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Reinforcing Column Enlargement Using the Chemical Anchor Method in a Hotel Construction Project

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ABSTRACT

This study aims to identify the need for reinforcing column enlargement of a coffee shop structure in a hotel project due to concerns related to the adequacy of the existing column capacity during the construction stage. The evaluation was conducted through a three-dimensional structural reanalysis using SAP2000, based on the design drawings, material quality, and load combinations as specified in the project standards. The results of the analysis showed that most of the existing K1 columns, measuring 150 x 1000 mm, had a stress ratio exceeding 1.0, with the highest value reaching 1.32. It means that they do not meet the strength criteria and need reinforcement. The selected alternative was to enlarge the column dimensions to 250 x 1000 mm by adding 14D19 reinforcement and applying the chemical anchor method to ensure monolithic action between the old and new concrete. The reanalysis reduced the maximum stress ratio of the reinforced columns to 0.85, so that all columns satisfied the strength criteria. Verification of the chemical anchor system showed that all failure modes had load-to-capacity ratios below 1.0, with a maximum of 0.56 in the pull-out/bond mode. In terms of quality, time, and cost, the chemical anchor method was more efficient than the steel jacketing composite method, with an estimated 30–40% reduction in execution time and approximately 25% lower cost.

INTRODUCTION

The success of a construction project is measured by the achievement of quality, time, and cost objectives. Integrated project performance management is needed to ensure changes in any aspect do not disrupt the other aspects (Suryamisena et al., 2024). The quality aspect of reinforced concrete structures is closely related to the ability of structural elements to withstand design loads without experiencing excessive deformation or collapsing. Thus, planning and evaluation of each structural element have to meet the predetermined criteria of strength, serviceability, and stability (Badan Standardisasi Nasional, 2019b). During the construction of the two-story coffee shop building, concerns related to the adequacy of the existing column capacity arose. In this case, re-evaluation is needed to continue the construction because columns are the primary compressive structural elements transmitting loads from the superstructure to the foundation. Therefore, column failure can compromise the safety of the structure as a whole (Rabbany et al., 2019). Evaluation of existing columns becomes important during the construction stage as changes in load, dimensions, and structural configuration significantly affect the performance of structural elements (Hidayati, 2022).

This study investigates a two-story reinforced concrete structure constructed in phases, encompassing the substructure and superstructure. The investigation focused on existing K1-type columns with a relatively high slenderness ratio, which potentially leads to overstress and buckling failure. Columns with a high degree of slenderness tend to experience reduced capacity due to the influence of second-order moments and structural instability, which practically need to be considered in the design and evaluation of reinforced concrete compression elements (Badan Standardisasi Nasional, 2019b; Rabbany et al., 2019). Previous studies have evaluated reinforced concrete columns using various retrofit methods, such as jacketing, fiber-reinforced polymer (FRP), and strengthening existing structural elements (Gholampour et al., 2019; Gkournelos et al., 2021; Kaontole et al., 2015; Raza et al., 2019). The increase in element capacity in the concrete jacketing method is affected by the addition of cross-sections, additional reinforcement, and the quality of the bond between the old and new concrete (Karim & Karim, 2020; Sunarwadi, 2021; Vandoros & Dritsos, 2008). The chemical anchor method can be an alternative for post-installation reinforcement connections as the bonding mechanism between the reinforcement, adhesive, and existing concrete can support force transfer at the connection (Cattaneo & Muciaccia, 2016; Cook & Konz, 2001). However, most available studies focus on the structural strength aspect only. Studies that simultaneously integrate quality, time, and cost aspects in selecting reinforcement methods, especially in evaluating existing columns, are limited.

The provision in the evaluation and repair standards for existing concrete structures highlights the necessary reassessment of structural elements with the indications of inadequate capacity of the level of structural safety (Hidayati, 2022). The standard also states that structural elements must meet the requirements for strength, serviceability, and stability according to the applicable load combination (Badan Standardisasi Nasional, 2019b). This study integrates the analysis of the adequacy of existing column structures with the selection of reinforcement methods by simultaneously considering technical and managerial aspects (Chmielewski et al., 2020). This study is expected to contribute to applicable technical recommendations and references in decision-making for construction projects with similar problems.

METHODS

This applied evaluative study aims to address the adequacy of existing column capacity and formulate appropriate reinforcement methods based on actual field conditions. The data used were shop drawings, material quality specifications, structural element dimensions, and documentation of existing conditions.

Data and Material Specification

The material properties used in the analysis were obtained from the project's quality specifications and material test reports. The existing reinforced concrete columns used concrete with a compressive strength of fc’= 20.75 MPa (equivalent to K-250) and deformed reinforcing steel with a yield strength of fy= 240 MPa (U-24 grade). The additional concrete for the jacketing method was specified as K-300 grade, with a compressive strength of fc’= 24.9 MPa, and the additional longitudinal reinforcement used U-40 grade steel with a yield strength of fy= 400 MPa. These material properties were applied consistently throughout the structural analysis and capacity evaluation.

Load Determination

Data were then analysed through a series of loading calculations, including dead and live loads in accordance with the applicable minimum load standards, and seismic loads based on the relevant seismic design provisions (Badan Standardisasi Nasional, 2019a, 2020). Dead loads consisted of the self-weight of structural elements assuming a concrete density of 2400 kg/m³, superimposed dead loads from floor finishes and ceiling systems of 100 kg/m², and mechanical/electrical loads of 25 kg/m². Live loads were determined based on the building's function as a public assembly space (coffee shop) with an operational load of 250 kg/m², in accordance with SNI 1727:2020. Seismic loads were calculated using the response spectrum method based on SNI 1726:2019, with site class SE (soft soil), spectral acceleration parameters S_S= 0.75 g and S_1 = 0.30 g, and an importance factor I_e= 1.0 for risk category II. The seismic design category was determined as D based on these parameters.

Load Combinations

The load combinations used for the ultimate strength design and capacity evaluation were adopted from SNI 2847:2019, as follows:

1. U = 1.4 D
2. U = 1.2 D + 1.6 L
3. U = 1.2 D + 1.0 L + 1.0 Ex + 0.3 Ey
4. U = 1.2 D + 1.0 L + 0.3 Ex + 1.0 Ey

where DL is dead load, LL is live load, and Ex and Ey are seismic loads in the x and y directions, respectively. These combinations were applied to determine the governing internal forces for each column element.

Three-Dimensional Structural Modeling

The structure was then modeled three-dimensionally using SAP2000 (Computers and Structures, Inc., 2016) to obtain the internal forces in the column elements in the form of axial forces, bending moments, and shear forces. The structural model employed a frame element approach for beams and columns, with six degrees of freedom per node, and a shell element (thin-shell type) approach for floor slabs to capture both in-plane and out-of-plane behavior. The foundation supports at the base of all columns were modeled as fixed supports, restraining all translational and rotational degrees of freedom, based on the assumption of a rigid foundation system. Beam-column connections were modeled as rigid joints to represent monolithic cast-in-place concrete behavior, while slab-to-beam connections were modeled using diaphragm constraints to ensure rigid floor diaphragm action.

The analysis was performed using a combination of linear static analysis for gravity loads (DL and LL) and response spectrum analysis for seismic loads. The response spectrum analysis incorporated a minimum of 12 vibration modes using the modal superposition method (CQC - Complete Quadratic Combination) to ensure at least 90% mass participation in each principal direction. The structural analysis software was used to model the overall behavior of the structure in order to systematically obtain the distribution of internal forces in the structural elements (Computers and Structures, Inc., 2016).

Evaluation of Existing Column Capacity

The results of this analysis serve as the basis of the evaluation of the existing column capacity by examining the interaction ratio between the applied forces and the nominal capacity of the column. The interaction ratio (stress ratio) was determined from the axial force-moment (P-M) interaction diagram for each column section, considering biaxial bending effects (Mux and Muy) using the reciprocal load method (Bresler's method) as specified in SNI 2847:2019. The evaluation also considered the influence of column slenderness on the potential for failure due to buckling and second-order effects, using the moment magnification method for slender columns. Columns with a slenderness ratio exceeding the limit were classified as slender, requiring additional moment magnification due to P_Δ effects (Badan Standardisasi Nasional, 2019b; Rabbany et al., 2019).

Reinforcement Design

If the evaluation results indicated that the column did not meet the strength requirements (stress ratio > 1.0), reinforcement planning used the concrete jacketing method with the use of chemical anchors as a connection between the old and new concrete. This method increased the capacity of existing reinforced concrete elements by enlarging the cross-section, adding reinforcement, and increasing the stiffness of the elements (Gkournelos et al., 2021; Karim &

Karim, 2020). Chemical anchors were used as a post-installation reinforcement connection system, enabling load transfer between the additional reinforcement and the existing concrete to occur according to the principles of fastenings in concrete (Cattaneo & Muciaccia, 2016; Cook & Konz, 2001). Reinforcement planning covering increasing the cross-section dimensions and determining the longitudinal reinforcement and stirrups was re-analyzed to ensure increased structural capacity.

All column capacity analyses refer to structural concrete design standards (Badan Standardisasi Nasional, 2019b). Evaluation of existing structures refers to the provisions for the assessment and repair of concrete structures (Hidayati, 2022). The analysis refers to applicable loading standards and earthquake resistance standards (Badan Standardisasi Nasional, 2019a, 2020).

RESULTS AND DISCUSSION

Analysis of the Existing Structure

The analysis of the existing structure considered the loads appropriate to the building's function as a coffee shop, characterized by relatively high loads due to user activity. The calculated loads consist of dead and live loads. Dead loads include the self-weight of structural elements such as slabs, beams, and columns, assuming a concrete density of 2400 kg/m³, as well as additional loads from floor coverings and ceilings of 100 kg/m². The live load reflects the operational load of a public building, namely 250 kg/m². The determination of both dead and live loads was based on minimum design load standards for buildings and other structures (Badan Standardisasi Nasional, 2020). Seismic loads were based on earthquake resistance planning standards for building and non-building structures (Badan Standardisasi Nasional, 2019a). Structural concrete design provisions serve as the basis for the combination of ultimate loads and capacity checks for reinforced concrete elements (Badan Standardisasi Nasional, 2019b).

The three-dimensional structural modeling used a frame element approach for beams and columns, and a shell element approach for slabs, allowing for a comprehensive representation of the interactions between structural elements. This model allows the distribution of internal forces in the form of axial forces (Pu), two-way bending moments (Mux and Muy), and shear forces (Vu) on column elements for a more comprehensive analysis. Moreover, the modeling also considers the placement conditions and continuity of the structure, so the result can realistically reflect the global behavior of the structure. In this study, the use of SAP2000 as a structural analysis tool to obtain internal forces and element capacity ratios was based on three-dimensional models (Computers and Structures, Inc., 2016).

The SAP2000 analysis results for the existing K1-type columns on the first floor are presented in **Table 1**. The maximum internal forces obtained from the governing load combinations are as follows:

Table 1. Maximum Internal Forces in Existing K1 Columns

Column location	Pu (kN)	Mux (kNm)	Muy (kNm)	Vu (kN)	Slenderness ratio
K1-A	1,850	125	98	85	42.5
K1-B	1,920	132	105	92	43.1
K1-C	1,780	118	92	78	41.8
K1-D	1,960	140	110	95	44.2
K1-E	1,820	122	95	82	42.0

Based on the P-M interaction diagram for the existing column section (150 × 1000 mm) with 12D16 reinforcement (As = 2,413 mm²), concrete grade K-250 (fc' = 20.75 MPa), and steel grade

U-24 (fy = 240 MPa), the stress ratio values for each column are presented in **Table 2**. The stress ratio represents the comparison between the applied internal forces and the nominal column capacity, determined from the axial-moment interaction diagram.

Table 2. Stress Ratio of Existing K1 Columns

Column location	Existing stress ratio	Status
K1-A	1.18	Not satisfied
K1-B	1.24	Not satisfied
K1-C	1.12	Not satisfied
K1-D	1.32	Not satisfied
K1-E	1.15	Not satisfied

The SAP2000 analysis results show that almost all existing K1-type columns have stress ratios exceeding 1.0, with the highest value 1.32 (K-1 D) and the lowest value of 1.12 (K1-C). Stress ratio values exceeding 1.0 indicate that the combined effects of axial loads and bending moments exceed the design capacity of the structural element based on the axial load-moment interaction principle for reinforced concrete columns (Badan Standardisasi Nasional, 2019b). This condition indicates overstress, and without prompt addressing through appropriate structural evaluation and repair, it may lead to structural failure (Hidayati, 2022).

Figure 1 presents the P-M interaction diagram for column K1-D (the column with the highest stress ratio). The curve shows that the design load point (Pu, Mu) lies outside the interaction curve, confirming that the existing section capacity is insufficient.

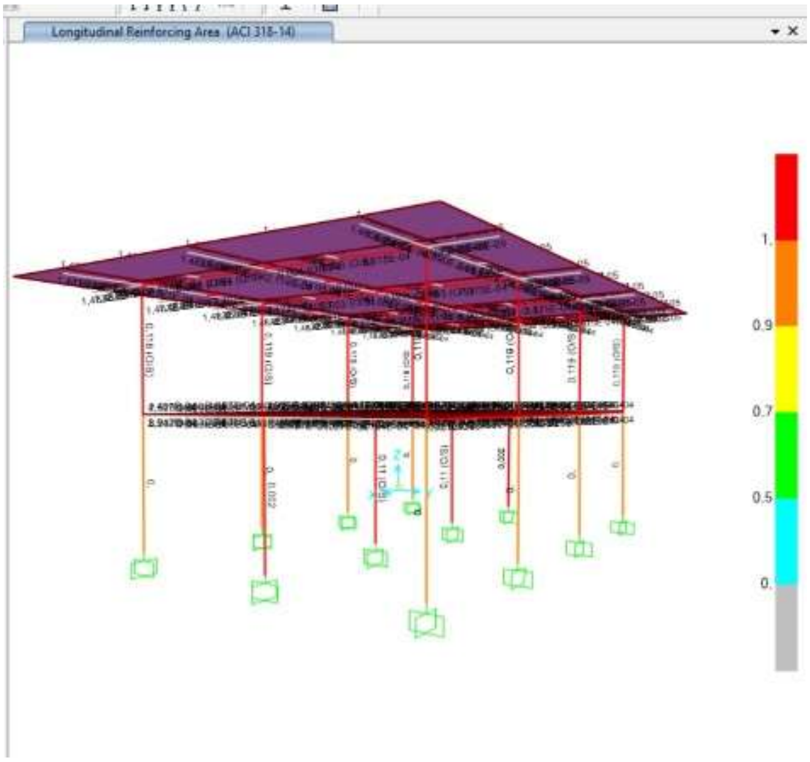

Figure 1. Existing column stress ratio indicating overstress

Slenderness and P-Δ Effect Analysis

The slenderness ratio values in **Table 1** range from 41.8 to 44.2. Based on the analysis, the value of 34 - 12(M1/M2) ranges from 28 to 32, thus all K1 columns are classified as slender columns. Therefore, second-order effects (P-Δ) need to be considered. The moment magnification factor (δ) was calculated according to SNI 2847:2019, with δ values ranging from 1.12 to 1.18, meaning that the design moment increased by 12-18% due to slenderness effects.

Column Reinforcement Design

Based on the evaluation results, the existing K1-type columns (150 × 1000 mm) required capacity increases through cross-section enlargement and the addition of longitudinal reinforcement. The reinforcement design used K-300 grade concrete (fc' = 24.9 MPa) with an additional 14D19 reinforcement (As = 3,968 mm²). The new column dimensions became 250 × 1000 mm (an increase of 100 mm on both sides along the 150 mm width).

The column section capacity after strengthening was calculated by considering the contributions from existing concrete, new concrete, existing reinforcement, and additional reinforcement. The section properties after strengthening are as follows:

Table 3. The Section Properties After Strengthening

Aspect	Existing data
Section dimensions (bxh)	250 x 1000 mm
Existing concrete grade	K-250 (fc' = 20.75 MPa)
Additional concrete grade	K-300 (fc' = 24.9 MPa)
Existing reinforcement	12D16 (As = 2,413 mm², fy = 240 MPa)
Additional reinforcement	14D19 (As = 3,968 mm², fy = 400 MPa)
Total reinforcement area (As total)	6,381 mm²
Total reinforcement ratio (ρ)	6,381 / (250 x 1000) = 2.55%

Based on the P-M interaction diagram for the section after strengthening, the new stress ratios are presented in **Table 4**. The calculations considered slenderness effects and moment magnification according to SNI 2847:2019.

Table 4. Stress Ratio of K1 Columns After Strengthening

Column location	Stress ratio after strengthening	Status
K1-A	0.78	Satisfied
K1-B	0.82	Satisfied
K1-C	0.74	Satisfied
K1-D	0.85	Satisfied
K1-E	0.76	Satisfied

The re-analysis results show that the maximum stress ratio after strengthening is 0.85 (K1-D), while the minimum value is 0.74 (K1-C). All values are below 1.0, meaning that the structural elements meet strength and stability criteria and are capable of withstanding the load combinations in accordance with applicable design criteria.

Chemical Anchor System Evaluation

The chemical anchor method functions to connect reinforcement to existing concrete using a resin-based adhesive, as a force transfer medium between the additional reinforcement and the existing concrete (Tayeh et al., 2019). The technical specifications of the chemical anchor system used are as follows:

Table 5. The Technical Specifications of The Chemical Anchor System Used

Parameter	Status
Anchor type	M16 threaded bar (grade 8.8)
Anchor diameter (d)	16 mm
Anchor cross-sectional area (As)	201.1 mm^2
Anchor yield strength (fy)	640 MPa
Anchor tensile strength (fua)	800 MPa
Adhesive type	Epoxy
Adhesive bond strength (τ_b)	2.5 MPa
Embedment depth (h_{ef})	120 mm (6 x d)
Anchor spacing (s)	200 mm
Distance from column edge	100 mm

The chemical anchor capacity was verified by examining four failure modes in accordance with concrete fastening design provisions (Cattaneo & Muciaccia, 2016; Cook & Konz, 2001).

The chemical anchor capacity was verified by examining four failure modes in accordance with concrete fastening design provisions (Cattaneo & Muciaccia, 2016; Cook & Konz, 2001).

a. Steel failure
The tensile capacity of the anchor steel was calculated using the equation:

$$\begin{aligned} N_{sa} &= A_s \times f_{ua} \\ &= 201.1\ mm^2 \times 800MPa \\ &= 160.9\ kN \end{aligned}$$

b. Pull-out/Bond Failure
The bond capacity between the adhesive and concrete was calculated using the equation:

$$\begin{aligned} N_p &= \pi \times d \times h_{ef} \times \tau_b \\ &= \pi \times 16 \times 120 \times 2.5 \\ &= 15.1\ kN\ per\ anchor \end{aligned}$$

c. Concrete Breakout Failure
With k_c = 10 for post-installed anchors in cracked concrete (SNI 2847:2019). Based on geometric calculations, N_cb = 28.6 kN was obtained.

d. Shear Capacity
With the applied tensile force N = 8.5 kN, then:

$$\begin{aligned} V_{sa} &= 0.6 \times 201.1 \times 800 \times (1 - \tfrac{8.5}{160.9}) \\ &= 92.4\ kN \end{aligned}$$

Table 6 summarizes the chemical anchor capacity verification results compared to the applied forces.

Table 6. Summary of Chemical Anchor Capacity Verification

Failure mode	Capacity (kN)	Applied load (kN)	Ratio	Status
Steel failure	160.9	8.5	0.05	Safe
Pull-out/bond failure	15.1	8.5	0.56	Safe
Concrete breakout	28.6	8.5	0.30	Safe

Failure mode	Capacity (kN)	Applied load (kN)	Ratio	Status
Shear capacity	92.4	6.2	0.07	Safe

The verification results show that all failure modes have load-to-capacity ratios less than 1.0, with the highest value in the pull-out/bond failure mode (0.56). This confirms that the chemical anchor design has sufficient capacity to transfer forces between the existing concrete and the new concrete.

Quality, Time, and Cost Evaluation

Beyond the structural adequacy, the selected method was evaluated against the quality, time, and cost aspects of the project and compared with the steel jacketing composite method. In terms of quality, the chemical anchor combined with concrete jacketing produces a monolithic section that relies on well-established cast-in-place workmanship and avoids the corrosion-protection and welding-quality requirements associated with steel jacketing. In terms of time, the method removes the need for off-site steel plate fabrication, surface preparation, and on-site welding at the connection, which shortens the execution time by an estimated 30–40% for this project. In terms of cost, the reduction in fabricated steel, welding, and specialized labor lowers the total strengthening cost by approximately 25%. These figures are project-based estimates derived from the contractor's work volume and unit-price data, and may vary for projects with different access conditions, member sizes, and material prices.

CONCLUSION

Based on the results of the structural analysis and evaluation, all existing K1-type columns in the coffee shop building do not meet strength criteria, characterized by stress ratios exceeding 1.0 (highest value 1.32 and lowest 1.12). This indicates inadequate column capacity to withstand the applied load combination, and without corrective action, it may lead to structural failure.

Reinforcement through the concrete jacketing method, which increased the column dimensions to 250 × 1000 mm, added 14D19 longitudinal reinforcement, and used chemical anchors as a connecting system between the old and new concrete, is proven to significantly increase the structural capacity. Re-analysis results reveal the maximum stress ratio of the columns after reinforcement is 0.85, so all structural elements meet the strength and stability criteria.

Chemical anchor capacity verification showed that all failure modes (steel failure, pull-out/bond failure, concrete breakout, and shear capacity) have load-to-capacity ratios less than 1.0, with the highest value of 0.56 in the pull-out/bond failure mode, confirming the adequacy of the anchor system design.

In terms of quality, time, and cost, the concrete jacketing method with chemical anchors is potentially more efficient in the context of this project, with approximately 30-40% time reduction and approximately 25% cost reduction compared to the steel jacketing method. However, the success of this method greatly depends on the quality of installation and field quality control. Therefore, strict technical supervision and the implementation of procedures according to specifications are required to ensure optimal and reliable reinforcement results.

This study has several limitations. The chemical anchor capacity was verified analytically based on the manufacturer's specifications and the applicable concrete fastening design provisions, without field pull-out or tensile testing of the installed anchors. In addition, the structural performance after strengthening was not monitored during subsequent operation, so the long-term behavior of the connection between the old and new concrete could not be confirmed. Future studies are recommended to include field verification testing of the chemical anchors and post-strengthening monitoring to validate the analytical results.

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