# ABSTRACT

The roof slab of a nuclear reactor acts as a thermal and biological shield by preventing radiation to the environment and also, it supports various nuclear components. The massive structure of the roof slab is fabricated through the welding process. The structural integrity assessment of the roof slab is very important for the safe and reliable operation of the nuclear reactor. 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 the present work, systematic integrity evaluation of the roof slab is carried out under four levels by carrying out both experimental and numerical investigations.

The Level I assessment deals with investigations on the linear static behavior of roof slab. The roof slab is subjected to its component loads and the corresponding deflection and stresses determined by the numerical and experimental methods are compared with design limits based on the French nuclear (RCC-MR) standard. The finite element model of the roof slab is developed using S8R shell elements. Special grade (low carbon) A48P2 steel specified in French code RCC-MR is chosen as the material. A maximum deflection of 4 mm and equivalent stress of 190 MPa are considered the design limits for safe operation. The weights of various components supported by the roof slab are considered static loads and applied at the respective locations.

Linear static analysis is carried out and the stress and deflection are obtained at various locations of the roof slab. The individual influence of component loads on the roof slab is analyzed and is found that the primary sodium pump and heat exchanger loads have a very significant impact on the deflection and stress induced in roof slabs under static conditions.

To avoid huge test structures, higher loading capacity, and higher costs, a scaled-down (1:10) model was fabricated for experimental investigation. The deflection and stress values of scaled-down numerical model are compared with full scale model and found to be in good agreement with the results obtained by using scaling laws. A rigid self-supporting loading structure was designed and fabricated to carry out an experimental investigation on the roof slab. The strain at critical locations along the longitudinal and circumferential directions of the roof slab was obtained. Numerical and experimental results are found to be in good agreement, and the deflections and stress levels are within the design limits, which ensures the Level I integrity of the roof slab.

Level II integrity of the roof slab is to be ensured by demonstrating that no crack initiation will occur at the critical location under fatigue loading, even with certain defects (marking lines, shrinkages, weld defects, cracks) left unnoticed. The above defects are considered a notch for crack initiation study as recommended by the RCC-MR code. The pulsation of sodium fluid passing through the primary sodium pump induces a fatigue load on the roof slab. The interface junction of the pump penetration shell and the top layer of the roof slab is considered more critical since the welded junction is subjected to fatigue load.

A benchmark study is carried out on a rectangular plate to validate the finite element method for determining stress at the notch tip using the sigma-d approach highlighted in the RCC-MR code. The crack initiation life is determined from the ASME design curve for the corresponding initiation stress. At the critical location of the roof slab, crack initiation stress is determined by considering a notch and the fatigue life was determined from the ASME design curve. ASME design curve predicts the fatigue life cycles above $1x10^6$ cycles which ensures no evidence of crack initiation at the junction of the PSP shell to the top layer of the roof slab; hence the integrity of the roof slab is ensured.

Level III assessment focuses on integrity assessment of roof slab based on crack propagation. The presence of a part through-wall surface crack which is a severe violation of manufacturing standards should not lead to a through-wall crack by propagation in the event of OBE loading. For the above assessment, weld defects are considered as the part through-wall surface crack. IIW postulates cracks as equivalent to weld defects and the same are considered for the above analysis. The most severe weld defect is found based on a ranking study and the same is incorporated into the roof slab for the above assessment.

In the roof slab, the pump penetration shell location is considered the critical zone for OBE loading, and hence the critical location was sub-modeled to perform crack propagation analysis until the crack becomes through-wall and the corresponding fatigue life was determined. Further, crack propagation analysis is also carried out on the roof slab by considering the global model. The fatigue life cycle determined is compared with the spectrum of OBE loading to ensure the safety of the roof slab.

Level IV assessment pertains to failure assessment of roof slab based on seismic considerations. Even under severe violation of acceptance criteria mentioned in codes, such as the presence of through-wall crack at critical locations left unnoticed, the integrity of the roof slab should not be affected under critical loading conditions such as safe shutdown earthquake and heavy impact load. An elastoplastic analysis by considering surface imperfection, material non-linearity, and geometric non-linearity, is carried out on the roof slab with and without through-wall crack and the predicted collapse loads are compared with that obtained by experimental determination. In the presence of a through-wall crack, failure of the roof slab is predicted using a Failure Assessment Diagram (FAD) under safe shutdown earthquake conditions. The roof slab is found to meet the Level IV integrity requirement. Thus, the present work ensures the structural integrity requirements of the roof slab of a nuclear reactor under operating and certain unforeseen conditions.