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FOUNDATION OF A LIGHTWEIGHT STEEL ROAD BRIDGE ON PEAT

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ABSTRACT: This paper presents the foundation study of the new road bridge in the valley of “Tenagi”, Kavala, Greece. Selection of a lightweight superstructure was mandated by the region’s poor foundation conditions (peat). Soil improvement techniques, such as deep soil mixing as well as construction of vertical sand drains and preloading embankments were also proposed.

KEY WORDS: Peat; Sand Drains; Soil Deep Mixing; Soil Improvement; Through-Truss Steel Bridge.

1 INTRODUCTION

Foundation of bridges on weak soils has always proven to be a great challenge for civil engineers, especially when the superstructure transfers heavy loads to the foundation system. In certain occasions, the geotechnical conditions determine the selection of the load-carrying system. This is the case for the new lightweight steel road bridge near Kavala, Greece, which will replace an old reinforced concrete one that is no longer in service due to failure (excessive rotation) of the foundation of the pier. Besides minimizing the weight of the bridge, techniques to improve the existing soil (peat with very poor geotechnical characteristics) were necessary to complete the foundation design.

2 DESCRIPTION OF THE BRIDGE

2.1 General Information

The studied steel road bridge is located in the valley of “Tenagi”, Kavala (northern Greece) and will serve as an overpass for a 40m wide aqueduct canal. The 67m long, 4.75m wide single-span bridge is considered of vital importance for the region, as it will facilitate the crossing of agricultural vehicles and will dramatically decrease transportation times among the local farmlands.

2.2 Description of the superstructure

The poor foundation conditions, which are discussed below, mandated the selection of a lightweight structural system for the bridge. After considering different alternatives, it was concluded that a through-truss steel bridge would be the most efficient solution. Its final configuration follows that of a Pratt truss and is shown in *Fig. 1*. More specifically, the bridge consists of two such trusses placed in the longitudinal direction. Their height varies from 2m (edges) to 5.5m (middle). In contrast to the straight bottom chord, the top chord consists of inclined straight members that follow a parabolic curve shape. The spacing of the vertical truss members is 5m, with the exception of the edges (3.5m). In the transverse direction, the trusses, which will be spaced at 3.75m to form the traffic lane corridor, are connected at the bottom chord via cross girders (at the location of the vertical members) and diagonal bracing. Top lateral bracing is only provided at the central portion of the bridge due to height restrictions. The bridge will be supported, via elastomeric bearings, on two spread footings (one on each side of the canal). The 16mm steel deck will have closed section stiffeners attached to its bottom and will be overlain by a 40mm asphalt layer.

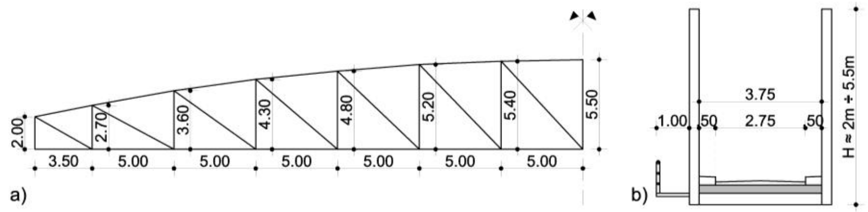

Figure 1. a) Side view of the superstructure of the bridge and b) Cross-section of the bridge

3 EXISTING FOUNDATION CONDITIONS

3.1 Site Investigation

A thorough geotechnical investigation was conducted to determine the soil profile in the foundation region of the bridge. Two boreholes were drilled (one on each side of the canal) to a depth of 23m and Standard Penetration Tests (SPTs) were carried out every 2m. The blow count in most cases was very low, ranging from 0 to 5. Samples taken from the field were subjected to laboratory testing. Additionally, four cone-penetrometer tests (CPTs) were carried out to depths ranging approximately from 26 to 33m. In all cases the measured resistance q_c at the tip of the cone was less than 0.5MPa.

3.2 Soil Profile

Based on the conducted geotechnical investigation, the soil in the foundation region of the bridge was identified as peat with poor geotechnical characteristics. The estimated characteristic values of the soil parameters, namely the unit weight γ, the undrained shear strength S_u, the effective cohesion c’ and internal friction angle φ’ as well as the constrained elastic modulus E_s, are summarized in Table 1.

Table 1. Estimated geotechnical parameters for the existing soil profile

Depth	γ (kN/m^3)	S_u (kPa)	c' (kPa)	φ' (^{o})	E_s (MPa)
0-10m	11	4	0.5	10	0.25
>10m	11	10	2.5	10	2.0

4 PROPOSED SOIL IMPROVEMENT TECHNIQUES

4.1 Necessity for improvement of the soil

Due to the extremely poor foundation conditions discussed in the previous section, a lightweight superstructure (through-truss steel bridge with a steel deck) was selected to minimize the loads transferred to the foundation system. Despite this, results from the preliminary foundation study showed that a shallow foundation on the existing soil was not applicable, due to low bearing capacity issues and excessive settlement, which would evolve slowly due to the low permeability of the soil. The deep foundation solution (piles) was not effective either, because the weak soil stratum extends to a great depth (more than 200m according to geological data for the region). For this reason, various techniques of soil improvement were proposed in conjunction with the shallow foundation solution. These are described below.

4.2 Vibratory soil replacement

The construction of vertical sand drains in the foundation region of the bridge was deemed necessary for the following reasons:

a) Increase of the bearing capacity of the soil by increasing the effective internal friction angle φ' and the unit weight γ
b) Increase of the constrained elastic modulus E_s that will result in a decrease of the expected settlement
c) Reduction of the consolidation settlement time after application of the preloading embankment

To cover the needs of the specific project, the construction of two sand drain grids (one for each footing region) was proposed. Each grid will be constructed in two phases. Initially (1st phase), 20m long stone columns with a diameter of Φ=80cm, will be constructed according to a triangular pattern at an axial spacing of 1.40m (*Fig. 2*). Each grid will extend to a rectangular area with dimensions (plan view) of 20.60m x 20.40m. Moreover, less compacted gravel infill will be placed at the bottom of each sand drain (forming 5m long piles with a diameter of 0.8m), to prevent possible collapse of their tip. A total of 247 stone columns will be constructed during this phase for each footing region. Afterwards (2nd phase), 475 shorter sand drains (3.5m long) of the same diameter will be constructed at the regions between the initial stone columns as shown in *Fig. 2.* The purpose of the shorter stone columns is essentially to create a strong top layer that will further increase the bearing capacity of the soil to meet the demand from the superstructure.

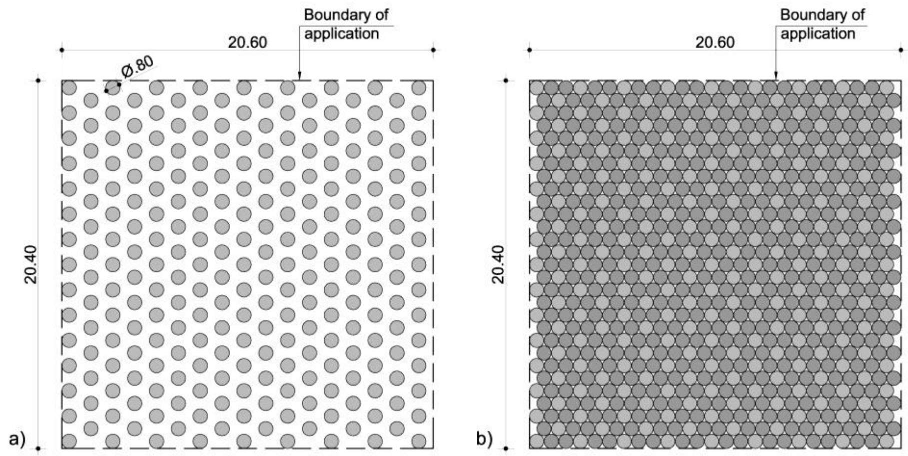

Figure 2. Arrangement of sand drains during construction of the a) 1st phase b) 2nd phase

It should be noted that the filling material for the sand drains will be well graded (with size ranging from 6mm to 38mm according to the Greek Technical Specification 1501-11-03-03-00:2009 [1]) angular gravels obtained from tough rock materials. The produced gravel infill will have a minimum effective internal friction angle $\varphi' = 40^o$, unit weight of γ = 20kN/m^3 and constrained elastic modulus of E_s =20MPa. After the construction of the stone columns, the improved soil parameters (Table 2) were calculated as the weighted average properties of the initial soil profile (peat) and the sand drain infill material. It should be noted that the already low cohesion of peat was further reduced by the addition of gravel. Consequently, cohesion was neglected for the improved soil.

Table 2. Improved soil parameters after the construction of sand drains

Depth	γ (kN/m^3)	c' (kPa)	φ' (^{o})	E_s (MPa)
< 3.5m	19.0	0	36.5	17
3.5-20m	13.5	0	19	6.0

The construction procedure will follow the Greek Technical Specification 1501-11-03-03-00:2009” [1] pertaining to vibratory soil replacement. The “driven closed tube” method will be used because of the weak nature of the soil, which might otherwise lead to the collapse of the holes drilled for the stone columns. Following the same specification [1], a trial sand drain grid (plan dimensions of 4.3m x4.45m) with the same stone column arrangement will be constructed in the vicinity of the project prior to the application of this technique.

4.3 Soil deep mixing

Besides the construction of sand drains, the deep soil mixing technique is also necessary for the materialization of the project, as it will improve the mechanical properties of the soil and, more importantly, increase the shear strength in the regions surrounding the stone columns. This will prevent possible slope stability failures arising from the proximity of the foundation to the canal.

The soil deep mixing technique will be applied to a depth of 30m and will result in the construction of intersecting cement columns with a diameter of Φ=80cm, spaced at a distance of 0.60m. These will be arranged symmetrically in four, 3.20m wide regions (buttresses) to surround the sand drains (*Fig. 3*).

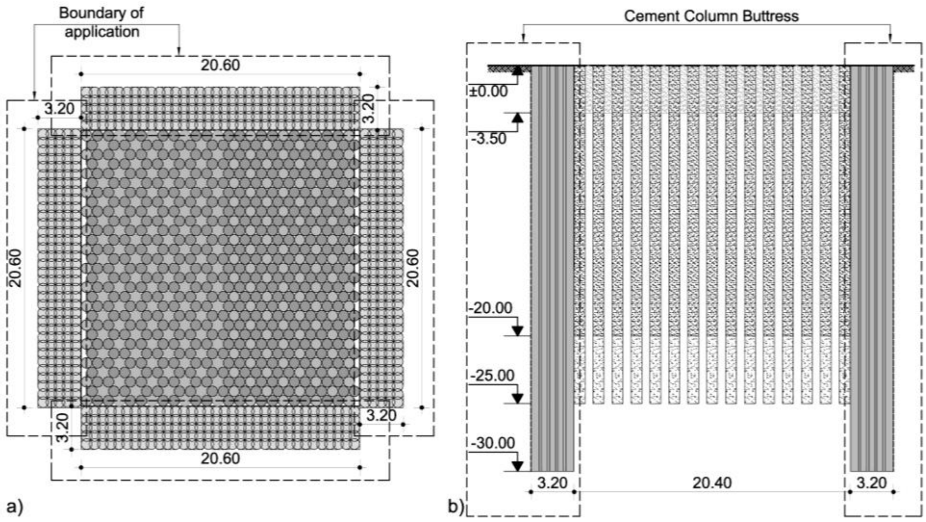

Figure 3. Arrangement and application of the soil deep mixing technique: a) plan view and b) vertical section

The cement columns will be constructed according to the methodology of the relevant Greek Technical Specification 1501-11-03-04-00:2009 [2], which also mandates the construction of a trial field (with plan dimensions of 3.20m x 3.20m) before applying the soil deep mixing technique. From this field, which will be constructed in close proximity to the foundation region of the bridge, samples will be taken for testing and verification of the improved strength of the soil. The type of binder was selected according to information on relevant experimental results given in the “Design Guide: Soft Soil Stabilization” [3]. Based on this, the use of cement was deemed the most appropriate for the needs of the project. Furthermore, according to recommendations from the same source [3], the binder quantity that will result in the greatest soil strength increase is 300kg/m^3. This quantity will be used to ensure the effectiveness of the soil deep mixing technique. It should also be mentioned that the resulting shear strength (according to the experimental results) for the improved soil should be at least 150kPa.

4.4 Preloading embankments

Despite the aforementioned soil improvement techniques, calculations showed that the expected settlement (≈ 7.0cm) is more than that permissible for bridges according to relevant specifications [4]. Therefore, to eliminate settlement during the working life of the bridge, the construction of two preloading embankments (one for each footing of the bridge) was proposed. Each embankment will have a total height of 2.20m at its top flat surface (rectangular with plan dimensions of 10m x 3.5m) and a slope inclination of 2/3. It will consist of a bottom sand layer (0.8m thick) for drainage purposes and a compacted top clay layer. The specified minimum dry unit weight for both materials is 20kN/m^3. The resulting load from the embankment is greater than the serviceability loads to be imposed during the working life of the bridge and, therefore, settlement will occur only during the preloading period. The temporary embankments will be removed after a period of six months. To calculate settlement time, the existence of sand drains was taken into account following a widely recognized methodology encountered in the literature [5].

5 DESIGN OF THE FOOTINGS AND CALCULATIONS

The bridge will be founded on two spread footings with plan dimensions 10m x 3.5m. The foundation depth is specified at -2.0m from the ground level. The subgrade modulus is estimated at approximately 2000 kN/m^3. Table 3 summarizes the safety factors pertaining to bearing, sliding and overturning calculated according to the regulations of EN 1997-1:2004 [6].

Table 3. Safety factors for the bridge footings

	Bearing	Sliding	Overturning
Safety Factor	1.40	1.85	2.25

Besides these checks, possible slope stability failures of the nearby region due to the proximity to the aqueduct canal were investigated. To this end, the specialized geotechnical engineering software LARIX-5 [7] was used. It should be noted that failure was investigated for both the preloading embankment phase as well as the operational stage of the bridge and the minimum calculated factor of safety was approximately 1.2. The critical sliding surface is depicted in *Fig. 4.*

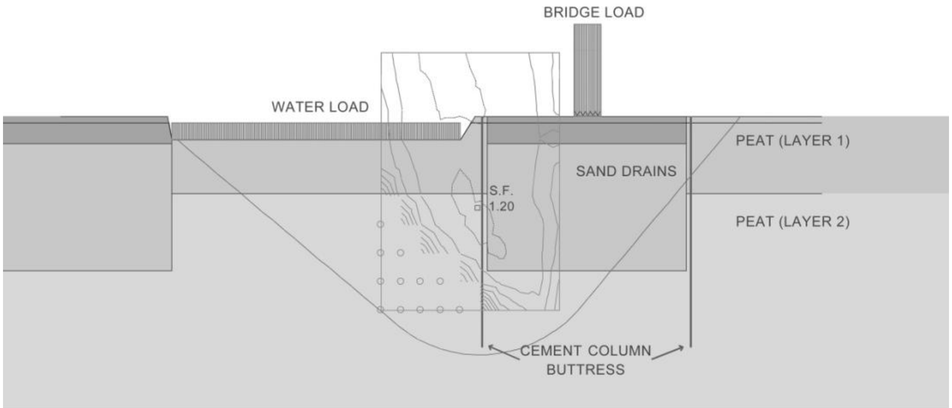

Figure 4. Critical sliding surface for slope stability failure of the foundation region

6 CONSTRUCTION STAGES OF THE PROJECT

The sequence of the construction stages for the project (*Fig. 5*) is listed below:

a) Creation of access zones for vehicles and site works, followed by construction of the sand drains in two stages
b) Application of the deep soil mixing technique
c) Construction of the preloading embankments and removal after six months
d) Excavation and construction of the spread footings

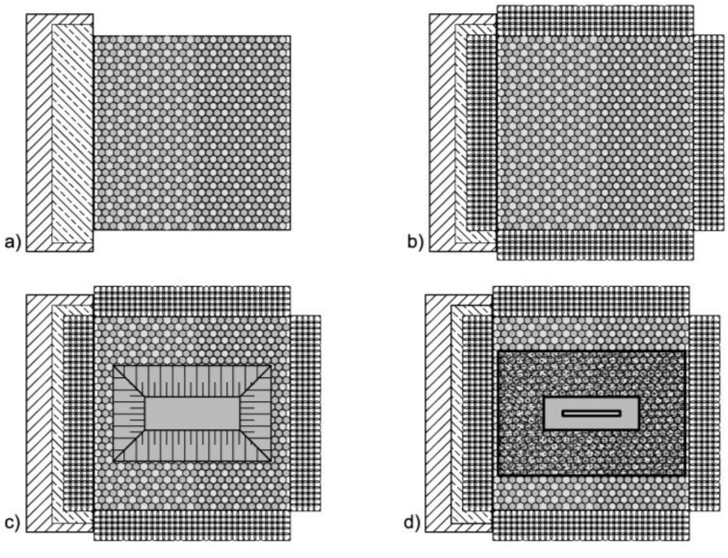

Figure 5. Sequence of the construction stages for the project: a) sand drains b) deep soil mixing c) temporary preloading embankments d) spread footings

7 CONCLUSIONS

This article presented the foundation study of the new bridge near Kavala, Greece. The design posed several design challenges because of the poor geotechnical conditions encountered in the region (the soil is peat with weak characteristics). For this reason, besides selecting a lightweight superstructure, several state-of-the-art soil improvement techniques were implemented. Construction of vertical sand drains placed in a triangular pattern was proposed to improve the bearing capacity of the soil, reduce consolidation settlement and accelerate its evolution. Slope stability issues arising from the proximity to the canal were resolved by deep soil mixing. Construction of two temporary preloading embankments was proposed to eliminate settlements.

REFERENCES

[1] Greek Organization for Standardization, “Vibratory soil replacement (stone column construction)”, Hellenic Technical Specification 1501-11-03-03-00, Athens, Greece, 2009.

[2] Greek Organization for Standardization, “Soil piles using jet grouting”, Hellenic Technical Specification 1501-11-03-04-00, Athens, Greece, 2009.

[3] BRE, *Design Guide: Soft Soil Stabilization. EuroSoilStab: Development of Design and Construction Methods to Stabilize Soft Organic Soils*, First Edition, IHS BRE Press, Watford, UK, 2010.

[4] German Institution for Standardization, “Road and foot bridges; design loads”, German National Standard DIN 1072, Berlin, Germany, 1985.

[5] Craig, RF, *Craig’s Soil Mechanics*, Seventh Edition, E&FN SPON, Chapman & Hall, London, UK, 2004.

[6] European Committee for Standardization, “Eurocode 7: Geotechnical design - Part 1: General rules”, European Standard EN 1997-1, Brussels, Belgium, 2004.

[7] Cubus Hellas, Ltd., LARIX-5 Geotechnical Engineering Software, 2005.