ABSTRACT

In nuclear power plants, it is necessary to minimize the likelihood of accidents and ensure that their consequences can be reliably mitigated. Hence, the need for a reliable design is becoming increasingly crucial in nuclear reactors. Structural integrity refers to the condition of a structural system and implies that the structure and its components remain intact over the intended lifetime of a structure.

In nuclear reactors, the roof slab forms the top cover for the main vessel. The primary function of the roof slab is to provide structural support in the upper axial direction. In addition, it acts as a part of the primary containment boundary supporting various reactor components. Hence, the structural integrity of the roof slab plays an essential role in the safe and reliable function of the reactor. The roof slab supports the main vessel of significant weight and is also subjected to fatigue loading due to the reaction and intermittent flow of sodium in the pump. Since the components made of thick shells are prone to buckling failure phenomena, it is crucial to predict the roof slab's static stress behavior and collapse load.

The primary objective of the research work is to develop an optimized model of dome shaped roof slab to meet the RCC-MR code with minimum weight and better reliability, and also ensure the structural integrity in the presence of weld defects.

The design by analysis technique is followed while exploring varying configurations of roof slab to achieve minimum weight and at the same time satisfying design limits and RCC-MR code, so that the structural integrity is guaranteed. Metamodels of triple layer roof slab configuration are developed using Response Surface Methodology (RSM) and the factors influencing the performance of the metamodel are investigated. Finally, the optimized model of the triple layer configuration of roof slab is found to satisfy the design requirements.

A scaled down model of triple layer roof slab was fabricated using IS2062. The hydraulic cylinders were fixed at the top plate of loading structure and the roof slab was mounted on it along with LVDTs and strain gauges. The component loads were applied to roof slab. The deflections and strains were monitored at PSP and IHX penetration shell locations using the PLC unit and NI-DAQ system. The results of experimental investigation were compared with that of the numerical analysis which shows a close correlation.

The static analysis of the roof slab showed that the pump penetration shell (PPS) that carries the primary sodium pump is subjected to higher stress concentration and is considered the critical part. However, in reality, the loading nature and other factors affecting the strength of the structure are not deterministic; they are random. Hence, the PPS is analyzed by incorporating the randomness of the design parameters like the flange angle and thickness for single, double and triple layered configurations.

The optimum design parameters of these three configurations of PPS were obtained using reliability-based design optimization technique. A comparison of the optimized results of single, double and triple layer configurations of PPS made of IS2062 shows a higher collapse load than A48P2 with a lesser weight.

While manufacturing the roof slab, one of the challenges faced is welding its sub-structures. As the weld is not always a homogeneous one, various defects occur in the weld zone. A numerical model developed using finite element software is used to determine the fatigue life of an arc welded butt joint having weld defects like lack of penetration, lack of fusion, undercut, and porosity, predominantly in welded structures. The finite element analysis approach adopted in the present work is validated using the results of the experimental method. The validated method is then adopted to predict the fatigue life of butt joint with above said defects modeled as cracks at specific locations using

ASME SEC-V codes. It was observed that increasing the stress levels have proportional decrease in crack propagation life for these weld defects. The weld defects are then ranked based on four different load cases.

The most severe weld defect is identified based on fatigue life of butt joint by using the ranking method and it is modeled as an equivalent slit based on RCC-MR code recommendations. The influence of slit on collapse load was studied for various configurations of slit on the single layer, double layer and triple layer PPS. It was found that the reduction in the collapse load of the triple layer PPS in the presence of slit is found to be very minimal as compared to that of single layer and double layer PPS. Thus, the proposed design configuration of dome shaped roof slab satisfies both functional and structural integrity requirements of the nuclear reactor.