SUGGESTED GUIDELINES FOR DESIGN AND CONSTRUCTION OF SHORT—SPAN BRIDGE ABUTMENTS WITH REINFORCED EARTHSYSTEM

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***Abstract**: The construction of small bridges is one of the real challenges in road construction because it has so many problems. The reinforced earth system is also known as mechanically stabilized earth wall (which is the same term as MSE Wall) using gabion and it could be suggested as better alternatives for the foundation of short—span bridges, especially in remote areas. The latest research was about to find the design of reinforced earth abutment on various heights of abutments and various lengths of bridge span on soft to very soft consistency cohesive soil. However, the results of this research were less representative because the field conditions can vary from very soft to stiff cohesive soil and very loose to dense non-cohesive soil. Therefore, further research for a wide range of soil conditions was conducted. Based on internal and external stability analysis, known that the number of geotextiles needed for MSE wall ranging from 2 to 5 layers per meter depth, depending on the grade and the depth placed of the reinforcement, while the length of geotextile needed ranging from 3.2 to 22.5 meter, depending on the bridge span, embankment height, and parameters of the soil. The construction of short-span bridge abutments using MSE Wall cannot be built on soft to very soft soil ($C_u < 2.79$ Ton/m^2). Based on circular failure analysis (overall stability), known that in cohesive soils with stiff consistency ($C_u = 6$ Ton/m^2) to very stiff ($C_u = 12$ Ton/m^2) and non-cohesive soils with dense consistency ($\phi = 38^0$) to very dense ($\phi = 42^0$) does not require additional reinforcement. While on other soil consistency, some need additional reinforcement ranging from 0 to 22 layers of geotextile and from 0 to 35 pieces of micro piles, depending on the bridge span, embankment height, and grade of the reinforcement. The number of gabions needed as a facing of MSE wall ranging from 5 to 8 pieces per 2-meter width of abutments, depending on the embankment height.*

Keywords: *Short—span (small) bridge, reinforced earth, mechanically stabilized earth wall, gabion, soil reinforcement*

INTRODUCTION

Indonesia is currently developing its road and highway network in all parts of the country, to connect all cities and harbors to the hinterlands. Considering the unique geographical condition of Indonesia, the development of roads is quite a challenge, since building road also means constructing a lot of big and small bridges along the roads. The construction of small bridges in Indonesia is one of the real challenges in road construction because small bridges "are not worth the effort". The main problems with the construction of small bridges in Indonesia can be summarized as follows[1][2]:

- Problems related to the number and cost of construction.
- Problems related to the remoteness of the bridge locations.
- Problems related to the relatively low volume of traffic.
- Problems related to the relatively soft condition of the ground where the bridge is to be constructed.
- Problems related to scouring during the swift current.

It is no wonder that many small bridges in rather remote areas in Indonesia will look like that of Figure 1. This is the typical condition of small bridges where their foundation could not be properly constructed due to lack of involvement of heavy construction equipment. The bridge foundations were constructed from stone masonry or simple timber formations that were easily damaged in a relatively short time[3].

The term short—span bridges use in this paper is the one that is with a total span of not more than 20 meters, since the Department of Public Work of Indonesia in the book "Pedoman Gambar Standar Pekerjaan Jalan dan Jembatan" considers that 20 meters are the maximum length that composite BM-70 bridges (composite steel girder and concrete slab deck with reduced 70% load) that can be constructed directly in the field[4]. Therefore, no heavy equipment is needed for the construction of this type of bridge and this composite concrete bridge has been the common choice in many rural areas of Indonesia for small bridges[3].

Figure 1 Condition of many small bridges in remote parts of Indonesia due to rapid deterioration of the bridge foundation[3]

The reinforced earth system is also known as mechanically stabilized earth wall (which is the same term as MSE Wall) using gabion can be suggested as better alternatives for the foundation of short—span bridges, especially in the remote areas of Indonesia. The advantages of using this type of reinforced system are as follows[3]:

- It does not need heavy equipment to install, since it could be done by men only, an advantage for remote areas of Indonesia.
- It is relatively low cost, when compared to other types of the bridge abutment, such as stone masonry or reinforced concrete structure.
- The bridge abutments may settle with the bridge embankment ramp due to the consolidation of the original soil under the embankment. This condition may prevent the appearance of a "sudden jump" between the bridge deck and the ramp. The road will stay even and

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smooth, albeit the consolidation settlement of the bridge abutments is still continuously progressing.

- This system is rather easy to construct so that no highly skilled laborers are needed. Construction can be done mostly using local laborers, with some short training conducted locally. This is certainly more cost-effective than having to bring many skilled laborers from outside (usually from Java, where the supply of more skilled laborers are in abundance) to construct the bridge, besides another benefit like creating sometimes much-needed employment for the local people.
- For softer soils, this system can be combined with micro piles reinforcement (in Indonesia this is commonly termed as reinforcement with a "cerucuk", bamboo or wooden piles about 10 to 15 cm diameter inserted into the ground to help reinforce the soft soil underneath the foundation)
- This system can also be designed to prevent scouring of the river bed surrounding the bridge abutment.
- The reinforced system using gabion can be applied also to prevent damages on bridge embankment ramp during flood water because bridge embankment ramp sometimes is not protected against any erosion so that the ramp is often washed out by the river.

Therefore, a guideline for the design and construction of short—span bridge abutments with a reinforced earth system (MSE wall) is needed so that bridge planning in Indonesia can be carried out more easily and effectively. Related to the development of these guidelines, several studies have been carried out. [5] have designed reinforced earth abutment on various heights of abutments (maximum 6.5 m) and various lengths of bridge span (maximum 20 m)[5]. In this reference, the amount of reinforcement was calculated for using geotextile and geogrid as the main reinforcement material, while for the larger thickness of the bridge abutment the additional reinforcement using micro piles under the abutment was specified and calculated. According to [3], some of [5] work were reconfirming the result of [6] and [7]. However, the results of this research were less representative of field conditions because the soil conditions analyzed were only very soft and soft clay.

Based on the results of the research as described above, further research needs to be done. To be a guideline for the design and construction of short—span bridge abutments with reinforced earth systems, it should be able to cover a wide range of types and consistencies of soil.

RESEARCH SIGNIFICANCE

This research was conducted to determine the design of the MSE Wall retaining structure for various lengths of bridge span (10m, 12m, 14m, 16m, 18m, and 20m) and various embankment heights (3.5m, 4.5m, 5.5m, and 6.5m) on cohesive soils and non-cohesive soils. Furthermore, this research can obtain a guidebook or "guidance" for the design and construction of short—span bridge abutments with reinforced earth systems (MSE Wall).

METHODOLOGY

In general, two main forms of stability should be investigated in MSE wall based on ultimate limit states stability, which is external stability and internal stability. External stability that needs to be checked includes the factor of safety against bearing capacity failure, sliding, overturning, and circular failure. Meanwhile, the internal stability of the MSE wall can occur in two different failure modes, which are safety against pullout and breaking failure[8].

The variable of this research consists of various types of soils, consistencies of soil, bridge span, embankment height, and type of reinforcement to be used which is presented in the form of a matrix as in Table 1. Cohesive soil with very soft to very stiff consistency is standardized and is expressed by the value of C_u (unconsolidated undrained, short term). Meanwhile, for non-cohesive soils whose consistency is very loose to very dense, which is standardized and expressed by the value of ϕ.

The output of this research is categorized into C_u minimum of subgrade (cohesive soil), number of gabions, and number & length of various types of reinforcement to be used on the design of the MSE wall retaining structure

ANALYSIS AND DISCUSSIONS

A. C_u MINIMUM OF SUBGRADE (COHESIVE SOIL)

Since the safety factor of bearing capacity control in cohesive soils cannot be increased by extending the Length of geotextile, the subgrade must be improved first so that the C_u value of the soil increases. Therefore, it is necessary to find the minimum amount of C_u required so that MSE walls with embankments as high as 3.5 to 6.5 meters and bridges with spans of 10 to 20 meters can meet the specifications. The relationship between C_u minimum and bridge spans for each embankment is presented in Figure 2.

In Figure 2 known that the smallest C_u value of the soil is 2.79 Ton/m^2. However, the C_u value of very soft to soft soil is ranging from 0 to 2.5 Ton/m^2 following the C_u value estimated by [9] which was determined using the UCT test. Therefore, it can be concluded that MSE Wall cannot be built on very soft to soft soil.

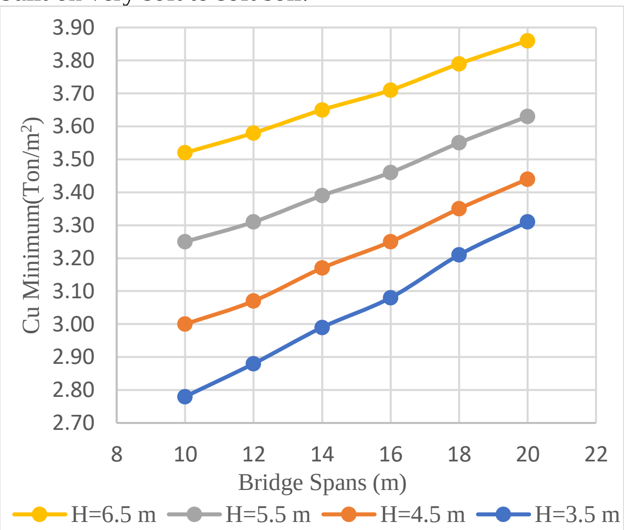

Figure 2 C_u minimum vs bridge spans for each embankment height on cohesive soil

B. SOIL REINFORCEMENT UNDER THE BRIDGE SEAT

Reinforcement specifications under the bridge seat (reinforced earth area) are the ultimate tensile strength, length, and amount of geotextile required at each depth. To prevent the occurrence of tension cracks behind the reinforcement zone, the top 2 rows of reinforcement must be 1 m – 1.5 m longer than the rows of reinforcement below[8]. Typical soil reinforcement under the bridge seat (reinforced earth) can be seen in Figure 3.

Table 1 Variation Matrix

Variation of Soil			
Type	Consistency	C_u (Ton/m^2)	Φ (degree)
Cohesive	Very Soft	0.75	0
	Soft	1.5	0
	Medium	3.0	0
	Stiff	6.0	0
	Very Stiff	12.0	0
Non-Cohesive	Loose	0	26
	Very Loose	0	30
	Medium	0	34
	Dense	0	38
	Very Dense	0	42
Variation of Bridge Spans (m)			
10			
12			
14			
16			
18			
20			
Variation of Embankment Heights (m)			
3.5			
4.5			
5.5			
6.5			
Variation of Soil Reinforcement			
Material	Type		
Geotextile	T ultimate = 50 kN/m		
	T ultimate = 100 kN/m		
	T ultimate = 200 kN/m		
Micro piles (f'_c = 25 MPa)	Dimension = 20x20 cm		
	Dimension = 15x15 cm		

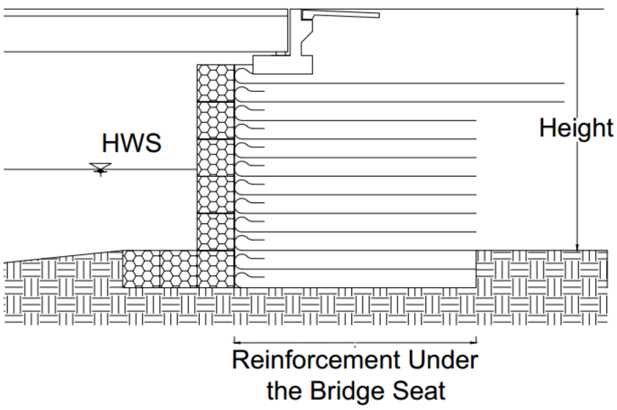

Figure 3 Typical reinforcement under the bridge seat

The relationship between C_u and Geotextile length for each embankment height can be seen in Figure 4. The relationship between ϕ and Geotextile length for each embankment height can be seen in Figure 5. The amount of reinforcement for ultimate tensile strength geotextile 200 kN/m, 100 kN/m, and 50 kN/m at each depth can be seen in Table 2.

From Figure 4 and Figure 5 know that the length of geotextile needed ranging from 3.2 to 22.5 meters, depending on the bridge span, embankment height, and parameters of the soil. While from Table 2 know that the number of geotextiles needed ranges from 2 to 5 pieces, depending on the grade and the depth placed of the reinforcement. About Geotextile with ultimate tensile strength 50 kN/m, from Table 2 known that this particular grade of geotextile cannot be used on depth 1.5-3.5 and 6.5-7.5 because it doesn't meet the requirement either from external stability or internal stability analysis.

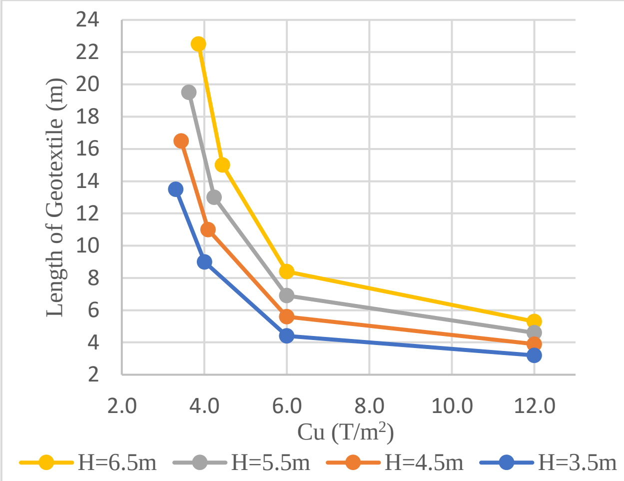

Figure 4 C_u vs Length of Geotextile for each embankment height

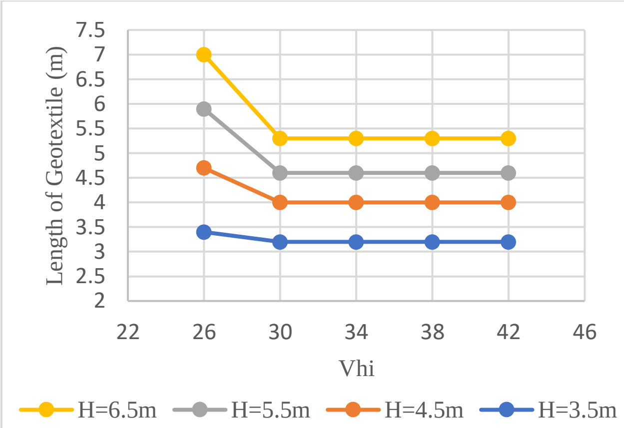

Figure 5 ϕ vs Length of Geotextile for each embankment height

C. ADDITIONAL REINFORCEMENT BASED ON CIRCULAR FAILURE ANALYSIS

After the soil under the bridge seat has been reinforced, the next step is to analyze the circular failure (overall stability) of the embankment. In this suggested guide, 2 types of reinforcement materials are used, namely Geotextile and Micro piles. In the geotextile reinforcement type, 3 types of ultimate tensile strength, which are 50 kN/m, 100 kN/m, and 200 kN/m. While the type of micro piles reinforcement uses 2 kinds of dimensions, which are 20x20 cm and 15x15 cm which both have a grade f'_c of 25 MPa. The stability analysis results show that in cohesive soils with stiff consistency (C_u = 6 Ton/m^2) to very stiff (C_u = 12 Ton/m^2) and non-cohesive soils with dense consistency (ϕ = 38^0) to very dense (ϕ = 42^0) does not require additional reinforcement against circular failure analysis (overall stability).

Table 2 Amount of Geotextile Reinforcement at Each Depth

Depth	Height of Embankments (m)			
	6.5	5.5	4.5	3.5
Amount of Geotextile Ultimate Tensile Strength 200 kN/m				
0-1.5	Location of Bridge Seat			
1.5-2.5	2	2	2	2
2.5-3.5	2	2	2	2
3.5-4.5	2	2	2	2
4.5-5.5	2	2	2	-
5.5-6.5	2	2	-	-
6.5-7.5	2	-	-	-
Amount of Geotextile Ultimate Tensile Strength 100 kN/m				
0-1.5	Location of Bridge Seat			
1.5-2.5	4	4	4	4
2.5-3.5	3	3	3	3
3.5-4.5	3	3	3	3
4.5-5.5	3	3	3	-
5.5-6.5	3	3	-	-
6.5-7.5	3	-	-	-
Amount of Geotextile Ultimate Tensile Strength 50 kN/m				
0-1.5	Location of Bridge Seat			
1.5-2.5	*	*	*	*
2.5-3.5	*	*	*	*
3.5-4.5	5	5	5	5
4.5-5.5	5	5	5	-
5.5-6.5	5	5	-	-
6.5-7.5	*	-	-	-

*Please Use Higher Reinforcement Grade

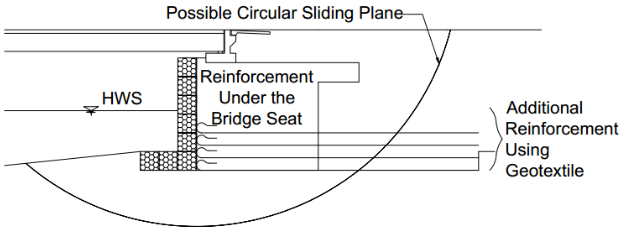

Figure 6 Typical of additional geotextile reinforcement based on overall stability analysis

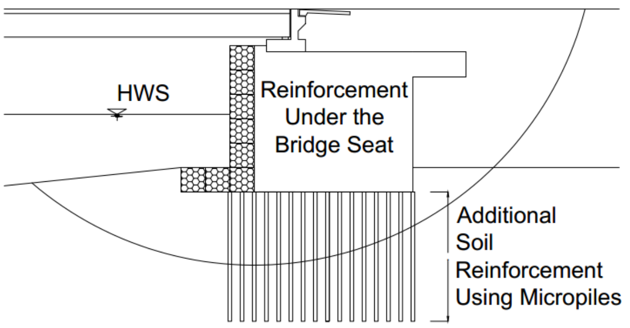

Figure 7 Typical of additional micro piles reinforcement based on overall stability analysis

This is because all bridge spans and embankment heights analyzed, the results of the XSTABL software show the SF value is more than the minimum required SF, which is 1,3[8]. While on other soil consistency, some need additional reinforcement ranging from 0 to 22 layers of geotextile or from 0 to 35 pieces of micro piles, depending on the bridge span and embankment height. For more detailed and complete information regarding the design of reinforced earth abutment on various types of soils, various heights of embankments, and various lengths of the bridge span, the information can be obtained from [10]. Typical geotextile reinforcement for overall stability can be seen in Figure 6 and Figure 7.

D. NUMBER OF GABIONS AS A FACING OF MSE WALL

The gabion size used in this suggested guideline is 2x1x1m with masonry brick as filling material with a density of 1240 kg/m3. The function of the Gabion on the MSE wall is to cover the face (facing) and prevent erosion. The typical about the gabion structure of the MSE wall can be seen in Figure 8.

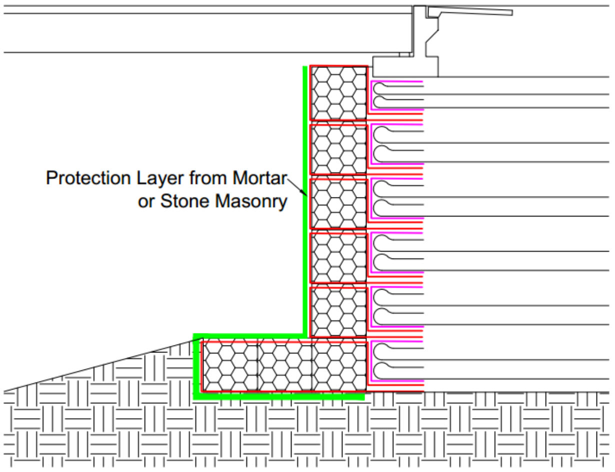

Figure 8 Gabion installation details

The relationship between embankment height and the number of gabions required per 2 meters wide MSE wall can be seen in Figure 9. From the Figure 9 known that the number of gabions needed ranges from 5 to 8 pieces per 2-meter width of abutments, depending on the embankment height.

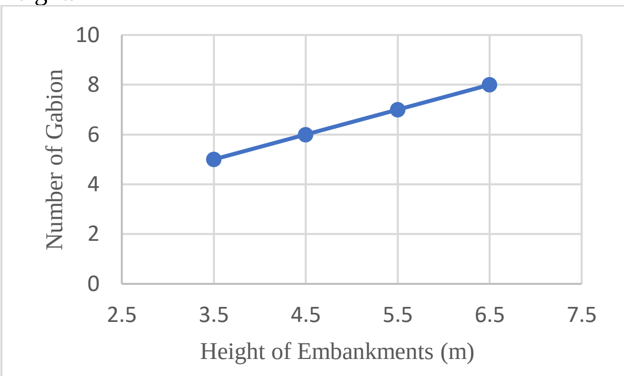

Figure 9 Relationship between embankment height and number of gabions

The only drawback of this MSE Wall structure is that the gabion material, which is an HDPE geogrid (HDPE = high density polyethylene, a type of plastic), is very likely to be directly exposed to local residents. It is possible that the gabions were accidentally broken due to the behavior of local residents. Therefore, it is recommended to cover or hide the exposed HDPE material with cement mortar or with an additional layer of masonry[3].

CONCLUSIONS

Based on the results of this research, it can be concluded that:

1. The construction of short-span bridge abutments using MSE Wall cannot be built on soft to very soft soil (C_u < 2.79 Ton/m^2).
2. Based on internal and external stability analysis, known that the number of geotextiles needed for MSE wall (reinforced earth structure) ranging from 2 to 5 layers per meter depth, depending on the grade and the depth placed of the reinforcement, while the length of geotextile needed ranging from 3.2 to 22.5 meter, depending on the bridge span, embankment height, and parameters of the soil.
3. Based on circular failure analysis (overall stability), known that in cohesive soils with stiff consistency (C_u = 6 Ton/m^2) to very stiff (C_u = 12 Ton/m^2) and non-cohesive soils with dense consistency (ϕ = 38^0) to very dense (ϕ = 42^0) does not require additional reinforcement. While on other soil consistency, some need additional reinforcement ranging from 0 to 22 layers of geotextile or from 0 to 35 pieces of micro piles, depending on the bridge span, embankment height, and grade of the reinforcement.
4. The number of gabions needed as a facing of MSE wall (reinforced earth structure) ranging from 5 to 8 pieces per 2 meter width of abutments, depending on the embankment height.

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