The Bond Strength and the Development Length of Reinforcing Deform Bars of Precast Concrete using Grouting

by Fauzri Fahimuddin

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Abstract. The objective of this research to obtain the value of reinforcement's bond strength, the development length (ld), and to find out the type of failure of the reinforcing barembeded intoprecast concrete using grouting material. The method in this research used a simulation model using ABAQUS program and the laboratory investigation. This research was divided by two steps, the first step was to obtain the value of the bond strength and development length (ld) and the second step was to find outthe failure models of the specimen. The specimen in the first step were made of 200×200×200 mm the precast concrete. Otherwise, there were made the cast monolith concrete with reinforcement as the comparison models. Models in the second stepswere made of 200×200×ld mm of the precast concrete. Furthermore, there were made the cast monolith concrete as the comparison models. The value of ld were made in 3 variations, IE, the development length was smaller (<), equal to (=), and higher (>). According to the research, there was relatively similar result to the test result with the ratio of 1.041 to 1.037 for monolith concrete and concrete using grouting. The bond strength of concrete monolith was smaller than concrete using grouting. The development length of monolith cast concrete was higher than concrete using grouting specimens. For the type of the failure, the specimens showed that the reinforcing bar reached the yeild stress.

Introduction

A precast concrete structure is an assemblage of precast elements which, when suitably connected together, form a 3D framework capable of resisting all of design load. The advantage of concrete precast are the construction more efficient, effective in limited area, and the product quality be guaranteed. The connection form the vital part of precast concrete design and construction. The joint connection can used steel bars and grouting. The connection strength is determined by development length and the type of grouting. If the bond strength of reinforcing bar not adequate then it will slip [1].

The study according the bond strength and development length in precast concrete use epoxy can be conducted with experimental testing in laboratory and modeling of specimens with finite element using software [2]. The experiment result and modeling are compared to bond stress of steel bar, development length, and the failure pattern.

Literature Review

The bond stress is the shear stress at surface concrete, the location of the load transfer between reinforcing bar and concrete around it so that make the interaction of reinforcing steel stress. The bond strength is transfered effectively and allows two materials to form a composite structure [3]. To get the bond stress using Eqs. 1–3.

$$T = l_d.\pi.d.\mu \quad \text{and} \quad T = A_b.f_s \tag{1}$$

$$A_b.f_s = l_d.\pi.d.\mu \text{ and } A_b = \frac{\pi.d_b^2}{4}, \tag{2}$$

$$\mu = \frac{f_s}{4.l_d}.d_b \tag{3}$$

and the development length is Eq. 4.

$$l_d = \frac{f_s}{4.\mu}.d_b \quad (4)$$

where T is the tension force (N), A is the section area of reinforcing bar (mm), l_d is the develpment length (mm), d_b is the diameter of reinforcing bar (mm), f_s is the stress of reinforcing bar (MPa), μ is the bond stress (MPa).

The development length is the length of reinforcing bar embedded into precast concrete as a reaction to the reinforcement when receiving tensile force until it reaches the yeild stress. The development length is function of yeild stress, diameter of bar, and bond stresstoresist the slip (Fig. 1).

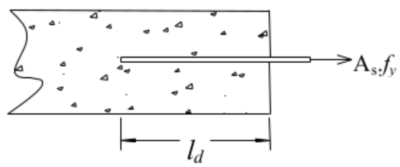


Fig. 1. Length of Embedded Reinforcing Bar (Id)

Based on the AASHTO LRFD 2010 code, the development length of tensile at least 12 inchesorsteel bar <db 36 should satisfy the requirements Eq. 5 [4].

$$\frac{1.25 \cdot A_b \cdot f_y}{\sqrt{f'_c}} \quad (5)$$

SNI–03–2847–2002 code arrangethe development length as Eq. 6 [5].

$$d = \frac{18.f_y.\alpha.\beta.\lambda.d_b}{25.\sqrt{f'_c}} \quad (6)$$

ACI 318-02 Building Code Requirements For Structural Concrete regulate the length of development on Eq. 7 [6].

$$l_d = \left[\frac{3.f_y.\alpha.\beta.\lambda}{50.\sqrt{f'_c}}\right].d_b \quad (7)$$

where f_y is the yeild stress of bar (MPa), A_b is the section area of bar, db is the diameter of bar (mm), f'c is the compresion stress of concrete, α is the reinforcement location factor, β is the coating factor, λ is the lightweight concrete factor.

The fist step of this research used the concrete specimens sized 200×200×200 mm, the compresive stress of concrete (f'c) = 30 MPa, the quality of steel bars grade 50, and the compresive stress of grouting = 60 MPa. There are two variations of specimen, namely monolith concretewithsteel bar and precast concrete using Smart NS grout to attach the reinforcement. The experiment in laboratory use the testing of monotonic pull out refer to ASTM 234-91a.

The first step of this research used the concrete specimens sized 200×200×200 mm, the compresive stress of concrete (f'c) = 30 MPa, the quality of steel bars grade 50, and the compresive stress of grouting = 60 MPa. There are two variations of specimen, namely monolith concrete withsteel bar and precast concrete using Smart NS grout to attach the reinforcement. The experiment in laboratory use the testing of monotonic pull out refer to ASTM 234-91a [7]. Test equipment used is Universal Testing Machine (UTM) [8]. Furthermore, the experiments specimen is made the modeling approach using Abaqus software. The analysis results based on experimental and modeling using software is bond stress. Furthermore, the length of development obtained of Eq. (4). The development length is also compared to the AASHTO, SNI, and ACI code.

The second step, the result data of first step used to determine the specimenvariation in the length of reinforcing bar embedded in concrete. The variation of specimen consist of bar embedded length 120 mm (<40%ld), 200 mm (=ld), dan 260 mm (>30%ld) for monolith concrete and specimen using grouting. The second step also to find out the failure pattern each specimen bese on experiment in laboratory (Fig. 2) dan modelling using software (Fig. 3) [9, 10].

Fig. 2. Specimens in laboratory: (a) hole for steel bar and grouting; (b) monolith concrete; and (c) curing process

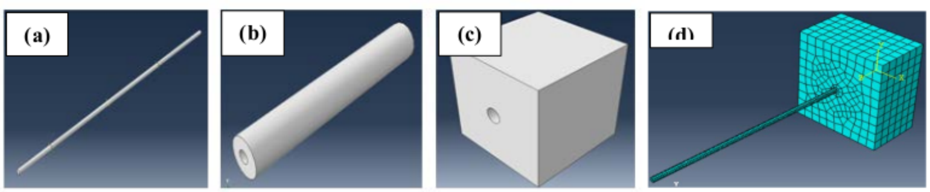
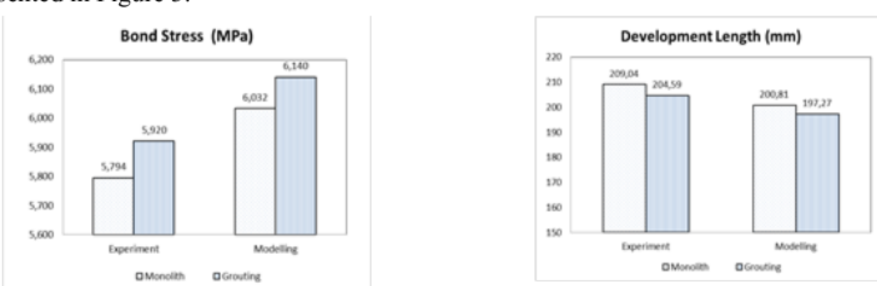


Fig. 3. Modelling of specimens: (a) steel bar; (b) grouting; (c) concrete; and (d) meshing of element

The testing result of experimental and modeling are the bond stress and the development length presented in Figure 3.



a. The bond stress of monolith concrete and specimens using grouting

b. The development length of monolith concrete and specimens using grouting

Fig. 4. The comparison of the bond stress and development lengthfrom experimental and modeling

Fig. 4 present the bond stress from modelling specimen and experiment relatively equal. Usage of Smart NS grout material with a thickness of 10 mm have bond stress greater than monolith concrete so the grouting specimen require the development length shorter than monolith concrete specimen. The results of this study present the bond stress at the precast concrete connection with reinforcement using grouting as good as monolith concrete and steel bar.

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Table. 1. Comparison of development length of steel bar refers to concrete codes

Specimens	Development Length (mm)				
	Experiment	Modelling	AASHTO	SNI 2847 2002	ACI 318-02
Monolith	209,04	200,81	304,80	584,33	590,16
Grouting	204,59	197,27	424,30	701,20	708,20

The Table 1 indicate requirement the developmen length of specimen using grouting shorter than concrete monolith.AASHTO code require the development length value for monolith specimen more than 304.8 mm and grouting specimen at least 424.3 mm.The development length obtained from this study is smaller than that required by AASTHO. This shows that AASTHO provide safety factor of 1.5 to 2. SNI code determine the development length value for monolith specimen more than 584.33 mm and grouting specimen at least 701.2 mm. The development length value of ACI code are 590.16 mm for monolith specimen and 708.2 mmforgrouting specimen. SNI and ACI code provides for safety factor of 3 to 3.5.

Figs. 5 and 6 present the stress and the failure patterns of specimen with the reinforcing bar embedded into concrete 120 mm (< 40% ld).

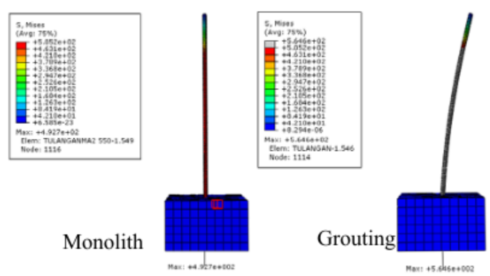

Fig. 5. The stress of modelling specimen with steel bar embedded into concrete 120 mm

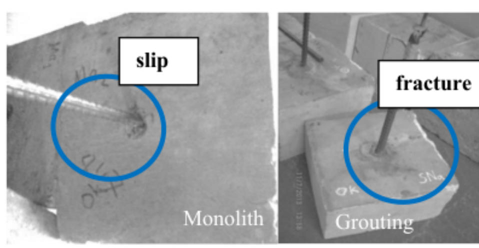

Fig. 6. The failure pattern of experiment spesimen with steel bar embedded into concrete 120 mm

Fig. 5 present that the modelling monolith specimen of steel has not yeild while the modelling grouting specimen of steel has reached the yeild stress of more than 505.15 MPa. The failure pattern of monolith experimental specimen show the steel bar slip after yeild. The steel bar of grouting experimental specimen have fracture (Fig. 6).

Figs. 7 and 8 present the stress and the failure patterns of specimen with the reinforcing bar embedded into concrete 200 mm (= ld).

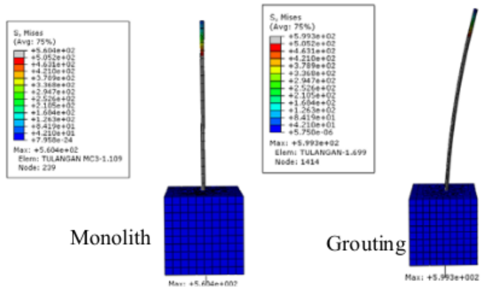

Fig. 7. The stress of modelling specimen with steel bar embedded into concrete200 mm

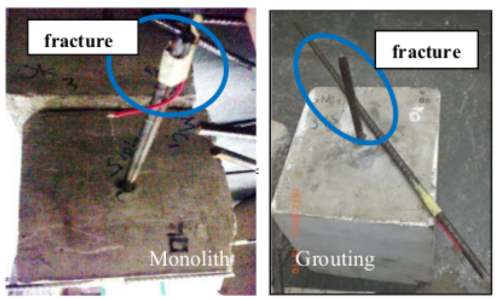

Fig. 8. The failure pattern of experiment spesimen with steel bar embedded into concrete 200 mm

Fig. 7, both of the modelling specimen has reached the yeild stress, the value of the maximum stess that occurs more than 505,15 MPa. For experimental speciment, the failure pattern both of them are fracture.

Figs. 9 and 10 present the stress and the failure patterns of specimen with the reinforcing bar embedded into concrete 260 mm (> 30% ld).

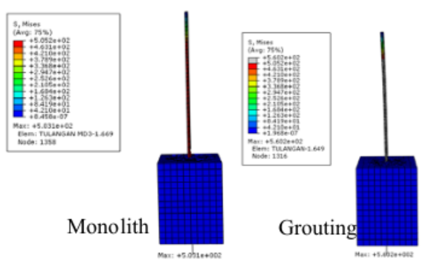

Fig. 9. The stress of modelling specimen with steel bar embedded into concrete260 mm

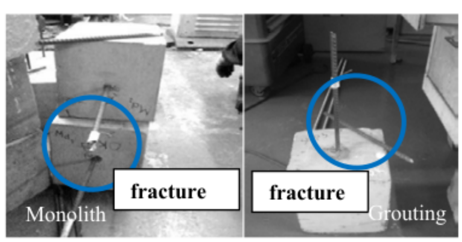

Fig. 10. The failure pattern of experiment spesimen with steel bar embedded into concrete 260 mm

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Fig. 9 present that the modelling monolith specimen of steel has not yeild while the modelling grouting specimen of steel has reached the yeild stress of more than 505.15 MPa. The failure pattern of both of experimental specimen show the steel bar fracture (Fig. 10).

Summary

The bond strength ratio of monolith concrete model and experiment was 1.037 and grouted concrete model and experiment was 1.041. The development length of the monolith and grouting spesimen of modelling and experimental also tend to be similar.The development length of modelling and experiment compared with concrete codes (AASHTO, SNI, dan ACI) are shorter.AASHTO provides a safety factor of 1.5 to 2 while SNI and ACI provide safety factor of 3 to 3.5. The failure pattern the modeling specimen are different from the pattern of damage to the experiment specimen. The modelling specimen obtained steel bars yeild and some bars not yeild. There were two failure pattern of experiment specimens, which slip of bars after yeild and fracture bars.

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