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OPTIMIZATION OF STEEL PROFILE DIMENSIONS AND BOLT CONNECTIONS IN INTAKE STRUCTURES FOR ENHANCED STRUCTURAL INTEGRITY

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ABSTRACT: Intake structures are facilities for clean water supply situated along riverbanks. These structures are reinforced concrete with pile foundations, and the intake structure comprises a profiled steel frame serving as the upper column-beam framework. The implementation of steel structures demands a high level of precision, particularly in designing connections between sectional steel beams and columns. This study, therefore, aims to determine the optimal dimensions for steel profiles by referring to the design of bolt connections as specified in SNI 1729-2020, particularly for steel beam columns subjected to pump loads and load combinations. The analysis concludes that all three material types meet the safety criteria, with a structural ratio value of ≤ 1 and structural deflection within the allowable limits. Additionally, after assessing the steel column and beam sections' capacity to bear pump loads, it was determined that the optimal bolt connection involved 8 bolts of 24 mm diameter. The ideal supplementary steel plate connection required a plate thickness of 13 mm.

KEY WORDS: Connection, Steel Column-Beam, Bolt and Momen Frame System.

1. INTRODUCTION

Intake structures, which supply clean water, are typically located on riverbanks and generally consist of reinforced concrete with pile foundations. However, in this model, the intake structure includes reinforced concrete and a profiled steel frame as the upper column-beam structure [1]. At the Karang Anyar Intake Structure in Pulokerto, a submersible-type pump is the primary engine that delivers clean water from the river to the surrounding community. The pump is positioned on the upper part of the intake structure, necessitating the construction of steel column and beam profiles using elastoplastic materials capable of bearing substantial loads [2]. Steel profile material was selected to effectively transfer the significant 8-tonne pump load from the upper structure to the lower intake area.

The construction of steel structures demands a high level of precision, particularly in designing the connections between sectional steel beams and columns. Previous research has indicated that steel structures often fail at the connection points to the main framework. Various studies have examined the failure of steel frame connections under different loading conditions [3].

The strength of the steel beam-column connection is crucial for enhancing the flexural performance of the steel beam-column [4]. Several studies have been conducted on steel profile connections to assess the impact of potential damage to these connections under fire conditions

[5]. The current study aims to identify the optimal steel profile dimensions and bolt connection design for steel beam columns subjected to pump loads and load combinations.

2. CASE STUDY DESCRIPTION

2.1 Pump Intake

This study's pump intake building is designed with a pier-type structure. This type was chosen due to the site's conditions on the riverbank, which have a strong current, making a pier structure appropriate. The intake building is intended to supply clean water to the local community, with the upper structure made of steel to support and position pumps weighing approximately 8 tonnes. The design includes composite elements such as deep foundations and reinforced concrete structures in the floor and pile cap areas. The steel structure has large profile dimensions to support the heavy pump load. Additionally, the strength of the joints and bolts in the steel profile is carefully considered to ensure that the entire steel construction has a robust load-bearing capacity.

2.2 Steel Structure Connection

Steel beams and columns in a building structure are linked through a connection system. The beam-column connection is considered rigid, meaning no rotation occurs at the connection's end [6]. In this type of structural connection, a high-quality bolted joint with extended end plates is specified without stiffeners. This bolted connection is designed to distribute the damage across the beam flange through plastic deformation rather than concentrating it on a single flange. The design criteria for the connection are based on moment capacity, shear strength, and local stability. The gap size is determined by the shear strength of the beam's reduced section [7].

3. MATERIAL AND METHODS

In this research, the Quantitative Analysis Method utilising the ETABS program is grounded in finite element model analysis. The finite element method was conducted using three dimensions and structural analysis. Employing computer models and analysing these models is a more reliable and practical approach in structural analysis to assess the extent of damage to buildings [8]. In specific steel structures, structural failure is evaluated based on structural parameters and is then related to the resistance-displacement relationship [9]. The design of the intake building incorporates steel, reinforced concrete, and composite concrete, with the materials used have the following qualities: concrete at f'_c 24.9 MPa, profile steel at f_y 400 MPa, and reinforcing steel at f_y 390 MPa and f_y 280 MPa.

3.1 Finite Element Modelling

The dimensions for the intake structure were determined during the Karanganyar intake building project in Pulokerto. The intake structure features a single floor with a building length of 38 meters, a width of 30 meters, and a total height of 11 meters. The pile cap beam measures 0.6 m x 0.65 m, with a composite pile foundation diameter of 60 cm and a depth of 8 m. The

H column size is 400x200, and the H beam size is 250x125, utilising a compact steel cross-section [10]. The research method employed is a case study, which involves reviewing, analysing, analysing, and comparing the research subject. The structure in Fig. 1 was analysed using the ETABS calculation program based on the Finite Element Method. The stages of the research are illustrated in the accompanying research flowchart.

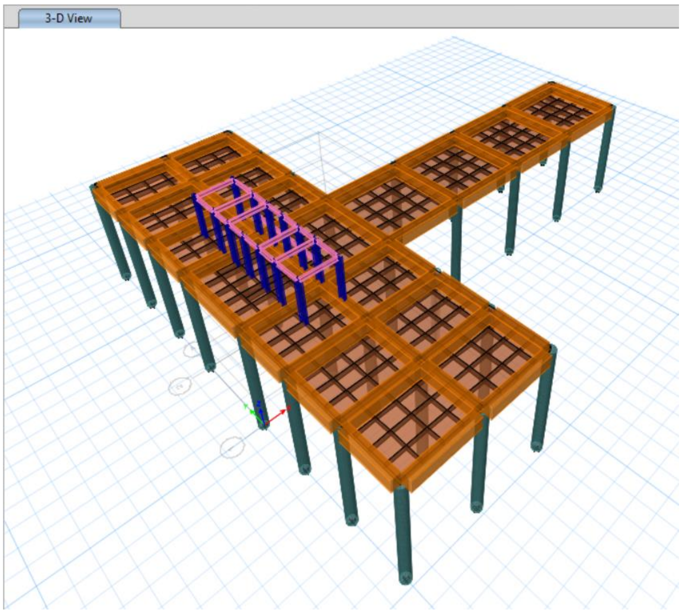

Fig. 1. 3 Dimension Modelling View

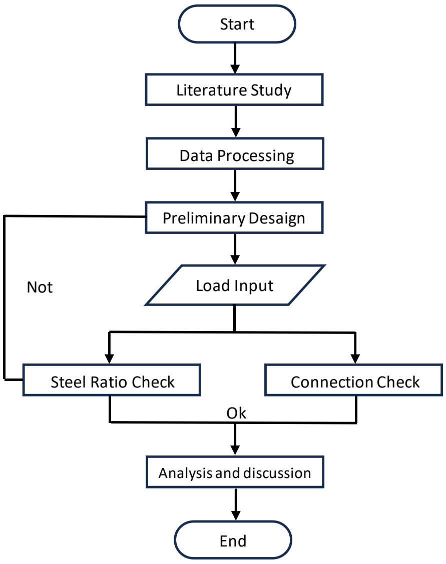

Fig. 2. Research Flowchart

3.2 Load Combination

In this research, the load combinations are based on SNI 1726-2019, which classifies loads into dead loads, additional dead loads, live loads, water loads, and soil loads [11]. Earthquake loads were not included due to the location of the building in Palembang City, where the probability of an earthquake is minimal [12]. The structural loads consist of a 3.92 kN/m² live load, a 0.98 kN point load as dead load, a superimposed dead load of 7.42 kN from a hoist crane, a 78.4 kN point load from the pump as a live load, a 1,176 kN/m hydrostatic pressure load on the composite pile section, and active earth pressure with a shear angle value of 0°, and cohesion ranging from 6 kN/m² to 221.87 kN/m² [13]. The loading combinations used for designing this intake structure are presented in Table 1.

Table 1: Load Combinations

Load	**Combo1**	**Combo2**	**Combo3**	**Combo4**	**Combo5**
Dead	1.4	1.0	1.0	1.0	1.0
Live	-	1.0	1.0	1.0	1.0
Water	-	-	-	0.75	0.75
Soil	-	-	0.75	-	0.75

4. RESULT AND DISCUSSION

4.1 Structure Failure Capacity Analysis

The parameters for structural failure analysis involve comparing and evaluating the values of base shear, shear force, and bending moment in the main beam, along with the axial force in the structural column [14]. The analysis was carried out across all load combinations to identify the maximum load output. A design check is performed if the steel frame ratio exceeds 1 to ensure the steel profile remains within the safe category. However, if the steel frame ratio exceeds 1, the structural profile has failed, necessitating replacement and re-evaluation [15].

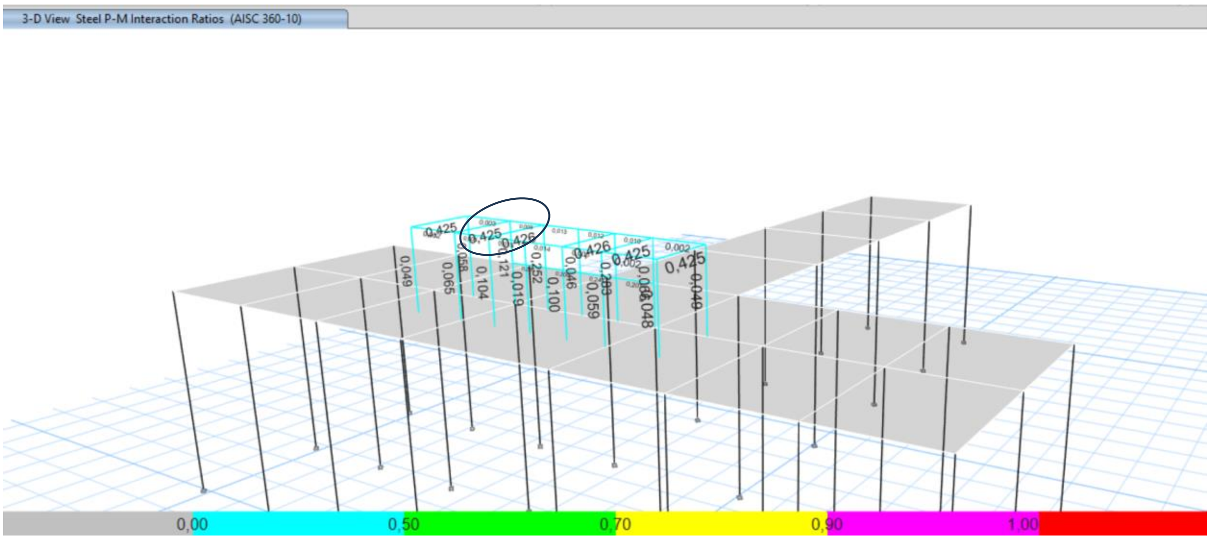

Fig. 3. Steel Ratio Capacity ≤ 1

Design evaluations are carried out when the composite column ratio is less than 1 to assess the failure potential of composite pile components. Local buckling in composite columns affects the axial strength of the column, which can lead to structural failure [16]. In this research model, as depicted in Fig. 3 and Table 1, the steel ratio value remains within safe limits, with the highest steel profile ratio being 0.426. Similarly, the composite ratio value satisfies the safety criteria, with the highest composite structure ratio being 0.532.

Table 2: Recapitulation of Steel and Composite Column Ratio

Type of Material Structure	Structure Ratio	Position	Permitted Ratio	Status (OK/Not OK)
Steel Beam	0.426	B11	1	OK
Steel Column	0.283	C24	1	OK
Composite Column	0.532	C38	1	OK

4.2 Beam Deflection

The deflection of the beam (Ln) is analysed at the location of maximum deflection, which occurs between 2m and 6m along each span. The maximum deflection is evaluated using an allowable Ln/240 mm limit, as specified in SNI 1729-2002 Article 6.4 [6]. Structural damage is categorised based on deflection into three failure levels: elastic limit with minimal damage, elastoplastic with moderate damage, and total failure at the ultimate limit [17]. Beams with deflection exceeding the allowable limits do not meet safety standards and may be prone to failure. The maximum deflection of the beam is summarised in Table 3, which shows that the reinforced concrete beams do not exceed the deflection limits. The concrete's stiffness and the reinforcing steel's bending capacity ensure that the deflection remains within safe limits. The position of maximum deflection on the beam is depicted in Fig. 4.

Table 3: Recapitulation Beam Deflection

Length (m)	Permitted deflection (mm)	Position	Structure Deflection (mm)	Status (OK/Not OK)
4	16.667	B45	1.550	OK
5	20.833	B4	1.532	OK
6	25	B26	9.835	OK

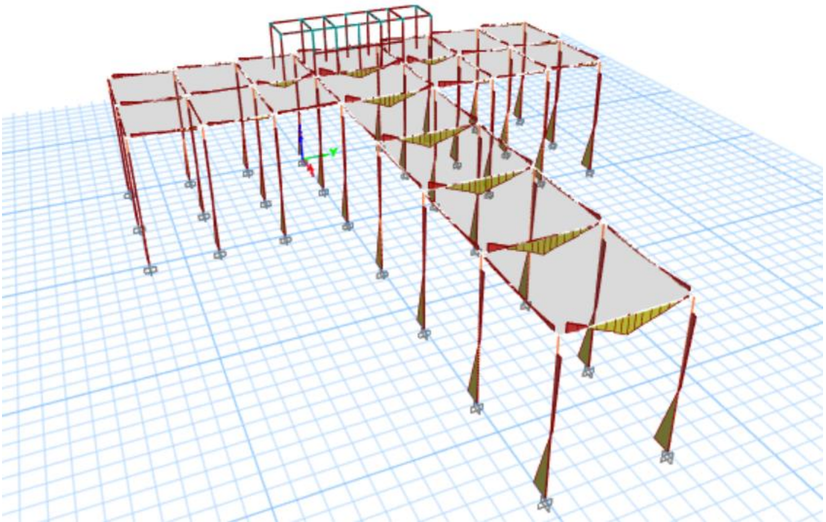

Fig. 4. Maximum Deflection Location at Beam 23

4.2. *Steel Connection Design*

The deflection of the beam (Ln) was analysed, with the maximum deflection occurring at spans between 2m and 6m. The maximum deflection was evaluated using an allowable Ln/240 mm limit, as stipulated by SNI 1729-2002 Article 6.4 [6].

Steel connection joints with additional welded plates can provide greater flexural strength and better resist fracture failure in beam-column connections than bolted angles [18]. In this case, the bolted connections involved roller connections, which allow movement and rotation along the surface they rest on—whether flat, vertical, or inclined at any angle. Pinned connections, commonly found in trusses, were also used; these joints are widely applied in mechanical engineering and bridge construction but cannot resist bending forces, instead transferring vertical and horizontal shear loads. These are often considered total hinge joints in structural design [19]. Fixed connections were also employed, capable of resisting vertical and lateral loads and developing moment resistance [20]. For beam and column connections, the strength of steel profiles also depends on the bolt connections.

The calculation of the bolt plan and plate thickness for the connection between the steel beam (IWF 250.125.5.8) and the column (IWF 400.200.8.13) yielded the following dimensions: Depth (H) = 248 mm, Web (W) = 124 mm, Web Thickness (tw) = 5 mm, Flange Thickness (tf) = 8 mm, Corner Radius (ro) = 12 mm, Sectional Area (As) = 32.68 cm², Moment of Inertia in X Direction (Ix) = 3540 cm^4, Moment of Inertia in Y Direction (Iy) = 255 cm^4, with steel grade fy = 410 MPa and fu = 550 MPa. The bolt connection was designed with 8 bolts of 24 mm diameter, with an ultimate axial load (Nu) of 2.505 kN, an ultimate shear (Vu) of 44.594 kN, and an ultimate moment (Mu) of 51.111 kNm.

- Checked Thickness of Plate (t):

$$t \geq (h+w)\,/\,90 \tag{1}$$

$$\mathrm{t} \geq (248 + 124)\,/\,90 = 4{,}13\ \mathrm{mm}$$

because the thickness was 4,13 mm, the plate's minimum thickness was 13 mm according to SNI 7972-2020.

- Checked minimum spacing of bolt (S):

$$S_1 > 1{,}5\, d_b = 30\ mm \tag{2}$$

$S > 3\, d_b = 60$ mm

- Checked maximum spacing of bolt:

$$S_1 < 150\ mm \tag{3}$$

$S_1 < 4\, t_p + 100$ mm $= 152$ mm

$S < 200$

Spacing of bolt taken between $S_1 = 30$ mm until $S = 60$ mm

- Checked bolt shear strength (R_{nv}) :

F_u bolt = 310 MPa (Bolt A307)

$$R_{nv} = 0{,}5 \times F_u \times A_b \tag{4}$$

$R_{nv} = 0{,}5 \times 310 \times (1/4\, \pi\, 24^2)$

$R_{nv} = 70148{,}571$ N

$R_{nv} = 70{,}148$ kN

- Checked bolt tensile strength (R_{nt}):

$$R_{nt} = 0{,}75 \times F_u \times A_b \tag{5}$$

$R_{nt} = 0{,}75 \times 310 \times (1/4\, \pi\, 24^2)$

$R_{nt} = 105222{,}857$ N

$R_{nt} = 105{,}222$ kN

- Checked the bolt shear the latitudinal force (R_{uv}):

$$R_{uv} = V_u/n \tag{6}$$

R_{uv} = 44,594/8

R_{uv} = 5,574 kN

- The bolt shares the normal force (R_{ut}) :

$$R_{ut} = N_u/n \tag{7}$$

R_{ut} = 2,505 /8

R_{ut} = 0,313 kN

- Checked tensile force due to moment ≤ 1 :

$$Ti = \frac{M \text{ x } y1}{\sum yi^2} \tag{8}$$

$$y_1 = y_2 \quad = (60 \text{ x } 2) + 32 + 64 = 216 \text{ mm}$$

$$y_3 = y_4 \quad = 60 + 32 + 64 \quad = 156$$

$$\sum y^2 \quad = 2 \text{ x } (216^2 + 156^2) \; = 141984 \text{ mm}^2$$

$$R_{ut} \quad = \frac{51{,}111 \text{ x } 216 \text{ x } 10^{-3}}{141984 \text{ x } 10^{-6}} \quad = 77{,}755 \text{ kN}$$

$$R_{ut} \quad = 77{,}755 \; + 0{,}313 \quad = 78{,}068 \text{ kN}$$

$$\left(\frac{Ruv}{\phi\text{Rnv}}\right)^2 + \left(\frac{Rut}{\phi\text{Rnt}}\right)^2 \;\leq 1$$

$$\left(\frac{5{,}574}{0{,}75 \text{ x } 70{,}148}\right)^2 + \left(\frac{78{,}068}{0{,}75 \text{ x } 105{,}222}\right)^2 \leq 1$$

$$0{,}989 \;\leq 1 \text{ (OK)}$$

According to SNI 7972-2020, the plate thickness in the design calculations is determined with a minimum standard thickness of 13 mm. Using A307 regular quality bolts, the bolt design specifies that 8 bolts with a 24 mm diameter provide a strength that falls within a ratio of less than 1 [21], see Fig. 5.

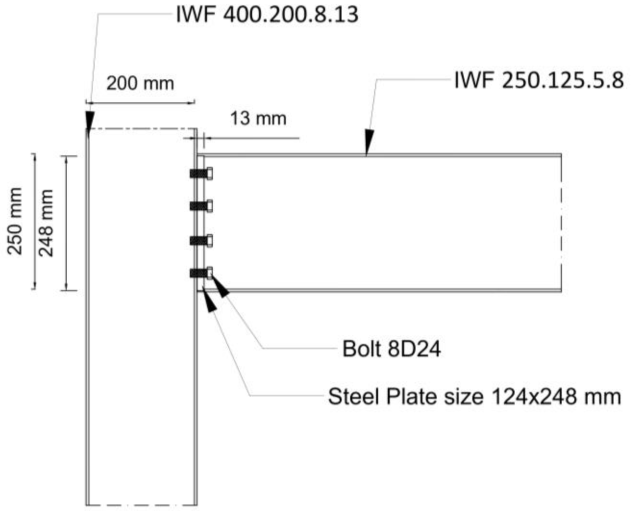

Fig. 5. Steel Connection Design

5. CONCLUSION

The intake structure was modelled using a particular moment frame system in the ETABS program based on finite element analysis. Five load combinations were applied to evaluate the structural capacity of composite materials, reinforced concrete, and sectional steel. The analysis concluded that all three material types meet safety standards, with structural ratios ≤ 1 and deflection values remaining within the allowable limits. After assessing the steel column and beam cross sections' ability to bear the pump load, the optimal connection was determined to be 8 bolts with a 24 mm diameter, and the ideal additional steel plate connection required a thickness of 13 mm.

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