# Instrumented Low Embankment on Stone Columns for the Ipoh-Padang Besar Double Tracking Project

**In Malaysia, pile load test settlement criteria are normally based on JKR's Standard Specification for Piling Works. The criteria recommended by JKR are as follows:**

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The Malaysian Transport Ministry had appointed MMC-Gamuda JV to construct 329km of railway line from Ipoh, Perak to Padang Besar, Perlis. The project, including the installation of double tracks, electrification work, construction of bridges, road-over bridges, stations and tunnels, cost over RM12 billion.

Various ground improvement techniques were employed in the course of the project, including driven piles, installation of prefabricated vertical drains and removal and replacement of soft soils. Among the ground improvement techniques used was Vibro stone columns.

An instrumented low embankment (consisting of two zones, 2m high-5m x 10m and 4m high-25m x 15m, including working platform) was constructed in Kodiang, Kedah, with the following objectives:

a) To see if the use of stone columns for low embankments would result in hard-points (the so-called "mushroom effect") on the embankment surface.

b) To determine if the design "rest periods" for the surcharge were adequate Confirming the absence of the "mushroom effect" was important because, if it happened, it would require the use of geosynthetics or a thicker load transfer layer.

Determining the correct rest period was important for planning the construction schedule and the amount of earth to be used as a surcharge - both critical factors in a large railway project with stringent performance requirements.

A photograph of the site is shown in Picture 1, while Picture 2 shows the constructed test embankment.

## SOIL CONDITIONS

Prior to stone column installation and embankment construction, a dynamic penetration test and a cone penetration test (CPT) were carried out. After the installation of stone columns, two additional CPTs were performed. The CPT plot, shown in Figure 1, was consistent with nearby boreholes.

Based on the CPT and taking into account nearby boreholes, the soil was idealised in Table 1.

*Photo 1: Photograph of test location*

*Photo 2: Photograph of completed test embankment*

The correlations between undrained shear strength and constrained modulus were based on past experience in Malaysia and was consistent with other published data such as Duncan & Buchignani (1976).

## STONE COLUMN LAYOUT AND EMBANKMENT GEOMETRY

For settlement analyses, apart from the design dead load of the embankment (Hgross x 20 kN/m$^3$) and the ballast (Hgross x 22 kN/m$^3$), an additional 12.5 kPa was assumed over the width of the ballast. (Live loads were only assumed for stability analyses, which were beyond the scope of this paper.)

Priebe's (1995) method was used to estimate total settlements. Based on an embankment height of 4m (1m working platform, 2m permanent fill, 1m surcharge), the total settlements were estimated

*Table 1: Idealised soil profile*

| LAYER | DEPTH | DESCRIPTION | UNDRAINED SHEAR STRENGTH (KPA) | CONSTRAINED MODULUS (KPA) | CONSOLIDATION PARAMETERS |
|---|---|---|---|---|---|
| 1 | 0.0 to 6.0 | Very soft silty clay | 10 | 1,000 | $c_v$ = 1m$^2$/ year<br>$c_h$ = 2m$^2$/ year |
| 2 | 6.0 to 9.0 | Stiff silty clay | 60 | 18,000 | $c_v$ = 4m$^2$/ year |
| 3 | 9.0 to 13.0 | Stiff silty clay | Settlements assumed negligible. Borehole data indicates SPT N values from 11 to 14, CPT indicates qc values greater than 1.5 MPa | | |
| 4 | > 13.0 | Limestone | Settlements assumed negligible. SPT hammer rebound. RQD values between 50% and 100%. | | |

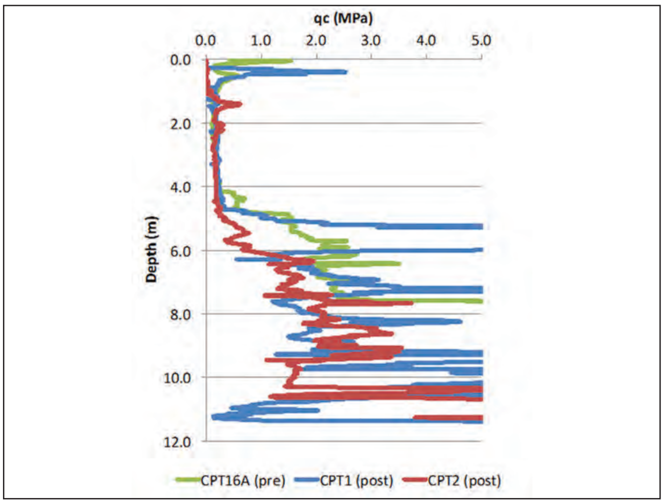

*Figure 1: Cone penetration test results*

at 250mm, with a 2.2m x 2.25m square grid. The design length of the columns was 6m.

The layout of the stone columns and test embankment is shown in Figure 2.

The track was required to have a maximum total settlement of 25mm over six months from start of service. Differential settlement was to be limited to 10mm over a length of 10m. (While the performance criteria also required minimum factors of safety against slope stability, only settlement performance would be discussed in this article.)

## STONE COLUMN INSTALLATION, INSTRUMENTATION AND EMBANKMENT CONSTRUCTION

First, a 1m-thick working platform was constructed using sand. The working platform was constructed in mid-May 2008. Then Vibro stone columns were constructed using the dry bottom-feed method of construction. The columns were installed in a grid below and beyond the embankment. For the 72 columns installed directly under the embankment, the average depth of the columns was 6.0m.

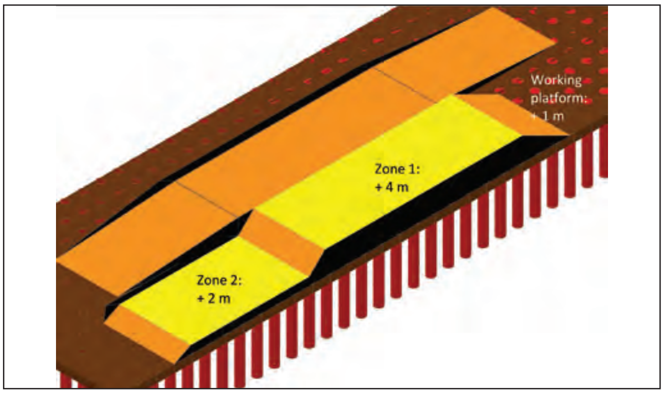

*Figure 2: Three-dimensional view of stone column layout under test embankments*

Key events are listed below:

- 10th to 31st May 2008. Construction of 1m working platform
- 1st week June to 1st week July 2008. Installation of Vibro stone columns
- 17th Nov 2008. Start of instrument installation
- Feb 2009. Start of embankment construction
- 2nd Sept 2009. End of embankment construction. Start of rest period.
- 31st March 2010. End of monitoring, removal of trial embankment

A variety of instruments were installed, including rod settlement gauges, surface settlement markers, total stress cell, extensometers, piezometers and ground heave markers. Due to the quantity of data collected, only some of the results from Zones 1 and 2 were presented and discussed.

## PREDICTION OF SETTLEMENTS AND CONSOLIDATION RATE FOR 4M EMBANKMENT (ZONE 1)

Initially, using parameters from Table 1, and based on a total fill height of 4.1m, Priebe's (1995) method was used to estimate total settlements, with a prediction of 250mm. The 4.1m included the 1m-thick working platform. However, as Table 2 indicated, there was a lapse of 7 months (July 2008 to February 2009) between the installation of the stone columns and the start of embankment construction. During this time, no settlement measurements were taken, meaning the settlement resulting from the 1m working platform was not recorded.

The theoretical period for 90% degree of consolidation from the working platform load was 3 months, calculated by Balaam & Booker's (1981) method. As the elapsed period was 7 months, we were confident that little or no settlement coming from the 1m working platform remained, when the embankment construction and monitoring started in February 2009.

As the embankment fill was placed progressively, the rate of settlement was estimated based on Han & Ye's (2001) method. Key input parameters include an assumed stress ratio (stress concentration on column) n = 3 and consolidation parameters indicated in Table 1. Settlement magnitudes were taken out of the Priebe analysis.

The plot of fill height, settlement (average measurements from rod settlement gauges 1 to 6) and time are shown in Figure 3.

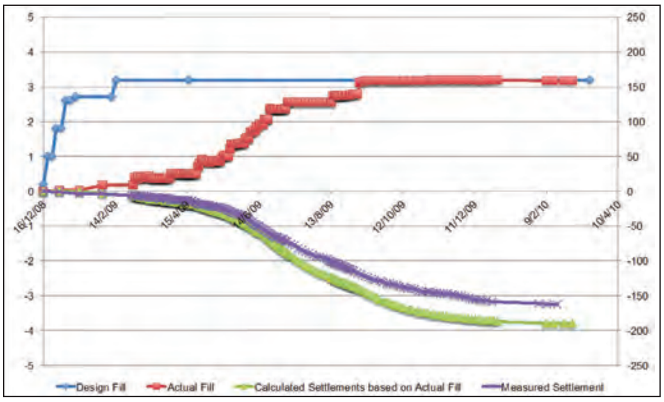

*Figure 3: Settlement results from rod settlement gauges, measured and calculated (Zone 1)*

As can be seen, actual filling took much longer than initially assumed at the design stage. Because of this, the same soil parameters were taken (Table 1), but the actual filling rate was used in a back-analysis. The results are also shown in Figure 3.

Based on the actual loading magnitude (3.2m of fill measured from the top of the working platform) and filling rate, the total long-term settlement was estimated at 197mm. Theoretically, 90% degree of consolidation would be reached 2 months after completion of filling. Observed settlements at the end of the trial was 163 mm (March 2010). 90% of these settlements (i.e. 147mm) were observed at about 2.5 months after completion of filling. Both magnitude of settlements and rate of consolidation were reasonably well predicted by the simple analytical methods employed.

## OTHER OBSERVATIONS AT ZONE 2

Figure 4 shows that Zone 2 surface settlement markers (SM1 to SM6) placed directly over the columns and in between the columns, indicated no differential settlement. Visually too, "hard points" were not observed on this test embankment, in spite of Zone 2 being only filled to little over 1m height, over the working platform. In reality, this observation is unsurprising, seeing that stone columns are relatively ductile elements and tend to bulge laterally when loaded.

## CONCLUSION

From this test embankment, we were able to conclude the following:

- With appropriately selected input parameters, Priebe's (1995) method adequately predicted the total settlements resulting from these low embankments.
- Similarly, Han & Ye's (2001) method adequately predicted the rate of settlements.
- No "hard points" were observed, either from settlement markers or visually

The test embankment was taken down in April 2010. Since then, the actual railway embankments had been completed. In April 2013, MMC-Gamuda handed over the completed embankment and track to the authorities and the track was opened to commercial rail traffic from June 2013. No performance issues have been raised to date.

In addition, data from settlement markers installed in March 2012 indicated that the embankment was performing as expected. In the first 6 months since the track was operational (June 2013 to December 2013), the surface settlement markers closest to the test area showed a settlement of 4-5mm, below the allowed values, confirming the effectiveness of the stone column solution. ■

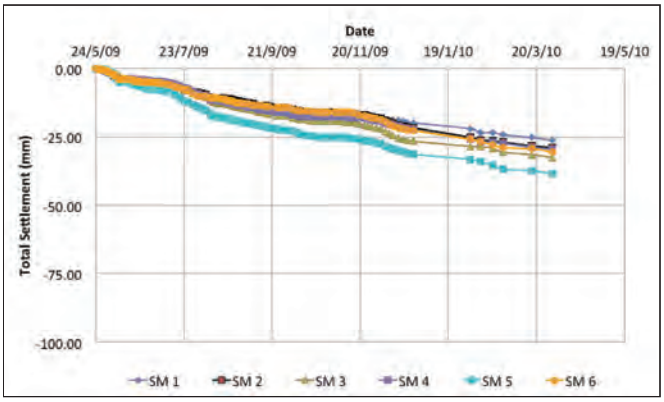

*Figure 4: Surface settlement measurement (Zone 2) calculated (Zone 1)*

## REFERENCES

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**3rd – 5th March 2015**

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|---|---|
| Organised by | : IEM Training Centre with Tunnelling and Underground Space Technical Division |
| Time | : 9.00 a.m. – 5.00 p.m. |
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