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Anchor plate effect on the breakout capacity in tension for thin-walled concrete panels

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ABSTRACT

Although provisions available in current design codes that take account of the presence of anchor plates, the existing provisions take no account of the effects of anchor plate size. In this study, the effect of anchor plate size on the concrete breakout strength in tension was evaluated for a single anchor system used in a thin-walled concrete wall panel. Twenty-seven specimens were tested to investigate the effects of anchor plate width and thickness. The test results show that concrete breakout strength is considerably improved with increased anchor plate size, with the rate of improvement diminishing in very large anchor plates. A simplified analytical model was proposed to determine the optimal width and thickness of anchor plates. The predicted optimal values were validated with the test results; the proposed analytical model is capable of determining the proper size of anchor plates in thin-walled concrete panels.

1. Introduction

The insulated concrete sandwich wall system has been actively used for energy-saving building envelope due to its structural and thermal efficiency. The concrete sandwich wall system is typically composed of three layers: insulation, and thin-walled inner and outer concrete panels. Thinner and lighter concrete panels hold clear advantageous for fabrication and installation [1,2]; however, anchorage problems may arise in thin concrete panels.

Traditionally, cast-in anchors are pre-installed in inner concrete panels to fix them to slabs or the beam members of building structures [3,4]. Fig. 1 displays examples of panel-frame connections for the typical concrete cladding system and sandwich wall systems. As shown in Fig. 1(a), typical concrete wall panels may have sufficient embedment depth to increase the resisting capacity subjected to wind load. The installation of a hooked anchor into a concrete panel improves the resisting force as well; however, it is difficult to ensure sufficient breakout strength in thin-walled systems, including concrete sandwich panels, and the hooked anchor may not be applicable in thin-walled panels of 40–100 mm (see Ⓐ in Fig. 1(b)) due to interference with flexural reinforcement as well as insufficient embedment depth for installation. In this case, the application of group anchors or addition of steel plates and washers into a single anchor can improve the breakout resisting capacity. The manufacturing process of the group anchor is quite complicated and higher in cost when compared to the case of simply double-installing single anchors. For these reasons, a steel-plate added to a single anchor in thin-walled concrete panel systems is a great option for improving breakout capacity, as shown in Fig. 1(b).

While studies on headed anchor systems have been often reported, studies that account for the presence of anchor plates are rarely available. Existing studies have focused on the development of accurate methods of estimation, with analytical and experimental validation [5–10]. Yang and Ashour [5] conducted a study on the concrete breakout capacity of a headed anchor in tension. This study suggested an optimum geometry of the failure surface for the anchor system through mechanism analysis based on the theory of plasticity; they evaluated the concrete breakout capacity of the headed anchor in tension. According to this study, the concrete breakout capacity of the anchor calculated by ACI 318 [11] was underestimated when compared to the results obtained from the mechanism analysis. In addition, the test results show that the concrete breakout strength increased in proportion to the width of the anchor head. Research related to application of the mechanism analysis to various types of anchor systems was carried out [12,13]. These studies concluded that the shape of the anchor plate is a significant parameter affecting the improvement in resisting capacity in tension. Furthermore, these studies proposed nonlinear coefficients for the shape of the anchor plate. Some studies on

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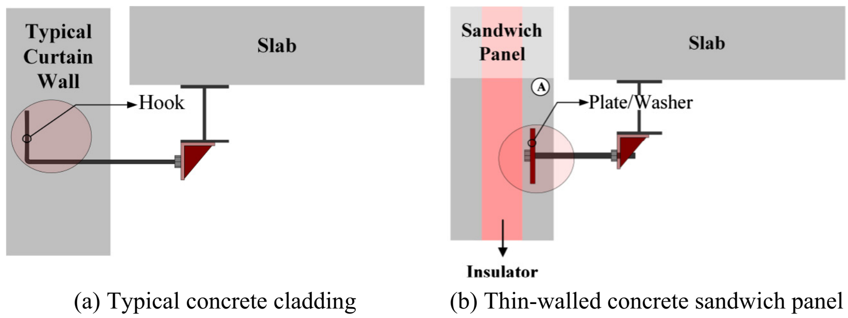

Fig. 1. Details of connection and anchor system.

plate-anchored reinforcement bars have been conducted [14,15]. These reported the role of plates in anchor system. Some recent studies presented analytical models for plates in anchor systems [16,17]. Existing literature regarding the anchor system suggests that the width of the anchor plate should affect the concrete breakout capacity in tension; though research is still limited regarding guidelines for determining optimal anchor plate size. In addition, most studies on concrete breakout capacity have been conducted for anchor systems with sufficient embedment depth, with no consideration of thin concrete panels such as concrete sandwich wall panels.

The purpose of this study is to evaluate the effects of anchor plates on the concrete breakout capacity of thin-walled concrete panels in tension. Twenty-seven anchor systems were tested with anchor plates of various widths and thicknesses. A simple elasticity-based analytical model is proposed to determine the optimal width and thickness of anchor plates, and the suggested optimal values are compared to the test results.

2. Review of anchor design methods

Current concrete structural standards suggest a design provision for the concrete breakout capacity of an anchor system that resists tensile force. In the past, the 45-degree Cone Failure Method was used to propose design methods for concrete breakout capacity; however, many recent studies have reported that the 45-degree Cone Failure Method adopted in American Concrete Institute (ACI) 349-90 [18] would tend to overestimate the breakout strength in proportion to the anchor embedment depth [19,20]. Thus, the current ACI 318 standard calculates the concrete breakout capacity based on the Concrete Capacity Design (CCD) method. The CCD approach idealizes the concrete breakout body as a conical form that protrudes from the bearing edge of the anchor to the concrete surface with an inclination of approximately 35 degrees.

In this approach, the breakout strength in tension is dependent on the effective embedment depth and the concrete compressive strength, and is related to simplified geometric parameters in the cases of anchors in edge, and cast-in/post-installed anchors, as well as anchors subjected to eccentric loads [19]. Fig. 2 shows the projected diameters of the failure surfaces both with considering a headed anchor or an anchor plate (solid line, b'_0), and without considering any anchor plate (dotted line, b_0). The ACI 318 estimates the projected area extended by the addition of a plate/washer when calculating the concrete breakout capacity; however, the extended projected area (b'_0) of ACI 318 refers to the distance between the point of extension by the plate thickness (t_P) from the anchor head edge and the 35 degree inclination regardless of plate width [21]. Therefore, the effect of the anchor plate width cannot be considered in the current standard method. In addition, there is no method to determine reasonable pairs of anchor plate width and thickness, simultaneously. The simplified analytical

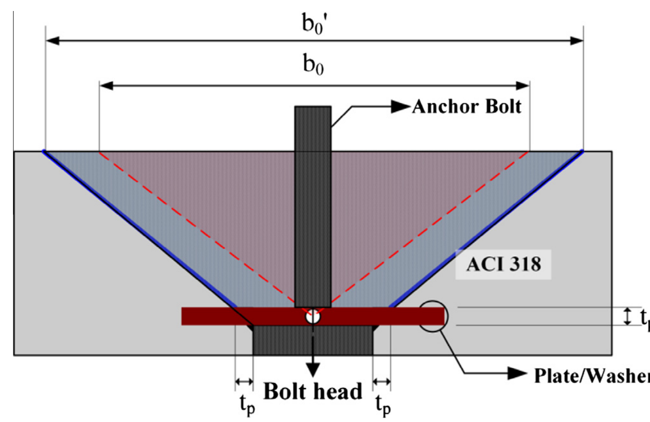

Fig. 2. Projected area of failure surface determined by ACI 318 [11].

model based on the CCD approach will be proposed later in this study to evaluate the effect of anchor plate size, and then stress level in the breakout capacity based on CCD approach will indicate the optimal size of the anchor plate.

3. Experimental program

An experimental program including a total of 27 specimens was conducted to identify the effects of anchor plate thickness and width. As shown in Fig. 3, the concrete thickness (d) of the test

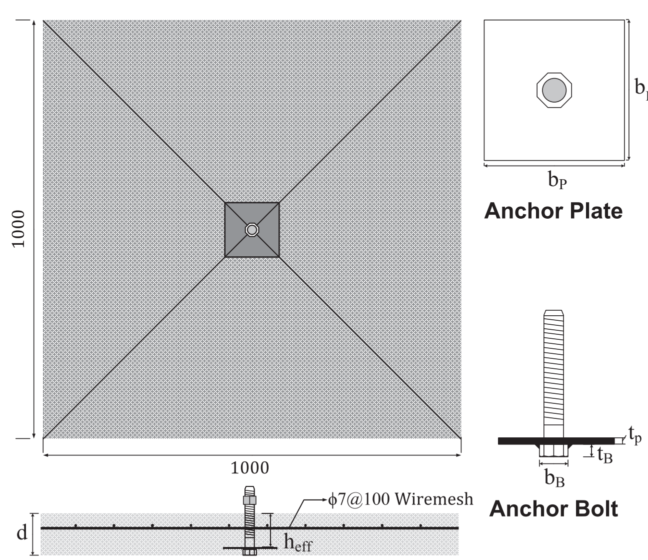

Fig. 3. Dimension of specimens (unit: mm).