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THE EFFECT OF BRIDGE'S PIER HEIGHT TO THE BEHAVIOR OF GROUP BORED PILE FOUNDATION DUE TO PUSHOVER ANALYSIS

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ABSTRACT

This study examines the behavior of pile foundations in relation to pier height as a result of pushover load analysis. The pier column was elevated in this investigation with fixed stiffness (EI) and by altering the EI value. A pushover analysis is performed on the bridge structure using the preset variables, and the behavior of the bored pile group foundation is examined owing to the pushover load. The bridge structure is analyzed using the Midas Civil Program, and the piling foundation response is analyzed using the FB-Multipier Program. By keeping the EI value constant at each height, the resulting pier pile base shear force diminishes with height. Meanwhile, by adjusting the EI stiffness value, the base shear force is kept roughly constant at each height. The fixed value of the EI stiffness has no effect on the depth of fixity. Meanwhile, varying the EI stiffness changes the pile foundation's depth of fixity.

Keywords: *Analysis pushover, Bridge's pier height, Foundation response, Stiffnes*

PRELIMINARY

The Tondano River bridge is part of a regional development project in Manado City, North Sulawesi. This bridge was built to connect two areas separated by the Tondano River. The total length of the bridge is 450 metres, with a height of 40 metres and a width of 34.1 metres. The main construction of the Pre-cast Tee Bulb main span bridge is a borepile foundation with a diameter of up to 1.5 m and a pile depth of 48 m.

In general, bridge structure construction is separated into two phases: upper building construction and lower building construction. Vehicle floors, girder beams, diaphragms, bridge piers and abutments are all used in the top building's construction. While the bottom building is made up of pile cap and foundation piles.

In order to calculate the lateral capacity of the pole using the Broms method, the bending moment, soil shear strength, and pile dimensions (diameter and depth of the foundation pole) must be combined with the pole clamping points and the condition of the foundation pile head ties (clasp end poles and free end poles). The depth of the foundation pile pinch point is typically 1.5 m for granular or rigid loam soils, and 3 times the diameter of the pile for soft loam and silt soils.

It is important to consider the value of these approaches in relation to the height of the bridge pier when evaluating the worth of frequently utilised approaches. A thorough higher structure analysis must be carried out in order to get the value of this method to the foundation and to produce output values that are consistent with the behaviour of actual conditions. This study was carried out with several ways for analysing bridges by selecting pushover methods to analyse bridge constructions. As a result, the author attempts to research and analyse the behaviour of the bored pile foundation group in response to variations in the height of the bridge pier caused by the pushover method.

The purposes of this study is to compare the depth analysis of the foundation pile clasp to changes in various pier heights caused by pushover analysis on the bored pile group's foundation.

Pushover Analysis

Pushover analysis is carried out by applying a static lateral load pattern to the structure, which is then gradually raised by a multiplication factor until the desired displacement is obtained. Pushover analysis generates a curve representing the relationship between the base shear force and the displacement of the reference point. The curve of the relationship between basic shear force and shift due to pushover analysis can be seen in the figure below. The capacity curve shows that there are linear circumstances before reaching the melting point, followed by non-linear situations.

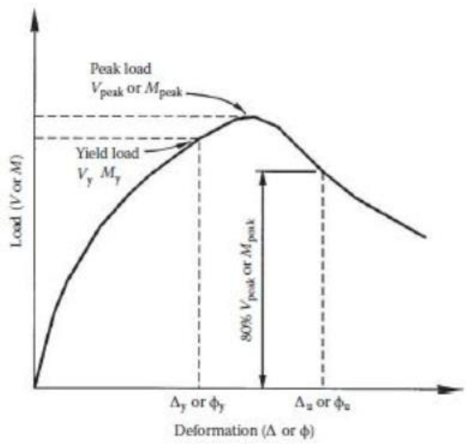

Figure 1. Lateral Force and Displacement Relationship Curve [Hakim, 2014]

The goal of pushover analysis is to estimate the maximum force and maximum deformation held by a structure and identify portions of the structure to be utilised as important regions so that repairs may be done when the structure is damaged.

Capacity Spectrum Method

The ATC-40 Method, Capacity Spectrum begins by developing a displacement force relationship curve that takes into consideration the structure's inelastic conditions, the results of which are shown in ADRS (acceleration displacement response spectrum) format.

The format is a straightforward conversion of the fundamental shear force relationship curve with the lateral displacement of the control point utilising the dynamic parameters of the system, and the result is referred to as the structural capacity curve. Ground motion from earthquakes is also transferred to ADRS format. As a result, the capacity curve is shown on the same axis as the earthquake forces. The vibrating time is shown as a radial line from the axis's centre point in this format.

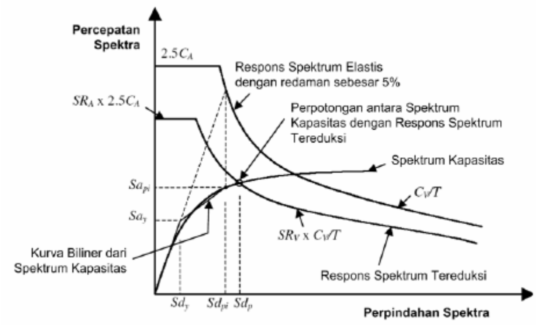

Figure 2. Determination of performance points based on the capacity spectrum method [Hakim, 2014]

Performance Grade

The performance level of a building is the state or amount of damage that happens when there is a plan echo load. The performance level is the highest limit condition of structural and nonstructural damage that happens in structures owing to projected seismic loads. The degree of performance is indicated based on the criteria of the level of physical damage that happens, the threat to human life, and the capacity to service structures after the earthquake.

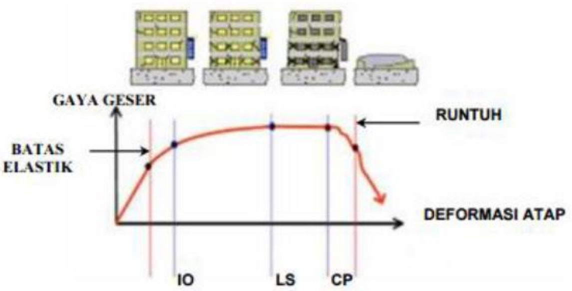

Figure 3. Performance levels according to FEMA 273 [Hakim, 2014]

The foundation is exposed to lateral loads

When designing foundation piles that accept axial, lateral, and moment forces, three criteria must be met: the pressure that occurs on the soil does not exceed the ultimate capacity that the soil is able to withstand, the deflection that occurs must not exceed the allowable capacity, and the structural integrity of the foundation system must be guaranteed quality.

In order to avoid failure owing to lateral forces operating on the building, the foundation piles must be designed to bear lateral forces as well as axial forces.

P-Y Curve

The determination of the ultimate soil pressure value under conditions of lateral soil pressure for the interaction of soil with structure requires a particular procedure.

Sub-section

The title of the sub-section is written in Cambria 11.5pt, bold and written in a sentence case style (capitalized only at the beginning). Sub-section title is written without chapter numbers. This problem necessitates the solution of a nonlinear problem involving the interaction of soil and structure. The py curve provides a solution in the connection between soil resistance (p) and pole deflection (y).

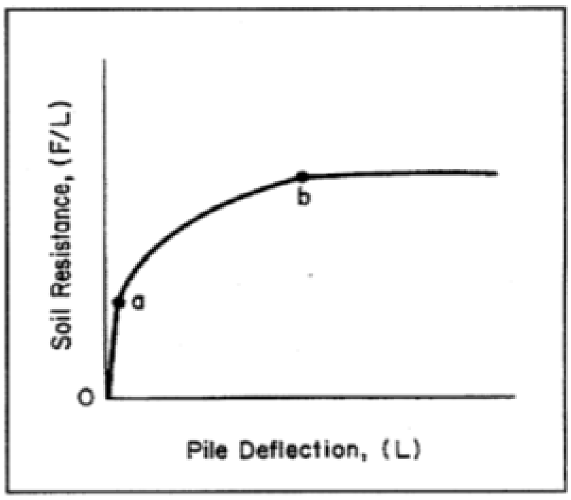

Figure 4. Basic concepts of the p-y curve [Reese, 1997]

The 0-a line on the curve represents the portion of the soil that is elastic at a modest deflection. The a-b line is the non-linear transition segment of the curve when the soil resistance (p) value at point b has achieved the ultimate value of soil resistance. The horizontal half of the py curve above demonstrates that the soil is malleable, with no loss of shear strength as strain increases.

The form of the p-y curve is decided by the field load test, making this technique semi-empirical. Based on the findings of field testers on fully instrumented poles, Reese (1977) established a number of empirical curves for typical soil types. The following equation is used to describe the interaction of the soil-pile foundation:

$$\frac{P}{P_{ult}} = 0.5\left(\frac{y}{y_{50}}\right)^{1/3} \quad (1)$$

Which:

P = Lateral resistance of the soil

Pult = Lateral resistance soil(Np C D)

Np = Coefficient of lateral resistance of ultimate soil

c = Strong undrained shear

D = Pie diameter

y = Pole deflection

P-Multiplier

Measurements of displacement and pressure in full-scale and centrifugal pile groups reveal that piles in a pile group are subjected to asymmetrical lateral stresses. Depending on its placement within a group of poles and the distance between poles. The unequal distribution of loads between these is caused by the shadowing effect, which is used to characterise overlapping failure zones and reduced ground resistance.

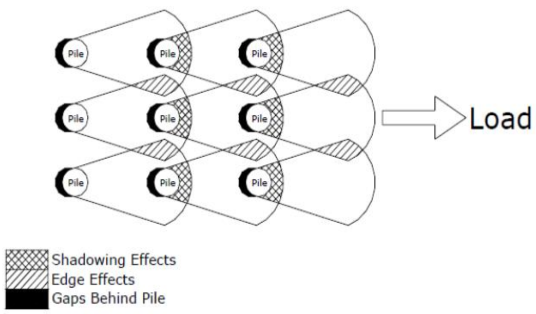

Figure 5. Distribution of lateral capacity

reduction of poles in pole groups [Fayyazi, 2012]

Brown et al (1988) introduced the P-multiplier (also known as the fm factor) as a method of accounting for the pole group effect by generating a p-y curve.

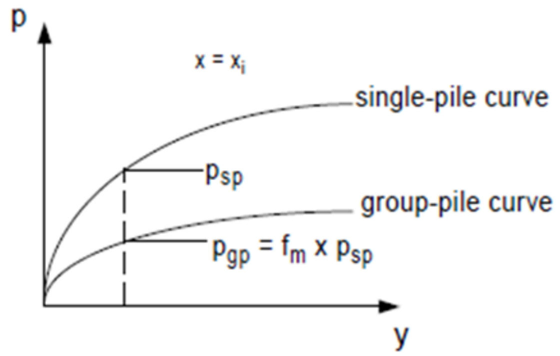

Figure 6. P-multiplier concept for mast groups [Mokwa &; Duncan, 1999]

Bend on foundation posts

As a result of the structure's load operating on it, the pile foundation not only gets axial loads and moments, but it also receives lateral loads that operate. When the pole is subjected to horizontal and vertical strains, it bends and is said to act jammed at a specific depth below ground level. When the pole clamps (zf), the maximum moment and shear strength of the pole are equal.

To bear vertical loads coupled with lateral loads and bending moments at the ends, embedded foundations may be required. Davinsson and Robinson found the rigid components R and T as equations. When the embedded pole is as high as e above ground level, it carries vertical loads P, horizontal loads H, and moment M.

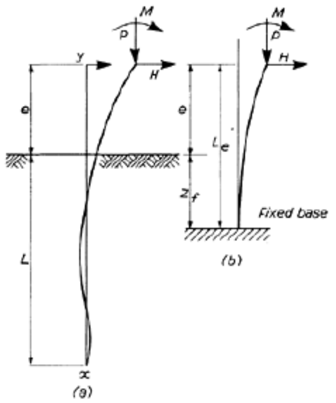

Figure 7. Bending on the mast due to vertical and horizontal loads on the head end [Davinsson, 1965]

The differential equation for stiffness was developed by Hetenyi (1946) as follows:

$$EI\frac{d^4y}{dx^4} + P\frac{d^2y}{dx^2} + K_z y = 0 \qquad (2)$$

Which :

EI = Stiffness of the pole

P = Axial load

k = Soil modulus

Terzaghi (1955) has a constant soil modulus value at each depth in figure (a) for cohesive soils that are overconsolidated, and a linearly rising modulus in figure (b).

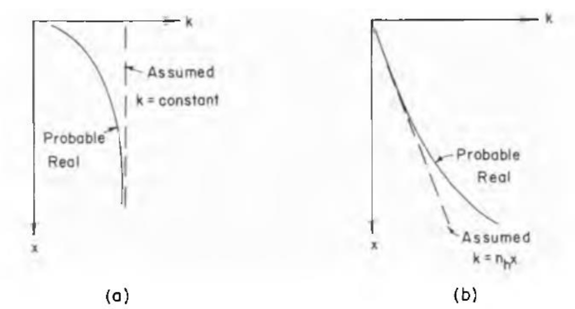

Figure 8. variation of subgrade modulus to depth (a) in over-consolidated cohesion soils (b) in granular, loam and silt soils under normal conditions

[Davinsson, 1965]

For soils with constant modulus:

zf = 1.4 R depth to point of fixity

Soils with a linearly rising modulus:

zf = 1.8 T

Which:

$$T = \left(\frac{EI}{n_h}\right)^{0.2} \qquad (3)$$

$$R = \left(\frac{EI}{k_h}\right)^{0.25} \qquad (4)$$

Information:

E = Modulus of elasticity (kPa)

I = Moment of inertia pole's cross section

kh = Terzaghi's subgrade modulus of Reformation

nh = Modulus coefficient of variation value

RESULTS AND DISCUSSION

The bridge construction was modelled in this study by gradually raising the bridge pier, with the following variables:

1. The pier height is gradually increased, with a height interval of 5 metres.
2. At each bridge height, the stiffness value (EI) remains constant, preserving the pier cross-sectional dimensions as specified in the design data.
3. Changing the size of the pier cross-section at each height to vary the stiffness value (EI). According to the planning data, the reference EI value relates to the fundamental shear force at a height of 40 metres.

Pushover analysis with constant inertia

Demand spectrum employs Ss and S1 values from the Manado earthquake map with a 1000-year recurrence period (7% in 75 years) for pushover analysis.

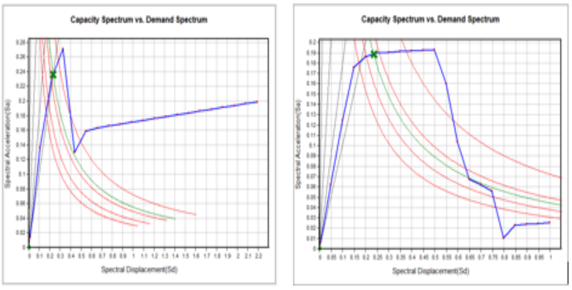

Figure 9. Pier height capacity curve 30 meters (a) direction – x, (b) direction – y

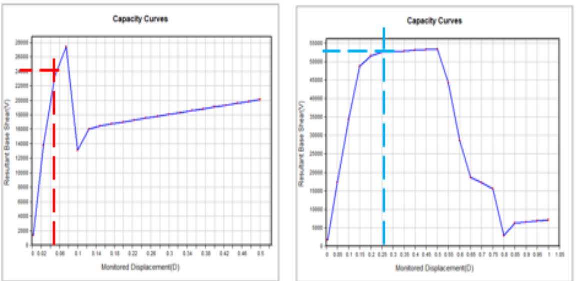

Figure 10. Pushover curve pier height 30 meters (a) direction x (b) direction y

According to the pushover study results for each pier column height, the higher the pier, the lower the base shear force value obtained at the performance point (Fpp). The accompanying table shows that the value of the laying reaction at each height does not vary greatly as a result of the decrease in the value of the base shear when the pier is lifted.

Table 1. Base shear and displacement at performance point conditions

Depth [m]	Direction	Fpp [kN]	Δ pp [m]
30	X Direction	23289.6	0.05
	Y Direction	52505.7	0.25
35	X Direction	26388.3	0.12
	Y Direction	43522	0.30
40	X Direction	26886	0.20
	Y Direction	36475	0.40
45	X Direction	27611	0.30
	Y Direction	29616	0.48
50	X Direction	27048	0.43
	Y Direction	28093	0.60
55	X Direction	25876	0.50
	Y Direction	24994	0.60
60	X Direction	25212	0.64
	Y Direction	22278	0.70

The following is the outcome of the foundation pile response analysis based on the pier column reaction.

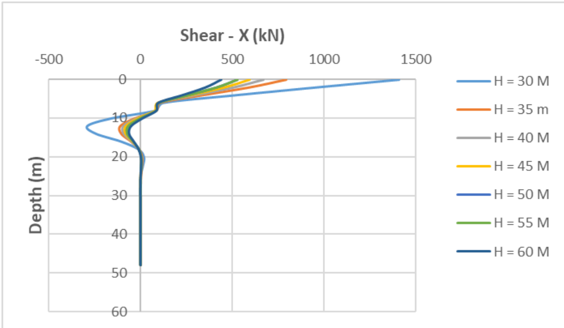

Figure 11. X-way sliding force graph

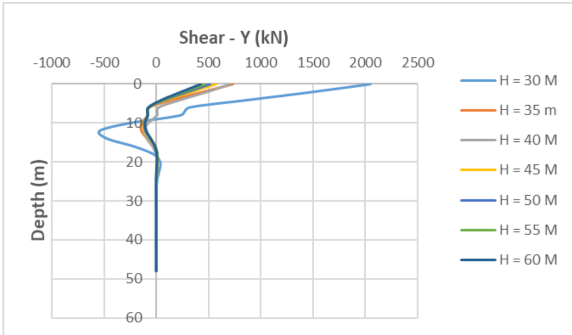

Figure 12. Y-direction sliding force graph

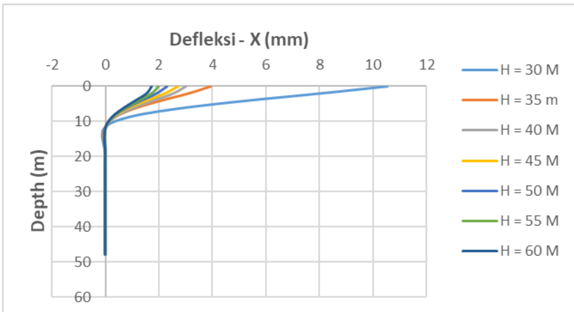

Figure 13. Deflection Graph – X

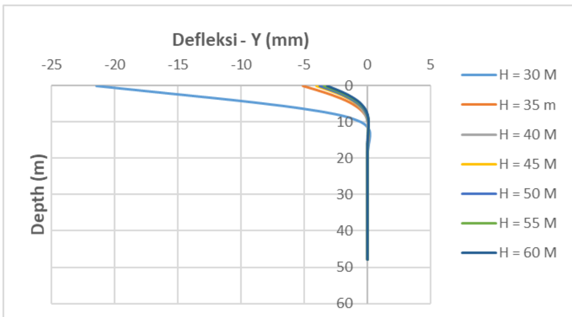

Figure 14. Deflection Graph – Y

Pushover with variation of inertial value

At this level, pushover analysis involves varying the cross-sectional inertia value at each height in order to produce the same fundamental shear force value at each height. On the pushover curve, the values of inertial stiffness and basic shear force correspond to the pier column at a height of 40 metres.

Table 2. EI value at pier height

Height	Concrete Quality	Pier Column Profile			EI ratio
[m]	F'c [Mpa]	B [m]	H [m]	I [m4]	
40	30	2.75	2.75	4.77	1.0
30	30	2.30	2.30	2.33	0.5
50	30	3.25	3.25	9.30	2.0
60	30	3.60	3.60	14.00	2.9

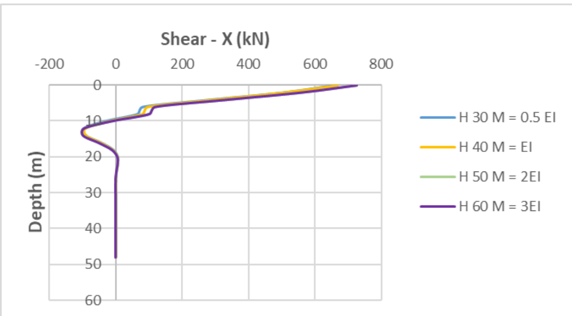

Figure 15. X-direction sliding force graph

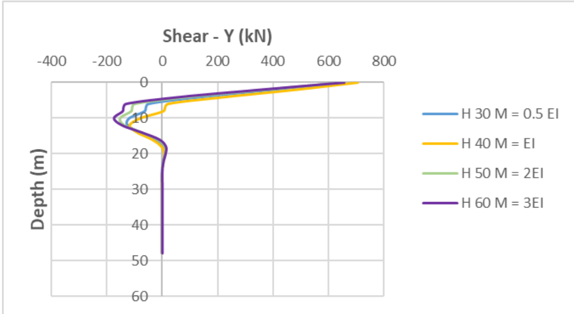

Figure 16. Y-direction sliding force graph

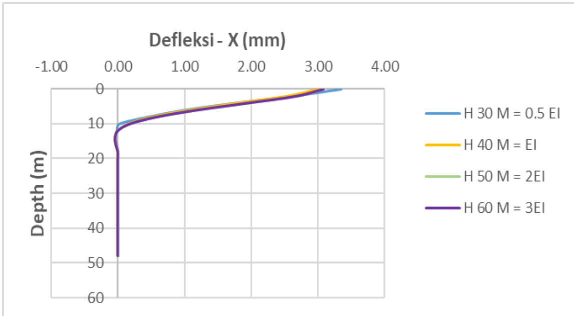

Figure 17. Deflection Graph – X

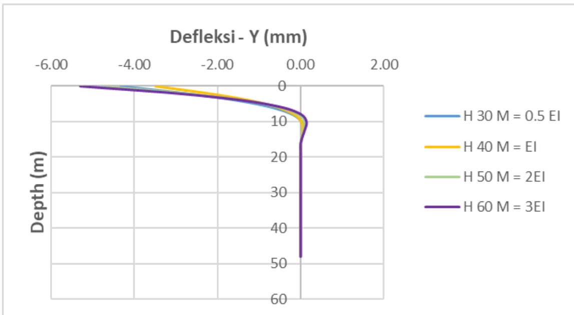

Figure 18. Deflection Graph – Y

Table 3. The clasp depth of the foundation pile with variations in inertial values

Depth	Pier Height [m]							
	30 [0.5 EI]		40 [EI]		50 [2EI]		60 [3EI]	
	X - Lateral	Y - Lateral	X - Lateral	Y - Lateral	X - Lateral	Y - Lateral	X - Lateral	Y - Lateral
[m]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
0	3.35	-4.33	3	-3.5	3.09	-4.76	3.08	-5.31
2	2.62	-2.78	2.53	-2.24	2.68	-2.8	2.67	-3.01
4	1.76	-1.53	1.79	-1.22	1.94	-1.36	1.94	-1.39
6	1.01	-0.68	1.08	-0.54	1.19	-0.48	1.19	-0.43
8	0.45	-0.19	0.51	-0.15	0.58	-0.04	0.58	0.02
10	0.02	0.02	0.16	0.02	0.18	0.1	0.18	0.14
12	-0.02	0.07	0	0.05	0	0.09	0	0.11
14	-0.04	0.04	-0.04	0.03	-0.04	0.04	-0.04	0.05
16	-0.02	0.01	-0.02	0.01	-0.03	0.01	-0.03	0
18	0.00	0.00	0	0	0	0	0	0

According to table 3, the depth of the foundation pile clasp at a pier height of 30 metres is -10 metres. The pinch point for piers 40 and 50 metres in height is at a depth of -12 metres. The bridge's pier is 60 metres high, an the pinch point is at a depth of -14 metres.

CONCLUSION

The following findings may be obtained from pushover studies on piers with varying bridge pier heights on the behaviour of the bored pile foundation group:

1. The shear force caused by height fluctuation is reduced by keeping the EI stiffness value constant, causing the shear force of the pier pole base to decrease with each rise in height. Meanwhile, by adjusting the degree of EI stiffness, we obtain a fundamental shear force with almost identical magnitude at each height.
2. The clasp depth of the foundation pile at various variations in the height of the bridge pier with a set EI stiffness has no effect on the value of the pile clasp depth. While the depth value of the foundation pole clasp is affected by height fluctuation by adjusting the amount of EI stiffness.

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