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Study Of The Behavior Of Anchor Connections In Concrete Based On Finite Element Analysis

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Abstract: The anchorage system is one of the techniques used to connect a new structure to the existing structure. The purpose of this study was to determine the behavior between the anchorage connection model in the existing column structure and the new beam using an adhesive anchoring system, and the monolithic column-beam structure model using a program based on the finite element method, Abaqus CAE. The analysis was executed on two models, the monolithic construction model and the anchor joint connection structure model. The same load was applied for both models at the ends of the beams. In the monolithic construction model, the interaction relationship between the column and beam is using a tie constraint, while the structure of the anchor joint connection was using surface-to-surface contact. The epoxy model in anchor joint structure were using a cohesive behavior-contact relationship. As the results of the analysis, it can be concluded that the monolithic construction has stiffer joints compared to the structures with anchor joint connections, it can be seen from the displacement value of monolithic construction is 4.263 mm meanwhile structure with anchor connection is 5.38 mm. The crack pattern in the monolithic construction is in the column face on the area around the beam connection, while in the anchor connection, the crack pattern forms a cone in the area around the column anchor.

Keywords: *anchor; finite element analysis; Abaqus CAE; modelling*

1. Introduction

The anchorage system is one of the solutions that can be used to overcome the problem of connecting the new structure to the existing structure. Study of the anchorage system was performed at Belleza Lampung Hospital using the post-installed anchor method which was located in the area of the connection between the existing column and the additional beam structure on the 4th floor of the building from the additional 3 floors to be added. Of the various types of anchors, post-installed anchors are known for its widely used in the world of construction due to factors such as easy and fast installation [1]. This type of anchor is using adhesive substances in the form of epoxy which is used to attach the anchor to the concrete, so it is suitable for uses as a connection solution for the new structure and the existing structure. Problems regarding the behavior of anchor connection with concrete need to be known to analyze what failure will occur when the ultimate load is applied and the difference with structural connections that are cast monolithically if the same force is applied. Therefore, this study's purpose is to analye the behavior of the connection model that will be produced between the post-installed anchor system in concrete and the connection system if the structure is cast monolithically with the help of the Abaqus CAE program.

2. Literature Study

According to SNI 2847-2019 [2], anchor is a steel material which is installed to concrete to transmit the load to the concrete. Type of anchor that is widely used is a post-installed anchor with a type of chemical anchor which has a way of working by transmitting loads through adhesive-based attachments. This adhesive is a mixture of chemicals intended to increase strength and resistance to humid and wet conditions. Bonding occurs due to several forces acting on the surface of the reinforcement, these forces include the adhesion force between the concrete and the reinforcement, the frictional force between the surface and the reinforcement and the concrete, and the bearing force on the ribs of the reinforcement against the concrete. The bonding and slipping abilities can be described in terms of an adhesive-slip stress curve. In this study, anchors with the trademark HILTI type HIT RE 500 V3 were used.

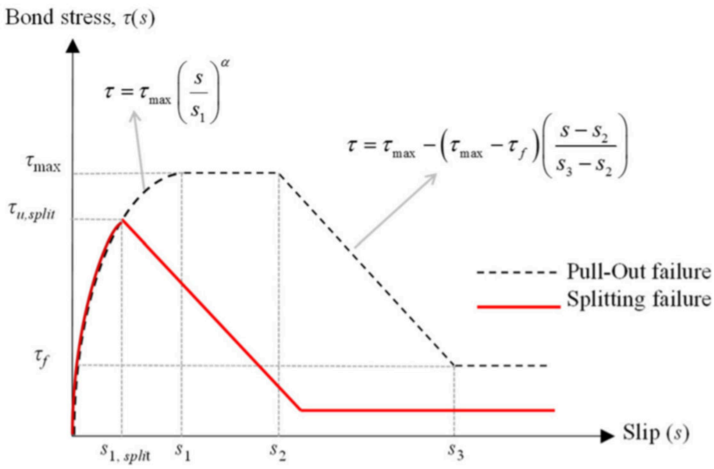


Fig. 1. Bond stress-slip curve [3], [4].

It is known that failure in bond stress can be in the form of pull-out failure and split failure. In this study, the curve used is a pull-out failure curve which can be written as:

$$\tau(\mathrm{s}) = \begin{cases} \tau_u \left(\frac{s}{s1}\right)^{\alpha} \; when\; 0 \le s \le s_1 \\ \tau = \tau_u \; when\; s1 < s \le s_2 \\ \tau = \tau_u - \left(\tau_u - \tau_f\right)\left(\frac{s - s2}{s3 - s2}\right) when\; s_2 < s \le s_3 \\ \tau = \tau_f \; when\; s_3 < s \end{cases} \tag{1}$$

Explanation:
τ_s = Bond stress (MPa)
τ_u = Bond stress ultimate (MPa)
τ_f = Residual bond stress (MPa)
s = slip (mm)
s_1 = slip at the initial ultimate bond stress
s_2 = slip at the end of the ultimate bond stress
s_3 = slip at the initial residual bond stress
α = curve fitting parameter

The curve model at Fig. 1 was further investigated by Tang and Cheng and the parameter values were obtained as shown in Table 1. In parameter s1, the parameter values is:

$$s1 = s3(0.025685s3 - 0.04244db + 0.566648) \tag{2}$$

From this Eq. 1, the value of s_1 is affected by the value of s_3. S_3 is the distance between the ribs of each reinforcement, which is 0.4-1.2 in diameter. The value of ultimate bond stress (τ_u) is influenced by the concrete cover (c) and the diameter of the reinforcement used. The value of τ_u is described in the Eq. 3:

$$\tau_u = 0{,}384702f'c - 1{,}73018d_b - 7{,}40325\frac{c}{d_b} + 65{,}90284 \tag{3}$$

Table 1. Parameter Values of Bond Stress-Slip Curve According to Tang and Cheng

Parameters	**Tang dan Cheng (2020)**
s_1	Eq. 2
s_2	3 mm
s_3	Spacing between ribs
α	0,3
τ_u	Eq. 3
τ_f	$0{,}4\tau_u$

3. Methodology

The method which used in this study is an analysis using finite element numerical methods (Finite Element Analysis) with the help of the Abaqus CAE program. The structural model which going to be analyzed is the beam-column elements, modelled in 3D with a column height of 2 m, a beam length of 1.89 m, and fixed supports at the ends of the columns. The models are divided into two models, The first model is a beam column model that cast monolithically (monolithic structure) and the second model is an existing column model and new beams with epoxy anchor connections (post installed anchors). The load applied to the model is the result of data processing using the ETABS program with a loading combination of U = 1.2D + 1.0L – 0.3Ex – Ey. From this loading, the largest moment value is 405.5319 kN.m and largest value of shear force is 222.2523 kN. The force used in the modeling is the shear force value of 222.2523 kN so the moment that will be produced is close to the moment value from the ETABS results.

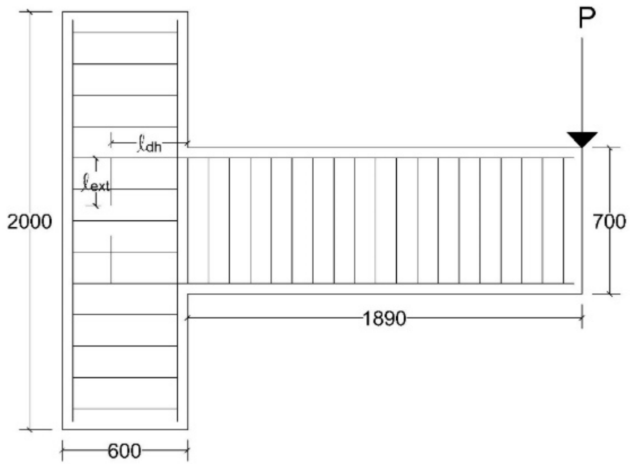


Fig. 2. Structure model in Abaqus CAE program

The difference between the two models lies in the amount of reinforcement used in the beam structure. In the monolithic construction, the amount of reinforcement used is 6D19 reinforcement. For structure with anchors connection, the number and diameter of anchor which is used is 3D30. The size of the selected anchor diameter refers to the Hilti catalogue by considering the spacing between the anchors used. The number of anchors used in the structure with anchor connection is the value of division between the total area of reinforcement in the monolithic structure with area of one anchor with a diameter of 30 mm, therefore the number of anchors used are 3.

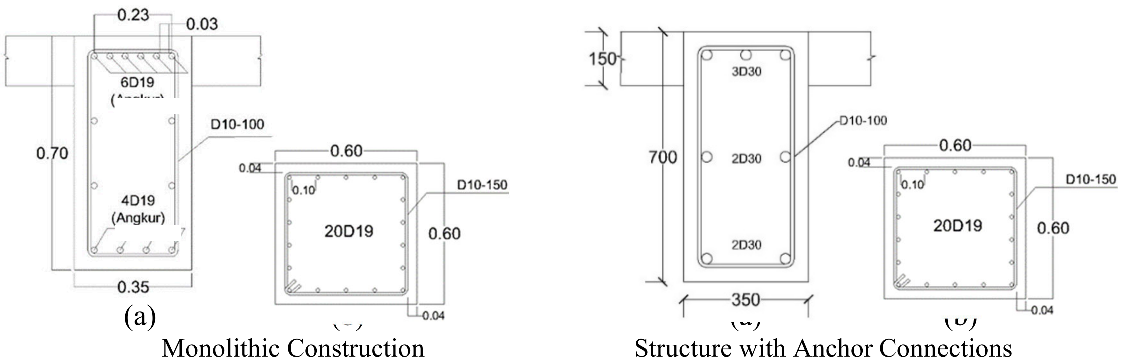


Fig. 3. Cross-sectional dimensions of (a) beam and (b) column in each structures

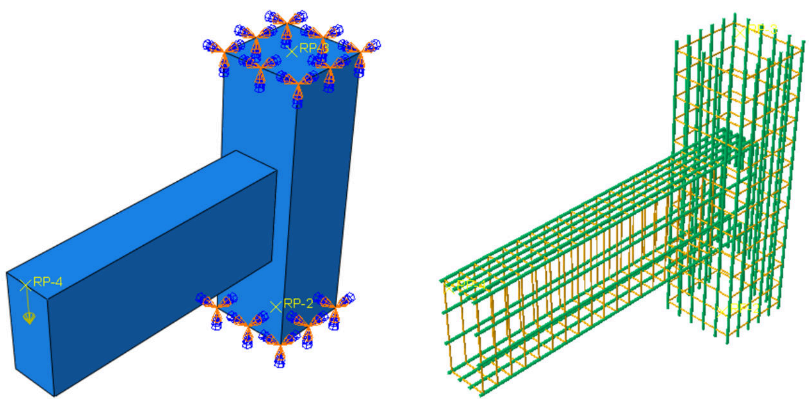


Fig. 4. Monolithic construction model in Abaqus CAE

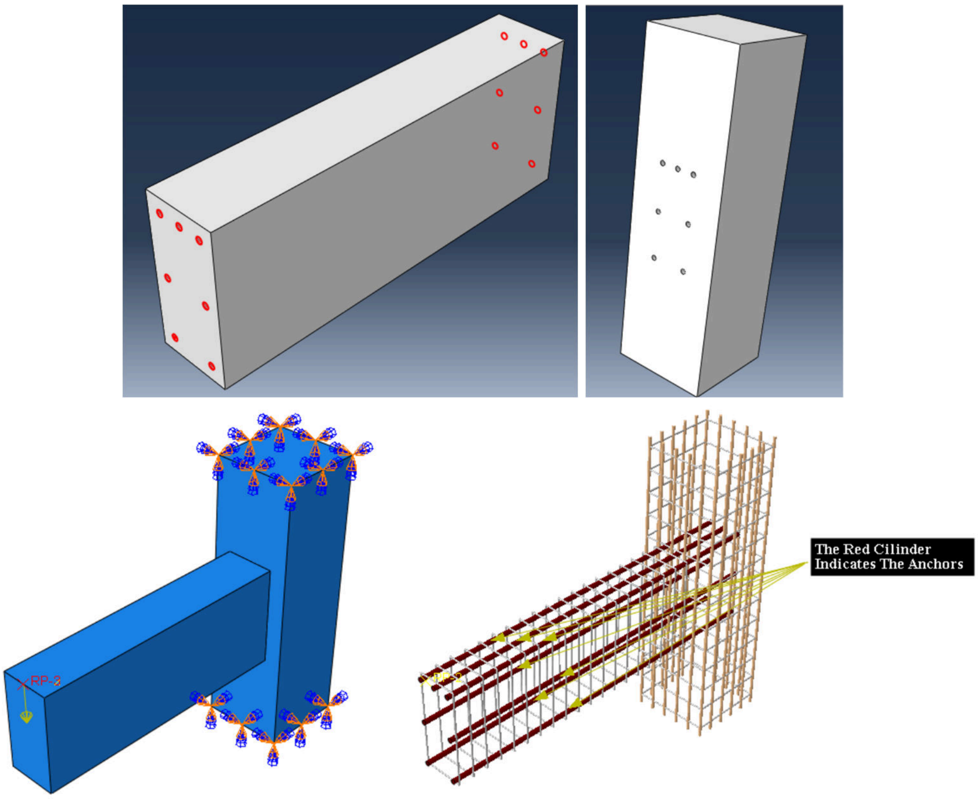


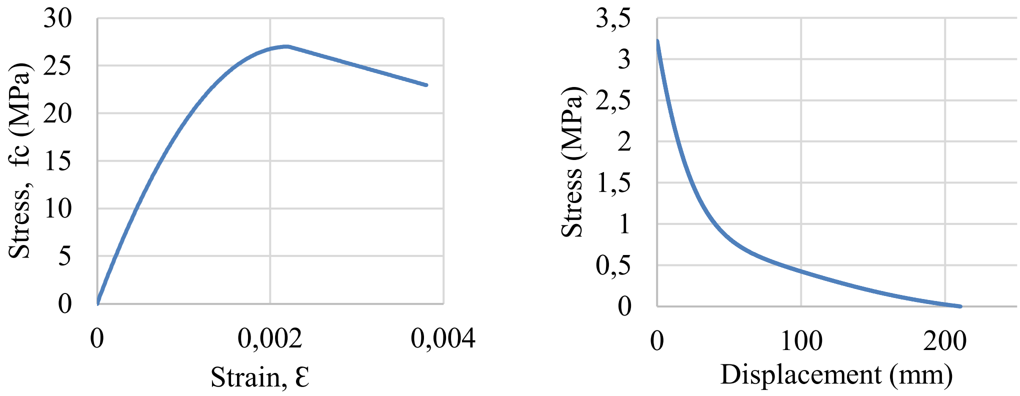
Fig. 5. Anchor connection structure model in Abaqus CAE

In addition to the differences above, the monolithic construction and the anchor connection structure were using different interaction at the connection between the face of the beam and the face of the column. For monolithic construction, the connection between the column faces and the beam faces used a tie-constraint interaction while in the anchor connection structure the interaction used the form of concrete-concrete interaction by entering a value of the friction coefficient of the two materials which is equal to 0.8 according to the PCI Design Handbook. In addition, the reinforcement in the monolith structure is designed to be embedded in the structure. For structures with anchor connections, the column structure needs to be perforated to install the anchors. Between the anchors and the holes in the column, a cohesive behavior interaction were used utilizing existing epoxy stress-slip bond data.

The data used in the Abaqus modeling were include data for concrete materials, reinforcing steel and anchors, as well as bond stress-slip data for epoxy. Toward data on concrete and steel materials, the parameters used are listed in Table 2. In addition, other data used for these two materials is stress-strain data. The compressive and tensile stress-strain curves for concrete were adopted from the Hognestad [5] and Hordijk [6] models, while the stress-strain curves for steel and anchors were adopted from the Eurocode 3 [4] model. In Abaqus, to determine the effect of damage on concrete, the stress-strain curve is processed into a Concrete Damage Plasticity (CDP) model.

Table 2. Materials properties for Concrete and Steel

Materials	Compressive Strength (Mpa)	Tensile Strength (MPa)	Modulus Elasticity (MPa)	Density (kg/m3)	*Poisson's Ratio*
Concrete	27	3,22	24421,92	2400	0,2
Steel	-	420	200000	7850	0,3



a) Concrete Compressive Strength [5] b) Concrete Tensile Stregth [6]

Fig. 6. Compressive and tensile strength curve of concrete

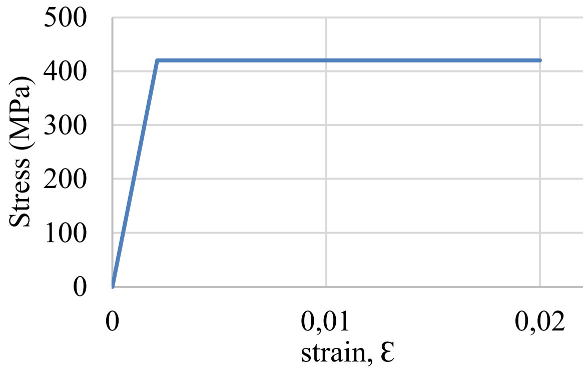


Fig. 7. Stress-strain curve of steel [4]

Epoxy data was processed using the bond stress-slip curve model research by Tang and Cheng [1]. The parameters used are include the values of s_1, s_2, s_3, α, τu, and τ_f. In parameter s_1, to get a positive value from Eq. 2, the distance between the ribs on the reinforcement is taken as 28 mm and the ultimate bond stress (τ_u) value in Eq. 3 is influenced by the value of the concrete blanket thickness of 40 mm and the diameter of the anchor used. The parameter values are shown in Table 3.

Table 3. Calculation Results of Bond Stress-Slip Curve Parameters

Parameters	Tang dan Cheng (2020)	Calculation Results
s_1	Eq. 2	0,354 mm
s_2	3 mm	3 mm
s_3	Spacing between ribs	28 mm
α	0,3	0,3
τ_u	Eq. 3	11,276 MPa
τ_f	$0{,}4\tau_u$	4,511 Mpa

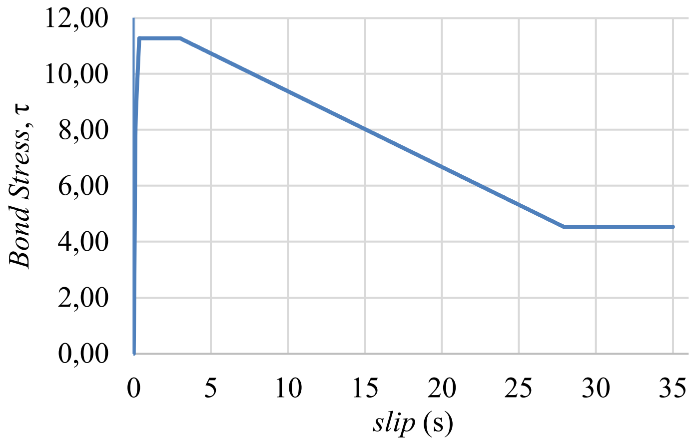


Fig. 8. Bond stress-slip curve of epoxy [1].

4. Results and Discussions

4.1. Displacement

When the load reaches the ultimate load of 222.252 kN, the displacement that happen in the monolithic construction is 4.263 mm while in the connection structure using anchors the displacement value happen at 5.38 mm. Deviation value between the two structures is 1.117 mm with a percentage reaching 26.20% of the displacement on monolithic construction. The larger displacement value in the anchor connection structure can be due to the distance formed by 0.725 mm at the connection between the column and beam when the ultimate load is applied. The distance which was formed on the anchor connection can be caused to the interaction relationship that was applied at the connection. At the connection structure with anchors, the interaction relationship that was applied is in the form of interaction between the concrete by entering the value of the friction coefficient of the two materials, which is equal to 0.8 according to the PCI Design Handbook [7]. In the monolithic construction, this distance was not formed in the monolithic construction because the interaction tie-constraint was applied.

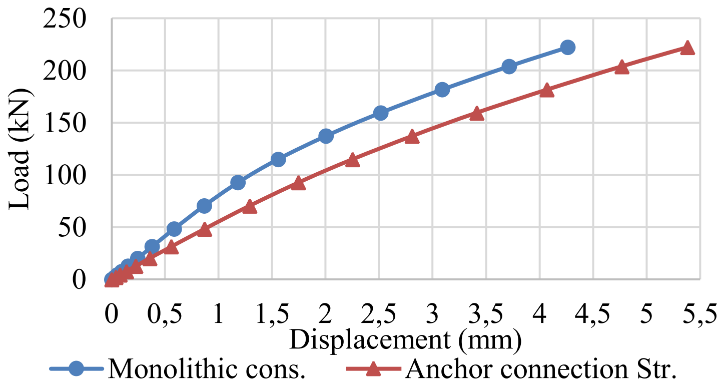


Fig. 9. Load-displacement curves on monolithic construction and anchor connection structure.

4.2. Stress

The stress values on both structures in Abaqus are seen in the global Y (S22) direction. The color pattern of stress in the monolithic conditions for both columns and beams has a similar pattern, which is a red to orange pattern at the top and a green to blue pattern at the bottom. The red to orange colors means that areas experiencing tension stress, while the green to blue colors means the areas experiencing compression stress. In structures with anchors, the connection area is dominated by light green color which indicates the area is experiencing tension and green to dark blue color indicates the area is experiencing compression.

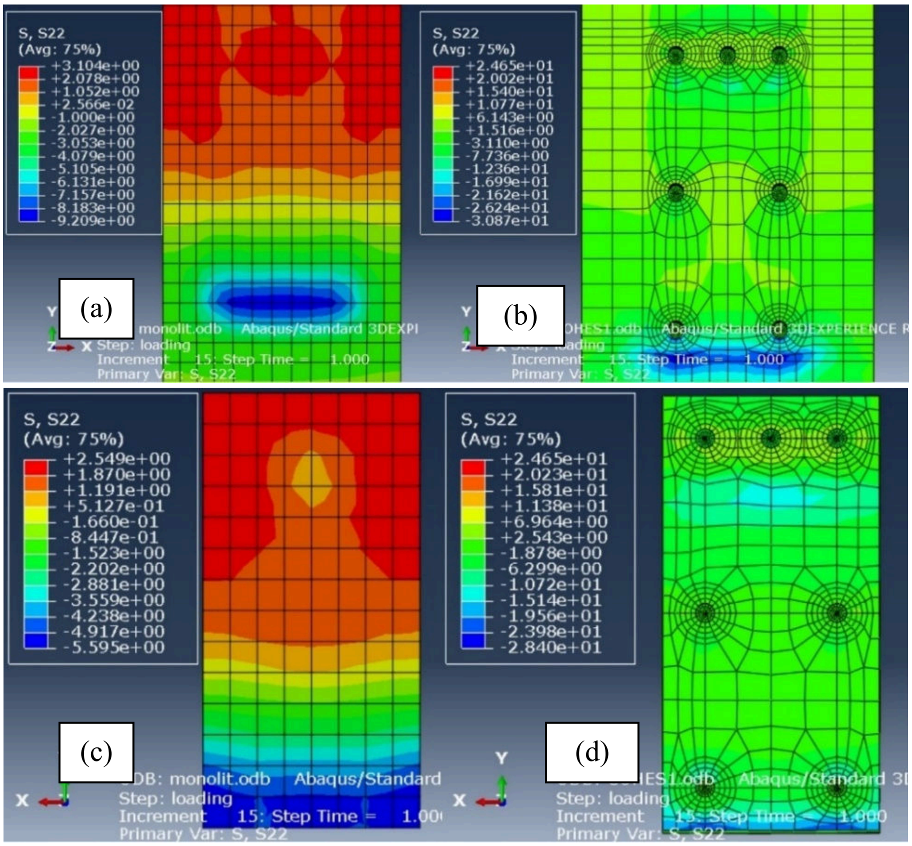


Fig. 10. Stress colour pattern in (a,c) monolithic construction and (b,d) anchor connection structure.

4.3. Strain

This study also looks at the strain behavior based on the tensile strain value of the concrete. The tensile strain value of concrete with a compressive strength of 27 MPa is 0.000131. According to Claisse [8], strain values can cause cracks if the applied strain exceeds the tensile strain of the concrete. The crack patterns in both models can be seen through the color patterns that refer to the strain values. In the monolithic construction, the first crack occurs when a load of 70.63 kN acts with a strain value of 0.00035. The first crack pattern occurs at the ends of the beam area near the joints which are marked in red to green.

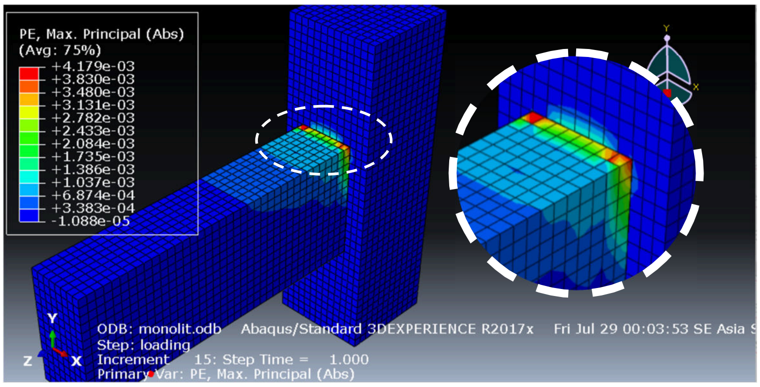


Fig. 11. Pattern of cracks in the monolith structure.

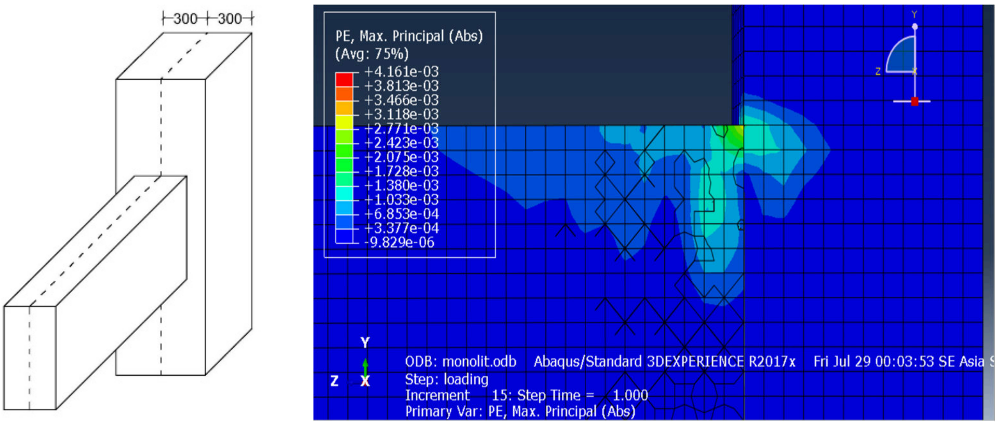


Fig. 12. Crack pattern in the center of cross-section in monolith structure.

In the anchor connection structure, the first cracks occur around the anchor in the beam connection area when a load of 31.53 kN acts with a strain value of 0.000398, then spreads around the anchor in the column connection when a load of 48.41 kN acts. The cracks in the column area continue to spread until they reach 2/3 of the anchor section and form a conical pattern in each anchor.

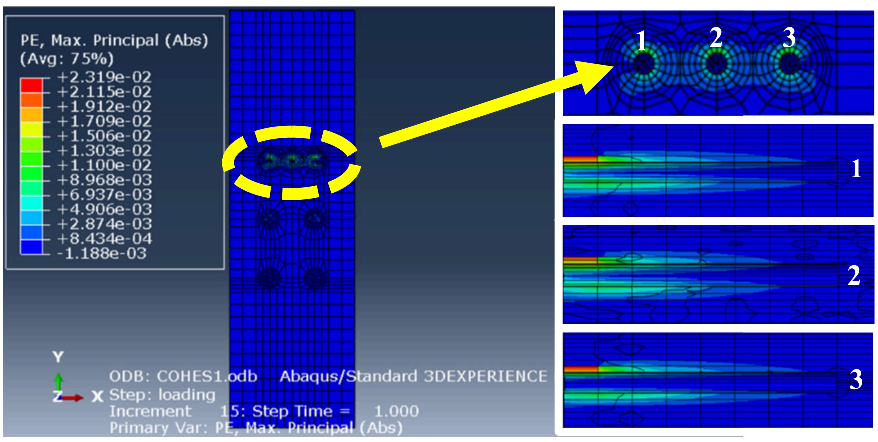


Fig. 13. Crack pattern in anchor connection structure.

4.4. Anchor Capacity

The strength capacity of the anchors in this study was obtained by analyzing the stress values on the anchors in the joints based on the concept of the equation below:

$$T = As.fy \tag{4}$$

T is the tensile force performed on the reinforcement. Considering the expense of safety factor, the value of the tensile force (T) must comply the criteria, which is design action (Sd) ≤ design resistance (Rd). The Rd value is smaller than the mean value of the anchor ultimate resistance and characteristic resistance (5% fractile), in this condition the anchor is considered to be able to reach 90-95% of its capacity. These things are explained in Fig. 14.

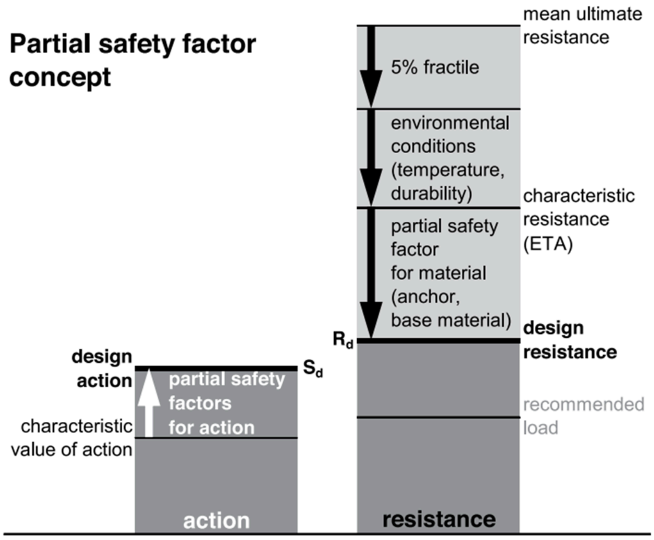


Fig. 14. Anchor safety factor [4].

From the results of the stress analysis results from the Abaqus program, the largest values of stress in each anchor include 321.67 MPa, 326.71 MPa and 321.474 MPa. From this value, 326.71 MPa was taken as the analysis sample. If the stress is 326.71 MPa multiplied by the area of an anchor with diameter of 30 mm, then the T force is 230.94 kN for 1 anchor. Sd and Rd values are values obtained from Hilti [9] product requirements.

Table 4. Comparison of Anchor Pull-Out Force with Hilti Parameters

	Anchors					
	1	**2**	**3**	**1**	**2**	**3**
Types of drill	***Hammer drill hole***			***Diamond core hole***		
Anchor Tensile Force (T) (kN)	227,375	230,938	227,237	227,375	230,938	227,237
Load/*Design Action* (Sd) (kN)	load is assumed to be evenly distributed over the 3 anchors, so 222,25 : 3 anchors = 74,083					
Design Resistance (Rd) (kN)	166,3			115,7		
Characteristic Resistance (kN)	249,4					
Explanation	Sd < Rd ; T < *Characteristic Resistance* SAFE					

From Table 4, it can be seen that the anchors that were installed are classified as safe. Several reasons that caused this conditions are first, the Sd ≤ Rd requirement has been fulfilled. Second, the tensile strength (T) value of each anchor is still in the partial safety factor region and it is still below the characteristic resistance value.

5. Conclusion

Based on the results and discussions, can be concluded as follows:

1) When the ultimate load of 222.252 kN is applied, the displacement value on monolithic construction is 4.263 mm meanwhile the structure with anchor connection is 5.38 mm.
2) Deviation between the monolithic construction and the anchor connection structure is 1.117 mm with a percentage of 26.20% of the monolith displacement.
3) First crack in the monolithic structure occurred when the load of 70.63 kN was applied, meanwhile for anchor connection structure the first crack occurs when the load of 31.53 kN was applied.
4) The crack pattern in the monolithic construction lies in the area of beam connection, while in the anchor connection structure it is clearly visible in the area around the anchor.
5) The crack pattern around the anchor area at the column forms a cone, so the type of failure that occurs indicates a concrete cone failure. This failure is the most common failure and the expected type of failure that happened.
6) The anchor capacity can endure a load of 222.25 kN. It has complied the requirements value of tensile force in each anchor according to HILTI HIT-RE 500 V3.

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