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Assessment of in-situ concrete creep: Cylindrical specimen and prototype nuclear containment structure

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HIGHLIGHTS

- Segregating concrete creep, shrinkage and instantaneous strain.
- Investigation of above strains on large prototype containment structure & small specimens.
- Experimental result comparison with B-3 model.
- Aging effect investigation.

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ABSTRACT

The paper is dedicated to develop an efficient methodology that assess and segregate the creep, instantaneous and shrinkage strains on small scale: concrete cylindrical specimens and large proto type structure: BARC Containment (BARCOM) test model. The evaluation of concrete creep, shrinkage and instantaneous strains helps in analyzing the long term behavior of the most critical safety barrier the concrete containment structure. The main purpose of the nuclear pre-stressed concrete containment is to prevent the radioactive leakage to the environment in the case of an internal design basis and beyond design basis accidents. During the initial design, the concrete creep is most important input parameter to be considered for the performance and safety evaluation of containment structure, and hence this work mainly focuses on creep studies.

The creep, instantaneous and shrinkage strain in concrete cylindrical specimens and BARCOM test model is experimentally computed from the installed embedded sensors. BARCOM test model consists of cylindrical wall portion headed with dome. The concrete cylindrical specimens and dome of BARCOM test model was cast with identical concrete mix in similar duration and therefore indistinguishable behavior were expected. The identical instantaneous and shrinkage strains are found in concrete cylindrical specimens and dome of BARCOM test model. However due to the aging effect, the dissimilarity in the experimental creep strain for concrete cylindrical specimen and dome of BARCOM test model is observed. The influence of elevation and boundary effect on creep strains of cylindrical wall portion of BARCOM test model is also investigated in this paper.

Further, the experimentally observed creep and instantaneous strain are validated with the famous B-3 model for concrete cylindrical specimens and BARCOM test model. The experimentally observed results and predicted through B-3 model are found to be in excellent agreement. A sufficient realistic data on concrete creep for long-time serviceability, durability, long-time stability, safety against collapse is useful for performing consistent non-linear analysis of BARCOM test model is explored. Thus the present work deals with the in-situ creep behavior of concrete structures to develop understanding of the mechanisms of creep, instantaneous and shrinkage behavior on concrete structures. The present formulated study is limited to linear basic creep in which the influence of humidity, temperature effect on creep parameters and superimposition of the cracking strain are not introduced.

1. Introduction

The concrete containment structure assessment in terms of durability, serviceability, simulation of the non-linear experimental

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model analysis, long-time stability and safety against collapse is of crucial importance. Therefore, it is necessary to carry out the realistic prediction of concrete creep, shrinkage and instantaneous strain for the most critical safety barrier, the concrete containment structure. The main purpose of the nuclear pre-stressed concrete containment is to prevent the radioactive leakage to the environment in the case of an internal design basis and beyond design basis accidents. The safety of the structure depends on the creep and shrinkage of concrete and relaxation of steel tendons. From the study on Swedish containment [1], it is concluded that the creep is the phenomenon with the biggest contribution to the losses. Creep is one of the most important structural factors to be considered for the performance and safety evaluation of a pre-stressed concrete nuclear containment structure during design, construction and maintenance. So it provides the determined motivation to investigate the concrete creep behavior for BARC Containment (BARCOM) test model and concrete cylindrical specimens [2,3] in the present research work. As a result the systematic methodology to assess and segregate the creep, instantaneous and shrinkage strain on small scale: concrete cylindrical specimens and the large proto type structure: BARC Containment (BARCOM) test model is evolved in this study.

The time dependent inelastic strain of concrete consist of shrinkage strain which is independent of stress and additional strain produced by mechanical stress called creep strain. The creep occurring at the constant moisture content is called the basic creep [4]. The aging in concrete refers to the increase in strength and elastic modulus with age at a gradually decreasing rate [5,6], as a result the concrete specimens loaded at a higher age will hold less creep.

In literature the study [7] predicted the concrete creep for 15 cm diameter standard cylinders according to ASTM using the same mix design as that for the construction of the reactor containment of nuclear power plant in Korea. A numerical approach [8], was developed to estimate the thermal and autogenous strain induced in the massive concrete structures with 1.2 m thickness due to temperature gradient inside the wall resulting in release of heat during hydration reaction. However in the presented work, due to relatively less thickness ~188 mm [2,3] of BARCOM test model, the thermal and autogenous strains are ignored. The study [9] performed the experimental investigation concerning the use of acoustic emission to analyze the physical mechanism of creep. Another study [10] focusing on concrete mixes lead to the development of formulas to estimate the long term creep and shrinkage.

Wide laboratory research for computation of concrete creep and shrinkage has been conducted as mentioned in above quoted literature and it is quite clear that mostly the experimental creep evaluation is based on small scale specimen focusing on the concrete mixes. However this paper deals with investigation of in-situ concrete creep, instantaneous and shrinkage strain evaluation which is not readily available in the literature, keeping in mind its applicability for a large scale structure such as nuclear containment with the help of data collected on (a) a large prototype structure e.g. BARCOM test model, (b) small scale: concrete cylindrical specimens from the same batch of concrete pour mix. An efficient methodology to assess and segregate the creep, instantaneous and shrinkage strains in concrete cylindrical specimens and BARCOM test model is explored. Further the "concrete aging" effect available in literature [5,6] has been validated through the small scale concrete cylindrical specimens and the dome of BARCOM test model. The study further evaluates the concrete creep and instantaneous strain on concrete cylindrical specimens and BARCOM test model by B-3 model [11] which is found to be in excellent agreement with the experimentally investigated results. Based on the present study the average values of creep, instantaneous and shrinkage strain for BARCOM test model are predicted. The developed methodology can be effectively utilized for the assessment of instantaneous and shrinkage strain in large size nuclear containment and general shell structures.

(a)

Fig. 1a. BARC Containment (BARCOM) test model at Tarapur site [2 and 3].

2. Background

As a part of nuclear containment structural safety assessment, Bhabha Atomic Research Centre (BARC) organized an experimental project BARCOM test model [2,3] in which concrete creep, shrinkage and instantaneous strain studies are investigated. The BARCOM test model located in BARC facilities-Tarapur is a 1:4 scale representation of 540 MWe Pressurized Heavy Water Reactor (PHWR) pre-stressed concrete inner containment structure of Tarapur Atomic Power Station (TAPS) unit 3&4. Around 1200 sensors including vibratory wire strain gauges (VWSG), surface mounted electrical resistance strain gauges, dial gauges, earth pressure cells, tilt meters and high resolution digital camera systems has been installed in BARCOM for structural response assessment under over-pressurization [12]. The BARCOM test model shown in Fig. 1a consist of free field location defined as south side (0°) shown in Fig. 1b. The free field location does not have any openings, and hence it is ideally suited location to carry out the creep, shrinkage and instantaneous strain studies. However the restraining effects are significant in the free field region close to boundary which is explained latter in this section. The other location with the openings are designated as MAL (main ail lock/West) at 270°, FMAL (fueling machine air lock/North) at 180° and EAL (emergency air lock/East) at 90° as shown in Fig. 1b.

BARCOM test model for which the creep, shrinkage and instantaneous behavior of the concrete due to pre-stress load is studied, consist of large cylindrical wall portion headed with dome as shown in Fig. 1a. In BARCOM test model, the construction of the cylindrical wall portion of the test model has been carried out in various stages lift-wise and the dome construction was carried in the last single lift. The J shaped longitudinal cables from ring beam