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# Capacity Analysis of Precast Pile Connection with Cast in Situ Pillars

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**Abstract (in English):** The dominant axial force on reinforced concrete bridge columns may affect the ability of the pillars to respond to various lateral excitations. The objective of this study is to analyze the strength of the concrete, tensile behavior and shear strength in the pillar structure of the bridge.The method used to identify the behavior of pillars is to carry out an analysis of the internal capacity of the pillars according to the characteristics of concrete quality, steel quality, cross-sectional shape, and the configuration of the reinforcement installed in three sections along the pillar height separately. By checking the adequacy of lap joints and the length of reinforcement distribution, assuming that the dominant pillar is in tension or compression. Assuming the dominance of tension in the reinforcement joints is in anticipation of a tensile response in the reinforcement joints when bending behavior is dominant (for tall pillars). Curvature, Analyzing the relationship of Force - Lateral displacement by simulating the height of the pillars from 1 – 5 m, and comparing it with the shear capacity of the pillars so that a confining reinforcement spacing of 50 mm is obtained both on the precast pile (PCP) and on the additional Cast in Situ Pier (PICP) has been increasing the compressive strength and strain of the pillars so that with a factored axial compressive force of 730 kN, it produces compressive stress at the effective cross-section of the pillar of 13 MPa, which means that the strength of the concrete on the pillars is still sufficient. The shear capacity of the pillar obtained by factored loading is Fu = 17 to 86 kN, so the pillar is still safe from shear failure along its height.
**Keywords (in English):** Bridge, Pile Connection, Precast Pillar, Pile Connection Capacity, Peatland

# 现浇柱预制桩连接承载力分析

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**摘要：**(Abstract in Chinese): 钢筋混凝土桥柱上的**主要**轴向力可能会影响柱子响应各种横向激励的能力。 **本研究的目的是分析**桥梁支柱结构中混凝土的强度、拉伸性能和剪切强度。识别支柱性能的方法是根据根据混凝土质量、钢材质量、截面形状以及沿柱高分三段安装的钢筋配置等特点。 **通**过检查搭接接头的适当性和钢筋分布的长度，假设主导支柱处于拉伸或压缩状态。 **假**设当弯曲行为占主导地位时（对于高柱），钢筋接头中的拉力占主导地位是预期钢筋接头中的拉伸响应。 **曲率**，**通**过模拟 1~5 m **的柱高**，**分析力**-侧向位移的关系，并与柱的抗剪承载力进行比较，从而在预制桩上得到 50 mm **的**围护钢筋间距（ PCP） **和附加的**现浇墩（PICP） **增加了支柱的抗**压强度和应变，因此在 730 kN **的分解**轴向压力下，它在支柱的有效横截面处产生 13 **的**压应力 MPa，这意味着柱子上的混凝土强度仍然足够。 **通**过因子

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加载获得的支柱的抗剪承载力为 Fu = 17 至 86 kN，**因此支柱沿其高度仍然不会**发生剪切破坏。
**关键词：**(Keywords in Chinese)：桥梁、桩连接、预制柱、桩连接能力、泥炭地

# 1. Introduction

The development of transportation infrastructure, including roads and bridges, plays an important role in improving the socio-cultural and economic development of a region [1,2]. The main function of bridges is as traffic infrastructure to support the smooth flow of goods and services and community activities across rivers or other obstacles [3]. The ability of a bridge to provide optimal traffic services is also closely related to the shape or dimensions of the bridge [4]. Meanwhile, another factor needed for a bridge to provide maximum service is the strength of the bridge construction itself. These things are the basis for consideration on constructing appropriate and tough structural elements in accordance with existing conditions in the field. Hence, the resulting structural elements can be safer, more comfortable and more economical [5]. For example, the construction of a bridge in Kalimantan Indonesia that crosses river and peat land barriers. Bridge construction in that ment must consider the details of the bridge's structural elements. One of the elements that need more concern is the pillars or columns.

Reinforced concrete columns on bridges should meet the requirements for detailed reinforcement, both the need for longitudinal and transversal reinforcement as well as the interaction of the composite with the concrete [6]. There must be enough confinement reinforcement to stop the internal breaking pressures that act laterally on the concrete core if bridge piers are to have a high compressive axial capacity. In addition, the concrete, transverse reinforcement, and compressive force effects must all provide sufficient shear strength to prevent rapid shear collapse of the pillars. In order for the pillars to work as intended, all of this must be realized in the detailing of probable plastification sites and outside plastic joints.

The application of additional pillars cast directly in the field (cast in situ) that have the same dimensions as the embedded precast piles may reinforce the configuration. The arrangement might be strengthened by adding additional pillars that are formed in situ—directly in the ground—and have the same proportions as the embedded precast piles. To achieve the characteristics of the concrete material and reinforcement of the new pillars that correspond with those of the old pillars is the major goal while managing the addition of new pillar connections (from precast pillars to cast-in-place pillars). If this is possible, it is also anticipated that deformation and rotation behavior will occur that is at least somewhat similar to that of the two connected reinforced concrete pieces. This behavior must be treated in the connecting area, namely, to ensure that it continues unaltered along the height of the pillar. This study aims to analyze the strength of the concrete, tensile behavior and shear strength in the pillar structure of the bridge.

# 2. Material and Method

The research was carried out by means of field testing, the object of this research was the Flyover Column in Kutai Kertanegara Regency, East Kalimantan. This bridge construction used a type of friction pile because land is composed of peat soil whose friction pile relies on the transfer of load from the structure to the ground with the friction force between the surface of the pile and the soil around the pile [7,8]. The entire surface of the pile works to transfer the load from the structure to the ground (Figure 1).

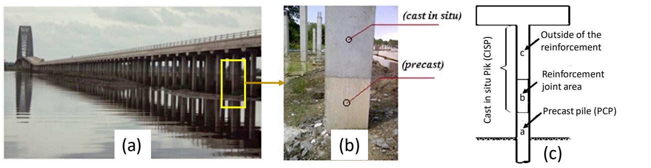


Fig. 1 Study site in (a) Bridge Column in Kutai Kertanegara Regency, East Kalimantan, (b) precast and cast in situ position, (c) diagram of column structure

In this construction, problems were identified in connection with technical measures in the form of adding/connecting new non-stressed pillars, so it was suspected that there would be a change in the pillar's capacity to carry loads, which was identified as follows:

(1) There is a possibility that the flexural capacity decreases in the connection area between the strands in the form of wire from the pile and the reinforcement from additional pillars as a result of: a. The length of reinforcement distribution to anticipate tensile behavior due to dominant bending and to anticipate dominant axial compression conditions is inadequate, b. The woven strands are loose and the bond to the new reinforcement is inadequate

(2) It is possible that the average concrete strength of piles and additional pillars is not the same and the

meeting of the two surfaces cannot be guaranteed as a monolith.

- There is a possibility that the short shear capacity of the pillars is vulnerable to the potential for dominant shear failure.

The method used to identify pillar behavior is to analyze the internal capacity of the pillar according to the characteristics of concrete quality, steel quality, cross-sectional shape and configuration of reinforcement installed in three sections along the height of the pillar separately. For this reason, the following analysis is carried out by a) checking the adequacy of lap connections and the length of reinforcement distribution assuming the dominant pillar is experiencing tension or compression. The assumption of tensile dominance in reinforcement connections is to anticipate the occurrence of a tensile response in reinforcement connections when bending behavior is dominant (for tall pillars); analyzing the increase in concrete compressive strength in the compressive stress-strain relationship due to confinement configurations on piles and additional pillars; c) analyzing the Moment - Curvature relationship of the pillar in three cross-sections in different segments along the height of the pillar (segments a, b and c) as in Figure 1c; d) predicting the position of the maximum moment and the potential for bending response; e) analyzing the Force - Lateral Displacement relationship by simulating the pillar height from 1 – 5 m, and comparing it with the shear capacity of the pillar.

The results of the analysis carried out will provide a qualitative picture of the piles, additional pillars and connection areas so that it can be concluded that the pillar capacity is still adequate for loading. The analysis of pillar cross-sections, apart from producing moment-curvature relationships, it also identifies the behavior of strains and internal forces in the cross-section according to the external axial forces applied. Parameters that influence the analysis are concrete quality and steel quality, including the stress-strain relationship model of the two materials as well as the configuration of longitudinal and transverse reinforcement.

Area A in Figure 2 is a cross-section modeled according to the condition of the precast pile, while in area C the cross-section is modeled according to additional pillars made by cast in situ. In the connection area (area B) the cross-section and configuration of the pillar reinforcement are modeled according to area A but using the quality of concrete as in area C. Cross-section analysis with Response 2000 Software was developed using Modified Compression Field Theory [9].

Connecting piles with new pillars is done by removing of the remaining concrete at the end of the pile, connecting the reinforcement rods for new concrete pillars to a strand of piles with a distribution length of 50 cm, bending the strand in such a way that it can adjust from a circular longitudinal reinforcement configuration to a square longitudinal configuration, creating the distance from the transverse reinforcement in the connection area to the top end of the new pillar is the same, namely 10 cm.

After handling the connection of additional reinforced concrete pillars in this project, several things have been identified that need special attention in the form of unusual conditions and their feasibility has not been regulated in the existing regulations. For this reason, a review is needed that provides a second opinion that can compare existing design results with actual practical handling in the field. This review was not carried out comprehensively but only focused on the case of handling pillar connections due to the height of the piles not reaching the planned elevation. This analysis uses Response 2000 v 1.0.5 software.

The basic formula for concrete confined under monotonic loads was done by adopting the compressive stress-strain relationship [10]. An illustration of the compressive stress-strain relationship of confined concrete is given in Figure 2 [11].

$$f_c = \frac{f'_{cc} x r}{r - 1 + x^r} \qquad (1)$$

$$x = \varepsilon_{co} / \varepsilon_{cc} \qquad (2)$$

$f'_{cc}$ = compressive strength of confined concrete (to be determined later).

$f'_{co}$ = unconfined compressive strength of concrete.

$\varepsilon_{co}$ = longitudinal compressive strain of unconfined concrete, 0.002.

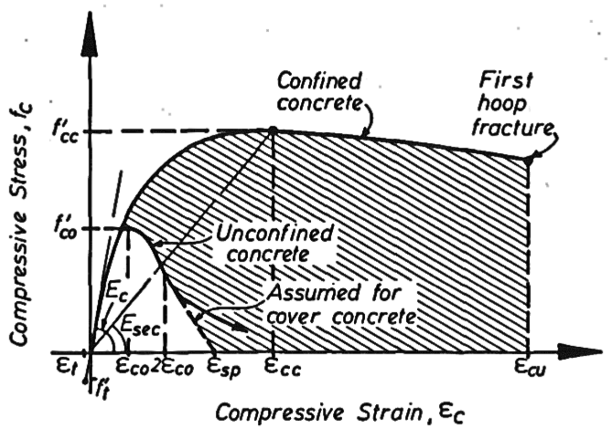


Fig. 2 Model of compressive stress-strain relationship for concrete with monotonic loads between confined and unconfined [12,13]

$$\varepsilon_{cc} = \varepsilon_{co}\left[1 + 5\left(\frac{f'_{cc}}{f'_{co}} - 1\right)\right] \qquad (3)$$

$$r = \frac{E_c}{E_c - E_{\sec}} \qquad (4)$$

where is the elasticity of concrete, $E_c = 4700\sqrt{f_c{}'}$ (adapted to SNI 1726 2012, (2012) and $E_{\sec}$ will be determined later according to the secant slope shown in Figure 1 or with the following formula:

$$E_{\sec} = \frac{f'_{cc}}{\varepsilon_{cc}} \qquad (5)$$

**2.1. Effective restrained lateral pressure and effective restraint coefficient.**

The maximum transverse pressure of the reinforcing steel restraining the concrete core can only be used effectively in the part of the concrete core where the restraining stress operates fully between the arching actions. Figure 3 shows the arching action that is assumed to occur between the transverse reinforcement. The area enclosed by center lines of transverse spiral or hoop reinforcement is a confined area, Acc, while the area enclosed by arching action is an effectively confined area with a smaller area so that $A_e < A_{cc}$.

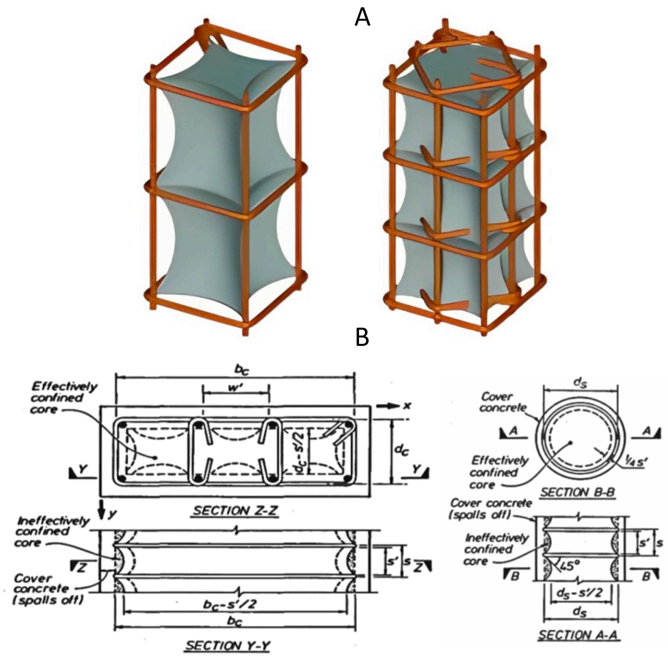


**Figure 3. Model of effective restraint area in a concrete core a) arching model, b) square and circular stirrup reinforcement [13]**

The effective lateral pressure on the concrete core is as given in equation V.7. For columns with a square cross section

$$f'_{lx} = f'_{ly} = f'_l. \qquad (6)$$

$$f'_l = k_e f_l \qquad (7)$$

$$k_e = \frac{A_e}{A_{cc}} \qquad (8)$$

$$A_{cc} = A_c\left(1 - \rho_{cc}\right) \qquad (9)$$

$$\rho_{cc} = \frac{A_s}{A_c} \qquad (10)$$

The area of the concrete core bounded by the center line of the perimeter of the transverse reinforcement is $A_c$ ($A_c = d_c b_c$ for square stirrups and $A_c = \frac{1}{4}\pi d_s^2$ for circular stirrups), whereas $\rho_{cc}$ is the ratio of the total longitudinal reinforcement area ($A_s$) to the concrete cross-sectional area $A_c$. The lateral resistance pressure contributed by the transverse reinforcement is $f_l$ as in Equation V.11

$$f_l = \rho_{sh} f_{yh} \qquad (11)$$

$$\rho_{sh} = \frac{A_{sh}}{s b_c} \qquad (12)$$

The transverse reinforcement ratio for a square column is $\rho_{sh}$ dan $f_{yh}$ is the quality or yield stress of the transverse reinforcing steel. The total area of hoop reinforcement is the number of legs of transverse reinforcement in the direction of the confinement under consideration expressed as $A_{sh}$, while $s$ is the spacing of transverse reinforcement from as to as of reinforcement. The outer dimensions of the concrete core from the center line of transverse reinforcement are symbolized as $b_c$ for length and $d_c$ for width so that $b_c > d_c$ for rectangular columns and$b_c = d_c$ for square columns.

For restraints with circular or spiral transverse reinforcement, the balance between uniform lateral pressure and tensile stress of the reinforcement is as follows:

$$s d_s f_l = 2 A_{sp} f_{yh} \qquad (13)$$

$$\rho_{sp} = \frac{4 A_{sp}}{s d_s} \qquad (14)$$

$$f_l = \frac{1}{2} \rho_{sp} f_{yh} \qquad (15)$$

when $A_{sp}$ is the cross-sectional area of the spiral or circular reinforcement.

The effective confined area ($A_e$) for square columns via transverse hoop reinforcement with or without using cross ties. determined by assuming the arching action is a parabola of degree two with a tangent angle of 45°. Arching action which is formed vertically between the transverse hoops and horizontally between the longitudinal reinforcement, is an ineffective area. The effective unconfined area is given in Equation V.16, where $w_i{}'$ is the clear distance of longitudinal reinforcement and n is the number of longitudinal reinforcements.

$$A_i = \sum_{i=1}^{n} \frac{(w_i')^2}{6} \qquad (16)$$

The area of the area that is effectively confined is the area of the concrete core that is confined minus the area of the part that is not effectively confined, so that it becomes as in Equation V.17.

$$A_e = \left(b_c d_c - \sum_{i=1}^{n} \frac{w_i^2}{6}\right)\left(1 - \frac{s'}{2b_c}\right)\left(1 - \frac{s'}{2d_c}\right) \qquad (17)$$

$$A_e = \frac{\pi}{4} d_s^2 \left(1 - \frac{s'}{2d_s}\right)^2 \qquad (18)$$

when *s'* clear spacing of transverse reinforcement measured from the outside. By referring to Equation V.8, the effective restraint coefficient is formulated as in Equation V.18 for square pillars and Equation V.19 for circular pillar sections.

$$k_e = \frac{\left(1 - \frac{1}{b_c d_c}\sum_{i=1}^{n} \frac{w_i^2}{6}\right)\left(1 - \frac{s'}{2b_c}\right)\left(1 - \frac{s'}{2d_c}\right)}{1 - \rho_{cc}} \qquad (19)$$

$$k_e = \frac{\left(1 - \frac{s'}{2d_s}\right)^2}{1 - \rho_{cc}} \qquad (20)$$

The compressive stress of confined concrete based on triaxial pressure can be expressed using the formula proposed by Mander, et al. (1988).

$$f_{cc}' = f_{co}'\left(-1.254 + 2.254\sqrt{1 + \frac{7.94 f_l'}{f_{co}'}} - 2\frac{f_l'}{f_{co}'}\right) (21)$$

### 2.2. Determination of the moment-curvature relationship of column sections

The moment-curvature relationship of the pillar cross-section provides an idea of the inelastic behavior of the structural element. This behavior is greatly influenced by the characteristics of the concrete and reinforcing steel materials. The concrete constitutive model in cross-section consists of a confined concrete constitutive model as in Equation V.1 and a concrete constitutive model without restraint, namely by assuming $f_l' = 0$. If the concrete compression block in the column cross-section analysis is modeled based on the stress-strain relationship conditions provided in Equation V.1 then the determination of the area of the compressed block in concrete is illustrated as in Figure 4 for a strain value of $\varepsilon_{cm}$ from the concrete stress-strain curve.

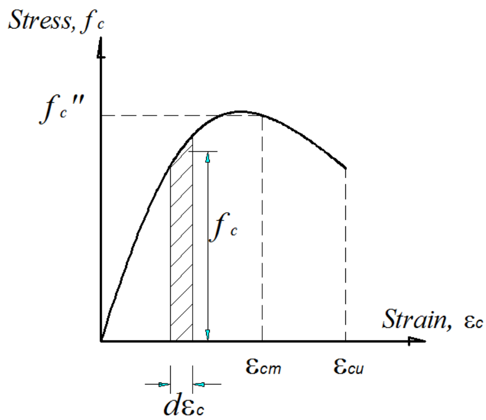


Fig. 4 Compressive stress block area from actual concrete stress-strain curve

The area under the curve in the form of a multiplier was done according to Equation $\int_0^{\varepsilon_{cm}} f_c d\varepsilon_c = \alpha f_c' \varepsilon_{cm}$ (22)

$$\alpha = \frac{\int_0^{\varepsilon_{cm}} f_c d\varepsilon_c}{f_c'' \varepsilon_{cm}} \qquad (23)$$

The central factor of the concrete compressive force ($\gamma$) on the cross-section is determined by the principle of the moment of the area under the concrete stress-strain curve according to Equation V.22.

$$\gamma = 1 - \frac{\int_0^{\varepsilon_{cm}} f_c \varepsilon_c d\varepsilon_c}{\varepsilon_{cm}\int_0^{\varepsilon_{cm}} f_c d\varepsilon_c} \qquad (24)$$

The compressive axial force under balanced conditions for longitudinal reinforcement spread over all four sides of the cross section is expressed in Equation V.23

$$P_r = \alpha f_c' b_{co} c_b + \sum_{i=1}^{n} A_{si}' f_{si}' + \sum_{i=1}^{n} A_{si} f_{si} \quad (25)$$

and the moment about the neutral line is expressed according to Equation V.24

$$M_r = (\alpha f_c' b_{co} c_b)\left(\frac{h_c}{2} - \gamma c_b\right) + \sum_{i=1}^{n} A_{si}' f_{si}'\left(\frac{h_c}{2} - d_i\right) + \sum_{i=1}^{n} A_{si} f_{si}\left(\frac{h_c}{2} - d_i\right) \quad (27)$$

where $C_s$ and $T_s$ are the compressive force and tensile force of the reinforcement, respectively, $A_{si}$ dan $A_{si}'$ are the cross-sectional areas of the *i* row of reinforcement in the tension area and in the compression area, respectively [15]. For every increase in compressive strain $\varepsilon_{cm}$ it will result in a change in the height of the neutral line *kd or c*, and a change in the strain of the reinforcing steel in the section area experiencing tension [16].

The stress-strain behavior of reinforcing steel is modeled using the following equations [16]:

If it is still in an elastic condition, that is if $0 \le \varepsilon_s \le \varepsilon_y$, so:

$$f_s = E_s\,\varepsilon_s \qquad (28)$$

When the first melting has been exceeded and $\varepsilon_y \le \varepsilon_s \le \varepsilon_{sh}$, so:

$$f_s = f_y \qquad (29)$$

When strain hardening has been exceeded, $\varepsilon_{sh} \le \varepsilon_s \le \varepsilon_{su}$

$$f_s = p.f_y \qquad (30)$$

with $p$ is the coefficient defined as follows:

$$p = \left[\frac{m(\varepsilon_s - \varepsilon_{sh}) + 2}{60(\varepsilon_s - \varepsilon_{sh}) + 2} + \frac{(\varepsilon_s - \varepsilon_{sh})(60 - m)}{2(30q+1)^2}\right] \qquad (31)$$

$$m = \frac{\left(\frac{f_{su}}{f_y}\right)(30q+1)^2 - 60q - 1}{15q^2} \qquad (32)$$

$$q = \varepsilon_{su} - \varepsilon_{sh} \qquad (33)$$

Furthermore, analysis of the curvature moment relationship was carried out using Response 2000 software. The cross-sectional analysis assumption in Response 2000 does not differentiate the behavior of the compressive stress-strain relationship between concrete in stressed areas and those without constraints (concrete blankets).

### 2.3. Bracing reinforcement requirements

Minimum stirrup reinforcement requirements for square restraints in plastic hinge areas are set out in AASHTO-LRFD *Bridge Design Specifications* (2010) sec. 5.10.11.4.1d which is no less than the largest in Eq V.29 and V-30.

$$A_{sh} = 0.3sh_c\left(\frac{f_c'}{f_{yh}}\right)\left(\frac{A_g}{A_{ch}} - 1\right) \qquad (34)$$

$$A_{sh} = 0.12sh_c\left(\frac{f_c'}{f_{yh}}\right) \qquad (35)$$

For columns with spiral or circular reinforcing reinforcement, this requirement is expressed in the reinforcement ratio $\rho_{sp}$.

$$\rho_{sp} = 0.12\left(\frac{f_c'}{f_{yh}}\right) \qquad (36)$$

These three equations are also recommended by ACI 343R-95, Analysis and Design of Reinforced Concrete Bridge Structures sec. 11.6.4.6 as well as within ACI-318M-11 (2011) sec. 21.6.4.4(b).

Minimum tie bar usage requirements for square columns based on CALTRANS Bridge Design Specifications sec. 8.18.2.3.1 [16], shall not be less than the greatest of Equations V-32 and V-33.

$$A_{sh} = 0.3sh_c\left(\frac{f_c'}{f_{yh}}\right)\left(\frac{A_g}{A_{ch}} - 1\right)\left(0.5 + \frac{1.25P_u}{A_g f_c'}\right) \qquad (37)$$

$$A_{sh} = 0.12sh_c\left(\frac{f_c'}{f_{yh}}\right)\left(0.5 + \frac{1.25P_u}{A_g f_c'}\right) \qquad (38)$$

For columns with spiral or circular confining reinforcement, this requirement is expressed in the reinforcement ratio $\rho_{sp}$. For columns with spiral or circular confining reinforcement, this requirement is expressed in the reinforcement ratio.

$$\rho_{sp} = 0.12\left(\frac{f_c'}{f_{yh}}\right) \qquad (39)$$

$$\rho_{sp} = 0.45\left(\frac{A_g}{A_{ch}} - 1\right)\left(\frac{f_c'}{f_{yh}}\right) \qquad (40)$$

If the compressive axial force is taken into account

$$\rho_{sp} = 0.45\left(\frac{A_g}{A_{ch}} - 1\right)\left(\frac{f_c'}{f_{yh}}\right)\left(0.5 + \frac{1.25P_u}{A_g f_c'}\right) \qquad (41)$$

$$\rho_{sp} = 0.12\left(\frac{f_c'}{f_{yh}}\right)\left(0.5 + \frac{1.25P_u}{A_g f_c'}\right) \qquad (42)$$

### 2.4. Column shear capacity

The shear capacity regulations ACI 434R-95 (1995) and ACI 318M-11 (2011) refer to the principle of shear capacity of structural elements as a contribution from the shear capacity of concrete and transverse reinforcement $V_n = V_c + V_s$. The shear force contributed by the concrete is as in Equation V-38.

$$V_c = 0.17\left(1 + \frac{N_u}{14A_g}\right)\lambda\sqrt{f_c'}b_w d \qquad \text{(MPa)} \quad (43)$$

In ACI 343R-95 (1995) all the Vc formulations do not consider the influence of the factor λ = 0.7 so that in all cases the value from ACI 318M-11 (2011) is always slightly lower.

For detailed calculations of the shear strength of structural elements that bear axial compression, bending and shear forces, you may use ACI 318M-11 (2011) sec. 11.2.2.1 sec. 11.2.2.2 as expressed in Equation V-39.

$$V_c = \left(0.16\lambda\sqrt{f_c'} + 17\rho_w \frac{V_u d}{M_u}\right) b_w d \quad \text{(MPa)} \quad (44)$$

where $\rho_w = A_s / b_w d$, and the value $M_m$ can replace $M_u$ which is expressed as

$$M_m = M_u - N_u \frac{(4h - d)}{8} \quad (45)$$

but the value of Equation V-39 cannot be greater than that given in Equation V-41.

$$V_c = 0.29\lambda\sqrt{f_c'} b_w d \sqrt{1 + \frac{0.29 N_u}{A_g}} \quad \text{(MPa)} \quad (46)$$

For pillars with the combined influence of bending, shear and axial compression forces must be met $V_u d / M_u < 1.0$, However, if the value $M_m$ replaces $M_u$ then it is permissible $V_u d / M_u > 1.0$. Component $\lambda\sqrt{f_c'}$ in the equations above is the tensile stress of concrete, with values $\sqrt{f_c'}$ may be taken to exceed 8.3 MPa.

Requirements for shear resistance contributed by transverse reinforcement perpendicular to the axial axis of the structural element for square stirrups according to ACI 318M-11 (2011).

$$V_s = A_v f_{yh} d / s \quad (47)$$

and for circular transverse reinforcement it is as follows.

$$V_s = \frac{\pi}{2} \frac{A_v f_{yh} d_s}{s} \quad (48)$$

### 2.5. Length of reinforcement distribution

It is assumed that the length of the strand prestress that is deliberately created at the end of the pile by removing part of the concrete before adding the new pillar is the length of the distribution of the $l_d$ strand reinforcement that enters the new concrete. Checking the adequacy of the distribution length refers to SNI 03-2847-2002, sec. 14.2.

$$\frac{l_d}{d_b} = \frac{12 f_y \alpha\beta\lambda}{25\sqrt{f_c'}} \quad (49) \quad \text{or}$$

$$\frac{l_d}{d_b} = \frac{9 f_y}{10\sqrt{f_c'}} \frac{\alpha\beta\gamma\lambda}{\frac{c + K_{tr}}{d_b}} \quad (50)$$

where $(c + K_{tr})/d_b > 2.5$, $K_{tr} = \frac{A_{tr} f_{yt}}{10sn}$, $\sqrt{f_c'} < 25/3$ and $l_d$ not less than 300 mm. The $\alpha$ factor is the reinforcement location factor, $\beta$ is the coating factor, $\gamma$ is the reinforcement rod size factor and $\lambda$ is the lightweight aggregate concrete factor, all of which are regulated in SNI 03-2847-2002. The value of $\alpha\beta$ must not be less than 1.7 and $c$ is the dimensional spacing of the concrete blanket and $d_b$ is the diameter of the reinforcement. Value $A_{tr}$ value is the cross-sectional area of all transverse reinforcement in the spacing range $s$. The required yield strength for transverse reinforcement is $f_{yt}$ and $n$ s the number of rods or wires distributed along the split plane [16].

The distribution length for threaded rods under compression is used at

$$l_{db} = \frac{d_b f_y}{4\sqrt{f_c'}} > 0.04 d_b f_y \quad (51)$$

### 2.6. Pass connection

The minimum length of a tensile lap connection must be taken based on the class requirements as regulated in SNI 03-2847-2002, sec. 14.15, i.e. 1.0 $l_d$. for class A connections and 1.3 $l_d$ for class B connections, but not less than 300 mm.

The minimum lap connection ($l_d$) for reinforcement under compression is checked in accordance with the general provisions in SNI 03-2847-2002, sec. 14.16 as well as in CALTRANS Bridge Design Specifications, sec. 8.32 [17] is as follows:

$$l_d = 0.07 d_b f_y \quad \text{for } f_y \le 400 \text{ MPa}$$

$$l_d = (0.13 f_y - 24) d_b \quad \text{for } f_y > 400 \text{ MPa}$$

for $f_c'$ less than 20 MPa the length of the pass must be multiplied by 1.3. If the tie stirrups along the joint area the gap exceeds $0.0015hs$ then the pass connection can be reduced by multiplying by 0.83.

Analysis of the lateral force-displacement relationship and some descriptions of the characteristics of pillar structural elements can also be obtained from the software after simulating several lengths of pillar elements.

# 3. Result and Discussion

### 3.1. Effect of restraint (confinement)

The increase in the compressive capacity of concrete pillars can be identified from the stress-strain relationship between confined concrete (CC) and unconfined concrete (UCC) as in Figure 5. The abbreviation PCP is Precast Pile and CISP is the abbreviation for Cast in Situ Pile. The compressive strength of concrete on piles and the characteristics of the stress-strain relationship appear to be still higher than those provided with additional pillars, both in unconfined and confined conditions [18].

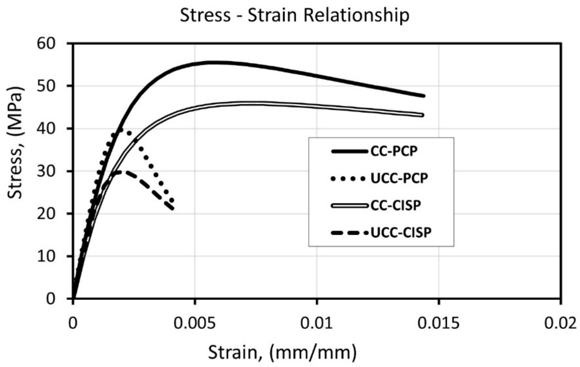


Fig. 5 Concrete stress-strain relationship

With a factored design compressive axial force of 730 kN, it produces a compressive stress on the effective cross-section of the pillar of 13 MPa. This means that the strength of the concrete in the pillars is still sufficient.

### 3.2. Moment-curvature relationships of cross sections

The results of the analysis of the moment-curvature relationship in three pillar cross-section conditions are shown in Figure 6. The cross-sections with codes PCP 40x40 (area A), Connection (area B) and CISP 40x40 (area C) are each assumed if the maximum moment or plastification occurs at that part.

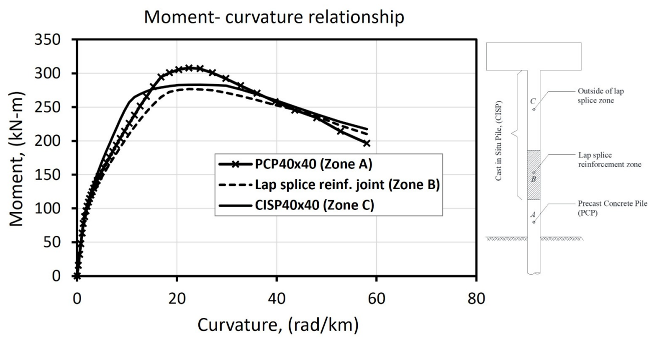


Fig. 6 Moment-curvature relationship of pillar cross-section

The moment-curvature behavior of the pillars in the three cross-sections considered still seems to coincide when they are still in a linear condition or in the condition before cracking. Likewise, the moment before the first melting occurred still did not experience a significant difference. These results can be seen in (Table 1).

Table 1. Moment identification results in several cross-sectional conditions

| Section | unit | $1^{st}$ crack | $1^{st}$ yield | peak | ultimate |
|---|---|---|---|---|---|
| PCP 40x40 (area A) | (kN-m) | 78 | 280 | 301 | 196 |
| Connection (area B) | (kN-m) | 71 | 265 | 276 | 210 |
| CISP 40x40 (area C) | (kN-m) | 76 | 257 | 282 | 218 |

Priestley, et al. provides an illustration of the potential for maximum moments in embedded pillars as in Figure 7 where the potential for plastification in pillars occurs in the range of 2D to 5D below the original ground level [19]. From the figure, the conditions that allow this to occur are: 1) if the connection is carried out on the original ground surface and the behavior of the pillar is as a single bending, then the maximum moment can be ensured not to occur in the connection area, or the spread of energy through damage will not occur at the connection, 2) If the connection is in the maximum moment area, this means that plastification will occur in that connection area, so it is necessary to check the pillar capacity by continuing to use precast cross-sections and reinforcement configurations but using concrete quality such as cast-in-place concrete quality (curvature in area B), 3) If the two previous conditions are safe and acceptable then further checking of shear is necessary.

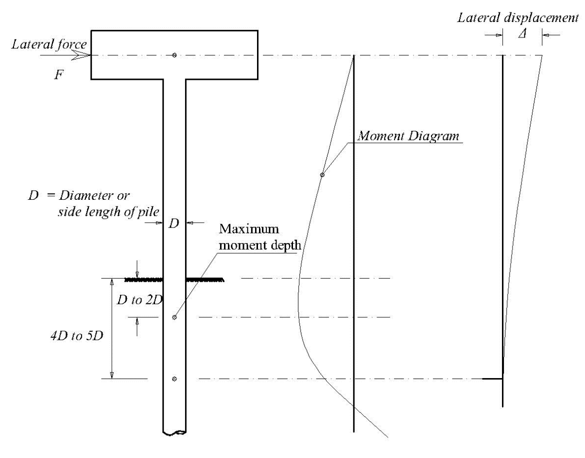


Fig. 7 Areas with the greatest potential to experience maximum moment and plasticization [5]

Looking at the conditions in the field where all connections occur at elevations above ground level, the potential for plastic joints to form will fall on the cross-section in area A or on precast piles. With this approach, the curvature moment relationship that best represents the actual condition of the pillar is the curvature moment relationship on the PCP 40x40 cross section (area A) in Figure 7.

If the factored moment in the design is 88 kN-m compared with the results of the cross-sectional analysis that has been carried out, it can be concluded that the pillar capacity is still sufficient and with a factored moment of that size and the pillar reinforcement has not experienced the first yield.

### 3.3. Lateral force-displacement relationships

The lateral displacement force relationship is obtained from further development of the cross-sectional analysis in Response 2000 by adding an element length component in the analysis. These results provide a better picture of the structural behavior of pillar elements which can be used as a basis for checking the strength and ability of pillar structures to undergo inelastic deformation. The lateral force-displacement relationship is also used to check that shear along the height of the pillar provides a uniform response (Figure 8).

Image of analysis results by providing variations in the span length of the cantilever pillar from 1 to 5 meters with a compressive axial force of 730 kN. If the length of the pillar is reduced, the shear strength of the pillar increases, but this increase is accompanied by a decrease in the lateral inelastic displacement deformation of the pillar. The characteristics of the lateral displacement force relationship of the pillars also do not appear to show significant differences between those modeled as precast pillars (PCP), connection conditions, or as cast-in-place pillars (CISP). The largest shear response is experienced by pillars with a height of only 1 meter, and in this condition the pillars are very brittle and less capable of inelastic deformation.

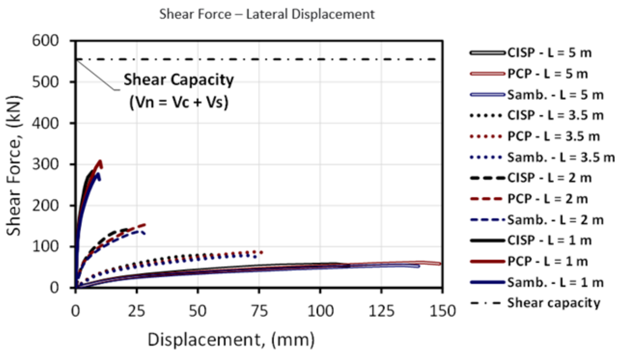


Fig. 8 Pillar lateral force-displacement relationship

The pillar shear capacity obtained from the contribution of concrete and transverse reinforcement also appears to be quite high compared to the shear response of each pillar element. If the factored shear force of the pillar works between Fu = 17 to 86 kN then the pillar is still safe from shear failure along its height.

### 3.4. Length of distribution and connection of reinforcement loops

The requirements for the length of strand wire distribution into additional concrete pillars and the length of the longitudinal reinforcement passing connections are shown in Table 2. The two connection lengths considered in tension and compression conditions are then compared with actual conditions. The calculation results show that the lap connections and actual distribution lengths in the pillar structure meet the requirements.

Table 2. Requirements for distribution length and length of reinforcing loop connections

| **Condition** | **Delivery Length** (mm) | **Late Connection** (mm) | **Actual Length** (mm) |
|---|---|---|---|
| Tensile | 466.22 | 389.1 | 500 |
| Strength | 303.53 | 465.5 | 500 |

# 4. Conclusion

The confining reinforcement spacing of 50 mm in both the precast pile (PCP) and the additional Cast in Situ Pier (PICP) has increased the compressive strength and strain of the pillar so that with a factored design axial compressive force of 730 kN, it produces compressive stress in the effective cross-section of the pillar of 13 MPa, which means that the strength of the concrete in the pillars is still sufficient. Seeing that the connection conditions all occur above ground level, the possibility of a maximum moment forming in the potential connection area is small. If the maximum moment is formed in the pile area (precast pillar, PCP) or in the additional pillar area (cast in situ pillar, CISP) then based on analysis of the moment-curvature behavior of the cross section, the pillar can still behave ductilely in all these conditions. The shear capacity of the pillar obtained from the contribution of concrete and transverse reinforcement is still quite high compared to the shear response of each pillar element when experiencing a factored load of $F_u$ = 17 to 86 kN, so that the pillar is still safe from shear failure along its height. The lap connections and actual length of distribution in the pillar structure have met the requirements so that the strength of the connection area is still sufficient to develop maximum reinforcement strain.

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# Sample cover letter

[Hanafi Ashad]
[Faculty of Engineering Universitas Muslim Indonesia]
[Jl. Urip Sumoharjo Km 05 Panaikang, Kec. Panakkukang, Kota Makassar, Sulawesi Selatan 90231]

[November 27, 2023]

Dear [Prof. Yi Weijian],

I/We wish to submit an original research article entitled “[Capacity Analysis of Precast Pile Connection with Cast in Situ Pillars]” for consideration by [Journal of Hunan University Natural Sciences].

I/We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

In this paper, I/we report on / show that Assuming the dominance of tension in the reinforcement joints is in anticipation of a tensile response in the reinforcement joints when bending behavior is dominant (for tall pillars). Curvature, Analyzing the relationship of Force - Lateral displacement by simulating the height of the pillars from 1 – 5 m, and comparing it with the shear capacity of the pillars so that a confining reinforcement spacing of 50 mm is obtained both on the precast pile (PCP) and on the additional Cast in Situ Pier (PICP) has been increasing the compressive strength and strain of the pillars so that with a factored axial compressive force of 730 kN, it produces compressive stress at the effective cross-section of the pillar of 13 MPa, which means that the strength of the concrete on the pillars is still sufficient. The shear capacity of the pillar obtained by factored loading is Fu = 17 to 86 kN, so the pillar is still safe from shear failure along its height.. This is significant because this contributes to the bridge stability.

We believe that this manuscript is appropriate for publication by [Journal of Hunan University Natural Sciences] because it contribute to development science in **[Engineering]**.

We have no conflicts of interest to disclose.

Please address all correspondence concerning this manuscript to me at [hanafiashad729@gmail.com].
Thank you for your consideration of this manuscript.
Sincerely,
[Hanafi Ashad]

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