Steel column planning using the American Institute of Steel Construction (AISC) 2010 method

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Abstract. The latest SNI rules for steel structure building has been published namely SNI 1729-2015 which refers to the AISC 2010. In AISC 2010, there is a new design method called Direct Analysis Method (DAM) as an alternative to the Effective Length Method (ELM). The aim of the study is to plan steel columns using the AISC 2010 method and calculate and also analyse the steel column capacity. In this study, ETABS computer analysis program that have been whole integrated includes the modelling, analysis and design were used, so as to produce safe and economical modelling, analysis and design. The results of trial and error showed that dimensions for the 1st and 2nd floor columns WF profile, 3rd and 4th floor columns used WF 250x250x9x14 profile, and the 5th floor column used WF 175x175x7.5x11 profile. The load that applied was only dead load and live load. ETABS analysis results obtained output in the column design in the form of axial force (P) 1688,971 kN, moment (Mux) 60,257 kN.m, moment (Muy) 23,009 kN.m. The calculation results of steel column design analysis using DAM method obtained the value of the ratio of the strengths of columns 1st and 2nd floors for 0.42, columns 3rd and 4th floors for 0.33 and the 5th floor for 0.15. The steel column material requirements for each 1st and 2nd floor are 352.66 kg, 2nd and 3rd floors are 271.35 kg, and the 5th floor is 150.75 kg. The design of steel columns by means of DAM results in a higher profile capacity, so that the profile designs used can be more economical.

1. Introduction

Column is a compressive structure element that plays an important role of a building, so the collapse in a column is a critical location that can cause the concerned floor collapse and also the total collapse of the entire structure. The latest SNI rules for steel structure building has been published namely SNI 1729-2015 which refers to the AISC 2010 [3]. There is a new design method called Direct Analysis Method (DAM) as an alternative to the Effective Length Method (ELM) [1]. The limitations in using first order with amplification factor or Effective Length Method make this method has begun to be abandoned by number of countries such as the British code, Australian code, Canadian code and Hong Kong code. AISC 2010 begun to adopt the mentioned codes, by using the Direct Analysis Method for second order analysis.

The aim of steel column design by using the AISC 2010 (American Institute of Steel Construction) method with Direct Analysis Method (DAM) is to see how much the value of column strength ratio in the DAM method, and also to analyse the capacity of the steel column by means of DAM. The planning of steel structure and designing steel column using the AISC 2010 method by means of DAM, for 5-storey building with a floor height of 4 m and floor height of two to fifth floor 3.75 m. The
building is planned to use Wide Flange (WF) steel with BJ-41 quality, which will be analysed using 2016 ETABS software.

The calculation results of analysis of column design using the AISC 2010 method using DAM obtained the value of the capacity ratio in the 1st and 2nd floor column is 0.42, 3rd and 4th floor column is 0.33, and the 5th floor column is 0.15. The steel column requirements for each 1st and 2nd floor are 352.66 kg; the 2nd and 3rd floors are 271.35 kg, and the 5th floor is 150.75 kg. In a different study conducted by Salmon et al. 2009, the different between the Direct Analysis Method (DAM) and Effective Length Method (ELM) was obtained by a difference of 7%. This shows that DAM column design results in a higher profile capacity than ELM column design, so that the profile design used can be more economical.

2. Literature review

2.1. Steel
Generally, the steel construction contains more than 98% iron and usually less than 1% carbon. Although the actual chemical composition varies for desired properties, such as strength and resistance to corrosion, steel can also contain other alloying elements, such as silicon, magnesium, sulphur, phosphorous, copper, chrome, and nickel in various amounts [14]. The mechanical properties of structural steel planning are set as follows:
- Modulus of elasticity (E) = 200.000 MPa
- Shear modulus (G) = 80.000 MPa
- Poisson’s ratio (μ) = 0.3
- Coefficient of expansion (α) = 12 x 10^-6 / °C

2.2. AISC regulations for steel column design
The basic rule for compressive rods are explained in Chapter E3-1 until E3.4-Design of Members for Compression [1]. Nominal compressive strength, Pn, is the smallest compressive strength for bending, torque bending and bend torque-bending conditions which depends on the shape of the column cross section as follow:

\[ P_n = F_{cr} A_g \]  
(1)

where \( P_n \) is smallest compressive strength for bending, \( F_{cr} \) is critical buckling stress, and \( A_g \) is column area. The \( F_{cr} \) can be searched based on the column compressive strength curve which is a function of slenderness. The critical buckling stress curve of the column formula, specifically bending only, is:

For \( KL/r \leq 4.71 \sqrt{E/Fy} \) or condition of column in-elastic buckling

\[ F_{α} = \left( 0.658 \frac{f_y}{f_e} \right) . F_y \]  
(2)

\( \alpha \leq 4.71 \sqrt{E/Fy} \) or condition of the columns with in-elastic buckling

\[ F_{cr} = 0.877 F_e \]  
(3)

where \( F_e = \text{strength of elastic critical buckling} \)

\[ F_e = \frac{\pi^2 E}{(KL/r)^2} \]  
(4)

The three formulas above for the AISC (2005) or (2010) version are the same. So if it is only based on the critical buckling stress of the column, which also directly is the compressive strength of the column, singly or individually or isolated, between the old methods (Effective Length Method) and the new one (Direct Analysis Method), then there is no difference between it. Identical are the same.
2.3. Direct Analysis Method (DAM)
Steel structure planning that is generally slim, requires stability analysis. The result is influenced by the presence of imperfection (nonlinear geometry). Direct Analysis Method (DAM) as a new way of planning on steel structure that has incorporated modern principles in stability analysis [1].

2.4. Stability design
DAM is needed to overcome the limitations of elastic structure analysis, which cannot access the stability. By using DAM, the influence of structural loading can be sought by calculating the influence of the imperfection (nonlinear geometry) and inelastic (nonlinear material) that occurs.

2.5. Notional load and inelastic attenuation
Notional loads can also be used to anticipate the weakening of flexural stiffness, \( \tau_b \) due to in-elastic conditions because of residual stresses. This strategy is suitable to simplify the calculation of DAM on the stem with a large compressive force \( \alpha Pr > 0.5 Py \), where the value \( \tau_b < 1.0 \). Based on the AISC 2010 Chapter C2.3.3, then \( \tau_b = 1.0 \) and additional notional load of:

\[
Ni = 0.001 Yi
\]

Information:
\( Ni \) = notional load used at the level \( i \), kips (N)
\( Yi \) = gravity load used at level \( i \) of the load combination, as appropriate, kips (N)

2.6. Nominal cross section strength
If a structural stability using the DAM method is used, then for calculating the nominal structural strength is sufficient to use the usual procedure as used in the ELM method, called Chapter E ~ I for nominal cross-section, or Chapter J ~ K for connection on AISC code (2005 or 2010), except the value of the \( K \) on the slenderness of the stem (KL/r) is taken constant at \( K = 1 \).

3. Research methods
3.1. Structure analysis
The structure analysis of this final project proposal uses the help of a computer program, the 2016 ETABS program.

3.2. The planning stages
The initial dimensions of the secondary structure planning will be used as input to plan the primary structure (main beams and columns) of ETABS 2016. The preparation stage, preparation was made to find the data and information that supported the structure design. The structural analysis of the structural model with the help of ETABS 2016 to determine the magnitude of the value of joint displacement, moment, shear force, and the compressive or tensile forces on the portal structure against the working load (external loads and gravity loads).

3.3. Research object and location
The research object of this study was the design of steel column structure, multi-story buildings (five floors), which were planned to be built in Banda Aceh.

3.4. Building plan data
Function : Office building
The main structure : Steel
Number of floor : Five floors
Steel material data
Column profile : Profile WF (BJ 41)
fy = 250 Mpa; fu = 410 Mpa
Beam profile: Profile WF (BJ 41) fy = 250 Mpa; fu = 410 Mpa
Modulus steel elasticity (E): 200000 MPa

Reinforced concrete material data
a. Concrete quality (f’c): 25 Mpa
b. Quality of reinforcing steel: BJTD 400 Mpa
   - BJTP 240 Mpa

3.5. Secondary structure planning
In this study, the secondary structure planning is only floor plates, roof plates and sliding connectors. For beam planning, using WF 150x150x7x10 profile without using joists.

3.6. Floor and roof plates
The thickness of the concrete slab according to equation 2.1 for the minimum slab thickness, the thickness of the roof plate is planned to be 100 mm, while the thickness of the floor plate is planned to be 120 mm.

3.7. Beam planning
The beam is planned to use the WF 150x150x7x10 profiles, with the data below:

|        |        |
|--------|--------|
| H = 150 mm | Weight = 31.50 kg/m |
| B = 1500 mm | A = 4014 mm² |
| t₁ = 7 mm | Iₓ = 1640 cm⁴ |
| t₂ = 10 mm | Iᵧ = 563 cm⁴ |
| r = 11 mm |        |

A beam bearing pure Mu’s factored bending load must be planned in such a way that the relationship is always fulfilled:

\[
\frac{Qn}{A} \leq \frac{f’u}{f'c} \leq \frac{K}{A}
\]

3.8. Slide connecting planning
For sliding connector used is the nail type with ds = 19 mm, Terms:
The number of studs needed is 20 studs for the entire span. So, the shear connector is installed with a distance of 20 m by 20 pieces for each span.

3.9. Dead load
The dead load calculated on a steel structure is the structure’s own weight and the planning dead load. Dead load structure calculation is done automatically with ETABS program and plan dead load is done manually. In the cross section of the column assumed that at the end it is considered pinch-pins.

3.10. Live load
The live load used is in accordance with SNI 2013 loading regulations as follows:

| Floor     | Load (KN/m²) |
|-----------|--------------|
| Office    | 2.40         |
| Corridor  | 3.83         |
| Meeting   | 4.79         |
| Computer  | 4.79         |
| Reading   | 2.87         |
3.11. Lead combinations
Strong needs $U$ to hold the dead load $D$ in this plan, namely:

$$U = 1.4D + 1.4SW$$

Strong needs $U$ to hold dead load $D$ and live load $L$, namely:

$$U = 1.2D + 1.6L + 1.2SW$$

3.12. Structural modelling
Modelling structure is done to make it easier to analyse the overall structure to be analysed. Structural modelling includes structural drawings, planned material manufacturing, insertion of dead and live loads and a combination of loading.

3.13. Column design
Cross section planning of the column is calculated based on the rod bending moment, shear force and maximum factored load produced by a loading combination.

4. Results and discussions

4.1. Steel analysis and column design
Using the force outputs from the ETABS program analysis a column will be planned for each floor. In this case, what is being examined is the design of steel columns using the AISC 2010 method by means of Direct Analysis Method (DAM) which will simplify the steel planning structure buildings. The maximum internal forces that occur for each floor can be seen in the Table 1.

| Story | P     | M2  | M3  | V2  | V3  |
|-------|-------|-----|-----|-----|-----|
|       | kN    | kN-m| kN-m| kN  | kN  |
| 1     | 1688.971 | 17.032 | 7.010 | 5.500 | 12.971 |
| 2     | 1318.823 | 60.257 | 23.009 | 13.286 | 33.427 |
| 3     | 928.535  | 41.079 | 17.247 | 9.081  | 22.802 |
| 4     | 531.795  | 55.834 | 22.446 | 13.398 | 32.260 |
| 5     | 133.407  | 19.408 | 10.173 | 6.037  | 10.068 |

The analysis results of the largest axial force occurred in column C17 on the 1st floor, showed that the largest moment and shear force occurred in column C17 on the 2nd floor, differences in the internal force variations that occur due to the differences in the steel profile used and the load work are not the same in every floor. While the axial force is caused by the 1st floor bears all the burden of the entire floor, so that the largest axial force occurs on the 1st floor.

Based on the calculation results of steel column analysis using DAM, the ratio capacity on the 1st and 2nd floors are 0.4, the 3rd and 4th floors are 0.33, and the 5th floor is 0.15. The smaller the ratio value on each floor due to the smaller steel profile used for the above floor, this is done to produce a more economical plan in accordance with the burden of working on the planned structure.

4.2. Steel column material requirements
From the trial and error results obtained an economical profile size for 1st and 2nd floors profile is WF 300x300x10x15, 3rd and 4th used WF profile 250x250x9x14, and the 5th floor used WF profile 175x175x7.5x11. To determine the steel column requirements for each floor, the steel column material requirements calculation is as follows.
For 1st and 2nd floors
WF 300x300x10x15,
As = 119.80 cm²
Steel weight = 119.80 x 10⁴ x 3.75 x 7850 kg/m³ = 352.66 kg
For 3rd and 4th floors.
WF 250x250x9x14
As = 92.18 cm²
Steel weight = 92.18 x 10⁴ x 3.75 x 7850 kg/m³ = 271.35 kg
For 5th floor
WF 175x175x7.5x11,
As = 51.21 cm²
Steel weight = 51.21 x 10⁴ x 3.75 x 7850 kg/m³ = 150.75 kg

With the data’s previously calculated obtained steel material requirements, material requirements for each column are shown in Table 2 and Table 3:

Table 2. Recapitulation of the column material requirements

| No | Story | Column Profile | As Cm² | Steel kg |
|----|-------|----------------|--------|----------|
| 1  | WF 300x300x10x15 | 119.80 | 352.66 |
| 2  | WF 300x300x10x15 | 119.80 | 352.66 |
| 3  | WF 250x250x9x14 | 92.18 | 271.35 |
| 4  | WF 250x250x9x14 | 92.18 | 271.35 |
| 5  | WF 175x175x7.5x11 | 51.21 | 150.75 |
|    | Total Volume |        | 1398.77 |

Table 3. Maximum story displacement

| Story | Elevation | Location | X-Dir | Y-Dir |
|-------|-----------|----------|-------|-------|
|       | m         | mm       | mm    |
| Story5| 19        | Top      | 0.062 | 0.072 |
| Story4| 15.25     | Top      | 0.103 | 0.127 |
| Story3| 11.5      | Top      | 0.075 | 0.1   |
| Story2| 7.75      | Top      | 0.049 | 0.073 |
| Story1| 4         | Top      | 0.048 | 0.039 |
| Base  | 0         | Top      | 0     | 0     |

Based on the table, graphs are made so that it can be seen more clearly displacement that occurs in combinations 1 for each floor
Based on the Figure 1, it can be seen that the X direction displacement tends to be smaller than the Y direction. The biggest displacement occurs in the Y direction of 0.127246 mm on the 4th floor as shown in Table 4.

**Table 4. Maximum story displacement**

| Story  | Elevation | Location | X-Dir | Y-Dir |
|--------|-----------|----------|-------|-------|
| Story5 | 19        | Top      | 0.082 | 1.372 |
| Story4 | 15.25     | Top      | 0.1   | 1.179 |
| Story3 | 11.5      | Top      | 0.075 | 0.553 |
| Story2 | 7.75      | Top      | 0.042 | 0.283 |
| Story1 | 4         | Top      | 0.04  | 0.16  |
| Base   | 0         | Top      | 0     | 0     |

**Figure 1.** Maximum story displacement in combination 1
From the Figure 2 above can be seen that the largest displacement on the 5th floor is 1.7 mm Y direction. Based on the analysis results of steel column design using the AISC 2010 method using DAM, the capacity ratio in the 1st and 2nd floors are 0.4, the 3rd and 4th floors are 0.33 and the 5th floor column is 0.15. The steel column material requirements for each floor are as follows:

Floors 1-2 = 352.66 kg steel
Floors 3-4 = 271.35 kg steel
Floor 5 = 150.75 kg steel

5. Conclusion
In a different study conducted by Salmon et al. 2009, the difference between the Direct Analysis Method (DAM) and Effective Length Method (ELM) was obtained by a difference of 7%, so that the profile design of the DAM method was more efficient compared to ELM method.

In different studies for different buildings, when viewed from the forces that occur, the weight of the building and displacement, composite columns tend to resemble steel columns. However, composite columns have advantages compared to steel columns in terms of price. Based on the analysis results of steel column design using the AISC 2010 method using DAM, the capacity ratio in the 1st and 2nd floors are 0.4, the 3rd and 4th floors are 0.33 and the 5th floor column is 0.15.

The steel column can be chosen for high-rise building plan, because steel has high strength compared to other materials. The existence ductility in steel makes steel construction cannot collapse suddenly when there is excessive load, this is very beneficial if the buildings experiences sudden large swings like earthquake loads.

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