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The Effect of Soil Load Variations on Cone Penetration Results in Shallow Foundation Dimensions: Case Study

Darlina Tanjung[1], Jupriah Sarifah[1], Dimas Prabowo[2*]

[1]Department of Civil Engineering, Faculty of Engineering, Universitas Islam Sumatera Utara, Medan, Indonesia
[2]Undergraduate, Department of Civil Engineering, Faculty of Engineering, Universitas Islam Sumatera Utara, Medan, Indonesia

Corresponding Author: Dimas Prabowo (dimasprabowo599@gmail.com)

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ABSTRACT

The purpose of this study is to determine the variation of load values on shallow foundations applied to short-span bridges in the Kutalimbaru Bridge Project, Deli Serdang Regency and the depth value has been obtained from cone penetration results, and to determine the value of the Kutalimbaru bridge floor plate. The variation of the value indicates per 10% of the actual value until it reaches the limit of the value used. The cone penetration test on this bridge was taken from 2 points with a depth of S-1 3.2 m and S-2 2.2 m. The test results show a Cone Penetration Resistance value of S-1 250 kg / cm2 and a Total Shear Resistance of 720 kg / cm S-2 250 kg / cm2 and a Total Shear Resistance of 420 kg / cm. So, the type of original soil is predominantly rocky sand with a little clay. The results of the analysis show that shallow foundations can withstand loads up to 98, 634 tons, with a foundation soil stress of 3.41 kg / cm2 and a soil allowable stress of 3.33 kg / cm2. The control value of the thickness of the bridge floor slab for K350 concrete quality, and for the permissible punching shear stress is 12.16 kg/cm² and the punching stress that occurs is 2.81 kg/cm which is smaller than the thickness value of the bridge floor slab.

Keywords: Shallow foundation, bridge, cone penetration

INTRODUCTION

Infrastructure plays a vital role in economic recovery, and proper planning and budgeting are needed to achieve development goals.[1] The city-linkage concept Mebidangro (Medan, Binjai, Deli Serdang, Karo) developed successfully the condition of neighboring regions between Medan City with Deli Serdang Regency.[2] Deli Regency undergoes increasingly rapid development and has indicators of success; one of which is the availability of good transportation facilities and infrastructure in the regency. This success, in addition to supporting access for social and economic activities, also supports infrastructure development. One of the supporting factors for this success is bridge infrastructure. Bridges are one of the vital buildings needed in the research location. The provision of bridge infrastructure is a form of excellent service from the Deli Serdang Regency Government through the Public Works and Spatial Planning Service in building infrastructure to support the development of the Deli Serdang Regency, especially the Kutalimbaru District. The lower structure of the building consists of foundations and supporting soil for the foundation. The foundation functions to support the entire load of the building and transfer the load of the building into the soil below. A foundation must be able to guarantee and to support the load of the building above it, including external forces such as wind, earthquakes, and others. For this reason, the foundation must be strong, stable, and safe so that it does not experience subsidence, because it is difficult to repair a foundation system.

LITERATURE REVIEW

Bridge

A bridge is a construction that is used to continue a road through an obstacle that is lower. This obstacle is usually another road (waterway or regular traffic road). If the bridge is above a regular traffic road, it is usually called a viaduct.[3] A bridge is a man-made structure built to avoid physical obstacles without closing the way underneath such as a body of water, valley, or road. It is constructed for the purpose of providing passage over the obstacle.[4] "Transportation networks are vital for the development of modern societies and hence their integrity must be protected. Bridges are the most sensitive elements of a transportation system. The closure of a bridge that represents the only or most important link between two areas separated by water or other geological feature would potentially lead to severe consequences for industry, commerce and society as a whole".[5] Due to the crucial importance of bridges in assuring the proper service of highway networks, maintenance of highway bridges plays a major role in this effort.[6] "Bridges are expensive and critical structures that connect communities and serve as regional lifelines. Over time, they are exposed to many degradation processes due to environmental factors and changing loading conditions. Current bridge evaluation techniques are mainly based on qualitative assessment and can fail to estimate the hidden strength reserve of aging bridge assets in many cases."[7]

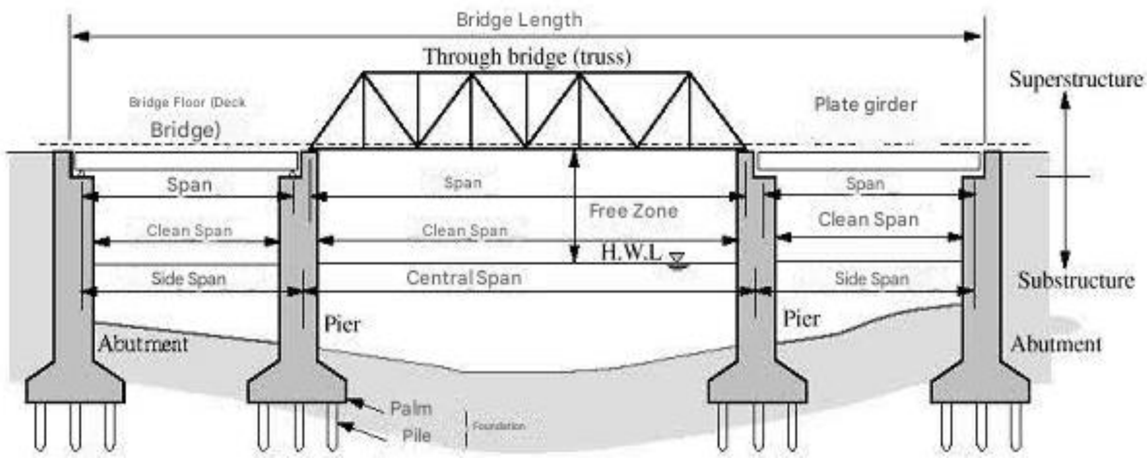

Figure 1. Bridge Parts
(Source: Chen and Duan,2000) [20]

Loading

"While some countries still require a load test on all or certain cases of newly constructed bridges, now load testing is mostly used for the assessment of existing bridges where routine analysis methods fail to represent their in-service performance".[8] "Nonlinear finite element (FE) methods are nowadays commonly used to solve engineering problems. One such engineering area is the efficient management of highway facilities, especially bridges, where the knowledge of actual dynamic load effects, load carrying capacity, and current condition is critical in making management decisions and in establishing permissible weight limits.[9] In planning and analyzing a building construction, the first thing that needs to be considered is the loading. The loading itself on the building construction structure is grouped into two based on its working direction, namely vertical load and horizontal load. Vertical load is the load that works on the building structure due to the building's own weight (dead load) and the live load of the building. While horizontal load is the load caused by wind load and earthquake load.

Foundation

"It has long been recognized that standard bridge design specifications based on the allowable or working stress design (ASD) approach does not promote a consistent reliability for design, thus, fails to ensure uniform levels of performance for bridges. Since the mid-1980s, the load and resistance factor design (LRFD) approach has been progressively developed with the objective of ensuring a uniform reliability for bridges.'[11] The quality of bridge foundation design and construction is the most fundamental issue in bridge building.[10] The foundation is a very important part of the building infrastructure, where it is necessary to choose the right foundation when planning a building. The choice of foundation depends on several aspects, including the function of the building, the type of soil, the amount of load received, the depth of the hard soil that supports the foundation and its cost. "Construction activities related to bridge replacement and rehabilitation are important contributors to traffic jams and reduced mobility and, most importantly, to safety hazards. Assuring the safety of the public needs to remain as number one priority by public agencies."[12]

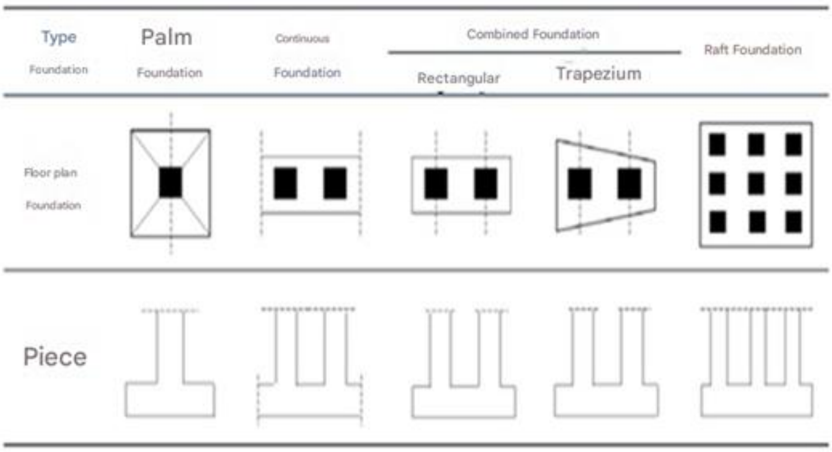

Figure 2. Types of shallow foundations
(Source: Setiawan, 2016:302)[21]

Soil bearing capacity

"Shallow foundations are typically considered as the simplest and most economical foundation for supporting small to medium size structures. They transfer the structural loads to the near surface soil that is mostly unsaturated and fluctuates with climatic condition. Recent studies show that the strength and deformation parameters of soil are influenced by the degree of saturation of the soil."[13] Soil bearing capacity is the ability of the soil to withstand pressure or building loads on the soil safely without causing shear collapse and excessive settlement. Soil bearing capacity is one of the important factors in planning foundations and structures above them. The expected bearing capacity to support the foundation is the bearing capacity that is able to bear the structural load, so that the foundation experiences a settlement that is still within the tolerance limit. Safe bearing capacity against collapse does not mean that the settlement of the foundation will be within the permitted limits. "… because of limitations in geological conditions and construction technology, the bearing mechanism of bridge pile foundations is not thoroughly understood."[10] "In geotechnical engineering, the bearing capacity of a

shallow foundation can be evaluated by using a deterministic approach in conjunction with a probabilistic approach. In the deterministic approach, available equations and charts are used to assess the allowable bearing capacity of the shallow foundation. Soil parameters required for the analyses are obtained from field and (or) laboratory tests."[14] "... a probabilistic approach for evaluating the bearing capacity of surface footings is discussed. The evaluation is based on a kinematic approach. The considered substrate consists of two different layers of soil: a top layer formed of medium or dense sand followed by a layer of soft clay."[15] "The use of geosynthetic materials to improve the bearing capacity and settlement performance of shallow foundation has gained attention in the field of geotechnical engineering. For the last three decades, several studies have been conducted based on the laboratory model and field tests, related to the beneficial effects of the geosynthetic materials, on the
load bearing capacity of soils in the road pavements, shallow foundations, and slope stabilizations."[16]

Cone penetration test theory

Static cone penetration tests are widely used in Indonesia, in addition to the SPT test. This test is very useful for obtaining the value of density variations in non-dense sandy soil. In dense sandy soil and gravelly and rocky soils, the use of sondir tools is ineffective, because it has difficulty penetrating the soil. The values of static cone resistance or cone resistance (qc) obtained from the test can be directly correlated with the soil bearing capacity and settlement in shallow foundations and pile foundations.[17] Although introduced in 1948, the electric penetrometer did not come into general use until the late 1960s. The electric penetrometer has an advantage over the mechanical penetrometer because it has the ability to record continuously and automatically end bearing resistance and local skin friction.[18]

The main features of the cones were as follows:[19]

(a) Cone I. Pore pressure measurement was via a pressure transducer located in the centre of the body. Pore pressure in the soil was transmitted through a thin annular sintered stainless steel filter to a thin annular space behind the filter, and thence via two small diameter holes to a small chamber in front of the sensing face of the transducer.

(b) Cone 2. Two miniature Druck pore pressure transducers with sintered stainless steel filters were used in the second cone. These were located at 180" separation on the body. The main design criterion was to make the water volume between the filter and the transducer as small as possible.

(c) Cone 3. The additional feature of this cone is that each of the two Druck pore pressure transducers is located in the centre of the sensing element of a total radial stress transducer, thereby allowing both pore pressure and total stress (and hence effective stress) to be measured simultaneously at two diametrically opposite points at all stages of cone penetration and pore pressure dissipation.

MATERIALS & METHODS

In the implementation of this research there are several stages, among the research stages include:

Direct Data Collection from the Field (Primary Data)

Direct data collection from the field is carried out with the aim of collecting data as initial calculations. Among them are study location data, cone penetration test results data and other supporting data.

Literature Study (Secondary Data)

Literature studies can be obtained from various sources, both from journals, books, the internet, documentation and libraries. The literature study method is a series of activities related to the method of collecting library data, reading and recording, and managing writing materials.[20]

Data Collection Method
The stages of the data collection method are:
a. Conducting a location survey on the project to see the conditions around the project.
b. Collecting data needed during the work process.
c. Looking for additional data from references related to the case study.

RESULT AND DISCUSSION

1. Original Data of Loads Working on the Foundation

A. Calculation of loads working on the foundation (take a stroke of 1 m)
Vertical load due to self-weight:
i) Self-weight
Abutment self-weight = 7.50 ton
GVI = ((btot x h7) +(2b7 + 2b5) x(h6))) x γbt = 7.25 ton
GVIII = bridge wings =1.73 ton

ii) Vertical weight due to soil
G1 = (b7) x (h1+h2+h3+h4+h5+h6) x γtnh = 3.02 ton
Weight of soil on foundation = 3.02 ton

B. Forces acting on the foundation (taken stroke 1 m)
1. Vertical Load (Normal Compressive Force)
Soil Weight above Foundation = 3.02 tons
Due to Supporting Reaction = 35 tons
Fountain Self Weight + abt Gpb = 16.478 tons +
Total = 54.498 tons
So the vertical load value (N) is 54.498 tons.

Figure 3. Sketch of the 54,498 ton Load Bridge
(Source: Own Documentation)

2. Horizontal Load
Where the value is known:
i) Load due to soil pressure (Ht)
ϕ = 30.00 °
δ = 22.50 °
Ka =

$$\frac{\cos^2 \emptyset}{\cos\delta\left[1+\sqrt{\frac{\sin(\emptyset+\delta)\sin\emptyset}{\cos\delta}}\right]}$$

Ka =0.3207
Ht =Ka [1+½ γtnh h5²] =2.19 ton
ii) Brake load
Hr = 5 % x Dbg =0.58 ton
iii)Earthquake load
Hg= (1/2 Kh x WDL + RDL A x fs)/L = (1/2 x 0.12 x 448.60 + 224.30 x 0.15)/9 = 6.73 ton
Where the value is known:
a) Load due to earth pressure (Ht) = 2,19 ton
b) Brake load = 0,58 ton
c) Earthquake force load = 6,73 ton + = 9.50 ton

From the total result of adding the known values, the horizontal load (D) is 9.50 tons.
3. Moment
Eccentricity
i) Supporting Reaction (ey1) = 0.250 m
ii) Self Weight (M) = 12.106 tons/meter

C. Ground voltage control

Area of the foundation base (stroke 1 m)
A = b3
A = 3,50 m2
A = 35000,00 cm2
With moment resistance (w)
w = 1/6*(2*b7+b5)3 m3
w = 2041666.667 cm3
Stress to the foundation ground

Max γsoil = G_{tot}/A + M/w…(from the equation 2.i)

$$= \frac{54{,}498\ x1000}{35.000} + \frac{12.106\ x\ 100000}{2041666{,}67}$$

$$\gamma_{soil} = 2{,}15\ kg/cm^2$$

The allowable soil stress at a depth of 2 m is:
γallowable soil = 3,33 kg/cm2
γsoil < γallowable soil----------OK

Table 1. Results of Variation of Added Load Values

No	Vertical load value (Ton)	(%) Additional load	Foundation soil stress (Kg/cm^2) (γ_{soil})	Allowable ground stress (Kg/cm^2) ($\gamma_{allowable}$ soil)	Status
1	54,498	0	2,15	3,33	OK
2	59,947	10	2,31	3.33	OK
3	65,397	20	2,46	3.33	OK
4	70,847	30	2,62	3.33	OK
5	76,297	40	2,77	3.33	OK
6	81,747	50	2,93	3.33	OK
7	87,196	60	3,08	3,33	OK
8	92,646	70	3,24	3,33	OK
9	98,096	80	3,40	3,33	Not OK

So, the value of the vertical load that does not meet the permit requirements is located at a load of 98.096 tons and the foundation soil stress is greater than the soil permit stress. The following is a graph of the results of the table above which will show the increase in the variation of the load value with the description of the red line indicating the soil permit stress while the blue line indicates the foundation soil stress.

2. Recapitulation of Soil Bearing Capacity Investigation Results

Table 2. Recapitulation of Soil Bearing Capacity

Point	Depth (M)	Cone Penetration Resistance (Kg/Cm^2)	Total Shear Resistance (Kg/cm)
S-1	3.2	250	720
S-2	2.2	250	420

In addition to the recapitulation table of the results of the soil bearing capacity investigation, the following are the conclusions obtained from the results of the sounding test:

i) The original soil type is predominantly rocky sand with a little clay. The sounding test must be carried out using a Ducth Cone penetrometer or other similar equipment that has a capacity of 200 Kg / Cm2 and is equipped with a friction jacket cone with a minimum capacity of 2.00 tons for bridges with spans of less than 60 M.
ii) The sounding test is carried out on each bridge head. For spans of more than 60 m, the sounding test is carried out in addition to the bridge head and also in the middle of the span. If the sounding results are inaccurate, the sounding test must be repeated.
iii) Measurements are carried out until the end resistance reaches 150 Kg / Cm2.
iv) The sounding tool works hydraulically equipped with a biconus and manometer to determine the end pressure (cone resistance) and friction.
v) The end pressure reading (cone) is carried out every 20 cm by pressing the

pipe (sounding rod) into a depth of 20 cm.

vi) The readings obtained from the sounding experiment are cone resistance or tip pressure (qc) and total resistance (tip pressure and friction).

Soil Bearing Capacity Value Using the Mayerhof Method [22]

A. By using the S-1 point sounding test data

q_{ult} = qc. B. (1 + D/B). 1/40

where:

q_{ult} = 250. 1. (1 + 3,2/1). 1/40

q_{ult} = 26,25 ton

$q = \frac{26,25}{3}$ = 8,75 ton

$q = \frac{qult}{Sf}$

B. Using the S-2 point sounding test data

q_{ult} = qc. B. (1 + D/B). 1/40

Where

q_{ult} = 250. 1. (1 + 2,2/1). 1/40

q_{ult} = 20 ton

$q = \frac{qult}{Sf}$

$q = \frac{20}{3}$ = 6,67 ton

From the results of the permit bearing capacity of the land at points S-1 and S-2, it was obtained that point S-1 = 8.75 tons and point S-2 = 6.67 tons using a safety factor of 3. Where the numbers 3 and 5 are safety factors.

3. Calculation of Soil Bearing Capacity According to Schmertmann and Awkati

A. On Granular Soil (grained/sand)

$qu = (48 – 0.009) (300 . qc)^{1.5}$

$qu = (48 – 0.009) (300 . 250)^{1.5}$

qu = 16.967, 380 kg/cm^2

qu = 166.994,062 ton/m^2

$qa = \frac{qu}{Sf}$

$qa = \frac{qu}{3}$

$qa = \frac{166.994,062}{3}$

qa = 55.664,68 ton/m^2

B. On clay soil

qu = 5 + 0.34.qc

qu = 5 + 0.34.250

qu = 90 kg/cm^2

qu = 885,785 ton/m^2

$qa = \frac{qu}{Sf}$

$qa = \frac{qu}{3}$

$qa = \frac{885,785}{3}$

qa = 295,261 ton/m^2

From the calculation of bearing capacity using the Schmertmann and Awkati method, the bearing capacity value of granular soil is 55,6664.68 tons/m2 and the value of clay soil is 295.261 tons/m2.

CONCLUSION

The conclusions obtained from writing this thesis are as follows:

1. The load value that does not meet the permit requirements is located at a load of 98.096 tons. Where, the foundation soil stress is greater than the soil permit stress, which is 3.40 kg/cm2> 3.33 kg/cm2.
2. The cone penetration test on this bridge was taken from 2 points with a depth of point 1 (S1) of 3.2 m and point 2 (S2) of 2.2 m. The results of the cone penetration test obtained the Cone Penetration Resistance value S1 is 250 kg/cm2 with a Total Shear Resistance of 720 kg/cm and S2 is 250 kg/cm2 with a Total Shear Resistance of 420 kg/cm. So the type of original soil is predominantly rocky sand with a little clay.
3. From the results of the variation in the load values obtained and the soil depth values obtained from the cone penetration results, it can be concluded that a depth of 3.2 m can be built with a shallow foundation with the provision that the foundation soil stress value must be smaller than the soil permit stress value.
4. If the load value is obtained exceeding the allowable soil stress value, the bridge

design can be redesigned with other supporting foundations.

SUGGESTIONS

The suggestions obtained from writing this thesis are as follows:

1. It is expected that for further writing, tests other than cone penetration will be carried out in the field to make a comparison of the results obtained.
2. It is expected that for further writing, laboratory tests will be carried out to determine the value of the soil conditions.
3. In order to create a complete and good thesis, it is expected to increase relations in the process of writing this paper.

Declaration by Authors

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