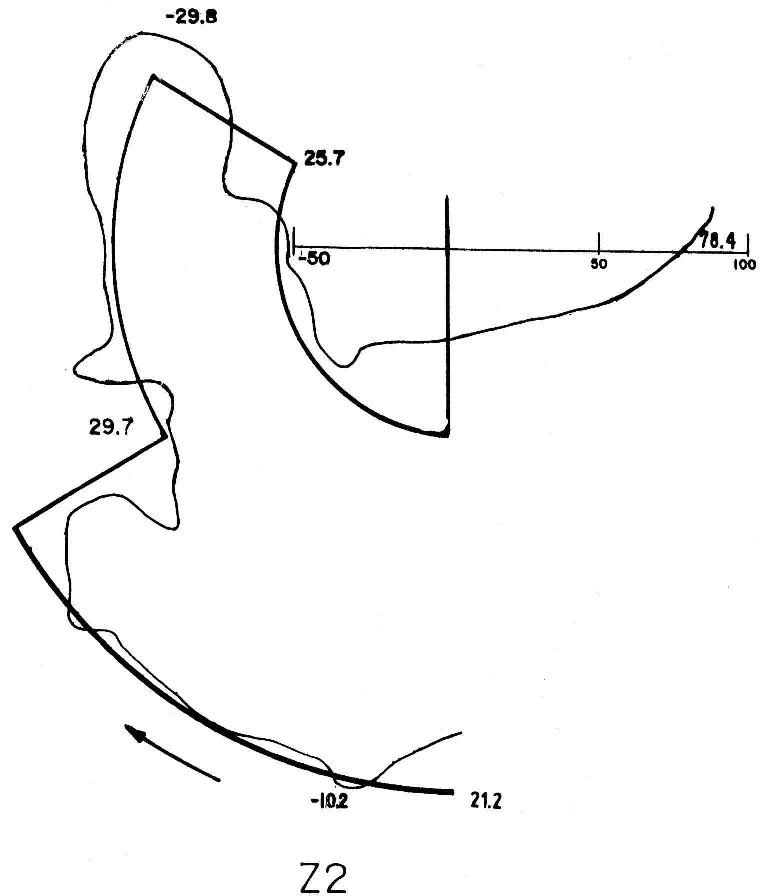

FIG. 7 STRESS VARIATION ALONG LINE Z2 FOR END PLATE TYPE-2