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Structural Analysis and Design of Superstructure and Roof Systems for the Canteen Building at Kalimantan Institute of Technology

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***Abstract*— Kalimantan Institute of Technology (ITK), established on October 6, 2014, in Balikpapan, East Kalimantan, currently lacks adequate canteen facilities, compelling the academic community to seek meals off-campus. This study aims to design a new canteen facility to be constructed above the campus reservoir, focusing specifically on the structural and roofing systems. The planned canteen is expected to fulfill the food and beverage needs of students, lecturers, and staff, while also serving as a hub for social interaction. Our research methodology incorporates both qualitative and quantitative approaches. The project phases encompass detailed load analysis, structural modeling, internal force analysis, and a thorough plumbing design. Structural design adheres to the relevant Indonesian National Standards (SNI) for reinforced concrete structures and earthquake resistance. The substructure utilizes deep foundations adapted to local soil conditions, while the superstructure comprises reinforced concrete elements and a steel roofing system. Structural analysis results indicate the use of beams B1 (500×300 mm) and B2 (400×200 mm), circular columns K1 (D600 mm), and slab thickness of 120 mm. The roof structure consists of IWF rafters (300×150×6.5×9 mm), HB columns (300×300×10×15 mm), and CNP 200–16. This integrated design demonstrates a feasible and sustainable approach to infrastructure development on water-saturated soils.**

Keywords— Canteen design, reinforced concrete structure, roof truss planning.

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I. INTRODUCTION

The canteen is a public facility intended to provide food and beverages to its users [1]. To date, the ITK campus lacks a proper canteen; instead, it only offers small booths selling only instant and non-fresh products. The provision of a dedicated canteen facility is therefore expected to eliminate the need for the ITK academic community to leave campus in search of cooked meals and drinks. Moreover, the canteen could serve as a space for rest and informal gatherings [2]. Given that ITK comprises over 5,000 individuals, including students, faculty, and administrative staff, there is a clear need for a well-designed canteen facility that meets design requirements aligned with the planned capacity [3][4].

Based on interviews with Mrs. Tiara Rukmaya, S.T., M.Sc., Chair of the Planning Team at the Kalimantan Institute of Technology (ITK), the construction of the canteen facility over the campus reservoir (embung) was selected due to its strategic location near surrounding academic buildings [5]. This site also provides a scenic view of the reservoirs, which can be enjoyed by canteen visitors. Additionally, the concept of the food to be served at the canteen involves on-site cooking, which makes this location particularly well suited to the concept. Mrs. Tiara further emphasized that the chosen site is free from contamination by hazardous materials potentially present elsewhere on campus, making it an ideal choice for the canteen development.

The canteen's superstructure will be constructed using reinforced concrete and will comprise two levels [6]. A building's superstructural system is the assembly that enables the structure to resist various loads such as dead load, live load, wind load, earthquake load, and others [7], [8]. Structural damage or failure often arises from suboptimal selection of structural systems that fail to deliver optimal performance under repetitive loading, notably seismic events [9]. Therefore, to prevent structural failure and degradation, it is critical to select an appropriate structural system at the planning stage of any construction project [10]. the advancement of sustainable and environmentally friendly infrastructure. Through meticulous planning and strict adherence to standards, this project is anticipated to be executed in a safe and efficient manner, delivering long-term benefits to the entire campus community.

The proposed canteen development over the campus reservoir is expected to serve as a new landmark for the Kalimantan Institute of Technology (ITK), symbolizing innovation and distinctiveness, while simultaneously supporting.

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II. METHOD

The research methodology employed is a comprehensive structural engineering design framework covering both the superstructure and roof system [11]. This study integrates quantitative and qualitative approaches. It begins with a thorough literature review of relevant standards (primarily SNI), textbooks, and peer-reviewed journal articles. Subsequently, numerical analysis and design are conducted using SAP2000 software to model and analyse the structure [12]. Load analysis include dead loads, live loads, seismic, wind, and rain loads in accordance with applicable SNI regulations. Internal force determination is followed by reinforcement design for all structural elements such as beams, columns, and slabs[13]. Previous studies demonstrate similar methodological frameworks for instance, analyses using SAP2000 under SNI 1726:2019 seismic provisions and SNI 2847:2013.

A. Research Procedure

The following research procedure outlines a rigorous and systematic approach to structural engineering design, encompassing both superstructure and roof system planning, numerical modelling with SAP2000 [14], comprehensive load analysis per SNI standards, and reinforcement detailing for all structural elements."

B. Reinforced Concrete Structure

Reinforced concrete structure is a composite system in which concrete resists compressive forces while embedded steel reinforcement carries tensile stresses resulting from flexural loads [15][16][17]. Structural elements such as beams, columns, and slabs must be designed in accordance with applicable standards particularly SNI 2847:2019, which governs structural concrete requirements for building construction, and SNI 1727:2020, which stipulates minimum applied loads. Initial dimensions of structural members are planned to satisfy serviceability requirements for example, minimum beam depth is specified to control deflection, and column dimensions are estimated based on factored axial loads they will support.

A beam is a structural element that receives forces acting in a direction transverse to its axis, resulting in bending moments and shear forces along its span [18]. Columns are structural elements designed to withstand axial forces from the applied loads on all floors above them, but it is not uncommon for columns to be designed to carry a combination of axial and bending loads caused by small eccentricity values [19]. The floor slab is the main horizontal element responsible for transferring transverse loads to the vertical frame in a structural system. Generally, the floor slab and beams are cast together to form a monolithic structure [20]. Furthermore, the floor slab functions as a structural diaphragm, meaning it transfers forces generated by seismic ground movements to the established structure [21].

The beam is one of the dominant structural elements in receiving bending moments. These bending moments occur due to the loads present on the beam, so if the beam is not strong enough, deformation and strain will occur, leading to cracks in the beam [22].

Structural analysis to determine internal forces and building response is conducted using numerical methods, commonly facilitated by software such as SAP2000. The analysis also includes evaluating the structural response under seismic loading in accordance with SNI 1726:2019. The design's safety is verified by ensuring that the nominal capacity of structural elements exceeds the applied factored loads ($\phi Rn \geq Ru$), and by confirming that inter-storey drifts do not exceed allowable limits to maintain building stability

C. Steel Roof Structure

A steel roof structure is commonly employed in wide-span buildings due to its high strength to weight ratio, making it more efficient than alternative materials [23]. The design of steel structural components such as rafters, purlins, and columns must comply with SNI 1729:2020, the Indonesian specification for structural steel buildings, to ensure adequate strength and stability [24]. The selection of steel profiles, such as IWF (I-Wide Flange) for rafters and H-Beams for columns, is based on their optimal performance under combined axial and flexural loading.

Structural failures in steel roof systems are often attributable to poorly designed bolted connections [25]. Bolted joints are critical components of steel structures, responsible for transferring loads between elements. High-strength bolts such as ASTM A325 (now part of ASTM F3125 Grade A325) are commonly used for beam-to-column and rafter-to-column connections due to their capacity to resist both shear and tensile forces [26].

The number, diameter, and arrangement of bolts must be determined carefully based on factored loads acting on the connection to prevent joint failure. Installation quality is essential: improper torque, lubrication issues, or misalignment can significantly reduce bolt performance

Moreover, studies indicate that the shear behavior of A325 bolts can degrade under elevated temperatures, further highlighting the importance of appropriate bolt selection, specification, and installation protocols.

III. RESULTS AND DISCUSSION

A. Modeling and Design of the ITK Canteen

Structural verification of the ITK canteen design is performed through computational modeling and analysis using SAP2000 software. Initially, the architectural design and preliminary dimensions of structural members are transformed into a three-dimensional mathematical model (3D frame), as illustrated in Figure 1. The modeling process follows industryrecommended procedures defining element geometry, assigning material and section properties, specifying load cases (static and seismic), applying boundary conditions, and executing analysis runs ensuring an accurate representation of the canteen superstructure.

The model is developed to accurately represent the geometry, connectivity between elements, and material properties of the structure. The model is then subjected to various load combinations including dead load, live load, wind, and seismic loads in accordance with applicable standards. This enables the evaluation of internal structural responses such as forces, stresses, and deformations [27].

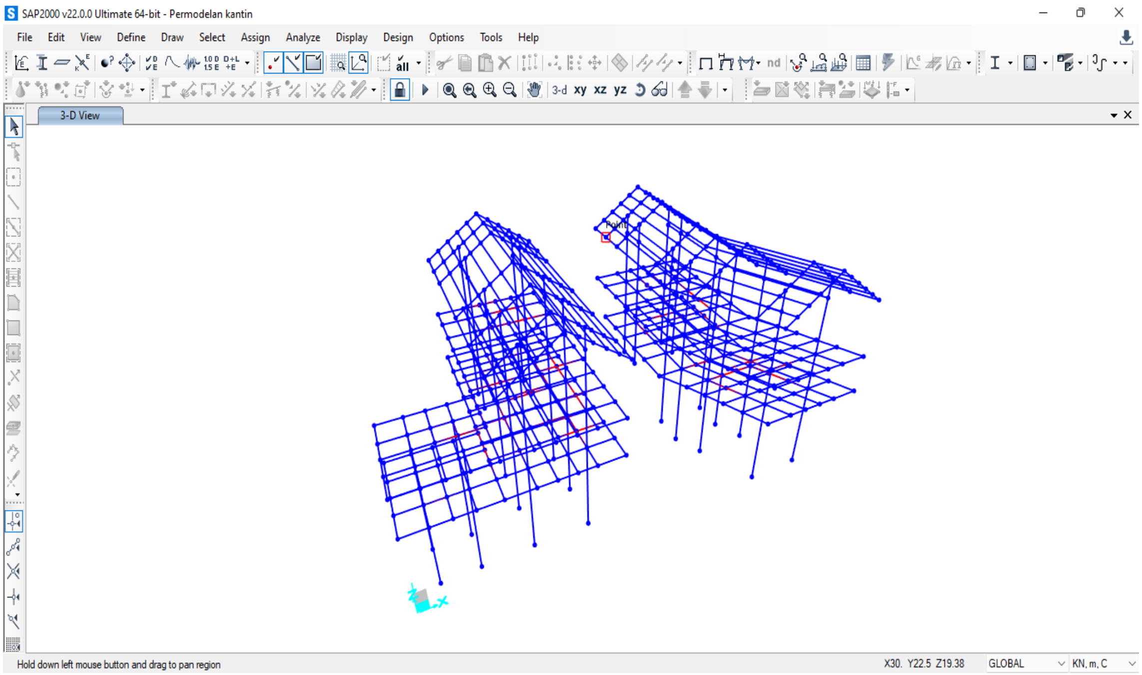


Figure. 1. Modelling on SAP 2000

Figure. 2. 3D Design at ITK Canteen

The three-dimensional architectural visualization of the ITK Canteen, presented in Figure 2, actualizes the previously defined design concept. The building adopts a modern tropical architectural style, featuring two principal volumes configured as elevated pavilions above the campus reservoir. Design elements such as an open-plan layout, expansive. decking, and steeply pitched gabled roofs are intentionally employed to optimize natural ventilation and daylight usage. These components also enhance the spatial experience by fostering visual integration with the surrounding environment.

B. Analysis of Superstructure Output

1. Fundamental Period Analysis

Fundamental period (Ta) refers to the natural Vibration period of a structure, which is influenced by its height and stiffness. In this analysis, the minimum period was calculated using the empirical *formula* from SNI 1726:2019 with parameters Ct = 0.0466 and x = 0.9, yielding Ta,min = 0.336 s. The maximum period was determined by multiplying the minimum Ta by the factor Cu = 1.5, resulting in Ta,max = 0.505 s. The period obtained from the SAP2000 model (Tc = 26.123 s) greatly exceeds the calculated maximum period, thus Ta,max = 0.505 s was adopted to ensure the seismic design satisfies safety requirements. This result indicates that the structure is relatively stiff and possesses adequate capacity to resist dynamic loads.

2. Modal Participation Ratio Analysis

Based on SNI 1726:2019, the number of modes in seismic analysis must be sufficient to achieve a combined modal mass participation of 100% of the structure's mass, with an allowance for at least 90% of the actual mass in each orthogonal horizontal direction.

TABLE 1.
MASS PARTICIPATION ANALYSIS IN SAP2000

Output Case Text	Item Type Text	Item Text	Static Percent	Dynamic Percent
MODAL	Acceleration	UX	99.83	95.88
MODAL	Acceleration	UY	99.71	95.95
MODAL	Acceleration	UZ	96.83	0.07

This analysis evaluates the structural mass participation in response to seismic loading. The results demonstrate a cumulative mass participation exceeding 95% in the horizontal directions (UX and UY) and approximately 96.8% in the vertical direction (UZ), thereby satisfying the SNI 1726:2019 requirement of at least 90% mass participation per orthogonal horizontal direction. The high participation percentages indicate that the structural model effectively captures the dominant vibration modes, ensuring that the dynamic analysis reliably assesses seismic response.

3. Base Shear Analysis

The base shear (static seismic shear force) is calculated using the seismic coefficient (Cs) and the total building mass (W). In this analysis: The coefficient Cs = 0.02313, derived from Sds = 0.185 and the seismic reduction factor R = 3. The static base shear is thus V_static = 32,420.80 kg. SAP 2000 dynamic analysis yields V_ex = 14,123.47 kg in the X-direction and V_ey = 19,047.99 kg in the Y-direction. Comparing static and dynamic results: X-direction ratio: V_static / V_ex = 32,420.8 / 14,123.47 ≈ 2.30 Y-direction ratio: V_static / V_ey = 32,420.8 / 19,047.99 ≈ 1.70

Both ratios exceed 1, satisfying the requirement of V_static ≤ V_dynamic per SNI 1726:2019 guidelines, which ensure the structure has adequate capacity to withstand factored seismic loads. The high ratios confirm that the structure has greater strength capacity than the demanded seismic forces, indicating a safe and reliable design.

4. Inter-Story Drift Analysis

The inter-story drift is evaluated to ensure structural stability under seismic loads. The maximum drift observed—3.114 mm in the X-direction and 3.097 mm in the Y-direction is significantly below the allowable limit of 90 mm specified by SNI (which, for Risk Category II, is 0.02 h ≈ 90 mm). These values were obtained by multiplying the elastic drift (δx) by the deflection amplification factor Cd = 5.5, as stipulated in the code.

Compliance ("OK" in Tables 2 and 3) confirms that the structure exhibits sufficient stiffness, effectively controlling lateral displacements to prevent damage to non-structural elements and maintain occupant comfort.

Risk Categories = II
Cd = 5,5
Ie = 1

TABLE 2.
VERIFICATION OF INTER-LEVEL DEVIATIONS IN THE X DIRECTION

Floor	hx (mm)	dx (mm)	Δx	ΔDeflection Clearence	Description
Window glass (2nd Floor)	3600	2.2232	3.114	90	OKE
Window glass (1st Floor)	3600	1.6569	9.113	90	OKE
2 (Straight)	3600	1.7932	0	90	OKE
2 (Turning)	3600	2.4247	3.552	90	OKE
1 (Straight)	3600	1.7932	9.862	90	OKE
1 (Straight)	3600	1.7788	9.783	90	OKE

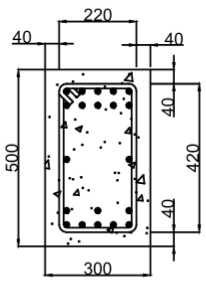
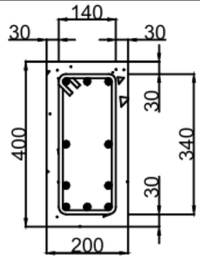
TABLE 3.
VERIFICATION OF INTER-LEVEL DEVIATIONS IN THE Y DIRECTION

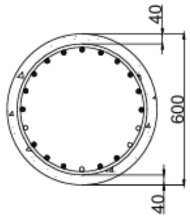
Floor	hx (mm)	dx (mm)	Δx	ΔDeflection Clearence	Description
Window glass (2nd Floor)	3600	2.2157	3.097	90	OKE
Window glass (1st Floor)	3600	1.6526	9.089	90	OKE
2 (Straight)	3600	2.2231	12.23	90	OKE
2 (Turning)	3600	2.2156	11.39	90	OKE
1 (Straight)	3600	0	0	90	OKE
1 (Straight)	3600	0.1454	0.799	90	OKE

Inter-floor drifts were evaluated to ensure structural stability under seismic loading. The results indicate that the maximum drifts in the X and Y directions—3.114 mm and 3.097 mm, respectively—are well below the SNI allowable limit of 90 mm. These values were obtained by multiplying the elastic drift (d_x) by the deflection amplification factor Cd (5.5). The “OKE” status noted in Tables 2 and 3 confirms that the structure possesses sufficient stiffness to prevent non-structural damage and maintain occupant comfort.

C. Results of the Structural Analysis Calculations for the ITK Canteen Superstructure

TABLE 4.
SUMMARY OF SUPERSTRUCTURE DESIGN RESULTS FOR THE ITK CANTEEN BASED ON STRUCTURAL ANALYSIS

Structural Element	**Images**	**Longitudinal reinforcement**	**Transversal reinforcement**	**Torsion reinforcement**
Beam B1 300 x 500		Pedestal: 10D16 Field: 8D16	Pedestal: 2D13 – 100 Field: 2D13 – 150	Pedestal: 2D16 Field: 2D16
Beam B2 200 x 400		Pedestal: 5D16 Field: 3D16	Pedestal: 2D13 – 80 Field: 2D13 – 100	Pedestal: 2D16 Field: 2D16

Structural Element	Images	Longitudinal reinforcement	Transversal reinforcement	Torsion reinforcement
Column K1 D600		20D19	Pedestal: 2D13 – 100 Field: 2D13 – 150	
Floor slab	With thickness: 120 mm		Pedestal reinforcement: Top section: D13 – 100 Bottom secton: D13 -150 Field reinforcement: Top section: D13 – 150 Bottom secton: D13 -150	

Based on SNI 2847:2019 and ACI 318-02, the calculated dimensions and reinforcement detailing for the ITK canteen building have been determined, summarized in Table 4.

Inter-floor drifts were evaluated to ensure structural stability under seismic loading. The results indicate that the maximum drifts in the X and Y directions—3.114 mm and 3.097 mm, respectively—are well below the SNI allowable limit of 90 mm. These values were obtained by multiplying the elastic drift (d_x) by the deflection amplification factor Cd (5.5). The "OKE" status noted in Tables 2 and 3 confirms that the structure possesses sufficient stiffness to prevent non-structural damage and maintain occupant comfort.

With a concrete compressive strength of f_n' = 30 MPa and reinforcement conforming to ASTM A615 with a yield strength of F_γ = 420 MPa, Table 4 shows that the superstructure elements vary as follows:

- Beams B1 and B2 have cross-section dimensions of 500 × 300 mm and 200 × 400 mm, respectively.
- Columns are circular with a diameter of 600 mm.
- The slab has a thickness of 120 mm and is reinforced with 13 mm diameter rebar.

D. Results of the Structural Analysis Calculations for the ITK Cafeteria Roof

Based on analysis, the dimensions of the roof structure elements for the ITK cafeteria are as follows in the Table 5:

- Roof column: HB 300 × 300 × 10 × 15 mm
- Rafter: IWF 300 × 150 × 6.5 × 9 mm
- Purlin: CNP 200 × 65 × 1.6 × 15 mm

Given the use of three distinct steel profiles, bolted connections are required to join the roof structural elements:

- Rafter-to-column connections: 16 bolts per connection, ASTM A325, metric M16
- Rafter-to-rafter (ridge) connections: 10 bolts per connection, ASTM A325, metric M22
- Rafter-to-purlin connections: 4 bolts per connection, 16 mm diameter (ASTM A325 assumed)

TABLE 5.
SUMMARY OF ROOF STRUCTURE DESIGN RESULTS FOR THE ITK CANTEEN

Steel Structural Elements	Description
Column	The roof framing that will be connected to the main column (D600) consists of HB steel sections with dimensions of 300 × 300 × 10 × 15 mm.
Rafter	The primary rafter is an IWF section with dimensions 300 × 150 × 6.5 × 9 mm, a wide-flange steel beam where flanges are 150 mm wide, web is 6.5 mm thick, and flanges are 9 mm thick.
Purlin CNP 200 – 16	The purlin structural element is a C-shaped section sized 200 × 65 × 1.6 × 15 mm. CNP sections are commonly used for roof support due to their light weight and ease of installation.
Rafter–Column Connection	Bolted with 16 bolts arranged in 8 rows, each bolt 16 mm in diameter, spaced 75 mm apart, with 37.5 mm edge distance.
Rafter–Rafter (Ridge)	Uses 10 bolts in 5 rows, each 22 mm diameter, with 100 mm spacing and 50 mm edge distance.
CNP–Rafter Connection	Comprised of 4 bolts, 16 mm diameter, with 50 mm spacing and 25 mm edge distance.
Base Plate	Measures 400 × 400 mm plate thickness 30 mm, anchored with 4 bolts of 22 mm diameter.

E. Theoretical Analysis Results (Frame Analysis and Number of Connections)

Control checks were performed on the previously calculated loads, resulting in internal force outputs obtained from SAP2000 software. The following presents the analysis results of key parameters used to assess the steel roof frame.

TABLE 6.
CONTROL PARAMETERS FOR THE STEEL ROOF FRAME ANALYSIS OF THE ITK CANTEEN

Steel Structural Elements	Description
Column	Axial–bending interaction check satisfied: 0.355 ≤ 1.
	Shear capacity on beams met.
Rafter	Shear–bending interaction check satisfied: 0.955 ≤ 1.
Purlin CNP 200–16	Shear–bending interaction check satisfied: 1.0482 ≤ 1.375.
Rafter–Column Connection	Beam Side:
	• Sag rod tension capacity: 1,248 N < 24,387 N — criterion satisfied.
	• Ultimate bolt shear vs shear failure strength: 1,194.31 kN (within capacity).
	• Ultimate bolt shear vs tear-out/bearing failure strength: 1,458 kN (within capacity).
	Column Side:
	• Factored shear vs bolt shear yield strength: 940.50 kN.
	• Factored shear vs local yielding of column web: 940.50 kN.
	• Factored shear vs gross web yielding capacity: 12,909.43 kN.
	• Factored shear vs block-shear capacity of column web: 19,809.58 kN.
Rafter–Rafter Connection	Combined shear–tension stress check: 309.4 MPa.
	Bearing strength at support: 653.4 kN.
CNP–Rafter Connection	Bolt shear capacity: 62,203.53 N.
	Bearing capacity: 178,560 N.
Base Plate	Concrete bearing pressure check: 13,559 N/mm ≤ 13,559.27 N/mm.
	Bolt shear capacity: 235,087 N.
	Concrete punching shear capacity: 8,725,016 N.
	Concrete pull-out capacity: 29,937.6 N.

Based on the analysis, capacity checks on all elements and bolted connections of the ITK cafeteria's steel roof structure have been performed and confirmed to satisfy safety requirements in accordance with Indonesian National Standard SNI 1729:2020. The design includes primary members such as rafters (IWF 300×150×6.5×9), roof columns (HB 300×300×10×15), and purlins (CNP 200–16). The primary focus was on high-strength bolted connections, critical points within the steel framework. All computed connection strength parameters were deemed adequate. Additionally, the base plate capacity was verified utilizing a 400 × 400 mm plate, 30 mm thickness, anchored with four 22 mm diameter bolts ensuring safe performance.

F. Plan view of the ITK canteen design

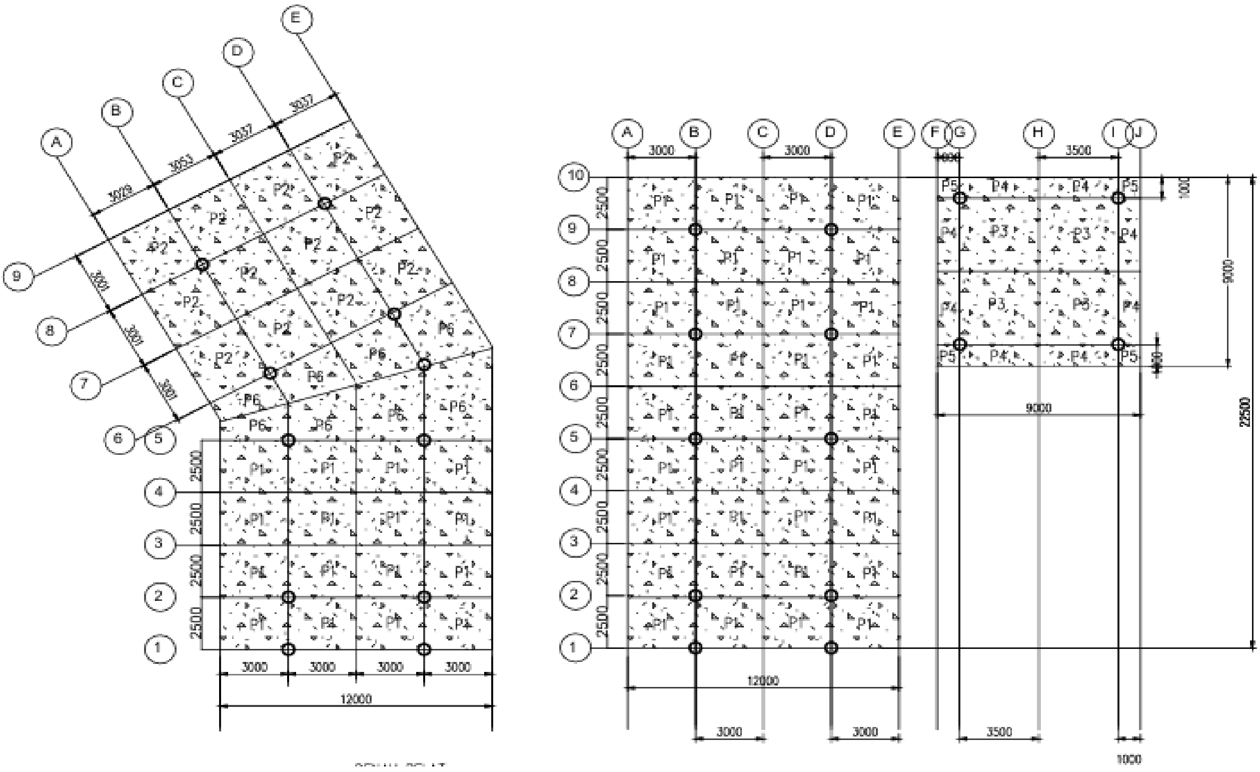


Figure. 3. Slab plan of the ITK canteen at 1 : 200 scale

Figure 3 illustrates the slab plan of the ITK cafeteria at a 1 : 200 scale, showing a reinforced concrete slab with a thickness of 120 mm covering the entire building area. The plan details the reinforcement layout, including support reinforcement of D13–100 mm at top surfaces and D13–150 mm at bottom surfaces, as well as field reinforcement at D13–150 mm in both orthogonal directions. This reinforcement scheme is designed to resist dead and live loads and flexural moments acting on the slab. The drawing also depicts openings for stairs, utilities, and functional areas such as the kitchen and dining zone ensuring the layout aligns with user requirements.

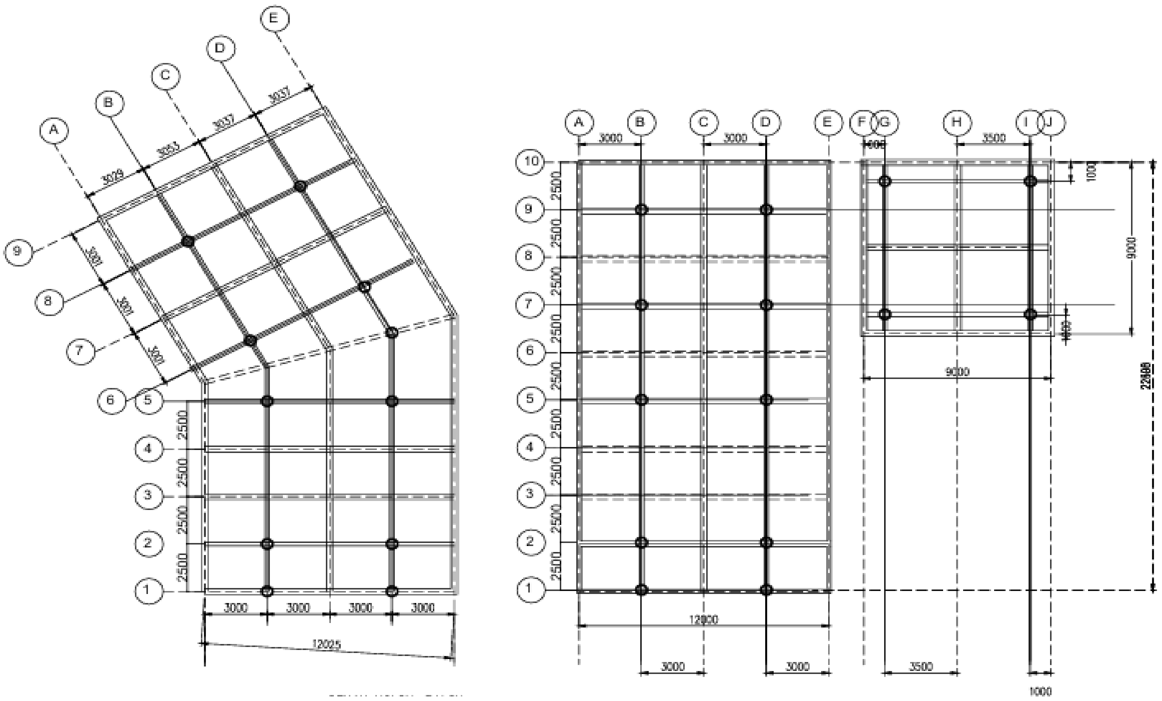


Figure. 4. Beam and Column Layout Plan for the ITK Canteen, Scale 1 : 200

Figure 4 illustrates the layout of the beam and column structure at a 1:200 scale. In this plan, the positions of the main beams (B1: 500 × 300 mm and B2: 400 × 200 mm) and the columns (K1: D600 mm) form the structural grid. The beams are designed to transfer loads from the slab to the columns, with reinforcement details calculated previously (for example, beam B1 uses 10D16 reinforcement at supports and 8D16 in the span). The columns are strategically placed to carry both vertical and lateral loads, including seismic forces. Additionally, the plan shows the connections between the beams and columns, which are critical for ensuring the overall rigidity and stability of the structure.

IV. CONCLUSION

Based on the findings and structural analyses, the research objective of developing a comprehensive and safe structural design has been successfully achieved. By employing numerical analysis methods by relevant Indonesian National Standards (SNI), this study produced a detailed structural plan for both the superstructure and the roof. The superstructure utilizes reinforced concrete components, including B1 beams (500 × 300 mm), B2 beams (400 × 200 mm), K1 circular columns with a diameter of 600 mm, and floor slabs with a thickness of 120 mm. Concurrently, the roof structure was designed as a steel truss system comprising IWF 300 × 150 × 6.5 × 9 mm profiles for the main rafters, HB 300 × 300 × 10 × 15 mm steel columns, and CNP 200–16 mm purlins.

The integration of reinforced concrete and steel systems in a single design framework offers a novel approach to constructing facilities over water bodies. This hybrid structural model not only meets safety and performance requirements but also addresses the spatial and architectural complexities inherent in modern campus infrastructure. The results demonstrate the technical feasibility and design synergy achieved through the combination of multiple structural systems, enabling the realization of innovative and functional architectural visions within a unified construction project.

All elements, including members and bolted connections, were evaluated under SNI 1729:2020 (Indonesia's steel-structure specification, which adopts AISC 360-16) and SNI 2847:2019 (reinforced concrete design standard). The resulting integrated structural scheme ensures robustness, constructability, and compliance with national code requirements—making it suitable for practical implementation.

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