STRUCTURAL STEEL ANALYSIS DESIGN OF COMMERCIAL FACTORIES FOR LOADING AND EARTHQUAKE RESISTANCE

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ABSTRACT

In the university my courses According to the widely used of "Steel buildings" in these days which taught us to analyze and design this flooring system that can achieve the requirements of this structure. Also use several programs like (ETAB, SAP, ROBOT & TEKLA etc), beside that I used different combinations for earthquake resistance. It analysis and design according to the eurocode AISC 14.0, in addition to that I used the program of Autodesk Robot Structural, AUTO CAD 2013 & Tekla Structure. while I have many components I used that program to help me for designing, by include the loads as input, then I got different diagrams and diameters for each part.

Keyword : Steel connection & Loading

INTRODUCTION

Most design tasks in structural engineering are based both on theoretical models and empirical evidence. The theory is developed into a design procedure, and this procedure is carried out and tested. The results of these tests are then used to formulate new and more accurate analysis procedures. So, to some extent, this is an iterative process. Centuries of experience with building structures as well as new developments in analytical procedures have led to a greater understanding of how structures work. This is especially true in the area of connections in structures. There is a fairly high degree of uncertainty in the behavior of connections, which makes their analysis and design difficult, and makes experimental verification so important. Many of the elements of the connections have variability in their properties, which, when analyzed together, further increase the uncertainties in the connection. The consequence of this is that careful and accurate design of connections can be crucial to the design of the structure. This thesis attempts to understand and compare various types of connections in structural steel buildings, including both the modeling theory of connections as well as the physical components of connections.

Formulation Of The Problem

1. How to make the building earthquake resistant?
2. How to make the building static and how to make the building economic and construction products relevant for steel structures?
3. Why we will use claddings working in one-way (horizontal) direction and an analyzed?

AIM

1. Agree exactly what a project is meant to do and what it is meant to deliver.
2. Agree the design, timescale, analysis and design and quality of project.
3. Understand and apply methods and approaches adopted by the code regarding the analyzed structure.
4. Comprehend the method of designing steel structures.
5. Establish a link between analysis of structures and the design process.
6. Enhance applying computer package programs such as: ROBOT, AUTOCAD, TEKLA and Microsoft office to determine the calculation process and obtain the required results.
7. Understand the exact and suitable ways to analyze and design.
8. Prepare myself for work environmental to be an engineer.

LITERATURE REVIEW

Design of Bolted Connections with Injection Bolts

- Design rules for static loading

As of now demonstrated previously, injection bolts might be non-preloaded load move through bearing and shear of the bolt and furthermore preloaded load move through bearing and shear of the bolt and through grinding between the associated plates. The ECC proposals give design rules for both types of shear connections.

- Bearing and shear:

The plan extreme shear load shall not surpass the plan shear opposition of the bolt nor the plan bearing obstruction of the resin.

Serviceability limit state:

\[ F_{b.Rd.ser.resin} = \frac{1.0 \cdot K_s \cdot d \cdot t \cdot \beta \cdot f_b.resin}{\gamma_{Ms.ser}} \]

Ultimate limit state:

\[ F_{b.Rd.ult.resin} = \frac{1.2 K_s \cdot d \cdot t \cdot f_b.resin}{\gamma_{Ms.ult}} \]

Shear resistance of the bolt (Eurocode 3, 1992), shear plane through through the shank of the bolt).

\[ F_{v.Rd} = \frac{0.5 f_{ub} A_s}{\gamma_{Mb}} KN \]

Design Methods for support and Bracing Connections

Accidental activities:

- Drifted snow decided utilizing Annex B of BS EN 1991-1-3 (see Section 3.3.3).
- Opening of a prevailing opening thought to be closed. Robustness requirements of BS EN 1991-1-7 and its National Annex

Combination

| Action                                                                 | \( \Psi_0 \) | \( \Psi_1 \) |
|------------------------------------------------------------------------|--------------|--------------|
| Impressed loads on buildings, category (see EN 1991-1-1)               | 0.7          | 0.5          |
| Category A: domestic, residential areas                                | 0.7          | 0.5          |
| Category B: office areas                                               | 0.7          | 0.7          |
| Category C: congregation areas                                         | 0.7          | 0.7          |
| Category D: shopping areas                                             | 0.7          | 0.7          |
| Category E: storage areas                                              | 1.0          | 0.9          |
| Category H: roofs                                                     | 0.7          | 0.0          |
| Snow loads on buildings (see EN 1981-2)                               | 0.70         | 0.50         |
| - for sites located at altitude H > 1 000m a.s.l.                     | 0.70         | 0.50         |
| - for sites located at altitude H > 1 000m a.s.l.                     | 0.50         | 0.20         |
| Wind loads on buildings (see EN 1991-1-4)                             | 0.5          | 0.2          |
| Temperature (non-fire) in buildings (see EN 1991-1-5)                  | 1.0          | 0.5          |


Serviceability limit state

\[ \sum_{j>1} G_{i,j} + Q_{i,j} \sum_{j>1} \Psi_{i,j} Q_{k,i} \]

Table 2. Suggested limits for vertical deflections

| Type of Structure | Suggested Limit |
|-------------------|-----------------|
| Cantilevers       | Length 180      |
| Beams carrying plaster or other brittle loads | Span 360 |
| Other beams (except purlins and sheeting nails) | Span 200 |
| Purlins and sheeting nails | To suit the characteristics of the particular cladding |

Loading to the Eurocodes:

Table 3. Suggested limits for horizontal deflections:

| Type of Structure | Suggested Limit |
|-------------------|-----------------|
| Tops of columns in single-story buildings, except portal frames | Height 300 |
| Columns in gateway frame structures, not supporting crane runways | To suit the qualities of the specific cladding |
| In every story of a structure with more than one story | Height of that story 300 |

Connections

Connections are initially assumed as pins, thereby implying that the centroidal axes of all members intersecting at a node point are coincident. Practical considerations frequently dictate otherwise, and it is quite common for member axes to be eccentric to the assumed node for reasons of fit-up and the physical constraints that are inherent in the truss structure. Such eccentricities induce secondary bending stresses of the node points, which must be accounted for not only by local bending and axial load checks at the ends of all constituent members, but also in connection design. Typical truss joints are illustrated. It is customary to calculate the net bending moment at each node point due to any eccentricities, and proportion this moment to each member connected to the node in relation to member stiffness.

Portal frames

By far the most common structural form for single-storey buildings is the portal frame. Various configurations of portal frame

Table 4

| Section 4.6 | Preliminary design of portal frames |
|-------------|------------------------------------|
| Section 4.7 | Bracing                             |
| Section 4.8 | Design of portal frames to BS EN 1993-1-1 |
Bracing
Bracing is required to resist lateral loads, principally wind loads, and the destabilising effects of the imperfections defined in Section 5.3 of BS EN 1993-1-1

**Bracing at plastic hinges:**

\[ Q_m = 1.5a_m \frac{N_{f,Ed}}{100} \]

**First-order and second-order analysis**

For portal frames with shallow roof slopes, provided that the axial compression in the beams or rafters is not significant and \( a_s, 2 > 0 \), the ‘amplification factor’ can be calculated according to:

\[ \left( \frac{1}{1 - 1/a_{cr}} \right) \]

**Secondary beams:**

Table 5. Beams as secondary beams (IPE/HE sections in S355 steel) of sizes

| Cellular beam | Maximum span |
|---------------|--------------|
| Opening diameter (mm) | 12 | 12.5 | 15 | 16.5 | 18 |
| Beam depth (mm) | 300 | 350 | 400 | 450 | 500 |
| Top chord | IPE 360 | IPE 400 | IPE 400 | IPE 400 | IPE 450 |
| Bottom chord | HE 260 A | HE 260 A | HE 300 A | HE 360 B | HE 40 M |

Table 6. Composite cellular beams as secondary beams (UC sections in S355 steel) of sizes

| Cellular beam | Maximum span |
|---------------|--------------|
| Opening diameter (mm) | 12 | 13.5 | 15 | 16.5 | 18 |
| Beam depth (mm) | 415 | 450 | 460 | 605 | 625 |
| Top chord | 355 UC 54 | 355 UC 67 | 355 UC 67 | 457 UC 82 |
| Bottom chord | 254 UC 80 | 355 UC 54 | 355 UC 137 | 356 UC 153 | 356 UC 267 |

**Tension members**

tension member (or tie) transmits a direct tensile force

\[ N_{pl,Rd} = \frac{A_f}{Y_{M0}} \quad , \quad N_{u,Rd} = \frac{0.9A_{net}f_u}{Y_{M2}} \]

**Columns and struts**

Members subject to compression are typically referred to as either columns

\[ N_{cr} = \frac{A_f}{N_{cr}} \quad , \quad N_{cr} = \frac{\pi^2 E I}{L_{cr}^2} \]

**Column buckling resistance**

Is a function of its slenderness, its material strength, cross-sectional shape and method of manufacture. Using BS EN 1993-1-1, column buckling resistance

\[ N_{pl,Rd} = \frac{\chi M_f}{Y_{M1}} \quad \text{for class 1, 2 and 3 sections}, \]

\[ N_{b,Rd} = \frac{\chi A_{eff} f_y}{Y_{M1}} \quad \text{for class 4 sections} \]

buckling reduction factor defined

\[ \chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \lambda^2}} \leq 1.0 \]
\[ \Phi = 0.5 \left[ 1 + a \left( \lambda - 0.2 \right) + \lambda^2 \right] \]

**Table 7. Imperfection factors a**

| Buckling curve | a | b | c | d |
|----------------|---|---|---|---|
| Imperfection factor | 0.13 | 0.21 | 0.34 | 0.49 | 0.78 |

**Beams**

Beams are possibly the most fundamental type of member present in a civil engineering structure.

**Table 8**

| Beam type | Span range (m) | Notes |
|-----------|----------------|-------|
| Angles    | 1-6            | Used for roof purlins, sheeting nails, etc. where only light loads have to be carried. |
| Cold-formed sections | 2-8 | Used for roof purlins, sheeting nails, etc. where only light loads have to be carried. |
| Rolled sections: UBs,PBEs, UCs, Hrs | 1-30 | Most frequently used type of section; proportioned to eliminate several possible modes of failure. |
| Open web joints | 4-40 | Perforated with angles or tubes as chords and round bars for the web diagonals, used in place of rolled sections. |
| Cellular beams | 6-60 | Used for long spans and/or light loads. Depth of rolled section increased by 50%; web openings may be used for services etc. |
| Compound sections | 5-30 | Used when a single rolled section would not provide sufficient resistance. |
| Plate girders | 10-100 | Made by welding 3 plates, often automatically, with web depths up to 3-4 m; may need stiffening - see Chapter 19. |
| Trusses | 10-100 | Fabricated from angles, tubes or if spanning large distances, rolled sections - see Chapter 20. |
| Box girders | 15-200 | Fabricated from plate, usually stiffened; used for overhead travelling cranes and bridges due to good torsional and transverse stiffness properties. |

**S355 steel:**

All but 1 Universal Beams are Class 1 (1 is Class 2). All but 6 Universal Columns are Class 1 (3 are Class 2, 3 are Class 2,3 are 3).

\[ M_{c,Rd} = \frac{W_{pl}f_y}{\gamma_{M0}}, \quad M_{c,Rd} = \frac{W_{el}f_y}{\gamma_{M0}} \]

\[ \varepsilon = \sqrt{\frac{235}{f_y}} \]

Determination of beam slenderness \( \bar{\lambda}_{LT} \)

Hence, lateral torsional buckling resistance \( M_{b,Rd} \) is given by:

\[ M_{b,Rd} = \frac{x_{LT}W_{pl}f_y}{\gamma_{M1}} \]

\[ M_{cr} = C_1 \frac{\pi^2 E I_z}{I_{cr}^2} \sqrt{\frac{I_w}{I_z} + \frac{I_{cr}^2 G I_t}{\pi^2 E I_z}} \]

**Bolted connections**

For many years, riveting was the accepted method used for connecting the members of steel structures.
Table. 9

| Bolt Diameter | Standard (Dia) | Oversize (Dia) | Short-slot (width X Length) | Long slot (width X Length) |
|---------------|----------------|---------------|-----------------------------|---------------------------|
| 1/2           | 9/16           | 5/8           | 9/16 11/16                  | 9/16 11/14                |
| 5/8           | 11/16          | 13/16         | 11/16 7/8                   | 11/16 9/16                |
| 3/4           | 13/16          | 15/16         | 13/16 11/16                 | 13/16 11/16               |
| 7/8           | 15/16          | 1 1/16        | 15/16 11/16                 | 15/16 11/16               |
| 1             | 1 1/16         | 1 1/4         | 1 1/16 11/16                | 1 1/16 11/16              |

Bearing-Type connections (Bearing strength):

- If deformations around bolt holes is a design consideration (that is, if we want deformations to be ≤0.25 in), that
  \[ R_n = 1.2 l_c F_{u} \leq 2.4 d t F_{u} \]

- If deformation around bolt holes is not a design consideration (that is, if deformations > 0.25 in are acceptable)
  \[ R_n = 1.5 l_c F_{u} \leq 3.0 d t F_{u} \]

- For bolts used in connections with long-slotted holes, the slots being perpendicular to the forces.
  \[ R_u = 1.0 l_c t F_{u} \leq 2.0 d t F_{u} \]

RESEARCH METHODOLOGY

Type of use – residential building;
Span – L=6m;
Bay – B1=6m, B2=6m;
1. Building size: 337.9 m²
2. Total plot area = 425.1 m²
3. Percentage of free space = 3 ~ 4%
4. Location in North Cyprus – Turkey – Near East University.
5. Grade of concrete – C30 – S420, S220 STIRRUBS (MPa)
6. Ground Floor height   400 cm.
7. Slab thickness   t=20 cm.
8. Type of column = W10x88
9. Type of Beam = W8x58
10. Type of slab beam = W8x40
11. Type of Purlin (1) = MC10x33.6
12. Type of Purlin (2) = L8x6x1
13. Type of Brace = PIPE10STD
14. Live load on slab = 3.0t/m² –
15. Dead load = 0.15t/m² –
16. Site located on Seismic Zone 2.

Scheme of the building is given on the following visualization:
Structural analysis
The structural model for the analysis was created in software ROBOT. Following input data is used for model consideration:

- Beams in plane xz are rigidly connected to the steel columns.
- The beams in plane yz are hinged at both ends. Releases for hinged connections are indicated in following directions: Ry, Rz.
- Elements defining bracing system are also hinged at both ends.
- Supports are pinned. Fixed directions of pinned support: Ux, Uy, Uz, Rz.
- Bracings in axis A1-A2, D1-D2, A3-A4, D3-D4 are represented by one bar per frame assuming that it will work in tension and compression.
- The concrete slab has a strong influence on the global stiffness of the structure. In ROBOT 3D model concrete slab was modeled by a horizontal bracing system, connected to main columns. Connection of these bracings are hinged.
- To identify the type of analysis which should be performed (1st or 2nd order) we calculate $a_{cr}$ for ultimate limit state combinations.

In all combinations $a_{cr} > 10$. Therefore, according to EN 1993-1-1 1st order elastic analysis should be performed.

MATERIAL:

ASTM A36 STEEL PLATE
CHARACTERISTICS
ASTM A36 plate is a low carbon steel that exhibits good strength coupled with formability. It is easy to machine and fabricate and can be securely welded.

A36 STEEL PLATE SIZES
3/16” – 28”

TYPICAL CHEMICAL PROPERTIES

| Table 10 |
|-----------------------|
| Carbon, Max %        | 0.026 |
| Manganese, Max %     | 0     |
| Phosphorus, Max %    | 0.04  |
| Sulphur, Max %       | 0.65  |
| Silicon, Max %       | 0.4   |
| Copper, Max %        | 0.20  |
ASTM A36 BEAM
ASTM A36 beam is an intermediate tensile strength carbon steel that is easy to form, machine and weld

✓ TYPICAL MECHANICAL PROPERTIES

| Property            | Value |
|---------------------|-------|
| Tensile Strength ksi| 58-80 |
| Yield Point ksi     | 36    |

ASTM A36 CHANNEL
ASTM A36 is a hot-rolled, low-alloy carbon steel that exhibits good tensile strength. Its properties include ductility, ease of machinability and welding.

SIZES

Depths: 0.5" thru 18"
Flange Widths: 0.125" thru 5"

TYPICAL MECHANICAL PROPERTIES

| Property            | Value   |
|---------------------|---------|
| Yield Point ksi, min| 36 min  |
| Tensile Strength ksi| 58-80   |
| % Elong. 2" Bend    | 23      |

Table 13. Flowchart Of Project

![Flowchart Of Project](image)
RESULTS AND DISCUSSION

Structural analysis

- Beams in plane xz are rigidly connected to the steel columns.
- The beams in plane yz are hinged at both ends. Releases for hinged connections are indicated in following directions: Ry, Rz.

| Table .14                           | Limit values |
|-------------------------------------|--------------|
| beam-to-column                      | W8x58 - W10x88 0.26 |
| beam-to-beam                        | W8x58 - 0.98   |
| beam-column (web) connection        | W8x58 - W10x88 0.54 |
| Fixed Column base design            | W10x88 0.87    |
| Bracing                             | PIPE10STD     |
| Horizontal deflection (δ)           | 2 2.4         |
| Horizontal deflection first floor (δ1)| 1.3 1.33      |
| Bolt bearing on the beam direction x| 2.50          |
|                                      | 0.69          |
| Bolt bearing on the beam direction z| 2.50          |
|                                      | 0.81          |

Bracings in axis A1-A2, D1-D2, A3-A4, D3-D4 are represented by one bar per frame assuming that it will work in tension and compression

Table .15

| Combination | $a_{cr}$ (mode 1) |
|-------------|-------------------|
| 1           | 10.95             |
| 2           | 10.95             |
| 3           | 11.46             |
| 4           | 11.46             |
| 5           | 11.66             |
| 6           | 11.66             |

- Design of fixed beam-to-column connection (Frame knee connections)

Weakest component:
BOLT RUPTURE
Remarks
The thickness of bracket web is less than the thickness of beam web
8 [mm] < 13 [mm]
The thickness of bracket flange is less than the thickness of beam flange
12 [mm] < 21 [mm]

Table . 16

|                       |             |
|-----------------------|-------------|
| Beam resistances      | 0.01        |
| Column resistances    | 0.14        |
| Connection resistance for compression | 0.07 |
| Connection resistance for bending | 0.26 |
| Connection resistance for shear | 0.02 |
| Weld resistance       | 24.30       |
|                       | 24.20       |
|                       | 12.15       |

Table . 17 SUMMARY TABLE OF FORCES

| Nr. | h  | $F_{LH}$ | $F_{LH}$ | $F_{LH}$ | $F_{LH}$ | $F_{LH}$ | $F_{LH}$ | $F_{LH}$ | $F_{LH}$ |
|-----|----|----------|----------|----------|----------|----------|----------|----------|----------|
| 1   | 132| 117.99   | 117.99   | 380.65   | 117.99   | 347.67   | 117.99   | 574.29   |          |
| 2   | 242| 111.50   | 117.99   | 380.65   | 117.99   | 347.67   | 117.99   | 574.29   |          |
| 3   | 142| 13.47    | 117.99   | 380.65   | 117.99   | 347.67   | 117.99   | 574.29   |          |
| 4   | 42 | 36.75    | 117.99   | 380.65   | 117.99   | 347.67   | 117.99   | 574.29   |          |
| 5   | 42 | 15.53    | 117.99   | 380.65   | 117.99   | 347.67   | 117.99   | 574.29   |          |

- Design of fixed beam-to-beam connection
  - Weakest component
  - FRONT PLATE – TENSION
  - Remarks

Distance of bolts from an edge is too small
20 [mm] < 20 [mm]
Bolts vertical spacing is too small.
35 [mm] < 37 [mm]
Table 18

| Force Type                      | Value |
|--------------------------------|-------|
| Beam resistance                | 0.00  |
| Connection resistance for compression | 0.03  |
| Connection resistance for bending | 0.98  |
| Connection resistance for shear | 0.00  |
| Weld resistance                | 97.03 |
|                                | 97.5  |
|                                | 48.52 |

SUMMARY TABLE OF FORCES
The remaining bolts are inactive (they do not carry loads) because resistance of one of the
connection components has been used up or these bolts are positioned below the Table 15

Table 19 center of rotation

| N | Fb (N) | Fd (N) | Fa (N) | Fb (N) | Fa (N) | Fd (N) |
|---|--------|--------|--------|--------|--------|--------|
| 1 | 117.89 | -      | -      | 117.89 | -      | 117.89 |
| 2 | 90.47  | -      | -      | 90.47  | -      | 90.47  |
| 3 | 63.35  | -      | -      | 63.35  | -      | 63.35  |
| 4 | 21.02  | -      | -      | 21.02  | -      | 21.02  |
| 5 | -      | -      | -      | -      | -      | -      |
| 6 | -      | -      | -      | -      | -      | -      |

- Calculation of the beam-column (web) connection

Remarks

Fig 5

Distance between plate horizontal edge and beam upper flange is too small
21 [mm] < 30 [mm]

Length of plate connecting the beam is too large
180 [mm] > 161 [mm]

Distance between bolt and edge of beam flange is too small
21 [mm] < 26 [mm]

Distance between bolt and plate horizontal edge is too small
20 [mm] < 20 [mm]
Weakest component: 
BASE PLATE – BENDING

Fig 6

Table . 21

CONCLUSION

Finally, I am going to summary what we have done in this project during the semester briefly:

1. Each student had his own dimensions of the construction then we learnt how to use ETAB program to design the buildings but I used ROBOT program instead of ETAB because I am familiar with ROBOT in addition both programs have the same functions after that we moved to another step which is putting the loads in the program (all the loads), after loading process we had learnt how to design the connection by using ROBOT program and we did so for our building actually it was sensitive step because the safety of construction depends on connection safety mainly

2. Then we used TEKLA program to draw the project after that we converted our drawings from TEKLA program to AUTOCAD program.

3. At the end, we had used four programs we got too much benefit from these programs and by finishing this project now we are qualified to work and design with a real projects but we still need more experience.
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