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The Redesign of the Ngadi Bridge Foundation Structure in Mojo District, Kediri Regency

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ABSTRACT

This research aims to (1) determine the condition of the existing foundation of Ngadi Bridge, (2) design an effective and efficient bored pile for Ngadi Bridge, (3) analyze the ratio of the concrete's volume required for the existing foundation to the redesigned foundation (bored pile) of Ngadi Bridge. This research is level 1 of Sugiyono's Research and Development with a mixed-method approach. There are two findings established in this research. First, the implementation of the existing foundation on Ngadi Bridge caused vibration and noise, and too many foundations in each abutment and pillar caused the need for concrete volume to be increased to 216,14 m3. Second, the bored pile design on Ngadi Bridge for Abutment 1 uses 12 bored piles with a diameter of 0,6 m and a depth of 15 m. The resulting group carrying capacity is 24501,99 kN. Abutment 2 uses 6 bored piles with a diameter of 0,6 m and a depth of 10 m, and the resulting group carrying capacity is 9068,82 kN. Pillar uses 35 bored piles with a diameter of 0,6 m, and a depth of 4 m, and the resulting group carrying capacity is 22430,43 kN. Third, the total concrete volume of the bored pile is 107,4425 m3. So the percentage of saving the required volume of concrete is 50,29%.

Keywords: foundation; bridge; bored pile; foundation carrying capacity.

INTRODUCTION

The bridge foundation as one of the bridge's structures has a very important role. In planning the foundation, it is necessary to consider all aspects of both safety and effectiveness of the structure. Choosing the right type of foundation will certainly expedite the bridge work process (Widyastuti & Hidayat, 2015). The choice of foundation type is related to the bearing capacity of the soil. Soil data that has been studied can determine the type of foundation to be used, i.e. sole foundation, bored pile foundation, or pile foundation (Masiku, 2019). Furthermore, the effectiveness of the structure related to the foundation dimensions and concrete volume requirements needs to be considered. This is by the statement of Yulistyawan (2022) quoting Suryolelono that if the distance between foundation piles is too wide, the pile cap area will increase and as a result, the volume of concrete will also increase.

One type of deep foundation that can be used in high-rise buildings, bridges and toll roads is bored pile foundation. Due to its cast in situ nature, bored pile dimensions can be varied at each point. In addition, the implementation process does not cause vibration (Asiyanto, 2007). As in the research conducted by Muluk, et al (2020), it was found that bored pile foundations are more profitable than pile foundations in terms of cost and time analysis. This is because bored pile foundations have a faster implementation duration, more efficient costs, and are suitable for placement in environments with densely populated areas.

Ngadi Bridge is a bridge that crosses a tributary of the Brantas River and connects Ngadi Village, Mojo District, Kediri Regency with Jeli Village, Karangrejo District, Tulungagung Regency. This bridge had collapsed in 2017, and was rebuilt in 2022. The Ngadi Bridge Construction Project uses an existing foundation type of 80 cm diameter concrete piles. Furthermore, the amount of concrete needed in the pile material in the project is considered excessive. This is in line with the number of foundation points in each abutment which can reach 40 points (CV Adhirajasa Ciptana Engineering, 2021). In addition, the installation of pile foundations can cause vibration and noise. Due to the proximity of the project site to residential areas, the effects of the installation process are felt directly by residents.

Based on the explanation above, the researchers conducted a redesign and analysis of the Ngadi Bridge foundation by using a bored pile foundation type. The choice of bored pile foundation is to cover the shortcomings of the existing foundation and is expected to reduce the need for concrete volume in the foundation. This research is expected to provide knowledge about bored pile foundation planning on bridges to achieve safe and efficient criteria.

Deep foundations are a type of foundation used to support buildings by distributing structural loads to soil layers at greater depths, which have better bearing capacity than surface soil layers. This foundation is usually applied to tall buildings or structures built on land with geotechnical conditions that are less stable or have low bearing capacity in the surface layer (Bagio TH et.al, 2021; Artiwi NP, Rosdiyani T, 2021).

The use of deep foundations requires careful planning and implementation, involving geotechnical studies to determine soil characteristics and ensure the foundation chosen is appropriate to the load to be supported and environmental conditions (RahmanA et.al, 2023).

There are several types of deep foundations, such as piles and bored piles. Piles are foundation elements that are installed by driving them into the ground until they reach the hard soil layer. Bored piles, on the other hand, are made by drilling into the ground first, then filling them with concrete to form a strong column. Deep foundations have several advantages, such as the ability to withstand heavy loads and minimize differential settlement, which can cause cracks in the building structure. In addition, deep foundations can reach greater depths, making them more stable and reliable in varying soil conditions (Sitompul ST, Pariatmono P, 2022; Lutfi M et.al, 2022).

Research Objectives

This research aims to:1) recognize the the condition of the existing foundation of Ngadi Bridge; 2) design an effective and efficient bored pile design for Ngadi Bridge; 3) analyzing the comparison of the volume of concrete requirements of the existing foundation with the redesigned foundation (bored pile) on the Ngadi Bridge.

RESEARCH METHODS

The research location is at the Ngadi Bridge Construction Project with a research time of 11 months. This type of research is Research and Development with level 1 research design from Sugiyono (2019) and uses a mixed method approach. Sources of data in the form of sources, namely project parties and residents, existing conditions of the Ngadi Bridge project, photos of existing project conditions, working drawing documents, calculations of existing foundation concrete volume requirements, and documents of SPT test results for the Ngadi Bridge project. Data collection techniques are interviews, observations, documentation, and document studies. Data analysis techniques used interactive analysis of the Miles and Huberman model for qualitative data, and descriptive data analysis for quantitative data.

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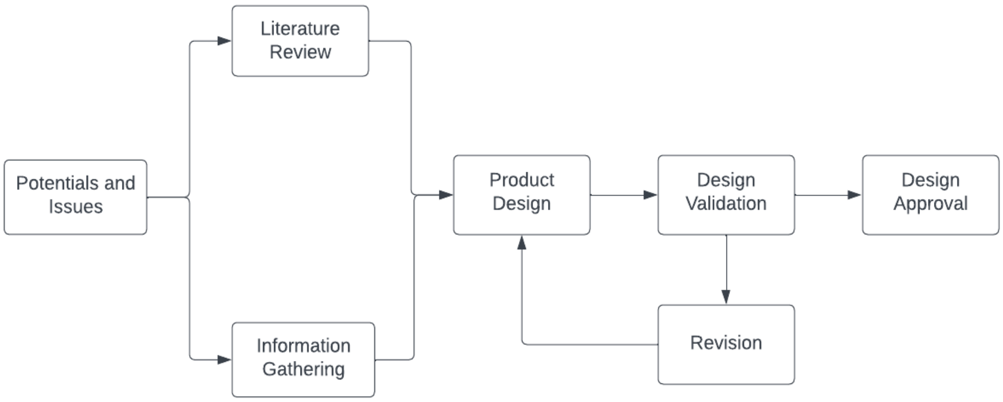

Figure 1. Research Procedure

RESULT AND DISCUSSION

Ngadi Bridge Construction Project

The Ngadi Bridge Development Project is a project owned by the Kediri District Government through the Kediri District Public Works and Spatial Planning Office. According to the results of interviews, the Ngadi Bridge collapsed in 2017 due to the bridge foundation not being able to withstand the overflow of river water carrying chunks of wood and mud, causing the foundation to collapse so that the bridge body was cut off. This is as expressed by one of the local residents:

Ngadi Bridge collapsed because of the flood. The Jugo River has its headwaters on Mount Wilis.When the water overflowed, the flood carried chunks of wood, pring, so the foundation was not strong.So it eventually collapsed. The flood also brought mud. (Im, 13.07.22/11.45 - 12.15)

Ngadi Bridge was rebuilt in 2022 using 80 cm diameter concrete pile type foundations. The project supervisor said that the dimension was too large, where foundations with a diameter of less than 80 cm can still reach a safe value in carrying capacity.

In addition, based on the results of observations made in July - August 2022, there are several notes including:

1. The piling process causes vibration and noise pollution. The proximity of the project to residential areas has caused vibration and noise effects to be felt by nearby residents. This is in line with the confession of one resident who lives close to the project:
2. Long work execution process. The different depths of hard soil at each point resulted in the remaining part of the pile that was not embedded. So, it is necessary to do time-consuming drilling.

Figure 2. Pile Breaking

Existing Condition

Foundation Site Plan and Depth

The foundation used is a concrete pile foundation with a diameter of 80 cm. The distance between foundations is 2 m with the distance between the outermost pile and the edge of the pile cap of 1.2 m.

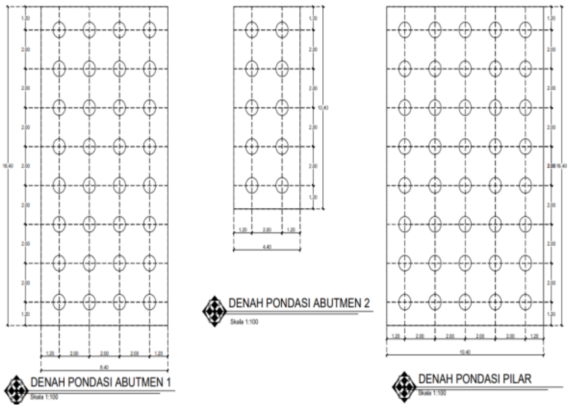

Figure 3. Foundtion and Existing Site Plan

At Abutment 1, the foundation length is 16 m. While Abutment 2 and Pillar have lengths of 10 m and 4 m respectively. This is based on the SPT test results on the south and north side soils.

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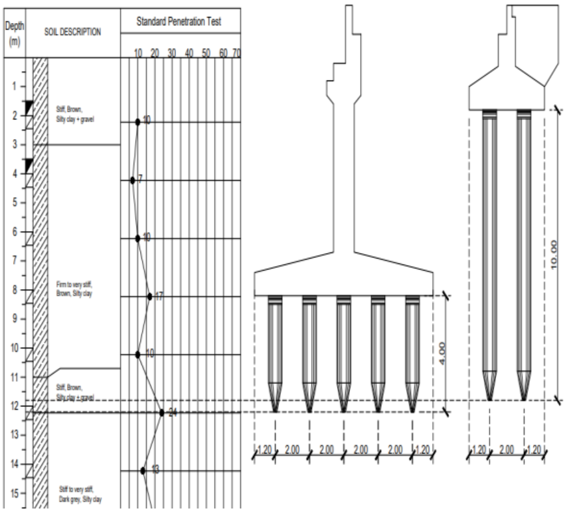

Figure 4. SPT Test Results of the North Side

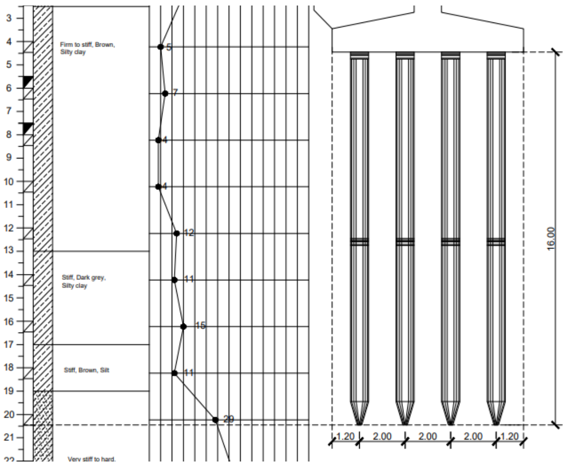

Figure 4. SPT Test Result of the South Side

Thus, the detailed data of the existing foundation can be summarized in Table 1.

Table 1. Foundation Existing Data

Specification	Position		
	South Abutment (1)	North Abutment (2)	Pilar
Diameter (cm)	80	80	80
Length (m)	16	10	4
Amount (pcs)	32	10	40
Depth (based on SPT test) (m)	20,5	12,25	12,25

Foundation Volume

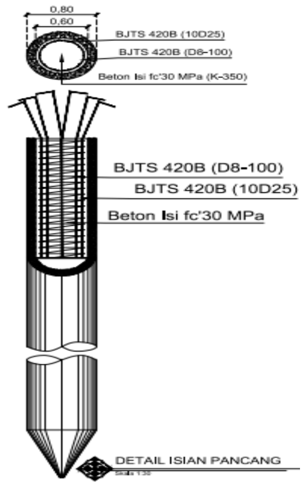

Figure 5. Pail Fill Detail

Based on Figure 6, not all parts of the foundation were filled with concrete castings (concrete fill fc'30 Mpa). According to the project contractor's disclosure, the depth of pile filling was only 2 m from the top of the pile.

Referring to Table 1 and Figure 6, the existing foundation volume can be calculated with the following steps:

a. Volume of inner side piles (0.6 m diameter)

$= \frac{1}{4}\pi D^2 \times \Sigma(\mathrm{L} \times \mathrm{n})$ ....Equation 1

$$= \frac{1}{4}\pi 0{,}6^2 \times (16 \times 32 + 4 \times 40 + 10 \times 10)$$

$$= 69{,}48\pi\ m^3$$

b. Volume of pile filling (0.6 m diameter and 2 m length)

$= \frac{1}{4}\pi D^2 \times L \times \Sigma n$ .... Equation 2

$$= \frac{1}{4}\pi 0{,}6^2 \times 2 \times (32 + 40 + 10)$$

$$= 14{,}76\pi\ m^3$$

c. Volume of pile void space

$= V\ inner\ side\ piles - V\ pile\ filling$ .... Equation 3

$$= 69{,}48\pi - 14{,}76\pi$$

$$= 54{,}72\pi\ m^3$$

d. Volume of outer side of the pile (0,8 m diameter)

$= \frac{1}{4}\pi D^2 \times \Sigma(\mathrm{L} \times \mathrm{n})$ .... Equation 4

$$= \frac{1}{4}\pi 0{,}8^2 \times (16 \times 32 + 4 \times 40 + 10 \times 10)$$

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$= 123{,}52\pi\ m^3$

e. Volume of final concrete for the existing foundation

$= V\ outer\ side\ of\ pile - V\ void\ space\ of\ pile$ .... Equation 5

$= 123{,}52\pi - 54{,}72\pi$

$= 68{,}8\pi\ m^3$

Through the above calculation, the total volume of existing foundation concrete is 68.8π m3 or 216.14 m^3.

Loading

The loading calculation has been analyzed by the planning consultant of the Ngadi Bridge Construction project. The loading is guided by SNI 1725: 2016. The loading combination on Abutment 1 is shown in Table 2.

Table 2. Abutment 1 Loading Combination

No	Action	Pu (kN)	Tux (kN)	Tuy (kN)	Mux (kNm)	Muy (kNm)
1	Strength I	15643,59	1601,50	0,00	-5161,42	0,00
2	Strength II	15036,55	2061,10	0,00	-3483,88	0,00
3	Strength III	12970,54	1893,80	55,37	-4094,53	367,43
4	Strength IV	12911,92	1893,81	0,00	-4094,53	0,00
5	Strength V	12928,67	1872,67	15,82	-4173,57	104,98
6	Extreme I	13367,2	2170,72	1664,18	-3489,88	3501,98
7	Bearing Capacity I	11283,08	1740,36	11,865	-2199,53	78,735
8	Bearing Capacity II	11725,8	1776,21	0,00	-2068,67	0,00
9	Bearing Capacity III	10967	1716,46	0,00	-2286,76	0,00
10	Bearing Capacity IV	9752,92	1624,27	0,00	-2622,53	0,00

The loading combinations on Abutment 2 are shown in Table 3.

Table 3. Abutment 2 Loading Combinations

No	Action	Pu (kN)	Tux (kN)	Tuy (kN)	Mux (kNm)	Muy (kNm)
1	Strength I	5524,51	329,70	0,00	-826,16	0,00
2	Strength II	5126,07	724,98	0,00	241,11	0,00
3	Strength III	3749,26	557,68	16,74	-210,60	84,03
4	Strength IV	5010,84	142,88	0,00	-1833,74	0,00
5	Strength V	3736,60	550,26	4,78	-230,65	24,01
6	Ekstrem I	4030,36	1021,28	476,07	867,98	755,73
7	Bearing Capacity I	3808,83	655,75	3,59	443,03	18,01
8	Bearing Capacity II	4103,86	691,60	0,00	539,82	0,00
9	Bearing Capacity III	3605,81	631,85	0,00	378,50	0,00
10	Bearing Capacity IV	2808,93	537,49	0,00	123,72	0,00

The loading combinations on the Pillars are shown in Table 4.

Tabel 3. Pillar loading combinations

No	Action	Pu (kN)	Tux (kN)	Tuy (kN)	Mux (kNm)	Muy (kNm)
1	Strength I	15806,68	236,76	0,00	-2531,63	0,00
2	Strength II	15269,64	537,57	0,00	-305,63	0,00
3	Strength III	13447,93	370,27	54,72	-1543,65	568,30
4	Strength IV	17873,23	25,99	0,00	-5376,40	0,00
5	Strength V	13406,55	348,61	15,63	-1703,91	162,37
6	Ekstrem I	12792,78	1027,86	1729,15	601,27	5482,29
7	Bearing Capacity I	11475,69	489,77	11,73	329,17	121,78
8	Bearing Capacity II	11866,06	525,62	0,00	594,46	0,00
9	Bearing Capacity III	11194,76	465,87	0,00	152,31	0,00
10	Bearing Capacity IV	10120,68	373,88	0,00	-528,42	0,00

Development

The foundation redesign of the Ngadi Bridge construction uses a bored pile foundation and aims to reduce concrete volume requirements. The product made is the result of the calculation of the bearing capacity of the bored pile foundation along with the concrete volume requirements. After the researcher makes the product, it is then submitted to experts for validation. The product was validated by experts for two rounds. The experts in question are Foundation Experts and Geotechnical Experts. The following are the results of the first round of validation:

1. The selection of bored pile foundation type for redesign is appropriate.
2. The calculation of the bearing capacity of the foundation is in accordance with the specified method.
3. The method for calculating the bearing capacity of the foundation is just one, because the resulting value is not much different.
4. Since the bored pile foundation can be placed in the medium to hard soil range, the foundation depth is shallowed as long as it is still in medium soil.
5. Changing the foundation diameter to 0.6 m on each abutment and pillar.
6. Due to the small number of redesigned piles produced, the pile cap size was also redesigned (reduced) as long as it was not less than the bridge width.
7. The pile cap size is reduced because there is a requirement for the maximum distance between the outermost pile and the edge of the pile cap.

After the researchers revised the product according to the comments and suggestions in the first round of validation, then the second round of validation was carried out by the same experts. The following are the results of the second round of validation:

1. The Foundation Expert assessed that the redesign of the bridge foundation structure was in line with the research objectives.
2. Geotechnical experts assessed that the redesign of the bridge foundation structure was in line with the research objectives.

Based on the results of expert validation, the following is the final product of the redesign of the Ngadi Bridge foundation structure.

Abutment 1

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Tabel 5. Redesign Data Abutment 1 Foundation

Existing Condition		Redesign Data	
Maximum Load (Pmax)	= 15643,59 kN	Maximum Load (Pmax)	= 15643,59 kN
Pile Cap Length (By)	= 16,4 m	Pile cap Length (By)	= 9,5 m
Pile Cap Width (Bx)	= 8,4 m	Pile Cap Width (Bx)	= 3,5 m
Pier Shaft Length	= 8,1 m	Pier Shaft Length	= *bored pile*
Pier Shaft Width	= 1,2 m	Diameter (D)	= 0,6 m
Foundation Type	=Concrete Piles	Length (L)	= 15 m
Diameter(D)	= 0,8 m	N-SPT	=25
Length (L)	= 16 m		
N-SPT	= 29		

The reason for choosing a diameter of 0.6 m is to streamline the concrete volume requirements, so a smaller diameter is chosen than the existing conditions. While the selection of a length of 15 m is in addition to streamlining the concrete volume requirements, based on the results of the SPT test the south side is at an N-SPT value of 25.

Reducing the dimensions of the pile cap from the existing conditions needs to pay attention to the requirements for the distance between the outermost pile and the edge of the pile cap. According to Sardjono (1991), the distance from the outermost pile to the edge of the pile cap is usually taken:

a. Cast in place pile, then the distance between the outermost pile and the edge of the pile cap ≥ the diameter of the pile or the diagonal of the pile section.

b. Foundation piles in the form of piles, then the distance between the outermost pile and the edge of the pile cap is 1.25 times the pile diameter or 1.25 times the diagonal of the pile section.

Another consideration of pile cap redesign is that the pile cap dimension must be larger than the pier shaft.

Based on the redesigned data and considerations above, the bearing capacity value and concrete volume requirements can be shown in Table 6.

Tabel 4. Abutment 1 Redesigned Calculation

Magnitude	Amount
End Resistance (Qp)	= 424,115 kN
Frictional Resistance (Qs)	= 2591,814 kN
Ultimate Reistance (Qu)	= 3015,929 kN
Allowable Resistance (Qa)	= 1507,964 kN
Total Pile (n)	= 10,37 ≈ 12 Piles
Allowable Load Capacity of Pile Group (Qg)	= 24501,99 kN **(Safe)**
Pile Volume (V)	= 16,2π m^3 = 50,8938 m^3

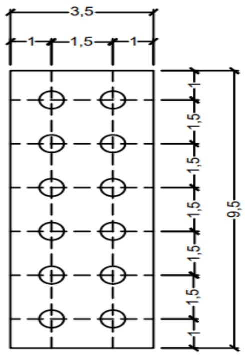

Figure 6. Abutment 1 Site Plan Redesign

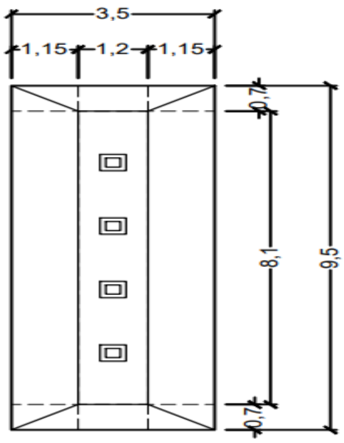

Figure 7. Top View of Abutment 1 Redesign

Abutment 2

Tabel 7. Abutment 2 Redesign Data Foundation

Existing Condition		**Redesign Data**	
Maximum Load (Pmax)	= 5524,51 kN	Maximum Load (Pmax)	= 5524,51 kN
Pile Cap Length (By)	= 10,4 m	Pile Cap Length (By)	= 9,5 m
Pile Cap Width (Bx)	= 4,4 m	Pile Cap Width (Bx)	= 2 m
Pier Shaft Length	= 8,1 m	Pier Shaft Length	= *bored pile*
Pier Shaft Width	= 1,2 m	Diameter (D)	= 0,6 m
Foundation Type	= Concrete Pile	Length (L)	= 10 m
Diameter (D)	= 0,8 m	N-SPT	= 22 m
Length (L)	= 10 m		
N-SPT	= 24		

The reason for choosing a diameter of 0.6 m is to streamline the concrete volume requirements, so a smaller diameter is chosen than the existing conditions. While the selection of a depth of 10 m is in addition to streamlining the concrete volume requirements, based on the SPT test results the north side is at an N-SPT value of 22. So it is still in hard soil. In addition, the reason for choosing pile cap dimensions with a length of 9.5 m and a width of 2 m is based on the dimensions of the pier shaft, the number of bored pile foundations produced, and the theory of Sardjono (1991) regarding the distance of the outermost pile to the edge of the pile cap.

Based on the redesign data and the above considerations, the bearing capacity values and concrete volume requirements can be shown in Table 8.

Table 8. Abutment 2 Redesign Calculation

Magnitude	**Amount**
End Resistance (Qp)	= 373,2212 kN
Frictional Resistance (Qs)	= 1520,531 kN
Ultimate Reistance (Qu)	= 1893,752 kN
Allowable Resistance (Qa)	= 946,876 kN
Total Pile (n)	= 5,8 ≈ 6 tiang
Allowable Load Capacity of Pile Group (Qg)	= 9068,82 kN **(Safe)**
Pile Volume (V)	= 5,4π m^3 = 16,9646 m^3

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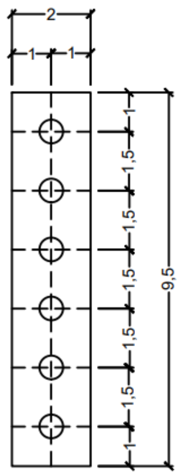

Figure 9. Abutment 2 Redesigned Foundation Site Plan

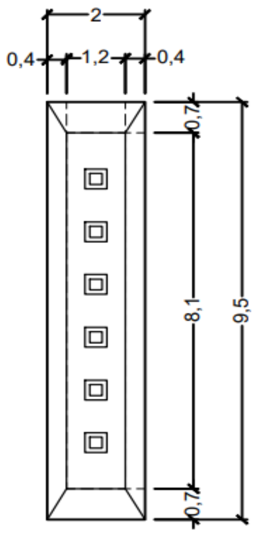

Figure 10. Abutment 2 Redesign Top View

Pilar

Table 9. Pile Foundation Redesigned Data

Existing Conditions		Redesigned Data	
Maximum Load (Pmax)	= 17873,23 kN	Maximum Load (Pmax)	= 17873,23 kN
Pile Cap Length (By)	= 16,4 m	Pile Cap Length (By)	= 11 m
Pile Cap Width (Bx)	= 10,4 m	Pile Cap Width (Bx)	= 8 m
Pier Shaft Length	= 8,1 m	Pier Shaft Length	= *bored pile*
Pier Shaft Width	= 1,2 m	Diameter (D)	= 0,6 m
Jenis pondasi	= Concrete Pile	Length (L)	= 4 m
Diameter (D)	= 0,8 m	N-SPT	= 24
Length (L)	= 4 m		
N-SPT	= 24		

The reason for choosing a diameter of 0.6 m is to streamline the concrete volume requirements, so a smaller diameter is chosen than the existing conditions. While the selection of a depth of 4 m or the same as the existing condition is based on trial-and-error calculations, an effective volume of concrete is obtained with a safe foundation bearing capacity. In addition, the reason for choosing pile cap dimensions with a length of 11 m and a width of 8 m is based on the dimensions of the pier shaft, the number of bored pile foundations produced, and the theory of Sardjono (1991) regarding the distance of the outermost pile to the edge of the pile cap.

Based on the Redesigned data and the above considerations, the bearing capacity values and concrete volume requirements can be shown in Table 10.

Table 10. Redesigned Pile Calculation

Magnitude	Amount
End Resistance (Qp)	= 407,1504 kN
Frictional Resistance (Qs)	= 663,5044 kN
Ultimate Reistance (Qu)	= 1070,655 kN
Allowable Resistance (Qa)	= 535,3274 kN
Total Pile (n)	= 33,38 ≈ 35 tiang
Allowable Load Capacity of Pile Group (Qg)	= 22430,43 kN **(Safe)**
Pile Volume (V)	= 12,6π m^3 = 39,58407 m^3

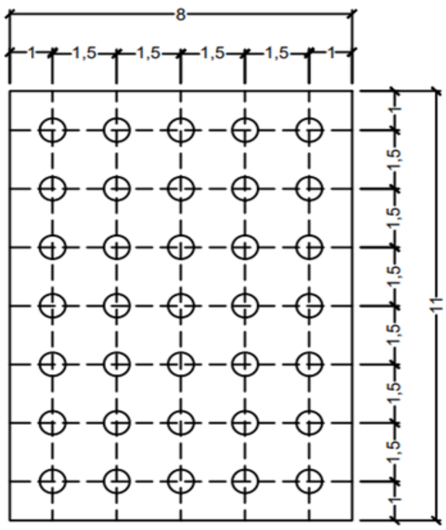

Figure 11. Redesign Pile Foundation Site Plan

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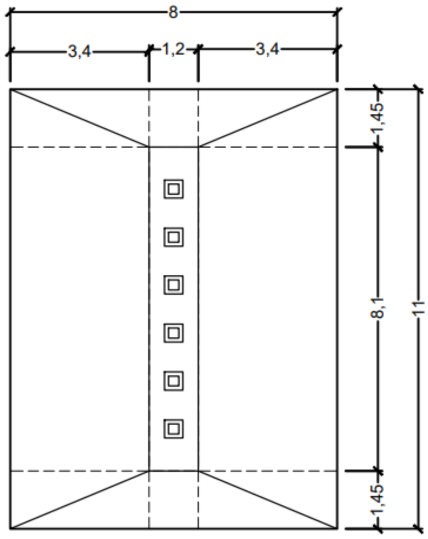

Figure 12. Redesign Pile Top View

Concrete Volume Settlement

The percentage reduction in redesigned concrete volume requirements against existing conditions is shown in Table 11.

Table 5. Reduction Percentage in Concrete Volume Requirement

Exsisting Volume and Redesign Volume Comparison	
Existing total volume	= 68,6π m^3 = 216,14 m^3
Redesign Volume:	
Abutment 1	= 16,2π m^3 = 50,8938 m^3
Abutment. 2	= 5,4π m^3 = 16,9646 m^3
Pile:	= 12,6π m^3 = 39,58407 m^3
Total Redesign Volume	= 34,2π m3 = 107,4425 m^3
Volume Reduction Percentage	= 50,29%

CONCLUSION

First, the implementation of the existing foundation (piles) in the Ngadi Bridge Construction Project caused vibration and noise, and the large number of existing foundation points in each abutment and pillar caused the number of concrete volume requirements to increase, namely 216.14 m3. Second, the design of bored piles on the Ngadi Bridge for Abutment 1 is to use 12 bored piles with a diameter of 0.6 m and a foundation depth of 15 m. The resulting group bearing capacity is 2450 m3. The resulting group bearing capacity is 24501.99 kN. For Abutment 2, using 6 bored piles with a diameter of 0.6 m and a foundation depth of 10 m. The resulting group bearing capacity is 9068.82 kN. Meanwhile, the pillar uses 35 bored piles with a diameter of 0.6 m and a foundation depth of 4 m. The resulting group bearing capacity is 22430.43 kN. Third, the total volume of existing foundation concrete needs is 216.14 m3. While the total volume of bored pile foundation concrete requirements is 107.4425 m3. So that the percentage of savings in concrete volume requirements reaches 50.29%.

SUGGESTION

First, when planning the foundation, it is necessary to consider the advantages and disadvantages of each design alternative in order to choose the most effective and efficient one. Second, accuracy in conducting soil investigation and reading the results of the investigation needs to be considered in order to obtain accurate planning calculations. Third, further development research can be carried out by using soil strength data sources from other tests to support the analysis of foundation bearing capacity calculations.

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