

Importance of the Properties of Steel Plate-Concrete Interface in the Local Behavior at Large Openings in the IC Dome of a Reactor Building.

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ABSTRACT

The interface (zone) formed between the surface of steel plate embedded in concrete and the main concrete has been found to have properties different from those of the main body concrete. Adequate consideration for the presence of such interfaces should be given in respect of analysis and design of structures in which steel plate-concrete composite constructions are adopted for main structural members, for connections between different members and for providing different means to facilitate attachments (required for operational reasons) of components on to the body of the main structures. Such a situation has been typically found in the Inner containment Dome of a present generation Indian Nuclear Power Plant, based on pressurised Heavy Water Reactor System. It is the properties of concrete occurring in the interface which govern largely the local behavior at interface. The present paper deals with the important issue related to the properties of interface with respect to separation. The paper discusses this central issue including the findings of an experimental study on the behavior of steel plate-concrete interface for different loading conditions.

INTRODUCTION

The design of the containment structure for the present generation Indian Nuclear Power Plants ((NPP) based on Pressurised Heavy Water Reactor (PHWR), has been developed using a complete double containment philosophy. The structural arrangement of a reactor building of a typical Indian PHWR consists of two containments; inner (primary) containment and outer (secondary) containment [1]. Both the containment structures have vertical cylindrical wall and segmented spherical dome as cap; and they rest on a common reinforced concrete base raft. The inner containment structure is made of prestressed concrete (PSC) while the outer one is made of reinforced concrete (RC). Both the PSC inner containment (IC) dome and RC outer containment (OC) dome are provided with four major circular (in plan) openings in them, which are called steam generator (SG) openings and are sealed with dished heads after erection of the SGs. The steel embedded parts, which are made of steel liner plates and located along the edges of the SG-openings, connect the dished head with the dome concrete (Fig. 1). The embedded part is anchored to the concrete with lugs and double-legged bars welded to it.

The anchors between the steel plates and adjacent concrete are provided to ensure a composite action of the structure in response to the design loading conditions. But, providing anchors for achieving a composite action, may not assure no-separation condition at the interface between steel plate and concrete at all the locations. Such separation may be critical in terms of servicability.

Chakrabarti et.al. [2,3] addressed the issue of leakage through the steel-concrete interface at the embedded parts of the SG openings in the IC dome of a typical Indian PHWR considering the strength development mechanism in concrete, and also the permeability of concrete at and around the interface. Chakrabarti and Basu [4] dealt with the issues related to the performance of the steel-concrete interfaces with respect to the separation that may occur in the IC dome due to the situations arising out of prestressing cable and other associated details for the prestressing anchorages, steel embedded parts at the dome openings, and passive reinforcements.

The reduction of tensile strength of steel-concrete interface compared to the tensile strength of concrete has been observed experimentally by Basu and Rajagopalan [5]. The reason for this reduction was assigned to the absence of any friction or interlocking phenomenon in between the two materials in case of tension acting normal to the interface plane. The adhesive force between steel and concrete, which appears to be only force resisting this tension is too weak compared to the aggregate interlocking and cohesive bond in concrete matrix.

Experimental and analytical studies were conducted on the profiled steel-deck concrete flooring system considering the presence of shear connectors [6,7 and 8]. Though some design recommendations have been made on such systems without shear connectors, nothing in specific has been observed regarding the behavior of the steel-concrete interface zone in such cases. Ong and Mansur [9] have carried out experimental studies on shear-bond capacity of similar composite slabs with and without anchors, both. For a similar test set-up, the shear-bond failure of a specimen without shear connectors has been observed to occur at a lesser load compared to that for a specimen with shear connectors; but the load-deflection behaviors have been almost the same.

Menrath et.al. [10] have proposed a friction model for the behavior of steel-concrete interface layer along with shear transferring devices, in a steel-girder concrete-deck composite system. The structure has been modeled for two-dimensional finite element analysis using line elements for modeling the interface layer with shear connectors, and two-dimensional planar elements for modeling the steel and concrete portions.

The present paper deals with the important issues related to the properties of interface at openings in the IC dome with respect to separation in the light of the findings of an experimental study on the behavior of steel plate-concrete interface for different loading conditions.

IMPORTANT ISSUES

Although efforts are made to provide appropriate concrete along with prestressing steel, embedded steel plates and passive reinforcements, and all joints are sealed using specially developed methods, any 'weakness' at the steel plate-concrete interface at and around SG openings in the IC dome, may cause problems in the serviceability of the containment system. 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 steel plate-concrete interface zone needs to be understood thoroughly in order to have better control over the possibility of leakage through this interface. In view of this, it is important to predict the performance of this interface in respect of separation that may occur under different conditions. This prediction-process involves knowing the properties of the interface for required modeling and analysis.

EXPERIMENTAL STUDY

Test-specimens were cast using high strength plain concrete having average cube strength of 55 N/mm² and embedded steel plate (one plate for each specimen) without anchors. These specimens were tested up to failure for different loading conditions, and strain and deformation data at specific locations of the specimens were recorded for all the load-increments using strain gauges, dial gauges and linear variable displacement transducers (LVDTs). These data were used for obtaining the linear elastic properties of the steel-concrete interfaces.

Direct Tension Test Set-up

In this set of tests, upward pull was applied to the embedded steel plate to cause tensile force acting normal to the contact surface between steel and concrete (Fig. 2). Each specimen was placed on the strong floor with its top concrete surface strapped to the strong floor by floor-anchors. 30 mm surface

strain-gauges were pasted vertically on the vertical surfaces of concrete at locations just below the steel plate. Dial-gauges and LVDTs were installed to measure the displacements at different locations.

Direct Compression Test Set-up

This set of tests was conducted on interface specimens by applying a vertical compression on the top surface of steel plate in a compression testing machine (Fig. 3). Strain gauges were pasted in a manner similar to the direct tension tests and LVDTs were used for displacement measurements.

Direct Shear Test Set-up

The specimens for this set of tests were similar to those of the direct tension tests, excepting for load application and anchorage of the specimen (Fig. 4). The lateral load was applied using a hydraulic jack at one of the side-edges of the steel plate, which in turn developed shear at the steel-concrete interface. The specimen was restrained from any rigid-body motion along the direction of applied force with the help of an abutment assembly anchored to the strong floor. Additionally, the specimen was strapped adequately to the strong floor. Strain-gauges were pasted horizontally at locations below the steel-plate.

Combined Tension and Shear Test Set-up

The tests specimens and the set-up (Fig. 5) are similar to those of direct shear test, excepting that an additional normal tension was applied at top of the steel plate using the pulley arrangement as was adopted in the case of direct tension test.

Combined Compression and Shear Test Set-up

The test specimens and the set-up (Fig. 6) are same as those of the direct shear tests, excepting that an additional normal compressive force was applied to the top of the steel plate with the help of a hydraulic jack.

Results

Based on detailed data analysis of the recorded strains and displacements for each of the loading cases, the linear-elastic properties of the interface zone were obtained for the specimens of steel plate-concrete interfaces without shear connectors. All data were first normalized to an average concrete characteristic strength of 55 N/mm^2 to facilitate comparison. Following were arrived at :

- The interface can be considered as a zone of uniform thickness extended up to about 4 mm below the steel plate into the body concrete.
- Young's modulus in tension, Young's modulus in compression and Poisson's ratio of the interface have been found to be 780 N/mm^2 , 5130 N/mm^2 and 0.1213 respectively, in average.
- The properties of the interface zone, though dependent on the properties of parent concrete, are different from those of concrete.
- The interface zone behaves as a brittle material, with a very small range of non-linearity beyond the elastic limit.
- The interface can be regarded as the weakest link of the whole steel plate-concrete assembly.

CONCLUSIONS

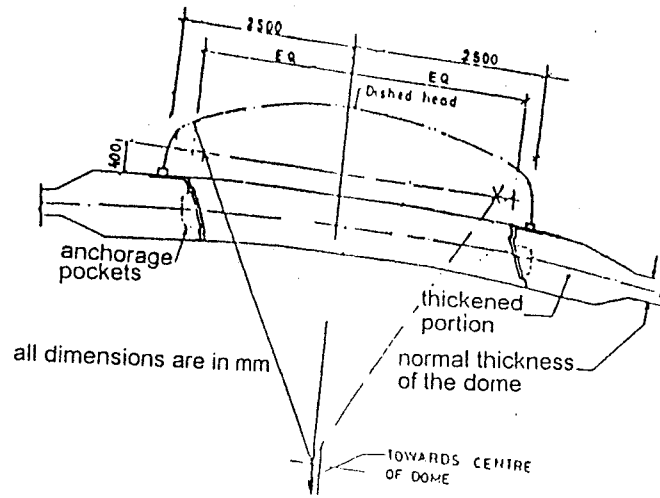
- Knowledge about the properties of the steel plate-concrete interface is important in predicting the local behavior for designing the interface adequately against any possible separation.
- The interface properties should be useful for three-dimensional solid modeling for analysing the local behavior at the interface.

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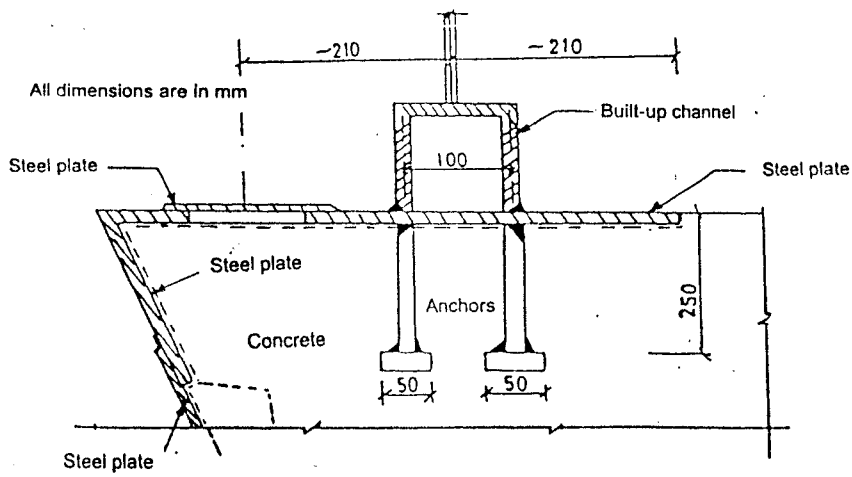
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Dome section near steam generator opening



Details of steel embedded parts

Fig 1 Steel embedded parts around the steam generator openings of an inner containment dome

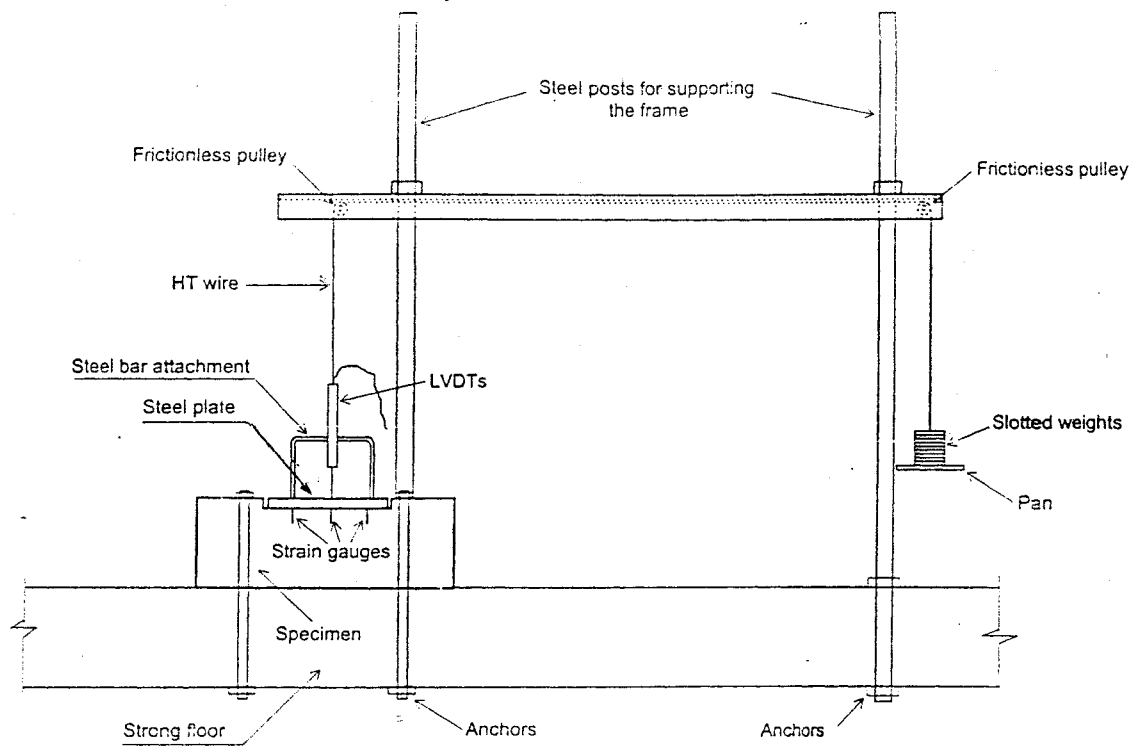


Fig. 2 Experimental set-up for direct tension test

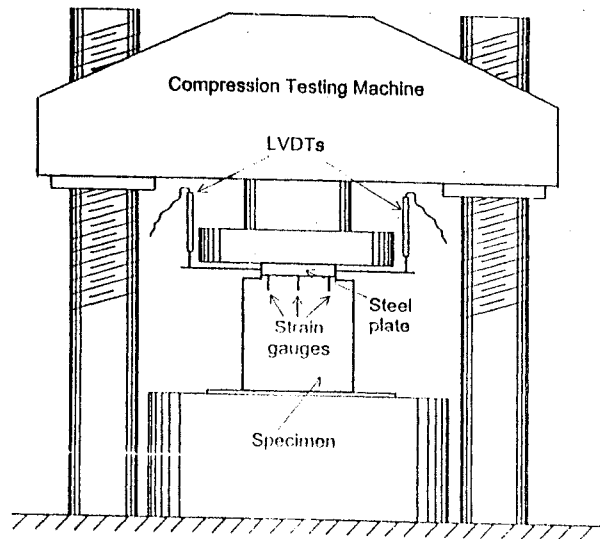


Fig. 3 Experimental set-up for direct compression test

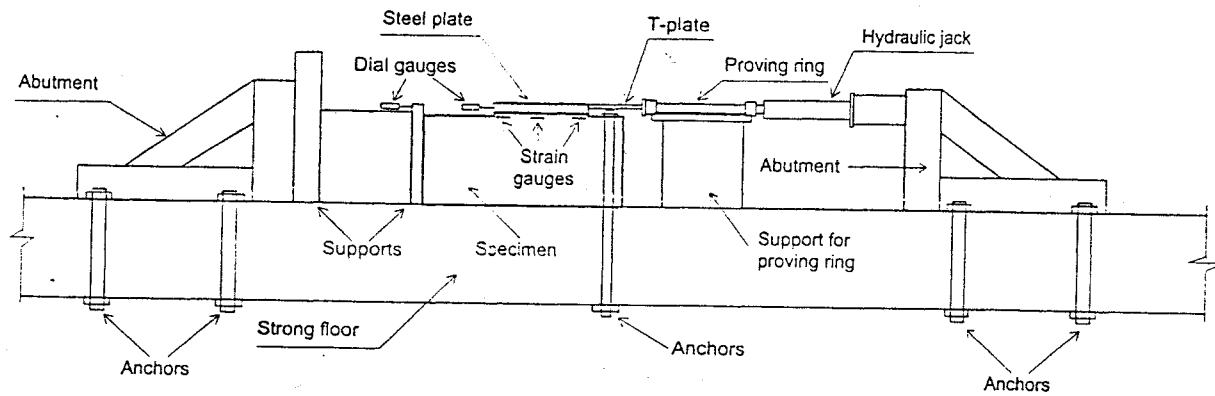


Fig. 4 Experimental set-up for direct shear test

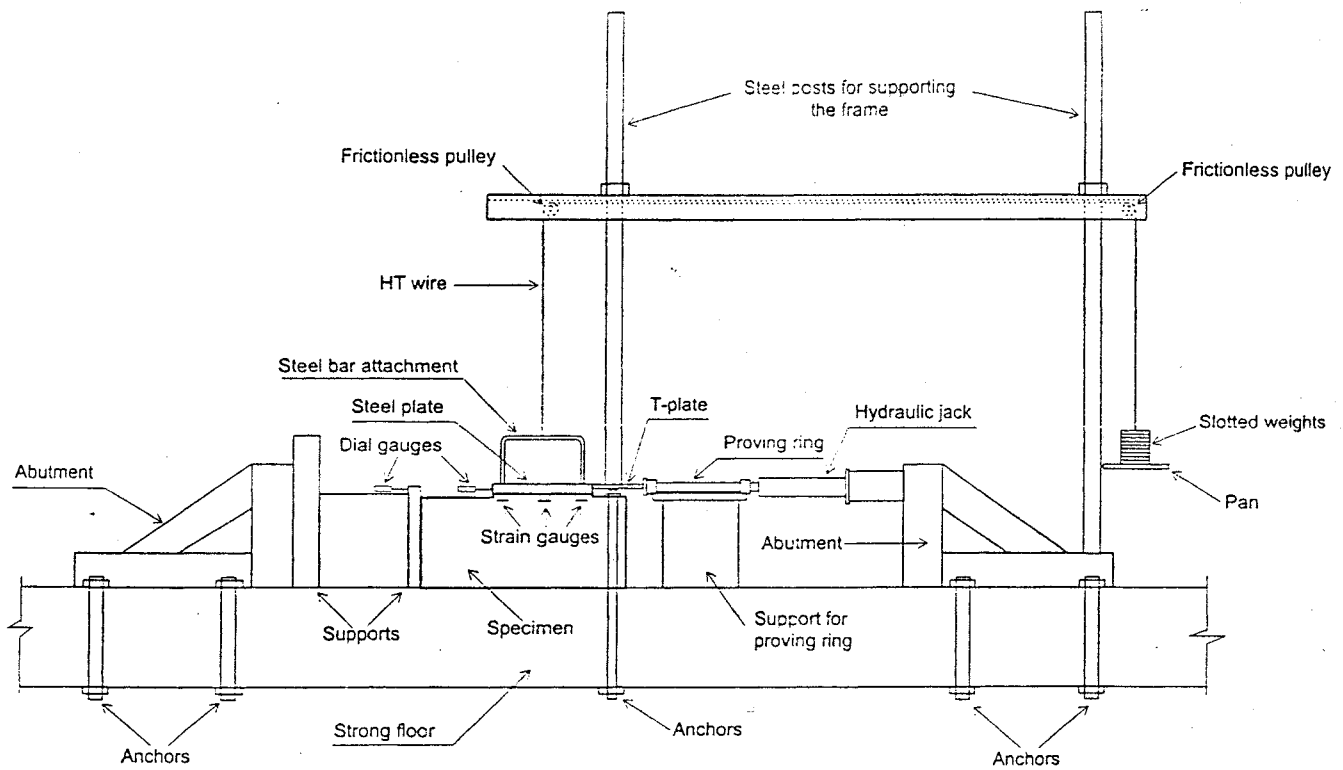


Fig. 5 Experimental set-up for combined tension and shear test

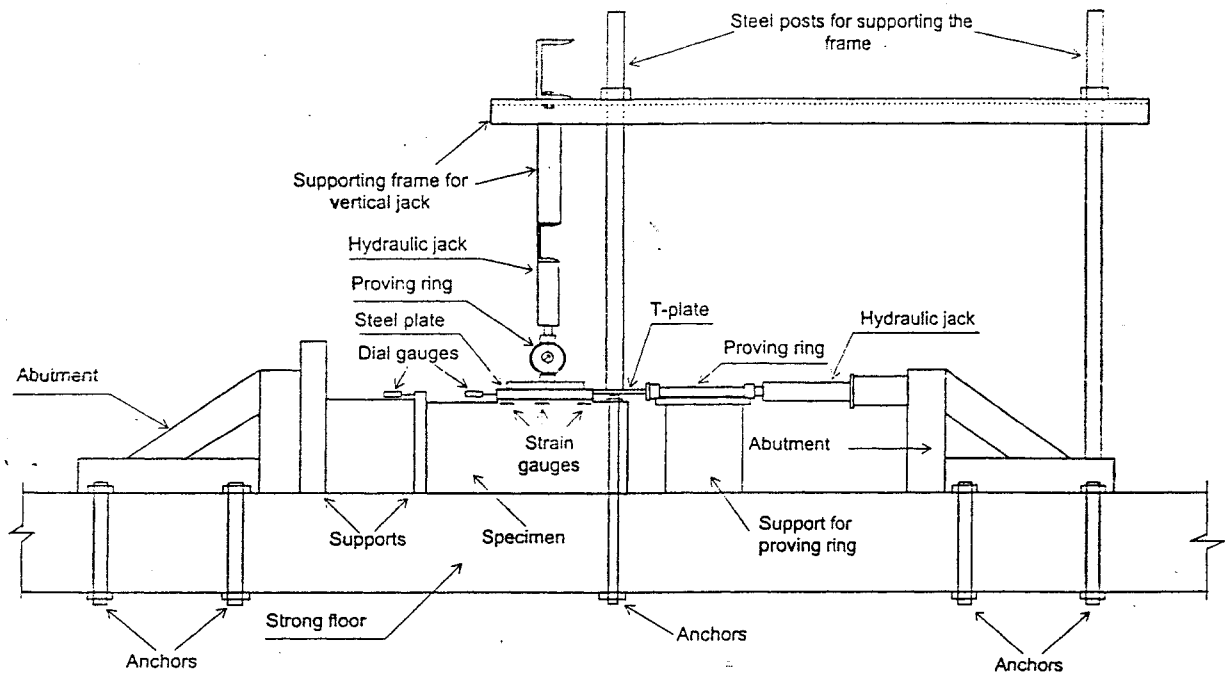


Fig. 6 Experimental set-up for combined compression and shear test