The contribution of CPT and PMT for optimization of a ground improvement project in Hungary

Babak Hamidi
Menard, Sydney Australia, bhamidi@menard.com.au

Serge Varaksin
Past Chair of ISSMGE TC-211, Paris France, s.varaksin@apageo.com

ABSTRACT: Excluding the staged surcharging period, the second section of the M7 Motorway along Lake Balatun in Hungary had to be constructed within a period of less than 2 years. The soil profile comprised very soft peaty soils that thickened in the southbound direction. As the embankment height also increased in the same direction, this would have resulted in severe stability issues and excessive settlement problems; hence, ground improvement was applied to allow the safe construction of the project within the specified performance criteria. In-situ tests using CPT and PMT were used to properly and appropriately select and execute suitable treatment methodologies over an area of approximately 400,000 m^2. Dynamic replacement, the combination of dynamic and CMCs, the combination of dynamic replacement and surcharging, and vertical drains with surcharge were used within the various section to satisfy the project specifications.

Keywords: dynamic replacement, CMC, pressuremter test, CPT

1. Introduction

Soil improvement is a well-established method for enhancing the ground conditions to an extend that treated subgrades would be able to safety support roads and road embankments. The techniques can be either without added material or by introducing material with superior properties into the ground. Chu et al [1] have described the various methods that can be used for treating the ground.

There are many publications on the use of ground improvement for roads and embankments. Hamidi et al [2] have described the application of dynamic compaction for improving the submerged sandy fill foundations of the embankment leading to a bridge, and Yee et al. [4] have authored a paper on the application of vacuum consolidation for a road embankment that was constructed on very soft and highly compressible clays.

Ground improvement techniques may be combined to achieve better results, e.g. Aripin et al. [3] have described the application of the combination of dynamic replacement and vertical drains for a road embankment that crossed over soft soils.

The problem of treating subgrades becomes more challenging when the soil is highly compressible, has a variable thickness that increases as the alignment approaches the bridge structure and at the same time the embankment height increases to reach bridge level. In such cases, untreated ground settlement would be most at the bridge location whilst the bridge will have been built on piled foundations with insignificant or minimal movements. Therefore, very stringent and limited embankment settlement criterion would be allowed. However, as the embankment height and soft soil thicknesses reduce settlements will also respectively reduce to a point where there may be minimal or no treatment required. The transition distance between stringent settlement requirements at the bridge and relaxed acceptable settlements at a distance away from the bridge will require the introduction of a differential settlement concept that will satisfy both ends of the transition zone.

M7 Motorway in Hungary is one such project, i.e. a road crosses over a very soft peat and clay deposit that reaches its maximum thickness at the bridge location, where embankment height is also at its peak.

2. Description of M7 Motorway in Hungary

M7 Motorway in Hungary connects Budapest to Croatia. A section of this motorway that was designated as Zone 3F passes next to Lake Balaton near Batonfenyves. This section includes an embankment that varies in thickness from 2.4 m to 10.5 at the bridge structure. Top of embankment width was typically 28 m.

To ensure the safe and sound performance of the road it was required that the below performance criteria be satisfied after completion of construction:

- Differential settlement: 50 mm per 50 m over 5 years
- At bridge interface: 20 mm

2.1. Ground Conditions

Along with laboratory tests, Menard Pressuremeter Tests (PMT) and Cone Penetration Tests (CPT) were performed to assess and characterize the ground conditions. The geotechnical investigations that were performed indicated that the ground was composed of:

- Approximately 3.5 to 4.5m of peat and soft organic clay with occasional bands of sand and silt. The clay thickness increased progressively as the alignment approached the bridge structure.
- Multiple sand layers with various qualities. The depth of sand was quite variable along the project alignment. A thickness of 10.5 m was considered for this layer.

- A 4 m thick clay layer. Thicker layers sometimes included cemented soil.
- A very dense sand layer that was considered incompressible.

Groundwater was very close to natural ground level and for design purposes it was assumed to be on ground surface.

Fig. 1 and Fig. 2 respectively show examples of CPT and PMT that were performed on site. It can be observed that the CPT cone resistance was typically in the order of 0.2 MPa in the soft peat. Similarly PMT limit pressure was in the order of 0.1 MPa.

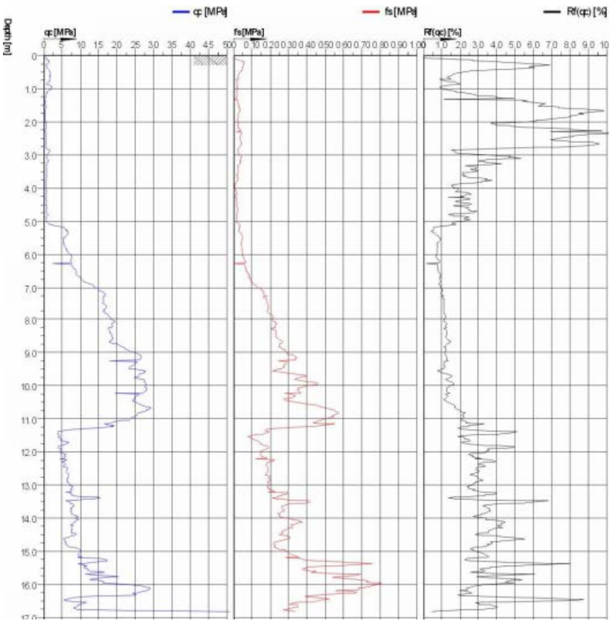

Figure 1. Example of CPT profile at M7 Motorway Zone 3F.

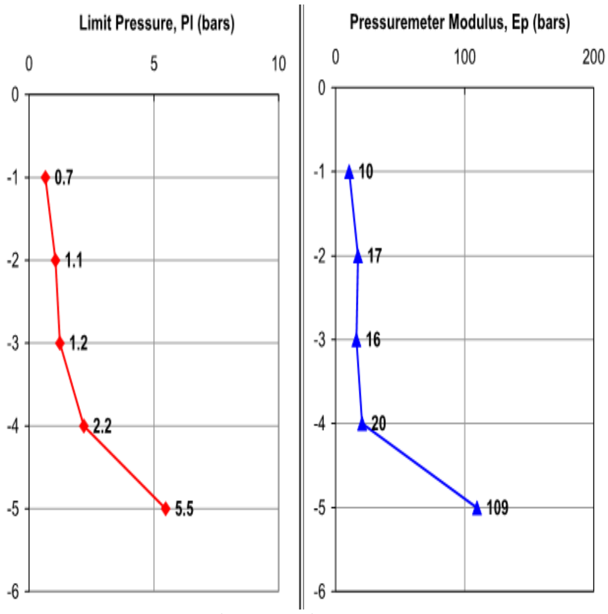

Figure2. Example of PMT profile at M7 Motorway Zone 3F.

Initial estimations indicated that the ground would settle excessively under the embankment load. For example, numerical analysis using an elasto-plastic model indicated that the ground in an area that included 4 m of peat and clay would settle 303 mm only under the working platform thickness of 1.5 m. when the embankment was built to its full height of 7.8m at that section, settlements were expected to accumulate to more than 2 m.

The extremely poor ground conditions and calculation results indicated that the ground was unable to safely support the embankment and specific measures were required.

2.2. Ground Improvement Solution

The complexity of the ground conditions, loading and project criteria required a foundations solution that was able to satisfy the project needs at the bridge structure and at the far end from the bridge. Implementation of a uniform solution throughout the alignment did not appear to satisfy such a need as a rigid treatment at the bridge would have induced unacceptable differential settlements away from the bridge. Vice-versa, a more flexible treatment would not have met the total settlement limit at the bridge.

The ground improvement works for this section of the project was awarded to a specialist ground improvement contractor in the form of a design and construct contract. The area that was included in this contract was approximately 400,000 m^2.

The proposed solution was composed of the combination of a variety of ground improvement techniques, namely:

- Vertical drains and surcharging at the furthest end from the bridge, where the thickness of the embankment was least, and settlements had to tie-in and be compatible with non-treated ground at a point.
- Dynamic replacement in the general area where thickness of soft soil and embankment were relatively constant. This technique was also used on the backside of the bridge.
- Dynamic replacement and surcharging in the transition zone where loading increased, and additional treatment was required to satisfy design requirements.
- Dynamic replacement and CMC (controlled modulus columns) in the severe zone were minimal settlement requirements were enforced.

When surcharging is used for ground improvement, fill is placed for a certain period to pre-consolidate and decrease the compressibility of soft ground [1]. Utilization of vertical drains that can be of natural granular material or more often of prefabricated petrochemical based products can significantly accelerate consolidation.

In dynamic replacement, aggregates are driven into soil by high energy impact to form large diameter columns. The material used can be sand, gravel, stone or demolition debris [1].

CMC are rigid inclusions of concrete or grout that are installed in the ground using specially designed augers.

The concept of the implementation of these techniques are schematically shown in Fig. 3.

Dynamic replacement was carried out in two phases with grid spacing in each phase equal to 7 m. This equates to a final column spacing of 4.9 m. Each column was

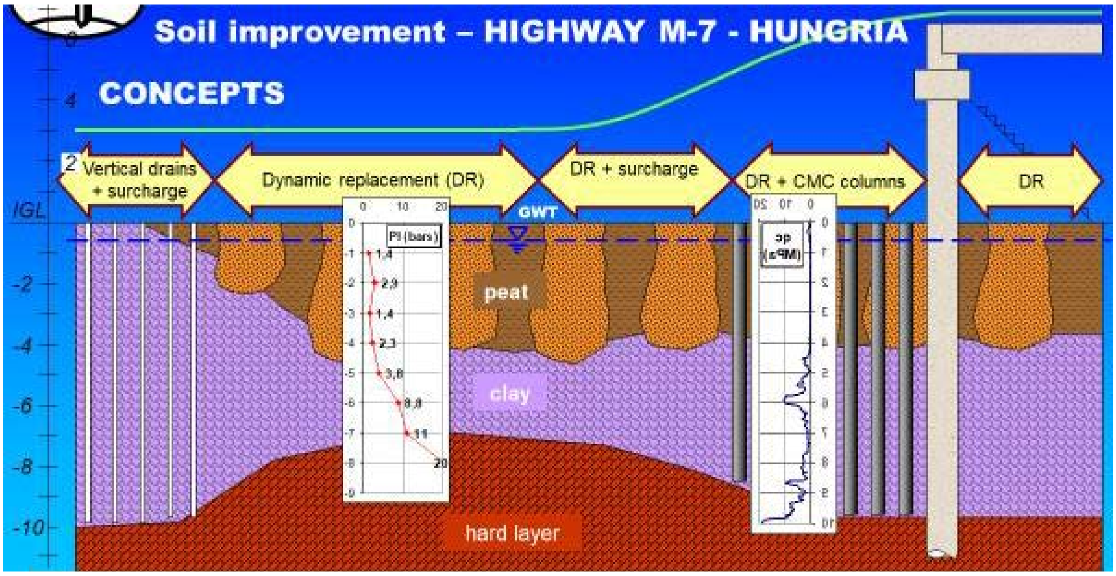

Figure 3. Concept of ground improvement in the project.

approximately 2.5 m in diameter, which results in a replacement ratio [5] of 20%.

With oedometric moduli of 0.3 MPa and 2 MPa respectively for the peat and clay layer, numerical analysis indicated that the settlements under embankment load would be reduced to less than half of the predicted value to approximately 0.88 m. It was calculated that applying 15 kPa live load that could have generated differential settlements during operation of the motorway would result in an additional 34 mm of total settlement, which was comfortably less than the allowed differential settlement.

Further calculation indicated that the deep and shallow clay layers would have reached approximately 60% to 70% of their consolidation within 3 months of embankment placement.

Stability analysis was also performed for using a software that was based on Bishop's method [6]. This analysis led to a decision to initially construct the embankment to 3.5 m height, which corresponded to the level of the bridge's piling platform, thene lifting the embankment to full height.

The impact of culverts on differential settlements was also considered. For this purpose, a plane strain numerical analysis was done along a 49 m length of the embankment with a half culvert profile on one side of the model. The dynamic replacement columns were modelled as equivalent walls of 2.5 m width. The wall properties were chosen in a manner to match the vertical displacement that was derived using the two-dimensional and axi-symmetrical models. The height of the embankment was assumed to be 5 m, which was the maximum embankment at a culvert location. Also, whilst the dynamic replacement columns' gridlines were not parallel to the culvert, it was conservatively assumed that this was the case. Similarly, the thickness of the soft soils was assumed to be the same as in the previous calculations. Consequently, it was observed that the culverts would have pessimistically generated a differential settlement of 26 mm, which was deemed

Figure 4. Application of dynamic replacement in the project.

Figure 5. Aerial view of the dynamic replacement platform at the bridge approach.

acceptable. Therefore, application of additional measures at culvert locations was not implemented.

Dynamic replacement was performed using five heavy duty cranes. Works were performed in two shifts per day and the maximum daily production was reported to be 8,750 m^2, which is a very impressive figure. Fig. 4 shows two of the ground improvement rigs during the works. Fig. 5 shows an aerial view of the dynamic replacement platform at the bridge approach.

The quality of CMC material, i.e. concrete or grout can be readily assessed, and its strength quantified by performing unconfined compressive strength (UCS) tests. However, such a test is not applicable for semi-rigid inclusions such as stone columns and dynamic replacement. In these techniques the natural backfill material is directly compacted in the column. Experience suggests that most geotechnical field tests that rely on static pushing or dynamic driving are unable to penetrate a semi-rigid inclusion to a meaningful depth. These tests would include commonly utilized and popular methods such as CPT and SPT (Standard Penetration Test). In these tests the probe would either reach refusal very early on or in the case of stone columns, may slip out of the column altogether.

The experience of the authors suggests that PMT can effectively be used for testing dynamic replacement columns. PMT can be performed without disturbance when the STAF method [7] is used. In this project 200 PMT were performed.

40 settlement plates, 26 piezometers and 32 tube settlement gauges were also installed for monitoring purposes.

Szepeshazi [8] who has monitored the ground deformations reports that settlements were somewhat smaller than calculated and that embankment movements generally decreased after the first month.

The construction sequence in this area was to:

- Install the dynamic replacement columns with the same grid size and the general area.
- Place 3.5 m of embankment to reach piling working platform level.
- Install CMC from this level into the dense sand layer using a square grid of 1.7 m
- Complete the embankment to the height of 10.5 m.

Consistent with the analysis that was used for assessment of settlements in the general dynamic compaction zone, numerical modelling was performed using the equivalent properties of the ground after improvement by dynamic replacement. Thereby, an axi-symmetrical model was developed that also incorporated a CMC element. The diameter of the CMC was 0.4 m.

Based on this design, a total of approximately 200,000 m of CMC were also installed in the project.

Verification of CMC quality is more straight-forward than dynamic replacement columns as they are constructed using factory produced concrete or grout. Both strength and workability can be readily assessed respectively by performing USC and slump tests.

3. Conclusion

Zone F of Hungary's M7 Motorway has been constructed on very soft and highly compressible peat and clay. The embankment thickness along the alignment is variable from 2.4 m to 10.5 m at the bridge structure. Whilst ground settlement was more tolerable away from the bridge, very stringent requirements had to be enforced at the interface of the bridge and embankment to ensure acceptable drivability of vehicles.

Various geotechnical field tests including CPT and PMT were performed to access the ground conditions. The results of these tests demonstrated that untreated ground would not be able to satisfy project requirements and consequently a combination of techniques, namely vertical drains with surcharging, dynamic replacement, dynamic replacement with surcharging, and dynamic replacement with CMC were used to meet the specifications.

Further quality control of dynamic replacement columns was only possible by using the PMT.

The outcome of the project has been very successful as witnessed by the results of long-term monitoring of embankment deformations.

Acknowledgement

The authors would like to thank Menard for providing the information that was used for preparing this paper.

References

[1] Chu J, Varaksin S, Klotz U, Mengé P. "State of the Art Report: Construction Processes", 17th International Conference on Soil Mechanics & Geotechnical Engineering: TC17 meeting ground improvement, 7 October 2009, Alexandria, Egypt, 2009.

[2] Hamidi B, Nikraz H, Varaksin S. "The Treatment of a Loose Submerged Subgrade Fill Using Dynamic Compaction", International Journal of Pavement Research and Technology, 4(2), pp. 124-30, 2011.

[3] Aripin LT, Yee K, "Settlement of Highway Embankment under a Combination of Dynamic Replacement and Vertical Drain Techniques", 14th Annual Meeting of the Indonesian Geotechnical Society: Development of Geotechnical Engineering in Civil Works and Geo-Environment; 2-3 December; Yogyakarta, Indonesia, 2010.

[4] Yee K, Jullienne D, Masse F, Varaksin S, "Performance of Road Embankment on Vacuum Consolidated Soft Clay in Bangkok", 4th International Conference on Ground Improvement Techniques, pp. 26-28 March, Kuala Lumpur, 2002.

[5] Aboshi H, Ichimoto E, Harada K, "The Compozer: A Method to Improve Characteristics of Soft Clays by Inclusion of Large Diameter Sand Columns", International Conference on Soil Reinforcement; Reinforced Earth and Other Techniques, pp. 20-22, Paris, 1979.

[6] Bishop, A. W. "The use of the Slip Circle in the Stability Analysis of Slopes", Géotechnique. 5(1), pp. 7–17, 1955.

[7] Arsonnet G, Baud JP, Gambin MP, "Pressuremeter Tests Inside a Self-Bored Slotted Tube (STAF)", International Symposium 50 Years of Pressuremeters (ISP5 - Pressio 2005), pp. 22-24, Marne-la-Vallee, France, 2005.

[8] Szepeshazi R. "Geotechnical challenges of motorway construction in Hungary (2000-2012) with focus on embankment foundation on unfavourable soft ground", XV Danube - European Conference on Geotechnical Engineering (DECGE 2014), paper No 28, Vienna, in German, 2014.