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CASE STUDIES ON DESIGN AND CONSTRUCTION OF DEEP FOUNDATIONS IN SARAWAK SOFT SOIL

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SUMMARY

Eight (8) structures using deep foundation are selected and discussed in this paper. The eight (8) structures located in difficult ground of Sarawak are namely the Sg. Rimbas Bridge in Pusa, Sg. Sawit Bridge, Sg. Palasan Bridge, and Pusa Ferry Ramp in Pusa; all in Betong Division, Batang Samariang Bridge in Kuching Division, Batang Samarahan Bridge and Batang Sadong Bridge; both in Samarahan Division and Batang Baram Bridge in Miri Division. During the design stage, several important engineering decisions were made in order to meet both the design code and statutory requirements. The design was not to compromise the difficult condition of the ground. The ground at all eight (8) locations were reported to be having low bearing capacity with Standard Penetration Test (SPT) N values between 0 and 5 found at depths from 0 to 20m and (SPT) N values less than 10 found at depths between 20m and 80m. Very soft to soft soil that is of recent sedimentary deposit was found at all locations. This paper emphasizes on decisions made in the design of the bridge foundation and ferry fender foundation. Background and localities of the projects, geological and geotechnical findings, design and types of foundation used, method of constructing the foundation and preliminary test pile results obtained are presented in this paper.

Keywords: *soft clay, deep foundation, Standard Penetration Test (SPT), Sarawak*

INTRODUCTION

Deep foundation design and construction in difficult ground condition involve many considerations to be made on suitable types of deep foundation and construction method. The type of foundation chosen will affect the overall cost of the structure. The selected construction method must be practical. In line with the infrastructure planning to support the economic development of the state of Sarawak in Malaysia, the construction of coastal roads including bridges to link all towns and population centres located in the coastal area is part of the strategy. Besides the many small rivers, a few major rivers need bridge crossings to be constructed. With the completion of the coastal roads network, the economic activities in these coastal regions will be enhanced.

Constructing structures at unfavorable locations on marginally stable river banks requires in depth assessment of the local soil conditions in order to achieve a sound decision. The Sg. Rimbas Bridge in Pusa, Sg. Sawit Bridge, Sg. Palasan Bridge, and Pusa Ferry Ramp in Pusa; all in Betong Division, Batang Samariang Bridge in Kuching Division; Batang Samarahan Bridge and Batang Sadong Bridge both in Samarahan Division and Batang Baram Bridge in Miri Division are the eight (8) bridges located in difficult ground condition (in terms of soil parameters) to be discussed in this paper.

BACKGROUND AND LOCALITY

Sungai Rimbas Bridge is located in Pusa town, Betong Division. It is a tributary to Batang Saribas. When completed, the bridge will link Pusa town and Kampung Pusa. This bridge will link the existing coastal roads network. Pusa Ferry Ramp is also located in Pusa which is used to cross the Sungai Saribas. Additional fendering system at Pusa Ferry Ramp was completed in 2012. The design is done in-house by Jabatan Kerja Raya (JKR) Sarawak. Sg. Palasan Bridge that links Pusa town and Sebuyau was completed in 2006 to replace the collapsed bridge structure. Sg.Sawit Bridge along Jalan Tanjung Assam/ Hilir Saribas/ Beladin is located in Betong. Fig.1 shows locations of all four (4) bridges.

Batang Samariang bridge is located in Kuching, Kuching Division as shown in Fig.1, linking Kuching city to Matang, Telaga Air, and the Lundu/ Sempadi coastal road. The 300m bridge was completed in 2014 and is presented in this paper to show the different soil properties compared with other locations.

Batang Samarahan and Batang Sadong bridges are both located in Samarahan Division, linking Kota Samarahan with other population centres in Sarawak. The construction of Batang Samarahan Bridge commenced in

2015. Load test has been carried out for this bridge. Batang Sadong bridge is under construction and is scheduled to be completed in 2016. A statnamic test has been carried out for this project.

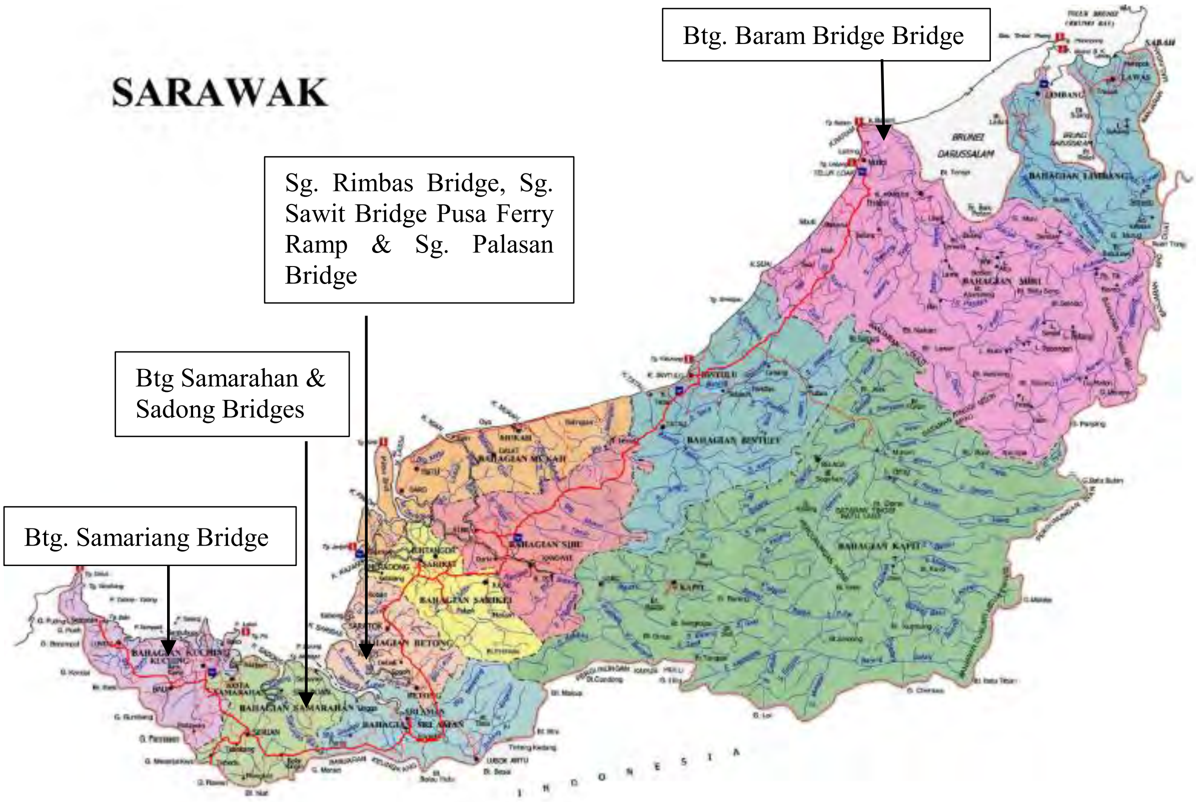

Fig. 1 Locality map of eight (8) bridges

The Batang Baram Bridge (also known as the ASEAN Bridge) is located along the Miri-Baram trunk road, linking Sarawak with Brunei, as shown in Fig.1. The bridge was completed in August 2003. The bridge is included in this paper for comparison with other similar soil condition for other projects.

SITE INVESTIGATION

For the Sg. Rimbas Bridge project six (6) boreholes were drilled; three (3) boreholes overwater and three (3) borehole on land. Typical borehole measurements of SPT are presented in Fig. 2(a). From depths of 0 to 20m SPT value is zero which indicates very soft soil and with top layer is generally of peat. From the depths of 20 to 50m the SPT N values were less than 10 which is classified as soft soil. The soil layers from top to bottom can be classified as very soft to soft clay, firm to stiff silty clay and hard silty clay. With the information derived from SPT the riverbank stability needs to be checked or analyzed prior to choosing the suitable type of deep foundation and treatment of the riverbank. SPT measurements from one borehole for Sg. Sawit Bridge are shown in Fig. 2(b). From depths of 0 to 20m, the SPT N value equals to 0 and from 20 to 40m, the SPT N values were less than 10. This borehole shows that the riverbank is marginally stable. SPT measurements from one of two (2) boreholes available for Sg. Palasan Bridge are presented in Fig. 2(c). The SPT N value equals to 0 from depths of 0 to 15m and greater than 10 from depths of 15m to 72m. The soil consists of mainly very soft to firm clay. The typical borehole of Pusa Ferry Ramp is shown in Fig. 2(d). There are eight (8) boreholes carried out for this project. Typical soils are very soft to soft clay, clayey silt and dense sand. Based on Borehole 4, the condition of soil indicates challenges in the construction of the fendering system. The SPT N value is less than 10 until the depth of 45m and the maximum SPT N value is 32 at depth of 80m. For this project, design requires the steel pipe pile be driven to a depth of at least 80 in order to provide adequate lateral resistance against the lateral force due to Ferry‘s impact. The above four projects share some similarities on the soil properties, particularly the top 15m to 20m in which the SPT value is equals to zero.

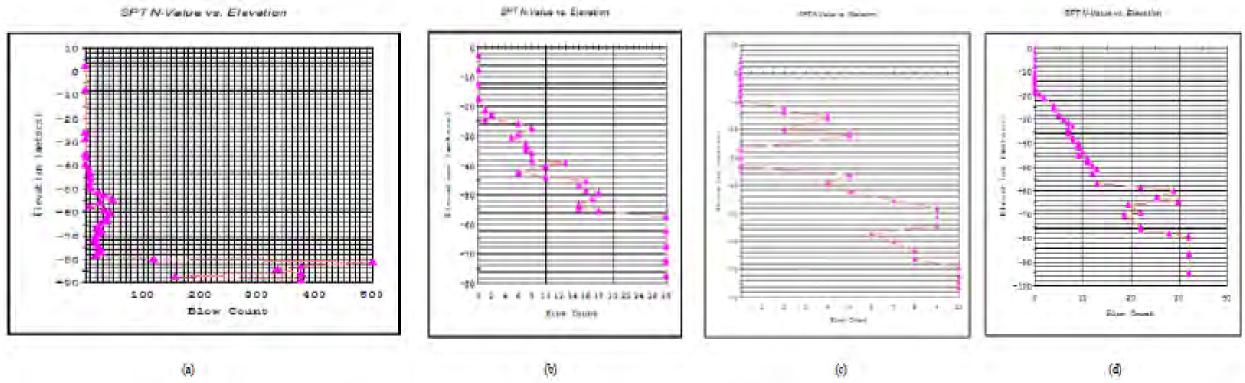

Fig. 2 (a) SPT for Sg. Rimbas Bridge, (b) SPT for Sg. Sawit Bridge, (c) SPT for Sg. Palasan Bridge, (d) SPT for Pusa Ferry Ramp

Batang Samariang Bridge is located in Kuching Division. It is included in this paper for comparison purpose. The soil condition is better but top soil need to be considered in design, particularly the slope stability analysis of the riverbank where the abutments are located and the type of pile to be used. The top 8 m is very soft soil. The soil could be described as very soft clay to soft clay, firm silt and weathered rock. Typical borehole is shown in Fig. 3(a).

At Batang Samarahan Bridge, twelve (12) boreholes were drilled. The SPT N values are presented in Fig. 3(b). SPT N values were recorded to a depth of 45m. It was also recorded that the SPT N values were zero until a depth of 5 m, indicating very soft clay with layers of peat. The soils could be described as very soft to soft clay, soft to firm clay, hard clayey silt and very poor mudstone. For the Btg. Sadong Bridge project, boreholes were drilled, with two at abutments and nine at the nine piers. The soil layers from top to bottom of the borehole are reported to be very soft to soft clay, firm clay, dense sand, highly fractured and weathered granite. It was also reported that SPT N value is equal to zero until depth of 18m. Fig. 3c shows typical borehole at Btg. Sadong bridge.

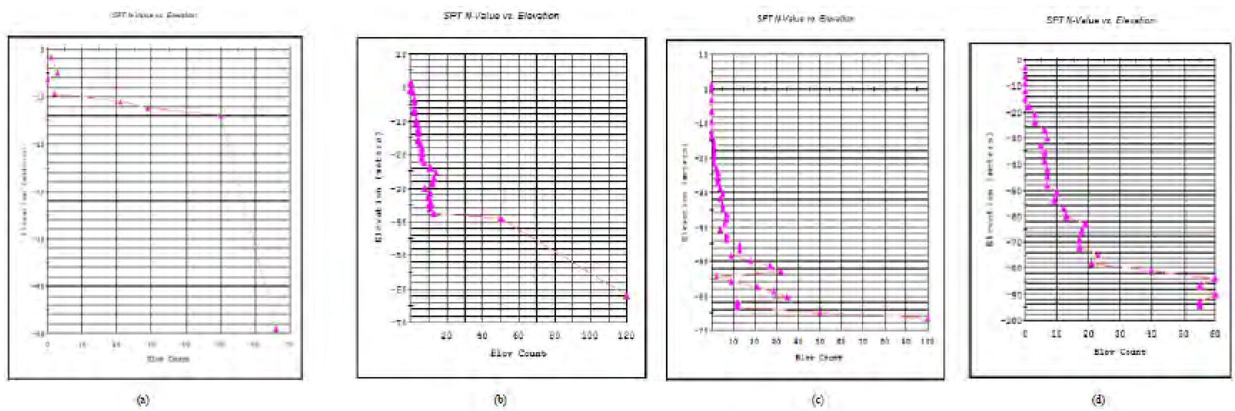

Fig.3 (a) SPT for Btg. Samariang Bridge, (b) SPT for Btg. Samarahan Bridge, (c) SPT for Btg. Sadong Bridge, (d) SPT for Btg Baram Bridge.

For the Btg. Baram Bridge thirteen (13) boreholes were drilled and a typical borehole is presented in Fig. 3(d). It was reported that SPT N values were recorded until depth of 93m. It was also recorded that soil layers from top to bottom of BH-101 are very soft to soft clay, firm clay, stiff to very stiff, hard clay (with SPT N value greater than 50).

DESIGN, CONSTRUCTION AND TESTING

The Sg. Rimbas Bridge is an 8-span bridge with a total length of 327.2m. The design of substructure for this bridge took into account the slope stability of both riverbanks in view of very soft soil. The recorded SPT N values showed values of 0 up to a depth of 40m. Slope stability analysis carried out for both riverbanks shows that the riverbanks need to be treated in order to increase the factor of safety from 1.06 to at least 1.4. 117 micropiles of 300mm diameter have been drilled and grouted with Grade 30 concrete to a depth of at least 36m between Pier 1 and Pier 2 at Pusa side and 99 micropiles of 300mm diameter between Pier 6 and Pier 7 drilled and grouted to a depth of at least 45m in order to increase factor of safety to about 1.4. It was decided 1000mm diameter steel pipe piles of thickness 19mm for land piers be utilized to support loadings from bridge superstructure and to improve riverbank stability. Some empirical formulas have been used to predict the allowable bearing capacity of 1000mm diameter steel pipe pile with reinforced concrete infill [2, 5]. Meyerhof method (1976) was used to predict the bearing capacity and the allowable bearing capacity obtained is 459 tonnes, with 2.5 factor of safety. With a combination of Alpha method and Meyerhof method the allowable bearing capacity obtained is 380 tonnes in which Alpha method is used for the skin friction resistance and Meyerhof method for tip resistance. Finally the safe working load of 350 tonnes and min length of 60 m was decided upon. This was confirmed by both static load test and PDA test. Vibro hammer was used to install 1000mm diameter steel pipe piles and 20 tons hammer was used to drive the pile to set. Vibro hammer was selected to avoid any damage to nearby building structures. All piles were installed to a depth of around 62m. The strength of the foundation system was mainly derived from its frictional properties. This bridge is expected to be completed in 2016. Fig. 4 shows long section of the bridge and riverbank‘s treatment with micropiles.

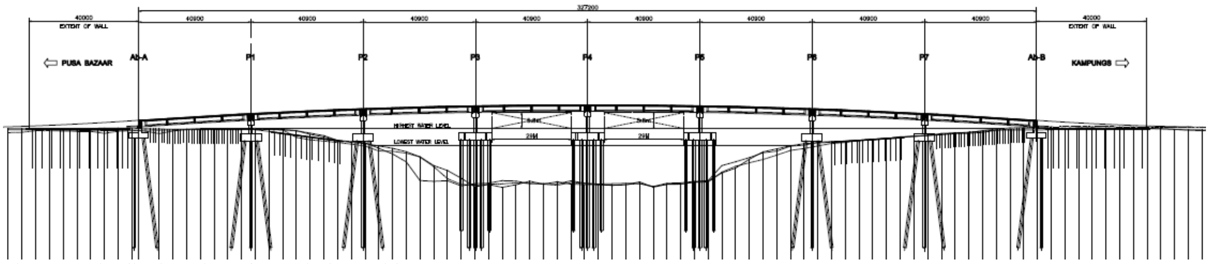

Fig.4 Longitudinal section of Sg. Rimbas Bridge

The second bridge in Betong Division is the Sg. Sawit Bridge, a 3-span prestressed beams bridge with a total length of 90m as shown in Fig. 5. After detailed analysis, it was decided to use 600mm prestressed spun pile for both abutments and piers. The safe working load is 80 tons. For this project 16 numbers of piles were used for each pier and 26 numbers of pile for each abutment. The strength of the foundation system was mainly based on skin resistance of very soft to soft soil. From the slope stability analysis of riverbank it was decided the foundation system for the abutments and piled slab behind each abutment should also be able to improve the riverbank‘s stability. A minimum factor of safety of 1.2 is required to be able to support embankment for the approach road. Meyerhof‘s method was used to predict the skin resistance which is approximately 28 kPa. It was decided that 600mm diameter piles with a minimum 60m length were to be driven using a hydraulic hammer of 5 tonnes weight. Static load test and PDA test are to be carried out to confirm the predicted bearing capacity of the pile. This bridge is under construction.

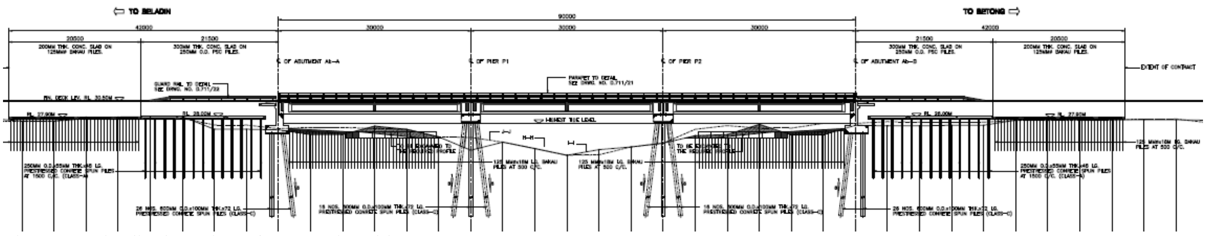

Fig. 5 Longitudinal Section of Sg. Sawit Bridge

The Sg. Palasan Bridge project has three (3) spans with a total length of 58m and the foundation system uses steel H-pile of 305x305x97 kg/m. The pile length was decided to be approximately 75m which is required to mobilize skin resistance. Site investigation report shows that the SPT N values were less than 10 until a depth of 75m and equals to 10 from a depth of 75 to 80m. The steel H-Pile was selected to replace the 450mm diameter prestressed spun piles earlier used for the collapsed bridge structure. The riverbank is marginally stable with a factor of safety around 1 and need to be improved by driving more steel H-piles at each abutment and pier. It was recorded that 24 numbers and 32 numbers were driven respectively for each of the pier and abutment.

For the fendering system in Pusa, it was decided to use 900mm steel pipe piles of thickness 16mm with reinforced concrete infill. Siahaan *et al* [3] has reported the design of this project. A 20 tons hammer was used to drive steel pipe piles through very soft to soft soil and penetrate through an average SPT N value of 26 from a depth of 55 to 80m. The driving was terminated when it reached SPT N values greater than 26. Four numbers of additional fender systems were designed not only to support the vertical loads but also to resist the specified ship impact loads sustained from ferries carrying 32 numbers of cars which have a total load of approximately 212 tonnes. All piles were driven to around 96m. The capacity of pile was mainly mobilized by skin friction.

The Batang Samariang Bridge has a soil condition better than the other bridges. Soil layers were classified as very soft to soft soil and were found from ground surface to a depth of about 8m. Weathered rock was found starting from a depth of 8m. The riverbank needs to be analyzed before deciding the type of deep foundation. A 1200mm diameter bored pile was decided for all piers. The piles were socketed around 8m into weathered rock. The embedment of the pile into rock will provide some amount of lateral restraint at the pile tip [1, 4]. The predicted settlement based on Vesic method (1977) is 6 mm under ultimate load 18,000 kN compared to measured settlement of 10.78mm from static load test.

For Batang Samarahan Bridge 1500 mm diameter steel pipe piles were used. Fig. 6 shows a 771m long Batang Samarahan bridge which has two piers on the river. Each pile was driven into weathered rock identified as highly fracture mudstone. Reese method was used to predict settlement in which the settlement was 5mm under working load 12,000 kN. Each pile needed to be socketed into weathered rock around 8m to handle lateral load due to ship impact. The load test on the instrumented test pile showed that under working load the measured settlement was 8.5mm compared to predicted settlement of 5mm. The difference was mainly due to the driving process that affects the mobilized skin resistance. The number of piles at the river piers was designed to support not only the loads from the bridge superstructure but also to handle the loads from barge impact load of around 2000 DWT.

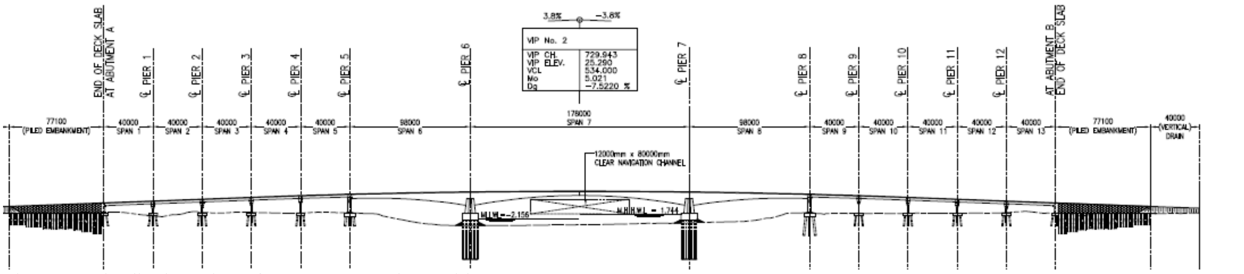

Fig. 6 Longitudinal Section of Batang Samarahan Bridge

The Batang Sadong Bridge which is included in this paper shows the similarities in the soil properties with Batang Samarahan Bridge. A statnamic test was carried out on the preliminary test pile. A 54.15 m long instrumented test pile of 1500mm diameter (hollow section) was performed on 6th December 2012 to confirm the bearing capacity of pile and the required socket length. Based on Reese method the predicted settlement was 7.1mm and 21mm respectively under working load of 9,000 kN and twice working load of 18,000 kN compared to measured settlements of 9.56mm and 23.68mm respectively. Fig 7 shows a longitudinal section of Batang Sadong Bridge in which 33 piles were driven at Piers 4, 5 and 6 on the river.

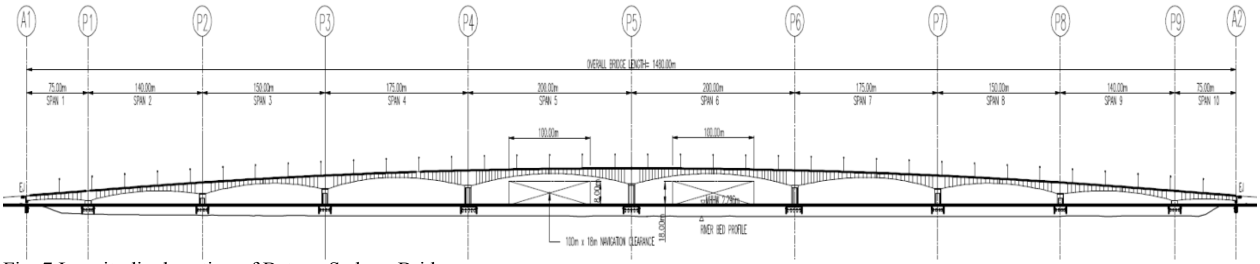

Fig. 7 Longitudinal section of Batang Sadong Bridge

Fig. 8 shows a 19 span Batang Baram Bridge with a total length of 1040m. 33 steel pipe piles of 1500mm diameter with reinforced concrete infill were driven for each river pier. For Batang Baram Bridge, the preliminary test pile of 600 mm prestressed spun pile was driven to 82m through very soft to soft clay and stiff clay. The predicted settlement was 17.5mm compared to measured settlement of 14.2mm from static load test. The pile capacity was mobilized primarily by skin resistance. The static load test was carried out from 9 to 12th December 2000. It was included in this paper because of the similarities of the soil properties with Sg. Rimbas Bridge. Steel pipe piles with concrete infill were used for all abutments and piers which were driven to around 82m.

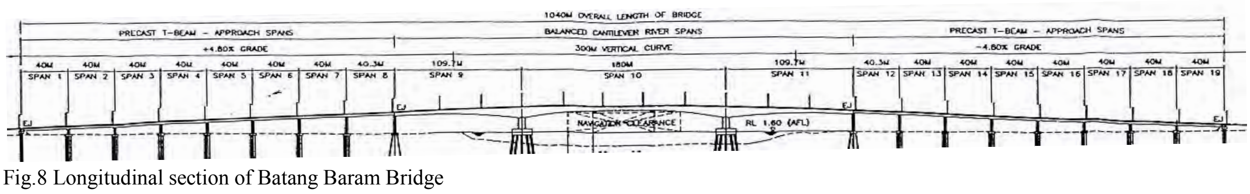

Fig.8 Longitudinal section of Batang Baram Bridge

CONCLUSION

- For deep foundation on very soft to soft clay, longer and larger piles are required to mobilize adequate skin resistance. Large steel pipe piles with concrete infill were utilized in almost all of the projects.
- The piles driven or bored into weathered rock required adequate socket length to mobilize skin resistance and to provide lateral restraint against ship impact load.
- The structures on very soft to soft soils require careful assessment of the stability of the riverbank and the treatment required before selecting the foundation system for the structure.

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