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ANALYSIS OF THE SPACE FRAME STRUCTURE OF THE CILEUNGSI FLY OVER TOWER BOGOR REGENCY

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ABSTRACT

This research is part of the plan of the Bogor Regency government, especially Cileungsi District, in arranging the Cileungsi flyover which is currently filled with garbage and used as a shadow terminal, making the area look slum. The arrangement effort is made to create a comfortable, neat flyover that can become an icon of Bogor Regency. The research aims to produce a portal tower flyover design that is aesthetic, unique, sturdy, and meets the strength and stability standards of the structure according to local conditions. The analysis was carried out using SAP2000 software to model the three-dimensional space structure and identify the strength, stability, and deflection of the structure. The LRFD (Load Resistance Factor Design) method is used in calculating the bearing capacity of the structure. The results of the analysis show that the space frame structure made of steel pipes has stable and rigid behavior, meeting all work loads, including dead loads, live loads, wind, and earthquakes. The design of the 13-meter deep pile foundation has also been proven to be able to withstand loads safely. The design of the space frame structure made of steel pipes for the Cileungsi flyover portal tower is declared strong, stable, and safe to implement. This structure can be used as a new icon for Bogor Regency, especially Cileungsi District. The implementation of this design requires detailed depiction as a construction guideline in the field.

KEYWORDS *Space FRame, Flyover, the balls, steel pipes*

INTRODUCTION

This research activity is part of the Bogor Regency government's plan, especially the Ciluengsi sub-district government, in the context of handling and

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arranging the Ciluengsi flyover or flyover (Rustiadi et al., 2021). Currently, the chaos of the Cileungsi flyover can be seen from the large number of piles of garbage, becoming a shadow terminal for public transportation, which makes the area a slum in the Cileungsi District area.

To make the flyover comfortable, smooth and neat, it is necessary to have an integrated arrangement and handling, between several stakeholders and related agencies (Abd El Gawad et al., 2019; J. Wang et al., 2022). The arrangement and management includes several fields of science such as lancsape planning, traffic engineering, lighting arrangement, social studies and portal tower construction, one of the reviews in the field of civil engineering is from the side of the design of the Fflyover portal tower structure so that it becomes an icon of Bogor regency, especially Cileungsi District.

The main purpose of this research is to obtain an *aesthetic, unique and sturdy flyover tower design for loads that work according to the standards used and in accordance with the conditions of the local area, namely* the Cileungsi flyover so that it becomes an icon for the Ciluengsi sub-district government (Bhandari et al., 2019; R. Wang et al., 2019).

The benefits of the research are expected from the results of this study, which can provide a technical overview of the structure of the arched portal tower that is safe from the point of view of strength, rigidity and stability according to the applicable standards in Indonesia. From the results of this analysis and design plan, it can be used as a guideline for the implementation of construction in the field and can be used as an icon of the Ciluengsi sub-district area (Plocher & Panesar, 2019).

In this study, the discussion is limited to:

1. Space frame portal tower *design*
2. The calculation method used is the LRFD *(Load Recistance Factor Design) method.*
3. Foundation and pile cap design
4. The data used is primary data from the results of soil surveys and investigations at the *Fly Over location*

There is a lot of research done to design *a Space Frame.* In previous research, the shape of *the Space frame*, especially in the field of architecture, was widely used as an aesthetic form and was suitable for wide spans. For this reason, further research is needed to continue or revise the existing research with updated standards. The concept of designing the construction *of a space frame* is based on an analysis of the boundary strength (*ultimate-strength*) which has enough ductility to absorb earthquake energy according to applicable regulations (Kociecki & Adeli, 2015). Various combinations of loading including dead load, live load, wind load, and earthquake load are calculated by modeling 3-D (*space-frame) structures*. Space frame structure analysis has a more stable and rigid behavior compared to field structure analysis (Ghali et al., 2017; Truong et al., 2017). So it is suitable for buildings with a wide span such as a portal that curves through the *flyover*. The shape of the *Space frame* that will be applied to this *fly over* with 4 legs and can be seen in the image below (Ravbar et al., 2019).

Figure 1. ***4 ft*** **Space Frame**

The portal structure is curved with a wide span with a span length of approximately 95 meters, to be stronger and stiffer using a 4-foot space frame.

The profile used is a steel pipe material with quality in accordance with the quality found in the market ST.37 or ST.41 quality. The consideration of the choice of this space frame structure is because of the curved architectural design form and to meet the futuristic building concept, steel pipe materials are used and steel structures are easier to fabricate in the workshop, steel structures are more futuristic and contemporary materials (Brown & Mueller, 2016; Sharafi et al., 2017).

The Cileungsi Flyover *plan* and the concept of the flyover plan can be seen in the image below.

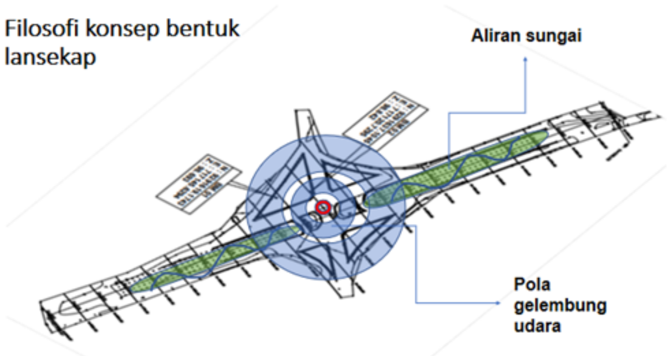

Figure 2. The Flyover Tower Plan Seen From Above

The tower plan on the *flyover* is seen from above with the placement of tower legs on each land at the location of the bend with a total of 4 points.

Figure 3. Design Plan Of The *Cileungsi* Flyover Tower

Analysis of rod force on the space frame structure and assumptions made in the analysis of the frame structure, as follows;

1. The rods are connected by perfect joints (without friction) at the ends.
2. In reality almost all elements are not connected by joints, such as welded or bolted. Even when a joint model is made, friction is also inevitable. But this assumption provides a great deal of simplification and gives quite accurate results.
3. Loads and reactions only work at the point of convergence.
   This assumption can be fulfilled by placing the sub-structure support at the gathering points only, so that the irregularly located load is distributed only at the gathering points. But this arrangement often cannot be fulfilled for practical/economic reasons.
4. The axis extends the rod straight and intersects with the line connecting the gathering points.

To prevent eccentricity, the cross-sectional axes connected at one gathering point must intersect at one point.

From the above assumptions have been fulfilled, the trunk truss only bears axial force and there is no bending moment or shear force on the rod in a truss (Schmidt & Finan, 2018). The axial force works in the same direction as the bar, so it can be decomposed into components based on the direction/angle of the bar, i.e. the shape of the triangle of the force of the rod with the triangle of the rod

The data on the width of the space frame is 95 meters, the height is 36 meters, the width of the lower leg is 3.5 meters x 3.5 meters, and the upper part is 3.5 meters wide and 1.8 meters high. In the segment division, it is divided into 4 sections, the bottom of the pipe size is D.12", D.10", D.8" and the top part D.5" with the specifications of the pipe used, the main pipe structure of the SCH-120 pipe and the quality of the iron pipe rod, with the quality equivalent to JIS G3444 STK 400, and the minimum melting strength is 2,350 kg/m2 or SNI 03-1729-2020. The dimensions of the pipe in the space frame structure vary, divided into 4 sections, at the top (section 4) a diameter of D.5" is used, then down is divided into 3 sections, each D.8", D.10" and D.12". For the dimensions of the pipe in the diagonal and horizontal sections, D.8", D.10", and D.6" are used, in the inner diagonal section, D.4" pipes are used with a thickness according to the type used by SCH-120.

For joints using welds and welding materials must meet the requirements of the American Welding Society AWS D1.069 Code For Welding in Building Construction and welding must be done by welding experts who have a 3G. and HTB A325 bout certificate.

Force analysis on the plane bar frame can be done using manual analysis or with the SAP2000 (*Structural Analysis Program*) structural analysis program.

Analysis of Strength and Stiffness of Space Rod Frame

The analysis of strength in the rod frame is divided into two parts, namely the analysis of the strength of the tensile rod;

$$\sigma_{tr} = \frac{N}{A_{netto}} \leq \sigma_{ijin}$$

N= is the Pull rod force

Anetto= net stem cross-sectional area

For the analysis of the compression rod, the stress that occurs is affected by the bending factor of the rod frame

$$\sigma_k = \frac{N_k}{A} \leq \sigma_{ijin}(tekan)$$

So that the tension due to the bending of the rod, becomes ;

$$\sigma_{tk} = \varpi \frac{N}{A} \leq \sigma_{ijin}(tekan)$$

where w = is the bending factor

$$\sigma_{cr} = \frac{P_{cr}}{A}$$

$$P_{cr} = \frac{\pi^2 EI}{L_k^2}$$

$$P_{cr} = \frac{\pi^2 EAi^2}{L_k^2}$$

$$\sigma_{cr} = \frac{\pi^2 EAi^2}{AL_k^2}$$

$$\sigma_{cr} = \frac{\pi^2 E}{(L_k / i)^2}$$

$$\sigma_{cr} = \varpi \frac{P}{A}$$

So that

E=Bamboo Elastic Modulus

A=Bamboo cross-sectional area

i= radius of inertia

Llk= Length of the stem bend

I=momen inersia

For the stiffness of the trunk frame, it is affected by the magnitude of the deformation of each rod where the deformation of the rod frame is used Hooke's formula:

$$\Delta_l = \frac{P.L}{AE}$$

L= Initial length
Dl = stem deformation

Steel quality: SS 400 (Fy 250 Mpa) and SS540 - New SS540 limited to Built-up section and 20% higher price with 60% higher strength (Fy = 400 Mpa) - Bolt quality A325 or M8.8 or above - Quality anchor bolt ASTM F1554.

RESEARCH METHOD

The method of calculating steel structures and concrete strutkur used is the *Load Resistance Design factor* (*LRFD)* method (Frangopol, 2019; Kanli, 2021). In this method, the nominal strength is calculated by the capacity reduction factor (ϕ, the number is less than 1.0) to account for the uncertainty in the amount of endurance. In addition, the force factor in the ultimate Mu with the overload factor (γ, number greater than 1.0) is also taken into account, to calculate the uncertainty in the structural analysis of various types of loads. Meanwhile, the structure of the *space frame* is designed using the concepts: ***strength, rigidity, ductility, energy dissipation*** and ***integrity*** so that the bars of the *space frame* are safe against working loads.

Combination of Loading:

According to SNI 1729:2020 article 6.2.2; thing; 13, the steel structure should be able to bear all the below loading combinations:

a. 1.4 D
b. 1.2 D + 1.6 L + 0.5 (La atau H)
c. 1.2 D + 1.6 (La or H + (γL L or 0.8 W)
d. 1.2 D + 1.3 W + γL L + 0.5 (La atau H)
e. 1.2 $D \pm 1.0$ E + γL L
f. 0.9 $D \pm (1.3$ $W + 1.0$ $E)$

7L = 0.5 < 5 kPa 7L = 1 > 5 kPa Where:
D = Dead load.
L = Life load
La = Roof living load
H = Rainfall load
W = Wind load

Design Planning Stages

The planning stages in the preparation of this Final Project are shown with the planning flow diagram below .

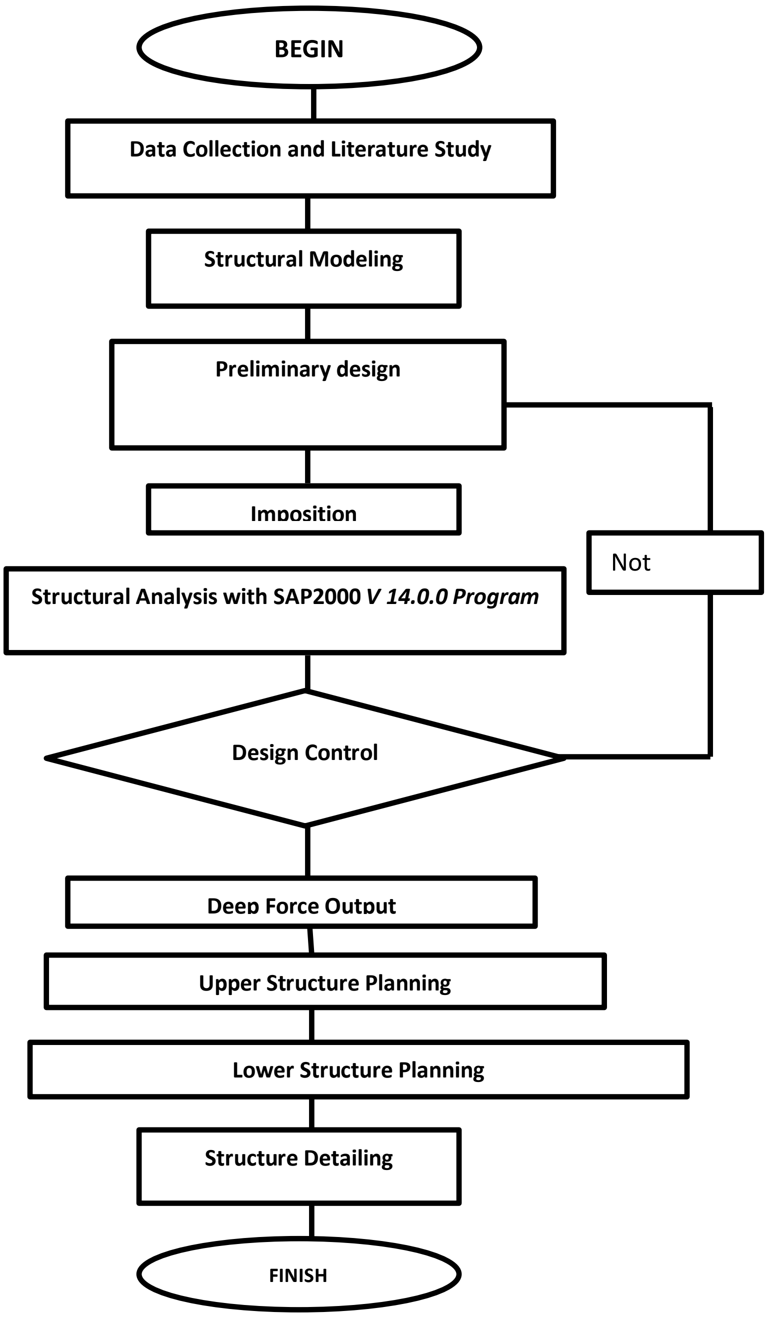

Figure 4. Flow Chart Of Research Steps

For analysis using the help of software program SAP2000 version 14.0.0 is a structural analysis calculation program, which is used to find internal forces, namely moment, latitude, torque, axial force and join

Requirements for press and bending rods with the equation:

When; $\frac{Nu}{\phi_n . Nn}$ >0.2

$$\frac{Nu}{\phi_n . Nn} + \frac{8}{9}\left(\frac{Mux}{\phi_b Mnx} + \frac{Muy}{\phi_b Mny}\right) \leq 1,0$$

When; $\frac{Nu}{\phi_n . Nn}$ < 0.2

$$\frac{Nu}{2\phi_n . Nn} + \left(\frac{Mux}{\phi_b Mnx} + \frac{Muy}{\phi_b Mny}\right) \leq 1,0$$

Then a loading test is carried out and analyzed with the help of SAP2000 software, the results of computer simulations are obtained, then the ratio value must be less than one, then the structure shows that it is safe.

RESULT AND DISCUSSION

The structure is modeled in *a 3-dimensional SPACE FRAME* with 6 degrees of freedom (*DOF)*

Figure 5. 3D structure modeling of the Flyover Tower in SAP2000

Basics of planning and loading

1. Requirements for structural concrete for buildings, SNI 2847-2020
2. Minimum load for the design of buildings and other structures (SNI 1727-2020)
3. Procedures for planning steel structures for SNI03-1729-2020 buildings
4. Procedures for earthquake resistance planning for SNI buildings 03-1726-2019
5. Geotechnical design requirements, SNI 8460 - 2017
6. Specifications for structural steel buildings, SNI 1729-2020

The loads on the tower, first the dead load consists of:

1. The load of the self-weight of the tower structure of the steel pipe is calculated automatically by SAP2000 software
2. The dead load at the top of the tower consists of the weight of the stand and a replica of a heavy Kujang object spread to each point (5 ton x4) ton.

3. The weight of tower equipment such as lights, the weight of work equipment during the implementation is estimated at 100 kg/person, totaling 6 people for a total of 600 kg.

Wind loads and earthquake loads follow the loading guidelines from SNI, according to the conditions of the location of the tower where it is placed.

Wind charging

Loading for wind loads follows : SNI 1727-2020

Based on SNI 1727 Article 26 - General Requirements for Wind Loads, for the calculation of

Wind load speed requires the following considerations and parameters:

a). Building Risk Category
b) Base Wind Speed, V = 39.9 m/s
c) Wind Direction Factor, KD
d) Exposure Category
e) Topographic Factors, KZT
f) Wind Blowing effect factor, G = 0.85
g) Classification of Closure
h) Internal Pressure Coefficient, GCPI
i) Pressure Exposure Coefficient of Velosity, KZ or KH
j) Elevation Factor, to
k) Pressure Velosity, q or qh
l) External Pressure Coefficient, Cp or CN
m) Wind Pressure, p

Earthquake Load

Dynamic earthquake load analysis using SNI-2020 earthquake regulations spectrum calculation from PUPR.

Determination of the type of land where the building is located based on the results of the soil investigation report, the location of the overpass and the open location

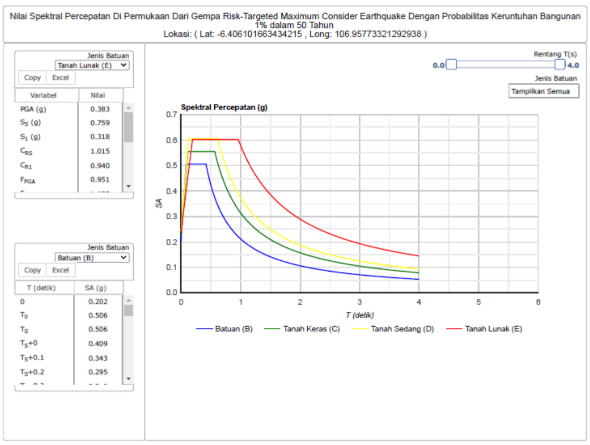

Figure 6. Fly over location spectrum response

Combination of Loading

Reduction factor r = 1.3

1. 1.4DL
2. 1.2DL+1.6LL
3. 1.2DL + LLr ± Ex ± 0.3Ey
4. 1.2DL + LLr ± 0.3Ex ± Ey
5. (1.2+0.2 Sds) DL + LLr + ρ (± Ex ± 0.3Ey)
6. (1.2+0.2 Sds) DL + LLr + ρ (± 0.3Ex ± Ey)
7. (0.9-0.2Sds)DL + ρ(± Ex ± 0.3Ey)
8. (0.9-0.2Sds)DL + ρ(± 0.3Ex ± Ey)
9. 1.2DL ± 1.0 WL+L
10. 0.9DL ± 1.0 WL

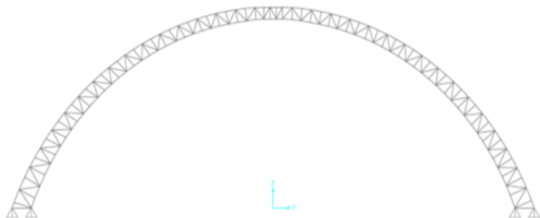

Figure 7. 2D plane visible structure modeling

The results of the structural analysis of SAP2000 are less than 1.0, so that the Flyover Tower structure is safe

FOUNDATION PLANNING

The foundation of a building serves to transfer the loads on the superstructure to the ground and the components of this substructure include the foundation and connecting beams or sloof beams.

In planning this pile foundation, the results of the soil investigation report from the soil and concrete mechanics laboratory of the civil engineering study program, Faculty of Engineering, Pakuan University are used as the basis for calculating the pile foundation. The depth of hard soil reaches 13 meters from the bottom soil surface with a qc value of 150 kg/cm^2, and the carrying capacity of piles of size (25 x 25) cm based on laboratory recommendations is 32 tons.

The load acting on the tower mast can achieve a normal working force of 92.5 tons and take a vertical load value of 100 tons and a horizontal force of 0.86 tons.

Analysis of Pile Foundation Carrying Capacity

1. Carrying Capacity based on Material Strength
   $P=(Ap*s_{bk})+(As*t_{au})$; dimana ; P = daya dukung tiang pancang ijin (kg)
   Ap = Pile cross-sectional area (cm^2)
   As = Area of pile reinforcement (cm^2)
   sbk = Concrete allowable tension (kg/cm2)
   tau = Allowable tension of reinforcement (kg/cm2)

2. Pile carrying capacity based on sondir data (CPT/Cone Penetration Test)

P =(qc*Ap)/3 + (JHL*Ka)/5 ; where; P = Allowable pile carrying capacity (kg)

qc = Conus value (kg/cm2)
Ap = Pile cross-sectional area (cm^2)
Ka = Pole cross-sectional circumference (cm^1)
JHL = Number of adhesion resistance
SF = Safety factor ; 3 dan 5

Based on cross-sectional strength:

The formula for the bearing capacity of the pillar/well foundation is as follows:

$$CPT(sondir) = \frac{q_c \text{ x A}}{3} + \frac{Tf \text{ x keliling}}{5} =$$

The piles used are minipile size 25 x 25 cm and concrete quality K-400 fy=400

L=13.0 m -----to the depth of hard soil.

From laboratory calculations, Pa = 32.0 tons
Based on cross-sectional strength:
Used piles size 25x25 with concrete quality K-400
K-400 then $\sigma_{bk} = 400\ kg/cm^2$

$\sigma'_b = 0{,}33 \times 400\ kg/cm^2 = 132\ kg/cm^2$

$\sigma'_b = 0{,}45 \times 0{,}83 \times 400\ kg/cm^2 = 149.4\ kg/cm^2$

$\sigma'_b = 0{,}2 \times 400\ kg/cm^2 = 80\ kg/cm^2$

Use:
Pa = 80 x Ap = 80 x 25x25 = 50000 kg
By = 45 tons
# So that the bearing capacity of the Pa foundation = 32.0 tons is taken
The number of piles needed is n= 100(0.85x32)=3.67 = 4 piles.

3. Lateral force of pile foundation
   qu= Unconfined compressive strength (kPa) = 2. Cu
   B = width/diameter of foundation pillars
   For parameter values from soil data:
   Cohession Undrained (Cu) = 1 t/m^2
   Cu = 1 t/m2 = 10 kN/$m^{2=100\ kPa}$ → n1 = 0,36
   Tiang beton, n2 = 1,15
   Values n1 and n2 for clay soils (cohesive):
   Values n1 and n2 for clay soils (cohesive):

Table 1. Unconfined relationship with n1 and n2 values

Unconfined Comp Strength, qu (kPa)	n1
< 48 kPa	0,32

48 kPa < qu < 191 kPa	0,36
> 191 kPa	0,40
Foundation materials for different types of piles	n2
Steel	1,32
Concrete	1,15
Wood	1,30

$$Kh = \frac{n_1.n_2.q_u}{B} = \frac{0{,}32 \times 1{,}15 \times 2 \times 10}{0{,}25} = 29{,}44\ kN/m$$

For static load kh = 1/3 kh = 1/3 x 29.44 kN/m = 9.81 kN/m.
Concrete pile size b = 0.25 m
Modulus elastisitas = Et = 21 x 10^6 kN/m^2
Momen tahanan = S = 1/6 bh^2 = 1/6 x 0,25 x $(0{,}25)^2$ = 0,0026 m3
Momen Inersia = I = 1/12 bh^3 = 1/12 x 0,25 x $(0{,}25)^3$ = 0,000326 m4
Pile of concrete K-350 → □ permit = 0.43 x 350 = 168 kg/cm2 = 1680 t/m2 = 16800 kN/^{m2}
In the stake = D = 15 meters
Ground level to pole head = ec = 0 meters
Momen maks = My = □izin x S = 16800 x 0,0026 = 43,68 kN-m
Determination of short or long poles on cohesive soils:

$$\beta_n = \sqrt[4]{\frac{Kh.B}{4.EI}} = \sqrt[4]{\frac{29{,}44 \times 0{,}25}{4 \times 21 \times 10^6\, kN/m^2 \times 0{,}000326}} = 0{,}072$$

□nD = 0.072 x 25 = 1.8 < 2.25 → Including short category piles
D/b = 15 / 0,25 = 60
ec/b = 0 / 0,305 = 0

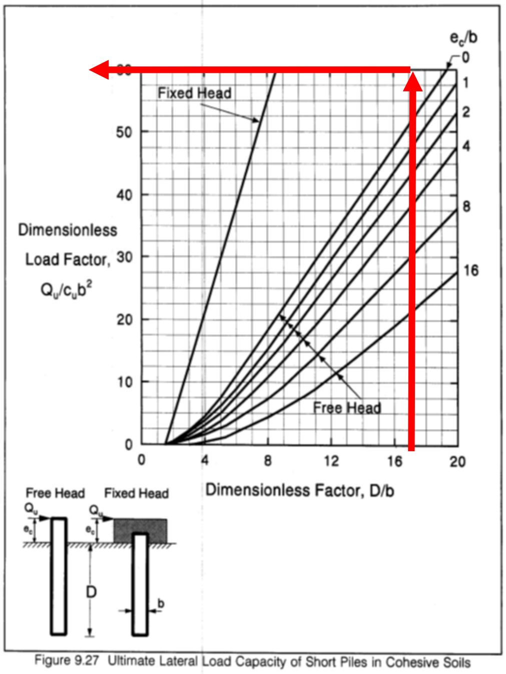

Figure 9.27 Ultimate Lateral Load Capacity of Short Piles in Cohesive Soils

Figure 8. Correlation graph of load factor with dimension factor

From the graph, the value of the load factor x $Qu/(Cub^2)$ = 60 x Qu/(cub2) is obtained.

Ultimate lateral load = Qu = load factor x (Cub^2) = 60 x 10 x 0.252 = 37.5 kN

The maximum lateral force capable of working is = Qa = Qu/2.5 = 37.5/2.5 = 15.0 kN = 1.5 tons.

CONCLUSION

Based on the results of the analysis of loading and calculating the steel structure with the help of SAP2000 software, the construction *of the Cileungsi Flyover* tower is strong and safe in accepting working loads and can be used as an icon of Bogor Regency. The foundation used is a pile foundation (25x25) with a depth of 13 meters from the ground level. It is necessary to depict in more detail for the *space frame structure of* the steel pipe truss as a guideline during the implementation of construction at the *Flyover site.*The determining factor in the planning of the space frame structure space frame is determined by the factors of strength and deflection.

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