EXAMINATION OF LEAKAGE ASPECTS THROUGH CONCRETE - STEEL INTERFACES AT AND AROUND CONTAINMENT PENETRATION ASSEMBLIES

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ABSTRACT

Penetration assemblies are parts required to be provided in the containment wall/dome to permit piping, mechanical devices, equipments, electrical cables, personnel movements etc. Integrity of arrangements with respect to leak tightness at or around these penetration assemblies, is of utmost importance for achieving safe functioning of containment. Considering the feasibilities in controlling leakages along different possible paths, it has been found necessary to examine in detail the leakage possibilities at concrete - steel interfaces at and around penetration assemblies. The present paper addresses this issue with respect to the important related aspects like constructional details, testing conditions, normal operating conditions, and the accidental situation associated with containment structures.

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1. INTRODUCTION

Assurance of safety of public and occupational workers, and protection of environment against unacceptable radiological hazards, are the main objectives in the design, construction and operation of a nuclear power plant (NPP). These objectives are required to be achieved during both normal and accident conditions. The reactor containment structure of a NPP is the last passive defense line to achieve these objectives.

The concrete containment structure, which are relatively common, has penetrations for various purposes. Penetration assemblies are parts required to permit piping, mechanical devices and equipments, electrical cables, personnel movements etc. Penetration assemblies used for mechanical services are referred as mechanical penetration. An electrical penetration assembly provides means for the passage of the electrical cables. The penetrations for movements of personnel, equipments etc. are typically known as airlocks. Generally, a number of such penetrations are provided in the containment shells at different locations. Shapes, sizes and other details of the penetrations vary, depending on the system requirements. Adequate arrangements for leak tightness are required to be provided at and around penetrations in order to achieve the desired functional requirements fulfilled in terms of containment pressure boundary. The integrity of these arrangements at/around the penetration area is important from safety considerations.

Although, the containment structure should, ideally be designed for no-leakage condition, but in practice this is not feasible. In view of this, one of the functional requirements of a containment is to restrict these leakages to an acceptable limit. If these allowable limits are exceeded, the containment may be considered to have failed in terms of leakage requirements, although structural failure in terms of strength and stability may not have occurred.

Studies have been conducted to investigate the possibilities of leakage at/around the penetration assemblies of containments [1,2]. There may be two general types of leakage paths at or around each penetration: one through the sealing arrangement provided between
the embedded part and the system components; and the second one through the interface zone of the steel embedded part with concrete (Fig.1).

The present paper addresses the issues related to the problem of leakage - possibilities through the interface zone of the steel embedded part with the concrete. Scope of the paper includes this aspect with respect to Indian prestressed concrete containment.

2. PAST STUDIES

In an analytical study on stress - distribution around the equipment hatch opening in a prestressed concrete containment wall, Harrop[1] had shown that the equipment hatch opening is a zone of stress concentration. He observed that the tensile stress limit of concrete is first attained in the local extreme fiber hoop stress around the hatch opening at an internal pressure of 1.5 times the design pressure.

In a report by a committee[2] on containment capability an overview of the state - of - the - art for containment integrity has been presented. It has been demonstrated that the local strains around the periphery of a large opening varies from point to point, thus causing an ovalling of the opening. It has also been reported that for concrete containments designers attempt to compensate for the ovalling by carefully balancing strains by varying amount of reinforcements in different directions.

Kumar[3] has made a study on the possible causes of leakage through the interface at the embedded parts of the steam generator openings in the inner containment dome of a typical Indian reactor. \[3,4\]

3. CONTAINMENT STRUCTURE

The containment structure of the Reactor Building of a typical Indian nuclear power plant (NPP)(Fig.2) based on pressurised heavy water reactor (PHWR), has been considered in the present context. The reactor building consists of internal structures, inner containment structures (ICW and IC - Dome), outer containment structures (OCW and OC - Dome), and base raft. Inner containment structures along with base raft provide pressure boundary in the event of Design Basis Accidents (DBA). It is a double containment system with inner containment (IC) structure as prestressed concrete and outer containment (OC) as reinforced concrete structure. The typical cross - section of the containment structure being considered, is shown in Fig. 3.
4. POSSIBLE LEAKAGE PATH THROUGH CONCRETE - STEEL INTERFACE ZONE.

Adequate steps can possibly be taken at the design and construction stages to control leakages through individual components, e.g., embedded steel, concrete, system components, and sealing between embedded steel and system component. However, the phenomenon of leakage through the interface zone, is not well understood. It needs to be appreciated that once the construction is over, it becomes extremely difficult to implement any corrective measures in case any leakage paths are identified in the interface zone of embedded steel and concrete.

In concrete containment shells, the leakage paths may occur through cracks/holes which are developed due to interaction between concrete and steel under the action of loads, secondary effects of concrete, permeability of hardened concrete, inherent constructional defects (e.g., construction joints, etc.) etc.

4.1 Interface Zone

The term interface, normally refers to the surface of contact between steel and concrete. Steel being inert, does not react with the constituents of the cement paste, and the bond between the two is largely due to van der Waal's force of attraction between chemical compounds present at the interface, friction, and mechanical interlocking. However, the presence of embedded steel at the penetration assemblies may alter the properties of concrete in the proximity of the interface due to bleeding, shrinkage, creep etc., and, thus, a transition zone (Fig.4) is formed; this transition zone has been termed as interface zone.

4.2 Possible Causes of Leakage

The leakages at the concrete - steel interface require paths such as cracks, or separations of the two surfaces, or simply the connected channels of pores, to exist in the interface zone. Such paths may originally exist due to the development of interface zone during construction, with additional paths developed due to different causes as listed below.

4.2.1 Flaws in Construction.

The following flaws in construction may be attributed to the development of leakage paths:
Improper concreting - Permanent through passages may be left in the interface zone due to improper concreting arising out of the type of design details for installation of embedded parts at the penetration assemblies. Generally, the zones are heavily reinforced, and concrete pouring becomes really constrained. Due to the presence of embedded parts, it becomes extremely difficult to verify the quality of concrete by normal visual inspection.

Improper materials - Normal technical specifications of the materials (e.g., concrete, steel, etc.) used in construction, may not be adequate for producing good interface zones (from the viewpoint of leakage) while ensuring strength and durability aspects.

Bleeding - At the penetration assemblies, existence of embedded parts provides barrier for the bleeding water accumulated in the vicinity. Thus, the water/cement ratio of the interface zone concrete becomes higher than that of the bulk concrete. It is obvious that relatively higher accumulation of bleeding water in the interface zone causes lowering of strength and impermeability.

4.2.2 Construction joints.

If construction joints, in casting the containment structure, fall in the areas of the penetration assemblies, the same may give rise to potential leakage paths.

4.2.3 Effect of secondary properties of concrete.

Heat of hydration of concrete - Hydration of cement is an exothermic reaction and during the time of hydration the concrete–steel bond formation takes place. After the hydration is over, there may be local slip between steel and concrete or local stresses generated at the interface due to differential expansion/contraction of concrete and steel at a temperature other than that at the time of hydration.

Shrinkage of concrete - Shrinkage of concrete is a time-dependent phenomenon which starts from the time of concreting. Shrinkage, alone, generates different types of stresses in the interface zone, depending on the details of the embedded parts relative to the directions of shrinkage strain. Containment prestressing should also be considered in relation to shrinkage, in order to predict the resultant effects on leakage possibilities.

Creep of concrete - For the present containment structure, prestressing can be considered as the only sustained loading on the concrete. The time-dependent deformations of concrete due to creep, caused by prestressing force, in the areas surrounding each
penetration assembly, may induce stresses in the interface zones. Such induced stresses can cause possible leakages.

4.2.4 Effects of Prestressing.

The basic sequence of construction of the containment shell in relation to the penetration assemblies, that is normally followed is given below:

- Erection of formwork.
- Placement of reinforcing bars and cable sheaths.
- Fixing the embedded parts.
- Concrete pouring.
- Removal of formwork.
- Prestressing.

It is important to consider the above sequence as well as details of embedded parts while designing/detailing the prestressing system (including sequence of prestressing), and to study the effects of stresses and deformations towards possible leakage paths.

4.2.5 Effects of Loading.

The following two types of loads are considered:

- Internal pressure - Containment is pressurised from inside by air during the time of testing. Generally, the test pressure is kept at 1.15 times the design basis accident pressure. Analysis of stresses and deformations are required to be performed at each penetration assembly in order to know the effects for possible leakage paths. It is to be noted that the pressure gradients through the interface zone due to the presence of air in the voids, can cause additional pressure forces.

- Temperature - The thermal loading on the interface zone can possibly cause differential movement of concrete shell and embedded parts, which in turn may lead to leakage paths.

5. CONCLUSIONS

The following conclusions are made on the issue related to leakage - possibilities through concrete-steel interfaces at and around penetration assemblies:

- It is important to consider the aspect of leakage through the interface-zones adjacent to embedded parts of each penetration assembly. For primary containments (e.g. prestressed concrete
containments) this should form one needed safety requirement to be fulfilled over other normal strength and stability requirements.

Once the construction is over, normally, the task of sealing leakages identified in the interface zones of embedded parts, is extremely difficult, if not infeasible; hence, adequate confidence needs to be gained in this area so that such leakages are kept well within limits through suitable means adopted in the construction stage.

To understand the phenomenon of leakage possibilities around penetration assemblies, an interface zone (concrete) of some extent into the main concrete body, needs to be identified and studied for its properties and behaviour since the time of construction and onwards up to testing, operating and accident conditions.

The major sources of problems for leakages in the interface zone may come from difficulties in concreting, bleeding, construction joints, secondary effects of concrete (heat of hydration of concrete, shrinkage and creep of concrete), prestressing and external loadings. While recognising these causes individually, a realistic approach has to be taken encompassing all of them as sequence of events in relation to the methods of construction, testing, and operation of containment.

REFERENCES


Fig. 1. Schematic Arrangement of Penetration Assembly. (Showing only Typical-Embedded Parts)
Fig. 2. Structural layout of a typical reactor building
Fig. 3 Typical Cross-section of Double containment structural System

All dimensions are in mm.
Fig. 4 Interface Zone