Engineering Structures 33 (2011) 1687–1697

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Experimental evaluation of the tension stiffening behavior of HSC thick panels

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ARTICLE INFO

Article history:
Received 29 July 2010
Received in revised form
4 February 2011
Accepted 7 February 2011
Available online 11 March 2011

Keywords:
Tension stiffening
Cracking behavior
High strength concrete
Offshore structures
Nuclear containments
Axial
Biaxial

ABSTRACT

The experimental investigation presented in this paper summarizes the test results of nineteen reinforced concrete panels. This research is focused on providing a clear understating for the tension stiffening response of thick high strength concrete (HSC) and normal strength concrete panels used for containment structures for nuclear power plants and offshore structures. Major variables include the concrete's strength, reinforcement spacing in the concrete section, thickness of the concrete cover, and applying the axial load in axial and/or biaxial directions. The contribution of the concrete's matrix between cracks is obtained by considering the difference between the bare bar and panel response.

The average tension stiffening contribution of HSC is found to be higher during the crack formation and stabilized cracking stages, compared with NSC panels. Concrete tension stiffening contribution between cracks for thick HSC panels is dependent on the spacing of the reinforcement in the concrete matrix. Applying the load in two directions causes an obvious decrease in tension stiffening response, compared with panels subjected to axial loading. A relevant constitutive model to simulate the tension stiffening response for HSC panels is recommended.

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1. Introduction

Offshore structures are unique structures that are constantly exposed to harsh environmental conditions, including exposure to seawater and sea spray, also, the containment walls of a nuclear power plant are subjected to high stresses. Such structures are now built using HSC with a thick concrete cover.

Tension stiffening is the contribution to the member stiffness of the intact concrete between the primary cracks and it plays a significant role in the cracking response of reinforced concrete. Under typical service load levels, the concrete between the primary cracks carries significant tensile stress and the actual member response is considerably stiffer than the response of the bare steel bar.

A detailed explanation for the mechanism of tension stiffening at different loading stages in a reinforced concrete member, before yielding of the steel reinforcement, was provided by Gilbert and Warner [1]. An earlier experimental program was conducted by Williams [2], to study the tension stiffening of reinforced concrete panels subjected to direct tension. Behavior of reinforced concrete panels subjected to axial and lateral loads was studied, and a tension-stiffening model for these panels was developed by Massicote et al. [3,4]. An experimental investigation was carried out by Wollrab et al. [5] to examine the influence of reinforcement ratio; reinforcing bar distribution; and concrete strength on the cracking behavior of axially loaded thin reinforced concrete slabs. Two extensive and independent testing programs were conducted by Rizkalla et al. [6,7] to study the cracking behavior of reinforced concrete members subjected to pure uniaxial tension. Marzouk and Chen [8,9] studied the cracking behavior of concrete prisms under direct axial tension loading and recommended a softening and tension-stiffening model for high-strength concrete considering the post-cracking behavior and fracture energy properties. Hsu et al. investigated the in-plane behavior of reinforced concrete membrane elements. Based on the test results, expressions were developed relating the average principal tensile stress in the concrete to the average principal tensile strain of the panel [10,11]. A tension stiffening model capable of describing the concrete response after cracking, was developed to predict the in-plane behavior of reinforced concrete membrane elements [12]. Cho et al. [13,14] conducted axial tension tests on concrete panels to derive a model equation for the stress–strain relationship of concrete under tension. Constitutive Models to express the average tensile stress–strain relationship of cracked concrete were developed [15,16].

Models to simulate cracking behavior (crack spacing and width) of axially loaded thick concrete panels were recently developed by Dawood and Marzouk [17,18]. These models are developed by considering the equilibrium and compatibility equations of reinforced concrete elements, and proved their capability to predict the cracking response of thick concrete members.

Existing research related to the tension stiffening response and cracking behavior of reinforced concrete structures mostly corresponds to tension tests for plain concrete specimens and axial tension tests for reinforced concrete members with normal

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0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.02.006