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Industrial Building Structure Planning With Cranes

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ABSTRACT
Industrial building structure planning complies with standards and regulations, such as Procedures for Earthquake Resistance Planning, Minimum Loads for Building Design, and Specifications for Structural Steel Buildings. Vertical and lateral loads are fundamental to the structure's load flow process. Industrial buildings handle roof, wind, earthquakes, crane, and wall loads. Structural design must consider these elements, including the choice of lateral force-resisting systems such as X-bracing. In determining building loads, including earthquake and wind loads, various parameters such as wind speed, exposure category, and other factors must be considered by standard requirements such as SNI 1727-2020 and SNI 1726:2019. Selection of site class, wind direction, topographic, and ground surface elevation factors are essential in determining wind loads. This research method focuses on supporting structures consisting of purlins and girts in the context of industrial buildings. Purlins, made from hot or cold rolled steel, generally use C and Z profiles. Girts, made from cold or hot rolled steel, have profile variations such as C, Z, or hollow square sections. The girt structure design process determines dimensions, rod sag, internal requirements, and sag rod capacity.
Keywords: Building structure planning, Cranes, Structural design

INTRODUCTION

Portal structures are prevalent in Indonesia due to their efficiency and ease of functioning (Hasan et al., 2023; Mulyani et al., 2024; Rahman, 2022). Portal types vary, such as gable frame, curved frame, and two-span gable frame. Broad flange profiles of hot-rolled steel are generally used, with variations of cold-rolled steel as secondary framing. 2d truss structures are an alternative, with W and N-type trusses being common choices. The choice of profile, truss height, and combination with columns considers needs and costs (Justo et al., 2023; Pereiro et al., 2023; Rady et al., 2024; Yang et al., 2024). Suspended structures, with tension rod supports from cable structures, are an option for extra wide spans, as implemented at the Pulogebang Main Terminal.

The supporting structure consists of purlins and girts. Purlins can be made from hot or cold rolled steel, with C and Z profiles commonly used. Girts from cold or hot rolled steel come in variations such as C, Z, or hollow square section profiles. Girt structure design involves determining dimensions, rod sag, internal requirements, and sag rod capacity.

Industrial building structure planning complies with standards and regulations, such as Procedures for Earthquake Resistance Planning, Minimum Loads for Building Design, and Specifications for Structural Steel Buildings (Bhandari et al., 2023; Bos et al., 2022; Dominguez-Santos, 2023; Stepinac et al., 2023). Vertical and lateral loads are fundamental to the structure's load flow process. Industrial buildings handle roof, wind, earthquakes, crane, and wall loads. Structural design must consider these elements, including the choice of lateral force-resisting systems such as X-bracing.

The importance of understanding load flow also arises in crane systems, which are an efficient solution for moving heavy goods in industrial environments. Cranes consist of several mechanical elements that function together to achieve this goal. There are various types of cranes with different characteristics and uses. Crane types include single-girder cranes with a single I-girder, single-girder cranes with a steel box girder, suspension cranes, and double-girder cranes with a steel box girder (Prasetyo & Naufal Yasir, 2024). Each type of crane is intended for different load-lifting needs.

Single-girder cranes with steel box girders are suitable for high-lifting loads with large spans, while single-girder cranes with a single I-girder are an economical choice for light loads with limited spans. Suspension cranes offer economy because they can be installed without additional support columns but have limited carrying capacity. Double-girder cranes with steel box girders are used for heavy lifting loads over wide spans, especially for lifting large machines in industrial buildings.

According to AIST TR-13 and CMAA, Crane classification is essential to determine the criteria for supporting structures that can help the crane structure with a particular lifting load. This classification involves load repetitions and load cycles during the service life of the building. The AIST TR-13 classification includes classes A, B, C, and D, while CMAA has classifications based on service conditions, ranging from Class A (Uncertain Service Condition) to Class F (Heavy Service). In determining building loads, including earthquake and wind loads, various parameters such as wind speed, exposure category, and other factors must be considered by standard requirements such as SNI 1727-2020 and SNI 1726:2019. Selection of site class, wind direction, topographic, and ground surface elevation factors are essential in determining wind loads.

It is also essential to pay attention to wheel loads and vertical impact loads on the structure, especially in the dynamic conditions when the crane is operating. Wheel loads must be carefully calculated, and sheer impact factors must be considered to accommodate dynamic load variations during crane use. By considering all these factors, structural planning to support the use of cranes in industrial buildings can be carried out more accurately and ensure safety and optimal performance (Hopkins, 2021).

Lateral loads on crane runways can come from several factors, such as runway misalignment, tilted crane installation, trolley acceleration, brake force, and crane drive (Walpole, 2020). Determining the lateral load due to sideways pushing is generally done by calculating 20% of the total crane carrying capacity plus the weight of the trolley and hoist (Al-Rubaye & Maguire, 2023; Xin et al., 2023; Zis et al., 2023). The crane vendor's technical specifications provide the necessary data, and the recommended load factor for LRFD analysis is 1.6, calculated using the formula H_crane=20%*P_lifted+P_(trolley and hoist), with P_lifted being the lifting capacity of the crane and P_(trolley and hoist) as the weight of the trolley and hoist.

The longitudinal force on the crane-supporting structure is calculated at 10% of the crane's maximum wheel load. This calculation considers that the longitudinal force must act horizontally on the traction surface of the runway beam in a direction parallel to the beam. Although SNI 1727-2020 and ASCE 7-16 do not provide load factor recommendations for longitudinal forces, Design Guide 7 recommends using a load factor 1.6.

Various loading conditions must be considered to obtain maximum wheel reaction on the crane. Four special conditions need to be considered, which involve a combination of maximum and minimum wheel loads on the left and right ends of the crane with lateral forces acting to the left or right. The loading combination is used to determine the internal force on the cell.

RESEARCH METHODS

This research method focuses on supporting structures consisting of purlins and girts in the context of industrial buildings. Purlins, made from hot or cold rolled steel, generally use C and Z profiles. Girts, made from cold or hot rolled steel, have profile variations such as C, Z, or hollow square sections. The girt structure design process determines dimensions, rod sag, internal requirements, and sag rod capacity. Industrial building structure planning is subject to standards and regulations such as Procedures for Earthquake Resistance Planning, Minimum Loads for Building Design, and Specifications for Structural Steel Buildings. The flow of loads on a structure, both vertical and lateral, is fundamental by considering roof, wind, earthquake, crane, and wall loads. The structural design also considers elements such as X-bracing to resist lateral forces. Understanding load flow is also essential in crane systems, which are an efficient solution for moving heavy goods in industrial environments. Different cranes, such as single-girder cranes with steel box girders or double-girder cranes with steel box girders, are intended for different load-lifting needs. According to AIST TR-13 and CMAA, Crane classification is the key to determining supporting structure criteria according to specific lifting loads. In determining building loads, parameters such as wind speed, exposure category, and other factors must be considered according to SNI 1727-2020 and SNI

1726:2019 standards. It is also essential to pay attention to wheel loads and vertical impact loads on the structure, especially in the dynamic conditions when the crane is operating. By considering all these factors, structural planning to support the use of cranes in industrial buildings can be carried out more accurately and ensure optimal safety and performance. The lateral load on the crane runway, which comes from factors such as runway misalignment, tilted crane installation, trolley acceleration, trolley brake force, and crane drive, is calculated by taking 20% of the total crane carrying capacity plus the weight of the trolley and hoist. The technical specifications from the crane vendor are used as a reference, and the recommended load factor for LRFD analysis is 1.6. The formula H_crane=20%*P_lifted+P_(trolley and hoist) is used to calculate the lateral load, with P_lifted as the lifting capacity of the crane and P_(trolley and hoist) as the weight of the trolley and hoist.

RESULTS AND DISCUSSION

In the structural planning process, ETABS is often used by engineers because of its ease of use and reliability. The ETABS program was first developed by a leading software company, Computers and Structures, in California, United States. The development of this program was born from research initiated by Dr. Edward L. Wilson in 1970 at the University of California, Berkeley.

Figure 1. ETABS software

The first step in modeling with ETABS software is to create a new file by clicking File – New Model or this can be done via the shortcut Ctrl+N.

Adjust the parameters according to the code used. For projects in Indonesia, the regulations used usually refer to regulations in America.

SNI 1729-2020 → AISC 360-16

SNI 2847-2019 → ACI 318-14/19

The next step in planning is to determine the properties of structural materials, including concrete, reinforcing steel and profile steel. The quality of the concrete is determined at 25 MPa with a specific gravity of 2400 kg/m3, and the modulus of elasticity of the concrete is calculated to produce an Ec value of 23500 MPa. Reinforcing steel meets the requirements of BJTS 420B class based on SNI 2847:2019. The hot rolled profile steel material has quality

BJ37/A36, specific gravity 7850 kg/m3, modulus of elasticity 200,000 MPa, yield stress Fy 240 MPa, and breaking stress Fu 370 MPa. The cross-sectional properties of structural elements such as columns, rafters, purlins, ring beams, roof tops, column posts, bracing, runway beam cranes, as well as main pedestal columns and pedestal post columns are determined via Define – Section Properties – Frame Sections – Add New Property in ETABS. Steel profiles used include WF.600X200X11/17, HC.675X200X9/14, CNP.150X50X20X2.3, WF.300X150X6.5X9, WF.450X200X9/14, 2L.70X70X7, WF.500X200X10/16, K60X80 (600X800 mm2) , and K40X70 (400X700 mm2). It is important to note that the strong axis moment of inertia (Ix) of the HC profile modeled with the WF profile needs to be modified with a stiffness modifier of 0.9 for I33, considering that the moment of inertia ratio between the HC.676X200X9/14 and WF.675X200X9/14 profiles is 0.9 . Reinforced concrete columns are also needed to support the main steel columns and post columns.

Table 1. Allowable Moment of Inertia and Cross-sectional Area for Elastic Analysis at Factored Load Level

Bagian dan Kondisi		Momen Inersia	Luas Penampang
Kolom		0.7 Ig	1.0 Ag
Dinding	Tidak Retak	0.7 Ig	
	Retak	0.35 Ig	
Balok		0.35 Ig	
Pelat datar dan slab datar		0.25 Ig	

The column cross-section properties can be determined by Define – Section Properties – Frame Sections – Add New Property – Concrete Rectangular. The cross-sectional properties can be determined as follows. The K60X80 column properties involve concrete material with quality K-300 (fc' = 25 MPa) and BJTS420B reinforcing steel. Assuming the initial amount of reinforcement is 1% of the cross-sectional area (Ag), the column dimensions are set at a height (c1) of 800 mm and a width (c2) of 600 mm.

The reinforcement ratio (ρ) is 1%, resulting in a reinforcement area (As) of 4800 mm2, with a reinforcement dimension (DB) of 19 mm. The K40X70 column properties are similar with the same material and quality but with different column dimensions, namely height (c1) 700 mm and width (c2) 400 mm. The number of reinforcement (n) required is 14, resulting in a reinforcement area (As) of 2800 mm2, with a reinforcement dimension (db) of 16 mm. The stiffness modification factor for these two columns is 0.7. The Tie Beam TB20/30 property, which also involves the same material and quality, has a shear reinforcement diameter (ds) of 10 mm and a longitudinal reinforcement diameter (db) of 16 mm. With a transparent cover (cc) of 40 mm and a stiffness modification factor of 0.35, the resulting cover to the longitudinal bar is 58 mm.

Modeling column elements begins with specific steps like display settings and property determination. Via the command Draw → Draw Beam/Column/Brace Objects → Quick Draw Column, column views can be created, and column properties can be defined. Selecting the column support from the joint to be the clamp on the pedestal column is also done by Selecting the lower joint of the pedestal column → Assign → Restraints → Fixed.

Modeling other columns, such as the K60X80 and K40X70, involves selecting the elevation and the Quick Draw Column command in the relevant View Plan. Meanwhile, modeling the HC.675X200X9/14 rafter requires elevation adjustments and the use of the Extend Frame command to connect it to the WF.450X200X9/14 post column. This process also involves doubling the rafter and defining cross-sectional dimensions.

For the rooftop (ridge) and ring beam, modeling is done by setting the view, adjusting the elevation, and connecting the frame from one point to another. Modeling the CNP.150X50X20X2.3 purlin requires dividing the rafter and extruding the joint into a CNP.150X50X20X2.3 frame. After that, the previously split rafters are replicated and recombined.

X-bracing is modeled to maintain building balance using View Elevation. Once created, the X-bracing is replicated to the other side of the building with appropriate settings. Modeling a runway beam crane involves adjusting the elevation view, making brackets, and using lateral trusses to prevent buckling. Next, the connection between the column and rafter is planned via IdeaStatica using moment connections. This process involves creating a model based on a joint template and adjusting the profile dimensions.

Loadings on Industrial Buildings

Determination of material properties for concrete, reinforcing steel, and profile steel is carried out by determining quality, specific gravity, modulus of elasticity, and yield stress according to applicable standards (Ortega-Lopez et al., 2021; Revilla-Cuesta et al., 2022). Determining the cross-sectional properties of structural elements, such as columns, rafters, purlins, ring beams, and others, involves selecting the steel profile and setting its dimensions via the Define – Section Properties – Frame Sections – Add New Property command in ETABS.

Roof bracing with a 25 mm rod is modeled on the span where X-bracing has been modeled. After one side is made, the roof bracing is replicated to the other side and removed on the side that is not needed. TB20/30 tie beam modeling involves setting up the view and determining the tie beam properties before drawing the elements in the required areas. With these steps, the modeling of these structural elements can be integrated comprehensively to support structural designs that comply with technical and safety requirements.

Loadings on Industrial Buildings

In industrial building design, loads are assumed first based on careful technical considerations. The loads considered include dead, live, earthquake, and wind loads. A structural design is safe if it has a capacity more significant than the existing load, so the structure is strong enough to support it.

Load Pattern Creation

Load pattern is the spatial distribution of a particular series of forces, displacements, temperatures, and other influences that act on a structure. Loading and kinematic conditions can affect any combination of joints and elements. Each load pattern is assigned a design type (DEAD, SUPER DEAD, WIND, SEISMIC, etc.), which classifies the applied load type and is computed according to the defined load type. In ETABS, determining the load pattern can be done by clicking Define - Load Patterns. Enter all kinds of loads, as shown in the image below.

Dead Load Calculation (Dead Load)

An additional dead load is a load that acts on the entire roof. This load consists of dead load, additional dead load, the structure's weight, the weight of the architectural finishing, and the weight of the ducting/cables/M/E pipes included, as well as other loads calculated as fixed loads on the structure.

Superimposed Dead Load (SIDL)

Own weight of structure (Calculated by program)

Roof cover (t = 0.55 mm + Insulation)	=	6	kg/m2
ME & Lampu	=	9	kg/m2 +
		15	kg/m2

SIDL load on roof = 15 kg/m2

In ETABS, structural load calculation involves automatic calculation of the structure's self-weight when the material type is input during material definition. Additional dead load or collateral load can be input as a line load on the rafter, with the conversion of area load to line load carried out based on the portal span for the middle rafter and half the portal span for the edge rafter. For example, the intermediate rafter with a distance between portals of 6 m has a line load (q) SIDL of 15 kg/m, converted to 90 kg/m by simple calculations. The edge rafter, with a distance between portals of 3 m, has q = 45 kg/m, calculated as half the area load multiplied by the portal span. Load input in ETABS involves selecting rafters and determining line load values; for example, the middle rafter receives a SIDL load of 90 kg/m, while the edge rafter receives 45 kg/m. A similar process is applied to the calculation of roof live load, rain load, and wind load, ensuring that the warehouse structure is designed by SNI 1727-2020 requirements and considering all relevant factors for safety and optimal structural performance.

Parameters and Coefficients Used

Roof angle, θ = TAN^(-1)*((11.65-9)/(30/2))
= 10 degrees
Average roof height, h = (h = (hr+he)/2, for roof angle >10 degrees)
= h = he, for roof angle <= 10 degrees
= 9 m
Roof height, h <= 60' (18 m) = YES
h <= L or B = YES

Because the building meets the two criteria above, the building falls under the criteria for a low-rise building.

Positive & Negative Internal Pressure Coefficient, GCpi (Table 26.13-1):
Positive internal pressure, +Gcpi = 0.18
Positive internal pressure, -Gcpi = -0.18

Velocity Pressure

Wind velocity pressure is determined based on previously determined parameters with the following equation:

$q\_z=0,613*K\_z*K\_zt*K\_d*K\_e*V^2$
$q\_z=0,613*0,98*1*0,85*1*39,1^2$=779,84 kPa
Width of Wall and Roof End Zones 'a' and '2*a'
Minimum span L or B = 30.00 m
0.1*(L or B) = 3.00 m
0.4*h = 4.13 m
0.1*(L or B) < 0.4.h = 3.00 m
0.04*(L, B) = 1.20 m
0.1*(L or B) > 0.04*(L, B) = 3.00 m
0.1*(L or B) > 0.9 m = 3.00 m
Then the end zone, a = 3.00 m
'2*a' = 6.00 m

Wind Load

Wind load is determined by the following equation:
p = q_h*[(GC_pf)- (GC_pi)]

With the calculated external pressure coefficients, Gcpi and Gcpf, according to Figure 28.3-1 SNI 1727-2020, the recapitulation of wind pressure calculations for each case and side is as follows:

Table 2. SPGAU Wind Load for Cases A and B

SPGAU Wind Load for Case A				SPGAU Wind Load for Case B			
Surface	GCpf	p = Net Pressures (kPa)		Surface	*GCpf	p = Net Pressures (kPa)	
		(w/ +GCpi)	(w/ -GCpi)			(w/ +GCpi)	(w/ -GCpi)
Zona 1	0,44	205	486	Zona 1	-0,45	-491	-211
Zona 2	-0,69	-678	-398	Zona 2	-0,69	-678	-398
Zona 3	-0,41	-457	-177	Zona 3	-0,37	-429	-148
Zona 4	-0,34	-403	-122	Zona 4	-0,45	-491	-211
Zona 5	---	---	---	Zona 5	0,40	172	452
Zona 6	---	---	---	Zona 6	-0,29	-367	-86
Zona 1E	0,67	385	665	Zona 1E	-0,48	-515	-234
Zona 2E	-1,07	-975	-694	Zona 2E	-1,07	-975	-694
Zona 3E	-0,58	-595	-314	Zona 3E	-0,53	-554	-273
Zona 4E	-0,50	-530	-249	Zona 4E	-0,48	-515	-234
Zona 5E	---	---	---	Zona 5E	0,61	335	616
Zona 6E	---	---	---	Zona 6E	-0,43	-476	-195

Wind loads for both transverse and longitudinal directions are inputted to the structure as line loads by multiplying the wind pressure by the tributary area served. This can be done by clicking the rafter that will be assigned the selected load then click Assign → Frame Load → Distributed → Load Pattern Name = Wx(+)/Wx(-)/Wy(+)/Wy(-) → Uniform Load = Input load amount. The load applied to the designed building structure is in the figure below.

For service loads, the wind speed used is 32 m/s. With the same calculation procedure as what was described earlier, the SPGAU wind pressure load is obtained in the table below.

Table 3. SPGAU Wind Load for Case A and B (Service Condition)

SPGAU Wind Load for Case A				SPGAU Wind Load for Case B			
Surface	GCpf	p = Net Pressures (kPa)		Surface	*GCpf	p = Net Pressures (kPa)	
		(w/ +GCpi)	(w/ -GCpi)			(w/ +GCpi)	(w/ -GCpi)
Zona 1	0,44	205	486	Zona 1	-0,45	-491	-211
Zona 2	-0,69	-678	-398	Zona 2	-0,69	-678	-398
Zona 3	-0,41	-457	-177	Zona 3	-0,37	-429	-148
Zona 4	-0,34	-403	-122	Zona 4	-0,45	-491	-211
Zona 5	---	---	---	Zona 5	0,40	172	452
Zona 6	---	---	---	Zona 6	-0,29	-367	-86
Zona 1E	0,67	385	665	Zona 1E	-0,48	-515	-234
Zona 2E	-1,07	-975	-694	Zona 2E	-1,07	-975	-694
Zona 3E	-0,58	-595	-314	Zona 3E	-0,53	-554	-273
Zona 4E	-0,50	-530	-249	Zona 4E	-0,48	-515	-234
Zona 5E	---	---	---	Zona 5E	0,61	335	616
Zona 6E	---	---	---	Zona 6E	-0,43	-476	-195

In calculating earthquake loads for factory building structures with category II risk, critical steps have been taken, including determining earthquake risk categories and priority factors based on the function and use of the building. Analysis of N-SPT data determines the medium soil site class. Spectral response graphs and design spectral acceleration data, including SS, S1, TL, Fa, Fv, SMS, SM1, SDS, SD1, T0, and Ts, are generated to determine the seismic design category, which places the structure in Seismic Design Category D (KDS D). The structural system was selected according to the SNI 1726-2019 standard, with ordinary moment-bearing steel frames in the transverse direction and ordinary concentric bracing in the longitudinal direction, considering the building height and roof tributary loads. Determination of the seismic design category permits the use of standard moment-resisting steel frame systems and steel frame systems with ordinary concentric bracing according to the provisions for single-story structures with specific loads and the permitted building height.

An ordinary moment-bearing steel frame system in the transverse direction has a response modification coefficient (R) of 3.5, an overstrength factor (Ω0) of 3, and a deflection enlargement factor (Cd) of 3. On the other hand, a steel frame system with concentric bracing Ordinary in the longitudinal direction has a response modification coefficient (R) of 3.25, an overstrength factor (Ω0) of 2, and a deflection magnification factor (Cd) of 3.25.

To calculate the fundamental period of a structure, the results of structural analysis need to be limited according to the coefficients and parameters determined based on SNI 1726-2019. In the transverse direction (OMF), the Cu coefficient is 1.4, the Ct coefficient is 0.0724, and the x parameter is 0.8. Calculation of the structure period shows that the fundamental period of approach (Ta) is 0.42 seconds, while the maximum period (Tmax) is 0.588 seconds.

Meanwhile, in the longitudinal direction (OCBF), the Cu coefficient is 1.4, the Ct coefficient is 0.0488, and the x parameter is 0.75. The calculation results show that the fundamental period of approach (Ta) is 0.254 seconds, and the maximum period (Tmax) is 0.355 seconds.

It should be noted that the results of the fundamental period calculation of the structure are then compared with the results of the entire period analysis via ETABS software. From the analysis results, the x-direction period (Tc, x) is 0.533 seconds, while the y-direction period (Tc, y) is 0.637 seconds. Because the analysis period (Tc) is greater than the maximum period (Tmax), the structure period used is 0.588 seconds for the x-direction (Tx) and 0.355 seconds for the y-direction (Ty).

Seismic Basic Shear Force Calculations

The seismic base shear force using the equivalent static method (V) for the x-direction and y-direction is calculated based on Article 7.8. SNI 1726-2019. The seismic base shear force is calculated based on the equation Equation 30 in SNI 1726-2019. The calculated effective seismic mass of the structure is as follows:

Self-weight of structure = Calculated by the program

SIDL Load (Roof + M/E) = 15 kg/m^2

Walls including girts = 15 kg/m^2

Crane rail load + M/E = 70 kg/m'

Weight of crane + trolley & hoist = 10966 + 839.1 kg = 11805.1 kg

Calculation of Seismic Response Coefficient in Transverse Direction (OMF)

Seismic response coefficient (CS) = SDS/(R/Ie)

= 0.614488/(3/1.25)

= 0.205

The CS value needs to be checked against the upper limit and lower limit. For the upper limit because the T value is less than or equal to TL, Equation 32 SNI 1726-2019 is used.

Meanwhile, the lower limit is because the S1 value is smaller than 0.6. So, Equation 35 SNI 1726-2019 does not need to be taken into account.

Upper limit, CS max = SD1/(T×(R/Ie)

= 0.271

Lower limit, CS min = 0.044×SDS×Ie > 0.01

= 0.027 > 0.01

= 0.027

Because the CS min < CS < CS max value, the CS value used is as follows:

Seismic response coefficient using the transverse direction, Cs = 0.205

Calculation of Seismic Response Coefficient in Longitudinal Direction (OCBF)

Seismic response coefficient (CS) = SDS/(R/Ie)

= 0.614488/(3.35/1.25)

= 0.189

The CS value needs to be checked against the upper limit and lower limit. For the upper limit because the T value is less than or equal to TL, Equation 32 SNI 1726-2019 is used. Meanwhile, the lower limit is because the S1 value is smaller than 0.6. So, Equation 35 SNI 1726-2019 does not need to be taken into account.

Upper limit, CS max = SD1/(T×(R/Ie)

= 0.251

Lower limit, CS min = 0.044×SDS×Ie > 0.01

= 0.027 > 0.01

= 0.027

Because the CS min < CS < CS max value, the CS value used is as follows:

Seismic response coefficient using the longitudinal direction, Cs = 0.189

In calculating the effective seismic weight in the transverse direction, the effective mass of the structure is calculated through a program with a combination of 100% dead load and additional dead load. In industrial buildings, wall loads in directions parallel to the direction under consideration are ignored, with the assumption that the walls also resist lateral forces. The wall load is calculated as half of the total wall area. At the end portal, the effective seismic weight was calculated by taking into account the dead load, additional load on the roof, and crane load, reaching a total of 23492.4 kg. The seismic base shear force in the transverse direction per end portal is 48.2 kN. At the middle portal, with a larger roof area and more portals, the effective seismic weight reaches 164822.4 kg, resulting in a seismic base shear force per middle portal of 337.9 kN. Calculation of the effective seismic weight in the longitudinal direction involves the structure's own weight, wall weight, SIDL load and crane load. In the longitudinal direction portal, the effective seismic weight reaches 188314.7 kg, resulting in a seismic base shear force per longitudinal direction portal of 355.9 kN. Checking the deviation between levels is carried out based on Table 20 of SNI 1726-2019, with a deflection enlargement factor of 3 for transverse direction portals and 3.25 for longitudinal direction portals.

Based on the results of the structural analysis, due to the x direction earthquake load, an elastic deviation of 9.603 mm was obtained which needs to be checked according to the permit limits in SNI 1726-2019. The elastic deviation is then amplified into inelastic deviation by calculating $\Delta_x = \Delta_{xe} \times (C_d/I_e)$, resulting in a value of 28.809 mm. Deflections in ETABS can be checked by running an analysis and checking the behavior of the structure after being exposed to earthquake loads.

Furthermore, the results of the structural analysis show that due to the y direction earthquake load, the elastic deviation is 1.537 mm which also needs to be checked according to the permit limits in SNI 1726-2019. The elastic deviation is amplified into inelastic deviation by calculating $\Delta_y = \Delta_{ye} \times (C_d/I_e)$, resulting in a value of 5.876 mm. This process ensures that the portal structure can meet the requirements for resistance and safety against earthquake loads in both directions, both transverse and longitudinal.

Checking Deviations Between Permit Levels

The previously calculated deviation between levels needs to be compared with the deviation between permitted levels to ensure that the structure does not experience excessive deviation between levels. The checking results show that the deviation between levels of the structure is still below the permitted limit.

Table 4. Checking Deviations Between Permit Levels

	Δ (mm)	$0,02h_{sx}$ (mm)	Check
Transverse Direction Portal	28,809	180	OK
Longitudinal Direction Portal	5,876	180	OK

The influence of P-Delta on the structure needs to be taken into account in accordance with Article 7.8.7. SNI 1726-2019. The effect of P-Delta needs to be compared to the stability coefficient (θ) value calculated based on Equation 45 SNI 1726-2019. The stability coefficient value needs to be checked against the stability coefficient limit (θ_{max}) which is calculated based on Equation 46 SNI 1726-2019 and the P-Delta influence limit of 0.1.

In the calculation of the stability coefficient for the transverse direction portal, the total vertical design load (P) was 2377.9 kN, and the seismic shear force (Vx) was calculated as 337.9 kN. With a story height (hsx) of 9 m, a deflection enlargement factor (Cd) of 3, a deviation between stories (ΔX) of 28.809 mm, the stability coefficient (θ) is calculated using the equation θ=(Px×Δ×Ie)/(Vx ×hsx×Cd), yields a value of 0.0066.

To calculate the stability coefficient for the portal in the longitudinal direction, the parameters used are the same as the previous calculation, except for the deviation between levels (Δy) which is 5.876 mm. The calculation result θ=(Px×Δ×Ie)/(Vy×hsx×Cd) is 0.0013. The maximum stability coefficient limits for transverse and longitudinal direction portals are 0.1667 and 0.1538, respectively. Thus, the stability coefficient at each level, for both the x-direction and y-direction, meets the value limit (θmax) and the P-Delta influence limit of 0.1. Therefore, it can be concluded that the structure does not need to take into account the influence of P-Delta. The checking results show that the θ value for the transverse direction is 0.0066 (<0.1667) and for the longitudinal direction is 0.0013 (<0.1538).

Crane Structure Planning

In planning the runway beam crane structure, the availability of crane data is important. This includes the weight of the bridge crane, trolley and hoist, as well as the crane's lifting capacity. In this project, a steel girder box type single girder crane with a lifting capacity of 10 tons was used.

In this project, a steel girder box type single girder crane with a lifting capacity of 10 tons was used. Based on information obtained from related vendors, several data were obtained which were used as design references as follows:

Type of crane used = Cab-operated
Crane capacity, Plifted = 100 kN
Bridge crane weight, Pbridge = 110 kN
Weight of trolley and hoist, Pth = 8.4 kN
Maximum wheel reaction (without impact factor), Rmax = 78 kN
Rail weight, wrail = 0.5 kN/m
Weight of electrical machine and clamp, wclamp + electrical = 0.23 kN/m
Crane span = 30.0 m
Runway beam crane span, Lsp = 6.0 m
Distance between wheels, Swheel = 2.0 m
Vertical impact factor = 25%
Crane Service Class (CMMA) = A
Vertical allowable deflection = L/600
Horizontal allowable deflection = L/400

The bending strength required for a runway beam crane is defined using AISC.

Distance between wheels = Swheel = 2.0 m
Runway beam crane span, l = Lsp = 6.0 m
0.586*l = 3.5 m

Check whether a < 0.586l = OK

Deflections due to maximum wheel loads and lateral loads need to be checked against permissible limits. Checking the deflection can be done by clicking Show Deformed Shape on the top ribbon → Set the case you want to display → Set the displacement you want to display → Apply → OK. The load combinations used to check vertical and horizontal deflections are as follows:

Vertical Service Combination = 1 Dead + 1 Crane Dead + 1 Crane Live

Horizontal Service Combination = 1 Lateral Crane

Based on the analysis results, the maximum deflection that occurs due to wheel load is 9.039 mm. Meanwhile the horizontal deflection that occurs due to lateral loads is 0.263 mm. The deflection that occurs needs to be checked against the permitted limits. For vertical deflections, allowable deflections are limited to L/600 for Crane Service Class A. For horizontal deflections, allowable deflections are limited to L/400 for Crane Service Class A.

Table 5. Checking Clearance Deflections

	Δ (mm)	$\delta_{allowable}$ (mm)	Check
Vertical Deflection	9,039	10	OK
Horizontal Deflection	0,263	15	OK

Steel structure design regulations in Indonesia refer to SNI 1729-2020, an identical adoption of AISC 360-16. The following is a runway beam structure calculation for SNI 1729-2020.

In checking flange tension due to combined loads, the initial runway beam crane data includes parameters such as profile, steel quality, dimensions, moment of inertia, elastic section modulus, elastic modulus, and others. Checking is carried out on the thickness ratio to wing width and body width, as well as the lengths Lp and Lr. Next, the yield bending strength (plastic moment) calculation is carried out to ensure the capacity meets the requirements. Checking the stress ratio due to the LRFD crane combination is also carried out to ensure structural safety.

Checking the compression flange due to combined loads includes checking the ratio of thickness to flange width, calculating the yield bending strength, and checking the stress ratio due to the combination of LRFD cranes. Next, a check on the web sideways buckling was carried out to analyze the potential for buckling on the runway beam profile, with the results showing that web sideways buckling on the profile did not need to be checked.

Fatigue design for runway beams involves analysis of various components such as tension flanges, welds between web and flange, tiebacks, support stiffeners, intermediate stiffeners, channel caps, cap plates, cap plates on crane columns, laced crane girders or backing trusses, and rail moorings. Checking the bending stress on the tension flange is also carried out by involving the moment due to the live load and calculating the stress ratio based on the design requirements.

Next, details of the runway beam and column design supporting the crane load are presented. Checking the bending stresses in the tension flange due to combined loads ensures that the runway beam design meets safety requirements. An overall evaluation of the building considering critical locations for frame portals was also carried out, and the results showed that the structure could withstand the crane load with a stress ratio that met safety requirements.

CONCLUSION

In planning the structure of the factory building, critical steps have been taken, including determining earthquake risk categories and priority factors based on the function and use of the building. N-SPT data analysis assigned the site a medium soil class, and spectrum analysis results placed the structure in Seismic Design Category D (KDS D). The structural system was selected according to the SNI 1726-2019 standard, with a steel frame system with ordinary moment resistance and a steel frame system with ordinary concentric bracing. The structure period calculation shows the fundamental periods of approach and maximum for both directions. Response modification coefficients, overstrength factors, and deflection magnification factors are considered for both structural systems. The seismic base shear force is calculated using the equivalent static method, and the seismic response coefficients for both directions are also calculated and meet the specified limits. Checking of inter-story drift and P-Delta influence was carried out, and the results showed that the structure met regulatory requirements. Next, planning the runway beam crane structure involves load analysis and structural design using the equivalent static method and ETABS software. Runway beam structural design refers to SNI 1729-2020 and consists of checking tension flange, compression flange, web sideways buckling, and fatigue. Permissible deflection checks were also carried out, and the results showed that the structure complied with the allowable limits. In addition, the industrial building design includes a loading combination of the crane load, and the check results show that the structure can withstand the crane load with a stress ratio that meets safety requirements. The overall structural planning covers critical aspects such as earthquakes, crane loads, and deformation resistance, ensuring industrial building structures' safety and optimal performance.

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