Engineering Structures 112 (2016) 172–183

Contents lists available at ScienceDirect

Engineering Structures

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

Theoretical and experimental short-term behavior of non-symmetrical wall pile retaining systems

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ARTICLE INFO

Article history:
Received 9 April 2015
Revised 30 November 2015
Accepted 12 January 2016
Available online 28 January 2016

Keywords:
Wall pile
Reinforced concrete
Short term deformation

ABSTRACT

Optimized non-symmetrically reinforced piles for retaining walls constitute a new structural element recently used in constructions such as the underground floors of San Antoni Market in Barcelona or in the Riyadh metro. Piles usually have circular cross sections with longitudinal reinforcement composed of bars of the same diameter and with constant clear distances between them. The use of non-symmetrical piles in retaining walls means savings of up to 50% in the weight of the longitudinal reinforcement, compared with traditional symmetrical piles.

Intuition suggests that a non-symmetrical pile, compared with its symmetrical counterpart -both having the same ultimate flexural moment-, deforms less and has smaller crack widths. This point is analyzed in this paper both theoretically and experimentally.

The majority of the studies conducted on RC members were developed only for rectangular cross sections. In this paper, results from an experimental campaign of circular RC cross-sections are presented. The main objective of this campaign is the formulation of the effective area of concrete in the tension stiffening effect of RC circular cross-sections.

1. Introduction

Optimized non-symmetrically reinforced piles for retaining walls [1,2] were used for the first time, excluding experimental campaigns, in the construction of new underground levels of the San Antoni Market in Barcelona, see Fig. 1, reaching savings of 30% in weight of the complete reinforcement cage of the pile in comparison with the symmetrical solution.

The strength design of reinforced concrete (RC) cross-sections is well established [3,4], yet recent advances such as the use of Reinforcement Sizing Diagrams [5], the description of Optimal Domains [6], and the Theorem of Optimal Section Reinforcement (TOSR, discussed by [7]) have contributed to a better understanding of traditional approaches such as Whitney's method of small and large eccentricities (see the textbook by Nawy [8]).

In the case of circular cross sections (e.g. columns, piers or piles), traditional RC design approaches consider longitudinal reinforcement, comprised of bars of the same diameter with constant clear spacing, as illustrated by the popular section analysis computer programs IECA 3.0 [9] or Davalath and Madugula [10].

Piers, having non-symmetrical distributions of reinforcement [11,12] are a new development that is applicable to retaining walls (Fig. 2). Previously, non-symmetrical longitudinal reinforcement [13] was used to provide more limited optimization involving only the spacing of bars around the perimeter; the mathematical approach employed did not allow the minimum reinforcement to be obtained, even in the case of spacing being the only variable considered. The approach presented by Gil-Martín et al. [12] allows the use of bars of different diameters and spacing, in doing so the minimum longitudinal reinforcement required for the ultimate strength design of circular sections is determined. It is interesting to note that additional constraints have to be added to the design of the reinforcement in order to allow the mechanization and erection of these structural elements.

The behavior of a circular cross section member regarding cracking and deformation, has not yet been widely studied.

In relation to symmetrically reinforced circular cross sections (henceforth SRCS), Wiese et al. [14] proposed an effective area of concrete in tension for SRCS, $A_{c,eff}$. This was based on test results.

However, the authors are aware of no previous work addressing the serviceability limit state of **n**on-**s**ymmetrically **r**einforced **c**ircular **s**ections (henceforth NSRCS). Recently, the authors [15]

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http://dx.doi.org/10.1016/j.engstruct.2016.01.019
0141-0296/

Fig. 1. Optimized non-symmetrical pile.

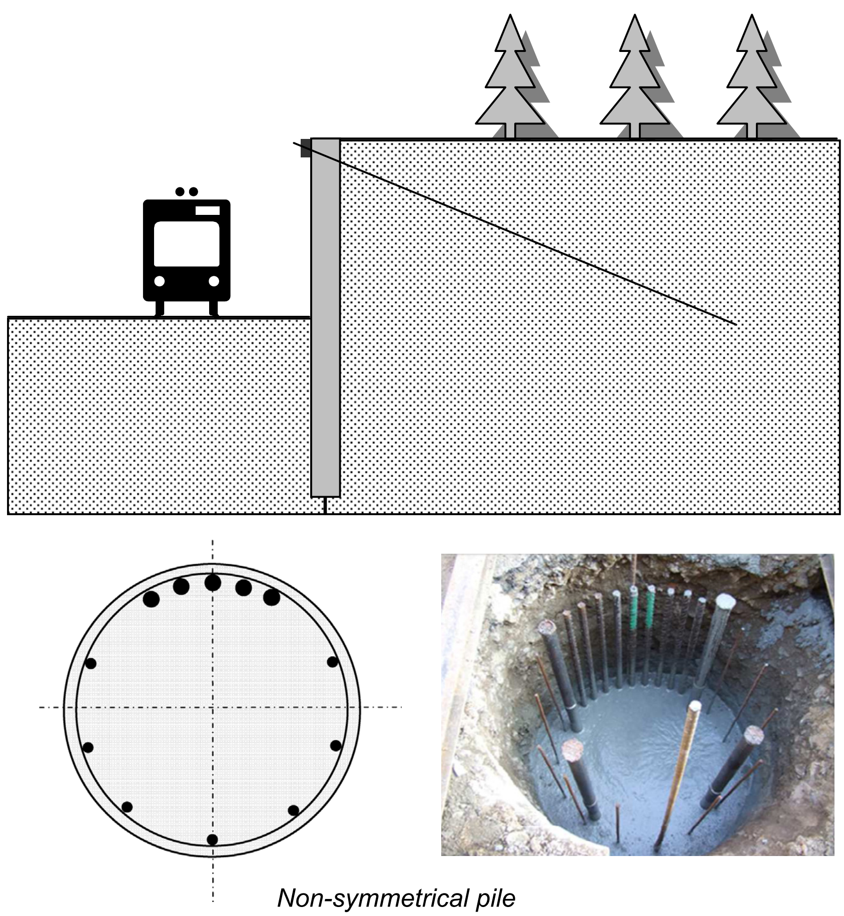

Fig. 2. Non-symmetrical piles.

proposed a general expression to evaluate the effective area of concrete in tension for **s**ymmetrically **r**einforced **c**ircular **s**ections (henceforth SRCS) and NSRCS. In the present paper different distributions of NSRSC have been studied, considering deformation and cracking. Improved expressions of the effective area of concrete have been obtained. Moreover, errors, which originated