BUILDING STRUCTURE DESIGN OF ENGINEERING FACULTY
UNIVERSITAS MUHAMMADIYAH SURAKARTA
FOUR STORIES USING INTERMEDIATE MOMENT RESISTING FRAME (IMRF)

Arranged as One of Requirement to Finish Bachelor Study Program in Civil Engineering Department Engineering Faculty

by:

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D 100 122 006

CIVIL ENGINEERING DEPARTMENT
ENGINEERING FACULTY
UNIVERSITAS MUHAMMADIYAH SURAKARTA
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APPROVAL SHEET

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SCIENTIFIC PUBLICATION

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Abstrak
Jumlah mahasiswa teknik UMS meningkat dari tahun ke tahun, karena terbatasnya lahan maka UMS harus memperluas lahan gedung fakultas teknik. Oleh sebab itu, untuk menyelesaikan permasalahan tersebut direncanakan gedung fakultas teknik empat lantai menggunakan Sistem Rangka Pemikul Momen Menengah (SRPMM). Perencanaan struktur gedung mengacu pada peraturan terbaru yaitu SNI-1726:2012 (Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung Dan Non Gedung) dan SNI-2847:2013 (Persyaratan Beton Struktural Untuk Bangunan Gedung). Perencanaan gedung ini meliputi struktur atap, struktur plat (plat atap, plat lantai, tangga), dan struktur gedung utama (struktur atas dan struktur bawah). Gedung ini berlokasi di Surakarta dengan nilai faktor keutamaan gempa (Ie) adalah 1.5 (untuk gedung sekolah), faktor gempa (R) adalah 5 menggunakan metode dinamik. Menggunakan kualitas beton (f′c) 25 MPa, dan kualitas tulangan utama (fy) 400 MPa dan tulangan geser (fy) 240 MPa. Struktur utama direncanakan dengan dua tipe dimensi kolom dan balok. Ukuran kolom yaitu 800/800 mm dan 700/700 mm, sedangkan ukuran balok yaitu 400/600 mm dan 600/800 mm. Struktur bawah menggunakan pondasi tiang pancang dengan diameter 400 mm dan dalam 18 m, ukuran poer 3200x3200x1250 mm untuk 4 tiang, dan ukuran sloof adalah 450/250.

Kata Kunci: Perencanaan struktur gedung, Sistem Rangka Pemikul Momen Menengah (SRPMM), metode dinamik

Abstract
The number of UMS engineering student is increased year by year, due to limited space so that UMS have to enlarge the area of building faculty. Therefore, to resolve that problem, it will be designed engineering faculty building four floors using intermediate moment resisting frame (IMRF). This design of building structure refers to the latest published SNI-1726:2012 (Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung Dan Non Gedung) and SNI-2847:2013 (Persyaratan Beton Struktural Untuk Bangunan Gedung). The design of this building includes roof structure, slab structure (floor slab, stairs), and main structure (upper and under structure). This building is located in Surakarta with the value of seismic importance factor (Ie) is 1.5 (for building school), seismic factor (R) is 5 using dynamic method. Using concrete quality (f′c) 25 MPa, and main reinforcement quality (fy) 400 MPa and shear reinforcement (fy) 240 MPa. The main structure designed with two types of column dimension and beam dimension. Column dimension are 800/800 mm and 700/700 mm, while beam dimension are 400/600 mm and 600/800 mm. The bottom structure designed using a pile foundation diameter 400 mm with depth 18 m, poer dimension 3200x3200x1250 mm for 4 piles, and sloof dimension 450/250.

Keyword: Building structure design, intermediate moment resisting frame (IMRF), dynamic method
1. INTRODUCTION

1.1 Background
Muhammadiyah Surakarta University is the largest private university in Central Java Province with total active students 24,787 people. The number of students each year has increased especially in engineering students, causes in limited space that a major requirement for students. Therefore, Muhammadiyah Surakarta University have to improve facilities with engineering faculty building larger to accommodate all the activities of engineering students and UMS staff. Due to limited area, the building is not only one floor but four stories to meet space requirements.

Basically to construct a building with stories more than one is needed a designed structure, from roof structure till foundation. The strength of structure sustaining all kinds of loads (gravity and lateral) that work is an important factor in designing, particularly for earthquake loads Indonesia lies between Circum Pacific and Asiatic Tran meeting.

The main principle in designing of earthquake resistant buildings is increasing deficiency of structures against lateral load (sideways) which is generally inadequate.

From some of the problems that have been explained above, so in this final project, the writer designs an engineering faculty building with four floors using intermediate moment resisting frame (IMRF) which refers to the recent regulations in Indonesia

1.2 Problem Formulation
On the issues that have been outlined in the background, it can be some formulation of the problem as follows:

1) What is dimension of truss design?
2) What is dimension of slab and stairs design?
3) What is dimensions of the beams and columns were able to carry earthquake loads the work plan and the formation of the structural elements of the reinforcement beams and columns?
4) What is dimension of bottom structure (pile, poer, and sloof)?
1.3 Design Objectives

This final project has the objective to obtain the design of reinforced concrete structures UMS Engineering Faculty building an efficient and earthquake-resistant in accordance with Intermediate Moment Resisting Frame (IMRF) based on the latest standards regulations in Indonesia.

1.4 Design Benefits

1) The benefit for the writer is to deepen the knowledge of the structure, especially in designing of multi-story building earthquake resistant and efficient start from the beginning of the design process, mechanical analysis, to the design of reinforced concrete.

2) Benefits for the reader is to increase knowledge and references about the planning structure of Terraced Building resistant to earthquakes and efficiently with Intermediate Moment Resisting Frame (IMRF).

1.5 Scope of Design

1) Regulation

Regulations used in this planning as a basic reference in the calculation of the structure is as follows:

a) SNI 1727:2013, Minimum Expense for Designing Building and Other Structures.


c) SNI 2847:2013, Requirements for Structural Concrete Building.

2) General Specification

a) Structural of engineering faculty building 4 floors using intermediate moment resisting frame.

b) Calculation design of structure includes reinforced concrete (slab, stairs, beams, columns, foundations)

c) Specifications of materials are used:

   a) Quality concrete f'c = 25 MPa.

   b) The quality of steel fy = 400 MPa (BJTs main reinforcement).
c) The quality of steel \( f_y = 240 \text{ MPa} \) (BJTP shear reinforcement).

d) Initial column dimension 400x400 mm, initial beam dimensions 300x600 mm, as well as the dimensions of 200x400 mm joists and beams sloof 250x500 mm.

e) Column height of the floor \( \pm 0.00, \pm 3.5, \pm 8.50, \pm 12.60, \pm 16.60 \).

f) The foundation used is the pile foundation.

1.6 Literature Review

General Review

In analyzing or designing a structure needs to set criteria that can be used as a standard to determine whether the structure is acceptable under the desired function or for the purpose of a particular design (Daniel L. Schodek, 1992).

Raju et al. (2013) said that it is not the earthquake which kills the people but it is the unsafe buildings that is responsible for the wide spread Devastation. Keeping in view the huge loss of life and property in the recent Earthquakes, it has Become a hot topic worldwide and lot of research is going on to understand the reasons of such failures and learning useful lessons to mitigate the repetition of such Devastation. If buildings are built earthquake resistant at its first place (as is being done in developed countries like USA, Japan etc.) the Devastation the caused by the Earthquakes will be mitigated most effectively. The professionals Involved in the design / construction of such structures are structural / civil engineers, who are responsible for building earthquake resistant structures and keep the society at large in a safe environment.

Earthquake Resistant Building Structure

According to Subramani and Vasanthi (2016), three important aspects to be considered in the design of earthquake resistant structures are given below:

1. The structure should be ductile, like the use of steel in concrete buildings. For these ductile materials to have an effect, they should be placed where they undergo tension and thus are able to yield.

2. Apart from ductility, deformability of structures is also essential. Deformability of structures is also essential. Deformability refers to the ability of a structure to dispel or deform to a significant degree without collapsing. For this to happen, the structure should be well- proportioned, regular and tied together in such a way that there are no area of
excessive stress concentration and forces can be transmitted from one section to another despite large deformations. For this to happen, components must be linked to resisting elements.

3. Damageability is another aspect to be taken into consideration. This means the ability of a structure to withstand substantial damage without collapsing. To achieve this objective “minimum area which shall be damaged in case a member of the structure is collapsed” is to be kept in view while planning. Columns shall be stronger than beams for that purpose and it is known as strong column and weak beam concept.

**Structure Load**

In designing building structure, needed load analysis, from characteristic and value. Load is interpretation from structure design needed which is created. Fault in load designing or load implementation on calculation will conduct fatal fault on design result.

Load factor is used as safety value if there is a load that over from design, while combination of load is combination from several kind of load because it is predicted those load will be happened together. This things is regulated in SNI-1727-2013 as follows.

1. 1,4D
2. 1,2D + 1,6L + 0,5 (Lr or R)
3. 1,2D + 1,6 (Lr or R) + (L or 0,5W)
4. 1,2D + 1,0W + L + 0,5(Lr or R)
5. 0,9D + 1,0W
6. 0,9D + 1,0E
7. 1,2D + 1,0E + L

With:

- **D** = *Dead Load*
- **E** = *Earthquake Load*
- **L** = *Live Load*
- **Lr** = *Roof Live Load*
- **R** = *Rain Load*
- **W** = *Wind Load*
**Earthquake Load**

Generally earthquake load analysis can be conducted with two methods, there are static and dynamic method. Both of method is regulated in SNI-1726-2012. It’s about kind of permitted analysis based on structure kind, analysis procedure and its limitation.

1) **Static Method Earthquake Load Analysis**

Equivalent static method analysis is simplification method that assume the real earthquake load is dynamic load which is static load that does not change against time. Soil vibration due to earthquake that has certain acceleration changed become reaction force that is product of mass and acceleration (F = m.a). At static method, forced due to
earthquake is assumed as horizontal load that centralized at center of mass (floor structure). This method usually called equivalent static method or equivalent lateral force (ELF).

Figure 3 Lateral Load Equivalent Illustration (Static Equivalent)

2) Dynamic Earthquake Load Analysis (Response Spectrum)

Spectrum response method for earthquake calculation is calculation method that use dynamic principal with review maximum response (acceleration, velocity, displacement).

Figure 4 Response Spectrum Design

General requirement SNI-1726-2012. Several requirements for spectrum response dynamic analysis, there are:

a) Number of mode which is privy in calculation have total mass participating minimum is 90%.

b) Dynamic earthquake load must be scaled, so that obtained shear force of dynamic earthquake not less than 85% static earthquake (ELF).
c) Combination method between modes which is used is CQC method (Complete Quadratic Combination) if the difference vibration period is not more than 15%. If more than that, the SRSS method (Square Root of the Sum of Sum Squares) is used.

2. METHOD

2.1 Design Data

Design data for the calculation of the structure in this final project is as follows:

1. The building structure which is designed is an engineering faculty building with four stories in Sukoharjo district.
2. The height of the first floor is +3.5 m, the second floor is +5 m, while the height of the third floor is +4.1 m and the fourth floor is +4 m.
3. The specifications of the materials used are as follows:
   a) Quality concrete $f'_c = 25$ MPa.
   d) The quality of steel $f_y = 400$ MPa (BJTs main reinforcement).
   e) The quality of steel $f_y = 240$ MPa (BJTP shear reinforcement).
4. Thick slab taken 12 cm. The dimensions of the initial beam are 30/60 cm, the original dimension joist and beam sloof are 20/40 cm 25/50 cm, and the initial dimensions are 40/40 cm column.
5. Foundation types used are bore pile foundation.

2.2 Analysis Tools

In designing structure, a software computer application tool was used to facilitate the work. The software computer used is as follows:

1. SAP2000 v.15
2. AutoCAD 2012
3. Microsoft Office 2013

2.3 Standard Used

Designing structure in this final project refers to the regulations applicable standards in Indonesia related to planning the structure of the building. The rules used are as follows:


3. SNI 2847:2013, Requirements for Structural Concrete Building.

2.4 Design Stage

Stages of structure design in this final project is as follows.

![Building Structure Design Flow Chart](image)

Figure 5. Building Structure Design of Engineering Faculty Muhammadiyah Surakarta University Flow Chart

3) RESULT & DISCUSSION

This discussion explains about main structure that consist of slab, beam, and column calculation. Completed other result will be presented on the conclusion of this paper.

3.1 Portal

Calculation of building structure analysis against earthquake load is referring to SNI 03-1726-2012, where structure analysis of multilevel stories building is conducted by Response Spectrum Dynamic analysis method that must be meet several requirement as follows

a) Number of mode which is privy in calculation have total mass participating minimum is 90%.

Table 1 Participating Mass Ratio

<table>
<thead>
<tr>
<th>StepNum</th>
<th>Period</th>
<th>UX</th>
<th>UY</th>
<th>UZ</th>
<th>SumUX</th>
<th>SumUY</th>
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<tr>
<td></td>
<td>Unitless</td>
<td>Sec</td>
<td>Unitless</td>
<td>Unitless</td>
<td>Unitless</td>
<td>Unitless</td>
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<td>0.00027</td>
<td>0.00000</td>
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<tr>
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<td>0.88511</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.88538</td>
<td>0.89049</td>
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<tr>
<td>4</td>
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<td>0.00002</td>
<td>0.00000</td>
<td>0.00023</td>
<td>0.88540</td>
<td>0.89049</td>
</tr>
<tr>
<td>StepNum</td>
<td>Period</td>
<td>StepNum</td>
<td>Period</td>
<td>StepNum</td>
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<td>Sec</td>
<td>Unitless</td>
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<td>Unitless</td>
<td>Sec</td>
<td>Unitless</td>
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<td>5</td>
<td>0.11733</td>
<td>6</td>
<td>0.08892</td>
<td>7</td>
<td>0.07961</td>
<td>8</td>
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<td>0.00028</td>
<td></td>
<td>0.03833</td>
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<tr>
<td>9</td>
<td>0.07197</td>
<td>10</td>
<td>0.01061</td>
<td>11</td>
<td>0.00304</td>
<td>12</td>
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<td></td>
<td>0.93400</td>
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<td>0.94461</td>
<td></td>
</tr>
<tr>
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<td></td>
<td>0.96019</td>
<td></td>
<td>0.99833</td>
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</tr>
</tbody>
</table>

b) Dynamic earthquake load must be scaled, so that obtained shear force of dynamic earthquake not less than 85% static earthquake (ELF).

Table 2 Base Shear Force Modification Output

<table>
<thead>
<tr>
<th>Earthquake Load Type</th>
<th>Fx</th>
<th>Fy</th>
<th>85% Static X</th>
<th>85% Static Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>Eqx</td>
<td>Eqy</td>
<td>-21717.2</td>
<td>00</td>
</tr>
<tr>
<td>Dynamic</td>
<td>RSPx</td>
<td>RSPy</td>
<td>17373.68</td>
<td>128.075</td>
</tr>
<tr>
<td></td>
<td>101.58</td>
<td>17373.824</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Periods

<table>
<thead>
<tr>
<th>Mode</th>
<th>Periods (T)</th>
<th>ΔT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.401532</td>
<td>19.59%</td>
</tr>
<tr>
<td>2</td>
<td>0.322855</td>
<td>25.61%</td>
</tr>
<tr>
<td>3</td>
<td>0.240157</td>
<td>45.47%</td>
</tr>
<tr>
<td>4</td>
<td>0.130947</td>
<td>0.00%</td>
</tr>
<tr>
<td>5</td>
<td>0.130947</td>
<td>2.69%</td>
</tr>
<tr>
<td>6</td>
<td>0.127423</td>
<td>0.00%</td>
</tr>
<tr>
<td>7</td>
<td>0.12742</td>
<td>5.21%</td>
</tr>
<tr>
<td>8</td>
<td>0.120785</td>
<td>0.01%</td>
</tr>
<tr>
<td>9</td>
<td>0.120777</td>
<td>8.16%</td>
</tr>
<tr>
<td>10</td>
<td>0.11092</td>
<td>0.01%</td>
</tr>
<tr>
<td>11</td>
<td>0.110906</td>
<td>1.20%</td>
</tr>
<tr>
<td>12</td>
<td>0.109576</td>
<td>-</td>
</tr>
</tbody>
</table>

Description:

ΔT : Difference period / time vibration is calculated by ΔT = (T1 – T2) / T1 x 100% and so on.
Based on the calculations in Table VII.18 showed that the structure mode value more than 15% so that in this design is used mode combination of SRSS.

3.2 Design of Floor Slab

Determined limit requirement and slab span is the first step of slab designing. Then can be determined one way slab or two way slab also determined the thickness of slab. The next step is calculate the load that worked on the slab, consist of dead and live load which raises moment on the slab.

For the next is calculating reinforcement diameter and the space between slab reinforcement. From calculation result is obtained main reinforcement x direction D10-150 and y direction D10-150.

![Diagram of Floor Slab Reinforcement Detail](image)

Figure 6. Floor Slab Reinforcement Detail
3.3 Design of Stairs

Stairs calculation is divided in two parts, there are calculation of stair and bordes slab. Result of bordes slab is D13-300 with stirrup reinforcement dp8-150. While for stair slab is D13-300 with stirrup reinforcement dp8-150.

![Diagram of Stairs Reinforcement Detail](image)

Figure 7. Stairs Reinforcement Detail

3.4 Design of Beam

On The beam 600x800 mm with span 11 m, obtained $M_u^+ 80.529$ kNm, $M_u^- 537.530$ kNm and shear force $V_u 169.562$ kN. After calculated so obtained main reinforcement 6D22 on the left and the right support, reinforcement 4D22 on the field area and shear reinforcement or stirrup 2dp10-180 on plastic hinge area and 2dp10-190 outside plastic hinge. Calculation result can be seen on the table as follow:
### 3.5 Design of Column

On the column 800x800 mm is obtained $P_u$, $M_u$ value from program analysis SAP2000, $P_u = 2196.71$ kN, $M_u = 801.645$ kNm. From calculation, is obtained main reinforcement 16D22 and stirrup 2dp10 - 75 for support and field area. Detailing of column reinforcement can be seen on The Figure 8 as follow:

![Figure 8. Column Reinforcement Detail](image-url)
4. CLOSING

4.1 Conclusion

Roof Structure Design
Based on result of calculation analysis, obtained roof structure design as follows:

1. Purlin Profile that used is Lip Channel 100.50.20.3,2 with steel quality BJ 34, distance between purlin is 1 m.
2. Truss construction using steel profile 2L 50x50x5 with steel quality BJ 37, distance between trusses 3 m.
3. Connection of steel profile that used is bolt A307 type, diameter 1/4” (6.35 mm) with the number of installed bolt is 2x2

Slab Design

Table 5 Reinforcement of Roof Slab Design

<table>
<thead>
<tr>
<th>Slab Type</th>
<th>Slab Size</th>
<th>Thickness of Slab (mm)</th>
<th>Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2x4</td>
<td>100</td>
<td>D10 - 175</td>
</tr>
<tr>
<td>B</td>
<td>2x3</td>
<td>100</td>
<td>D10 - 175</td>
</tr>
<tr>
<td>C</td>
<td>4x4</td>
<td>100</td>
<td>D10 - 175</td>
</tr>
<tr>
<td>D</td>
<td>3x4</td>
<td>100</td>
<td>D10 - 175</td>
</tr>
<tr>
<td>E</td>
<td>3x3</td>
<td>100</td>
<td>D10 - 175</td>
</tr>
</tbody>
</table>

Table 6 Reinforcement of Floor Slab Design

<table>
<thead>
<tr>
<th>Slab Type</th>
<th>Slab Size</th>
<th>Thickness of Slab (mm)</th>
<th>Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2x4</td>
<td>120</td>
<td>D10 - 125</td>
</tr>
<tr>
<td>B</td>
<td>2x3</td>
<td>120</td>
<td>D10 - 125</td>
</tr>
<tr>
<td>C</td>
<td>4x4</td>
<td>120</td>
<td>D10 - 125</td>
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<tr>
<td>D</td>
<td>3x4</td>
<td>120</td>
<td>D10 - 125</td>
</tr>
<tr>
<td>E</td>
<td>3x3</td>
<td>120</td>
<td>D10 - 125</td>
</tr>
</tbody>
</table>

Main Structure Design using IMRF
1. Beam Dimension and Installed Reinforcement
Table 7 Dimension and Reinforcement of Beam

<table>
<thead>
<tr>
<th>Beam</th>
<th>Position</th>
<th>Main Reinforcement upper</th>
<th>Main Reinforcement under</th>
<th>Plastic hinge</th>
<th>Outside Plastic Hinge</th>
</tr>
</thead>
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<tr>
<td>400X600</td>
<td>Left Support</td>
<td>7D22</td>
<td>5D22</td>
<td>2dp10-125</td>
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</tr>
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<td></td>
<td>Field</td>
<td>2D22</td>
<td>2D22</td>
<td></td>
<td>2dp10-175</td>
</tr>
<tr>
<td></td>
<td>Right Support</td>
<td>7D22</td>
<td>5D22</td>
<td>2dp10-125</td>
<td></td>
</tr>
<tr>
<td>600X800</td>
<td>Left Support</td>
<td>6D22</td>
<td>4D22</td>
<td>2dp10-150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field</td>
<td>4D22</td>
<td>4D22</td>
<td></td>
<td>2dp10-175</td>
</tr>
<tr>
<td></td>
<td>Right Support</td>
<td>6D22</td>
<td>4D22</td>
<td>2dp10-150</td>
<td></td>
</tr>
</tbody>
</table>

2. Column Dimension and Installed Reinforcement

Table 8 Dimension and Reinforcement of Column

<table>
<thead>
<tr>
<th>Column Dimension</th>
<th>Longitudinal Rebar</th>
<th>Stirrup</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inside Plastic Hinge</td>
<td>Outside Plastic Hinge</td>
</tr>
<tr>
<td>800/800</td>
<td>16D22</td>
<td>2dp10 - 75</td>
</tr>
<tr>
<td>700/700</td>
<td>16D22</td>
<td>2dp10 - 150</td>
</tr>
</tbody>
</table>

Foundation Design

The bottom structure consists of pile foundation and sloof

1) The pile is used with a round diameter of 400 mm, a pole length of 9 m. The foundation depth of 18 m is divided into 2 segments

2) Poer is used with main reinforcement D25-100 on top and D25-100 on bottom position.

3) Sloof Dimension and Installed Reinforcement

Table 9 Dimension and Reinforcement of Sloof

<table>
<thead>
<tr>
<th>Sloof Dimension</th>
<th>Position</th>
<th>Longitudinal Rebar</th>
<th>Stirrup</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inside Plastic Hinge</td>
<td>Outside Plastic Hinge</td>
</tr>
<tr>
<td>450/250</td>
<td>Left</td>
<td>3D22</td>
<td>2dp10 - 75</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>2D22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>3D22</td>
<td>2dp10 - 75</td>
</tr>
</tbody>
</table>

4.2 Suggestion

1) In order to structure, architecture design takes effect also on building resistance against earthquake.

2) Building material choices are adjusted with availability on the market.

3) Column design rectangular section more economic than square section but it have complex analysis. Because simple formula is designed for square section.
4) Designing all of structure component that should match in real field condition.

BIBLIOGRAPHY


