Automation in Construction 20 (2011) 830–836

Contents lists available at ScienceDirect

Automation in Construction

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

Computer simulation of complex-shaped formworks using three-dimensional numerical models

E. Gallego [a,*], J.M. Fuentes [b], A. Ramírez [c], F. Ayuga [b]

[a] BIPREE Research Group, Universidad Politécnica de Madrid, Ciudad Universitaria s/n. EUIT Agrícola, 28040 Madrid, Spain
[b] BIPREE Research Group, Universidad Politécnica de Madrid, Ciudad Universitaria s/n. ETSI Agronomos, 28040 Madrid, Spain
[c] BIPREE Research Group, Universidad Politécnica de Madrid, Ciudad Universitaria s/n. EUIT Industrial, 28040 Madrid, Spain

ARTICLE INFO

Article history:
Accepted 1 March 2011
Available online 5 April 2011

Keywords:
Formworks
Lateral pressure
Computer simulation
Finite element method
3D model

ABSTRACT

This work describes a three-dimensional numerical model, developed with the ANSYS finite element software package, which simulates the behaviour of fresh concrete and formwork walls to obtain the resulting pressures in complex-shaped formworks. The results obtained with the proposed model highlight the influence of the inclination of a formwork on the lateral pressures exerted on its walls by fresh concrete. The normal pressures on the lower inclined formwork wall were found to be larger than those exerted on the upper inclined wall. In addition, it was also found that normal pressures vary along the formwork wall in the longitudinal direction in a different way depending on the sidewall. The proposed computer model allows examining load distributions in complex-shaped formworks, which is not contemplated in current standards.

1. Introduction

Formworks play an important role in civil engineering projects, retaining fresh concrete until it sets and acquires adequate resistance. The determination of the lateral pressures exerted by fresh concrete on formwork walls is important, and should always be borne in mind when designing formworks and the structures that support them [1,2]. Underestimating the size of these pressures can lead to the deformation of support elements or even the rupture of the formwork itself, with the danger to the workforce and the economic losses that this entails.

The size of the lateral pressures exerted by Normal Vibrated Concrete (NVC) on formwork walls are conditioned by numerous variables such as the composition and consistency of the mix, the temperature of the concrete during setting, the shape of the formwork, the rate of placement (the rate at which the concrete rises vertically up the form), and the surface properties of the formwork walls [3–7]. In recent years, research has led to the proposal of different empirical equations for determining the lateral pressures exerted by fresh concrete on formwork walls, and the appearance of standards for use in engineering and architectural practice [5,8,9].

The pressure distribution laws generally abide by a hydrostatic model similar to that corresponding to a non-viscous fluid, at least until a certain depth is reached when the maximum pressure remains constant until the bottom of the formwork.

American standard ACI 347–04 [9] proposes that the lateral pressures be calculated using Eq. (1), where P_{max} is the maximum lateral pressure on the formwork wall expressed in kPa, R is the rate of placement (between 2.1 and 4.5 m/h), T is the temperature of the concrete during pouring (°C), Cw is a non-dimensional correcting coefficient relative to the specific weight of the fresh concrete, and Cc a coefficient that depends on the type of concrete in question and the additives in the mix.

$$P_{máx} = Cw \cdot Cc \cdot \left(7.2 + \frac{1156}{T+17.8} + \frac{244 \cdot R}{T+17.8}\right) \quad (1)$$

German standard DIN-18218 [8] proposes a series of expressions, such as that shown in Eq. (2):

$$P_{máx} = K_1 + K_2 \cdot R \quad (2)$$

where K_1 and K_2 are coefficients dependent of the consistency of the fresh concrete determined by the Abrams cone assay, and R the rate at which the concrete rises vertically up the form (in m/h). This standard contemplates an increase or reduction in the maximum pressure of 3% for every 1 °C difference between environmental temperature during setting and a baseline temperature of 15 °C.

Finally, monograph 108 of the CIRIA [5] proposes the lateral pressures be measured by Eq. (3):

$$P_{máx} = D \cdot \left(C_1 \cdot R^{0.5} + C_2 \cdot K \cdot \sqrt{H - C_1 \cdot R^{0.5}}\right) \quad (3)$$

where P_{max} is the maximum lateral pressure exerted (kN/m^2), D is the specific weight of the fresh concrete (kN/m^3), R is the rate of placement (m/h), H is the height of the formwork (m) and C_1 and C_2

* Corresponding author. Tel.: +34 913363705; fax: +34 913365406.
E-mail addresses: eutiquio.gallego@upm.es (E. Gallego), jm.fuentes@upm.es (J.M. Fuentes), alvaro.ramirez@upm.es (A. Ramírez), francisco.ayuga@upm.es (F. Ayuga).

0926-5805/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.autcon.2011.03.001