Embankment Support Using Geogrids with Vibro Concrete Columns

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ABSTRACT: The Second Severn River Crossing in the UK required embankment construction over highly compressible estuarine clay and peat soils to form a Toll Plaza. The paper describes the background, design and construction of the adoption of an innovative concept for the required embankment support. A geogrid-reinforced mattress was employed to transfer the embankment loads via arching to a grid of Vibro Concrete Columns which further transfer the loads through the weak alluvial soils to the underlying sands and gravels.

INTRODUCTION

In the past in the U.K. most infrastructure projects have been government-financed. Projects have been designed by the government or its consultants, and constructed by contractors after a competitive tendering process. The Second Severn Crossing is a privately financed project to construct a new Crossing linking England and Wales (Fig.1). The Laing GTM Joint Venture are contracted to carry out the design and construction of the new bridge on behalf of Severn River Crossing Ltd who have a concession agreement with the Department of Transport to fund, design, construct and operate the new Crossing. The Halcrow - SEEE Joint Venture are the Design Engineers for the project on behalf of Laing GTM.

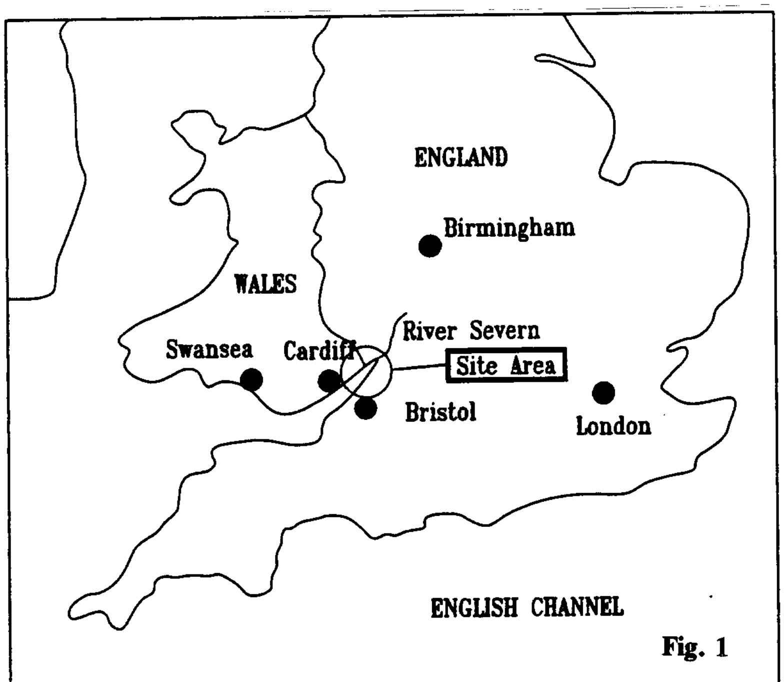

Fig. 1

In addition to the bridge structure, the works include the construction of a Toll collection plaza on the Welsh side, providing a row of toll booths and an adminstration area. The Toll Plaza, which is located in an area of low-lying pastureland crossed by shallow ditches, is constructed on a rockfill embankment which varies from 2.5m to 6.0m in height. The fill material is a source of local limestone supplied as 380mm down in size.

GROUND CONDITIONS

Ground conditions were investigated by means of boreholes, trial pits and static cone penetrometers. Extensive laboratory and in situ testing was carried out. The soils at the Toll Plaza comprised some 4.4m to 6.4m thickness of highly compressible peat and estuarine clay deposits. Typically the peat was some 2m to 3.5m thick representing between 50 and 60% of these deposits. In places this proportion was as high as 74%. These soils were underlain by medium dense sand and gravel deposits 2m to 6m thick, except at the western end where the deposits were predominantly fine and medium sands. The superficial deposits rest on Triassic sandstones. The sequence of strata along the length of the Toll Plaza are illustrated on Fig.2.

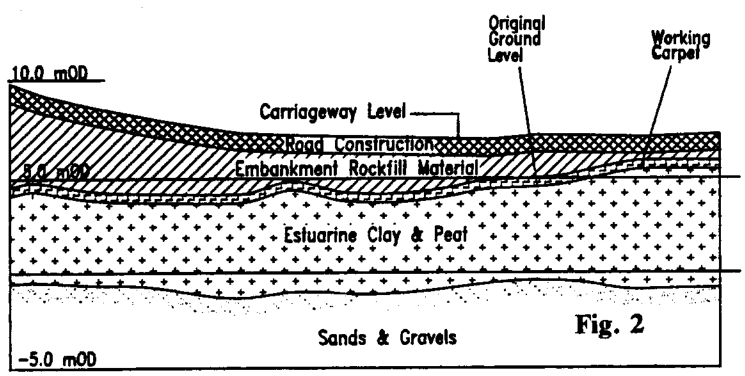

Fig. 2

DESIGN OF FOUNDATION SUPPORT SYSTEM :

Owing to the compressible nature of the peat and clay deposits, ground treatment was necessary to remove primary settlements and reduce long term secondary settlements and differential movements to acceptable levels. Treatment options originally considered were
- Surcharging and vertical drains
- excavation and replacement
- piles plus high strength geotextiles to carry the embankment

Cost estimates showed that the latter two options were about twice as expensive as the surcharge scheme, and were not further pursued. However, a major drawback with the surcharge scheme was uncertainty with regard to the time for consolidation of the peat deposits with consequent potential for delay to the construction programme. An alternative system of comparable cost which eliminated the time uncertainty was proposed by Keller Foundations and Netlon.

The foundation support system proposed (Fig. 3) comprised an innovative combination of two geotechnical techniques - Vibro Concrete Columns (VCCs) and geogrids. The use of Vibro Concrete Columns was recognised as a means of

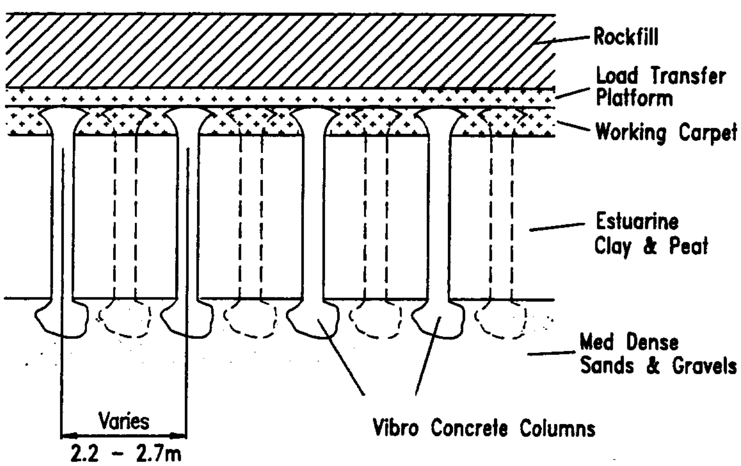

Fig. 3

transferring the embankment loadings (including a 20 kN/m² design live load) through the weak soils to the granular layers below. It was also recognised that arching would take place in the coarse granular rockfill forming the embankment, although this would be insufficient on its own to effectively load the columns. A transfer platform consisting of geogrid-reinforced granular fill was thus designed to complete the arch transfer between rockfill loadings and the Vibro Concrete Columns (Fig.4).

The VCC construction technique (Jebe and Bartels 1983) employs an electric bottom feed vibrator which penetrates the weak subsoils and concrete is placed by a high pressure pump through the poker to form a high capacity plug in the underlying granular layers which are compacted and improved by the vibratory action. As a consequence, high load bearing capacity can be attained with relatively short lengths and the penetrability of the poker ensures fast production. A further advantage of this system is the facility to form an

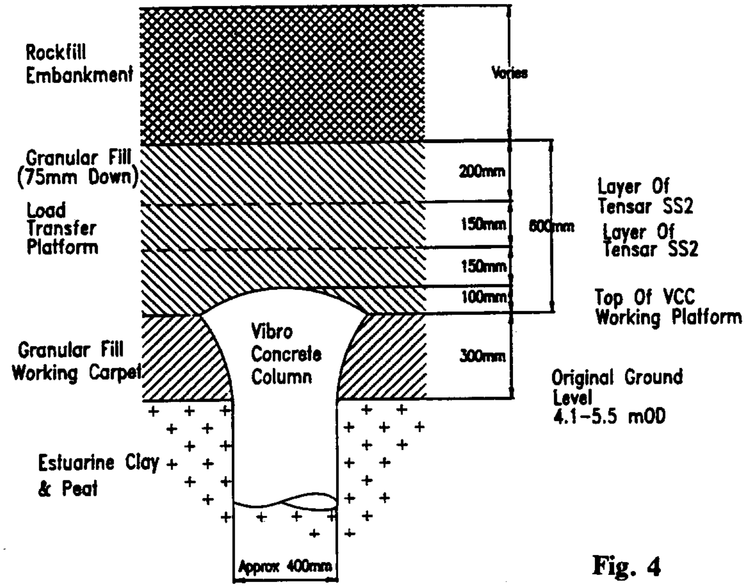

Fig. 4

enlarged "mushroom" head to the column during construction.

The mechanism by which the embankment loads are transmitted into the columns is a key component of the system and the method adopted on this project was a geogrid reinforced granular load transfer platform. This development uses the principle of enhanced arching within the granular layer to mobilise the maximum shear strength of the granular layer to distribute the imposed loads efficiently and evenly into the piles.

Work by Guido et al 1987, showed how the inclusion of stiff biaxial geogrids within granular layers below footings can improve the bearing capacity of the foundation soils. The essence of Guido's work, and others, is that the angle of load spread through geogrid reinforced cohesionless soil can conservatively be taken as 45 degrees.

Application of this philosophy in the present case requires that the embankment has enough thickness above the load transfer platform for the arch within the platform to be loaded and fixed. If the thickness of the embankment above the platform is not sufficient, then there could be a reflection of the column head at the top surface of the embankment.

It is, of course, important that the grading of the fill is compatible with the geogrid so that the particles interlock into the apertures of the geogrid and are, as such, restrained by the geogrid. This restraint then enables the granular layer to mobilise its full peak shear strength. A typical grading on this project is a 75mm maximum size well graded material. The mechanism of interlock where the granular particles are restrained by the geogrid aperture requires that aperture to be stable and capable of providing the restraint in all directions. The granular particles must also have a surface against which to bear, i.e. the geogrid rib, and hence provide the buttress which enables the restraint to be mobilised.

Analysis suggested a maximum safe working load of 600 kN for the Vibro Concrete Columns. This provided a column spacing on a triangular grid of 2.7m beneath the low embankment decreasing to 2.2m beneath the highest sections. The strength and number of geogrids

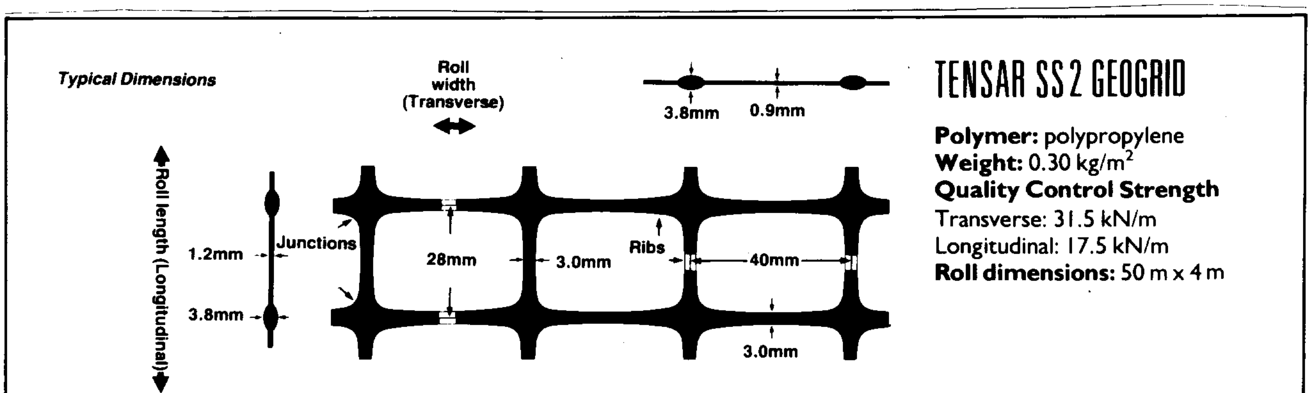

Fig. 5

required in the load transfer platform to promote arching and carry the fill below the arch was determined from a simple analysis assuming the geogrid forms a catenary between the Vibro Concrete Columns. This suggested that two layers of Tensar SS2 geogrid (Fig.5) placed in orthogonal directions would be sufficient. More rigorous finite element analysis confirmed this view.

PRECONTRACT ASSURANCE TESTING :

In view of the innovative nature of the proposal, precontract testing was performed inlate 1992. Two VCCs were installed and tested by vertical static loads and by SIMBAT dynamic tests. Results are summarised in Table 1.

Settlement (mms) at	Static Load 600 kN	Static Load 1200 kN	Dynamic Load 600 kN
Test 1	7.9	30.4	9.0
Test 2	8.8	35.2	8.9

TABLE 1

Analyses of the Static and Dynamic Load tests showed the total ultimate capacity of a columns to be in the range 1600 to 1800 kN and the ultimate base resistance to be about 1000 kN.

In addition, a "trial embankment" of nominal base area 7.2 x 7.2m and 1.3m tall was constructed over four VCC columns. The base Transfer Platform incorporated two layers of Tensar SS2 as designed for the full scale embankment (Fig 6). Settlement plates were also incorporated at the levels of the two geogrid layers, the heads of the VCCs and the surface of the embankment to measure the profile of settlements across and between the VCCs. The loading, spacing of columns and geogrid restraint conditions for the trial embankment were more onerous than for the intended contract works.

Once the fill was placed settlements were monitored for four days. Kentledge blocks were then added to apply a further surcharge equivalent to about 3.0m height of embankment. Two kentledge loading cycles of 6 and 49 days were then monitored.

The settlement results (Fig.7) were analysed by Halcrow - SEEE, using finite element methods to confirm the load-bearing mechanism of the embankment and VCC interaction and tensile forces within the upper and lower geogrid layers.

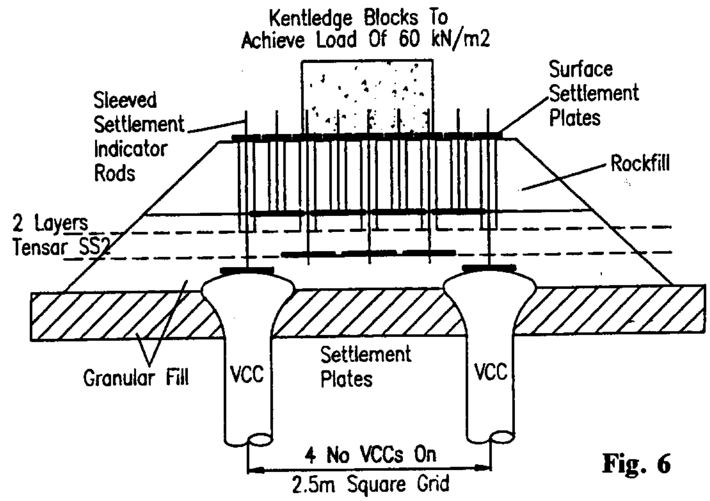

Fig. 6

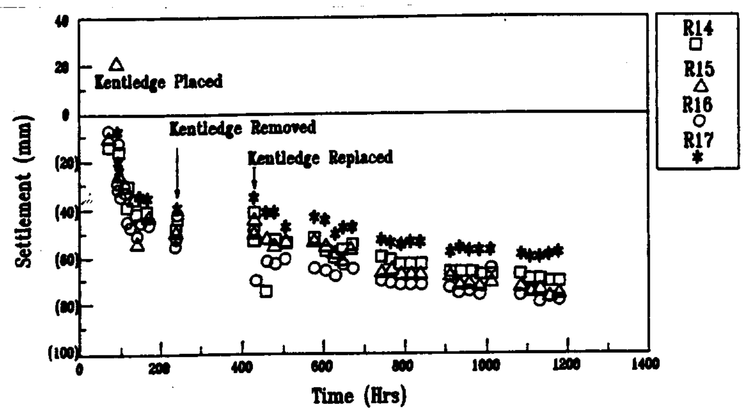

Fig. 7a Settlement Plates on Top of Load Transfer Platform (Ref. Fig. 6)

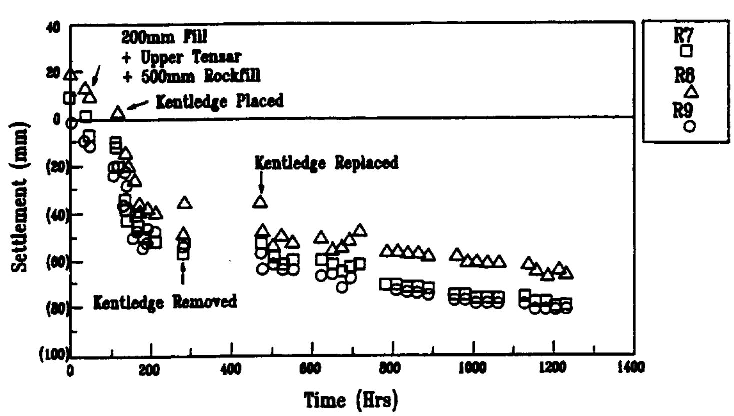

Fig. 7b Settlement Plates on Top of Lower Geogrid (Ref. Fig. 6)

On completion of monitoring, the "trial embankment" was excavated to examine the geogrids and one VCC exhumed to 3.5m depth for detailed measurement confirming the expected nominal shaft diameter of 430mms.

CONSTRUCTION AND PERFORMANCE :

Construction of the foundation support system commenced in early 1993. Two Vibrocat units were used to install 11,700 VCC's in a period of 5 months. The columns were approximately 6.0m in length and were formed from low slump concrete with a compressive strength of $25N/mm^2$ minimum. Control of the installation process was facilitated by electronic monitoring on each rig, which recorded length; rate of construction; energy consumption; and concrete consumption for each column. Five static load tests and over 150 dynamic load tests were performed on the VCCs. These confirmed the performance suggested by analysis and as indicated by the pre-contract tests.

Construction of the geogrid mattress, covering an area of almost $60,000m^2$, commenced soon after the start of the column construction and followed on. Individual rolls of geogrid 50m long x 4m wide were laid, and braided into adjacent rolls with a minimum 75mms lap or alternatively laid with a simple 400mms overlap.

The granular mattress was built up in three layers with varying compaction to protect the integrity of the VCC's. The initial layer over the column tops was compacted with a Bomag BW6 vibrating roller - using dead weight only.

The intermediate layer was compacted with a Bomag BW6 vibrating roller with vibration. The top layer was compacted with a Bomag BW10 vibrating roller with vibration.

During construction, three areas of the embankment (areas 1,2,3, respectively located in the East, Centre, and West of the site) were instrumented to enable performance monitoring of the full scale rockfill embankment. Settlement plates were installed to monitor mattress settlements above the heads of the columns and between columns. Pressure cells were employed to measure the loads carried by the columns and the ground between columns to confirm that the intended arch had formed. A typical layout is shown on Fig. 8. Results obtained to March 1994 together with predicted values are given on Table 2.

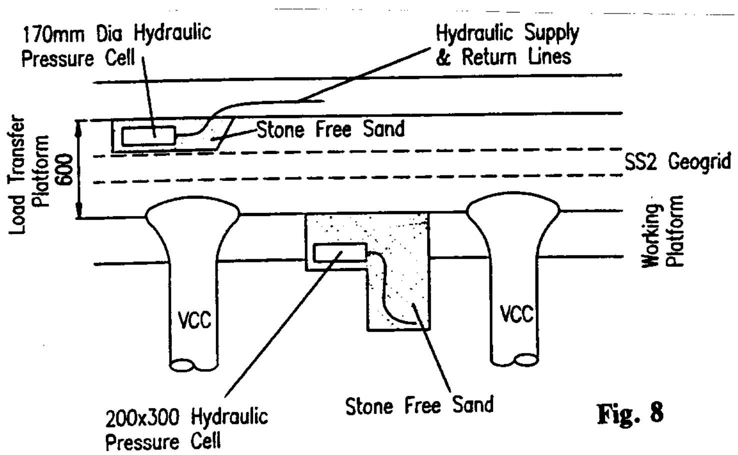

Fig. 8

	Predicted [a]	Measured [b]	Measured [b]	Measured [b]
	Sand and Gravel	Sand and Gravel Area 1	Sand and Gravel Area 2	Sand Area 3
Settlement above heads of VCCs (mm)	10	1 - 7	6 - 9	30 - 32
Settlement at mid-span between VCCs (mm)	15 - 30	5 - 13	9 - 15	40 - 50
Stress above head of VCCs (kN/m^2)	160 - 200	50 - 150	150	125 - 150
Stress on original ground at mid-span between VCCs (kN/m^2)	Minimal	< 5	< 5	< 5

[a] for maximum embankment height [b] for partially complete embankment

TABLE 2 : Summary of Predicted and Preliminary Measured Settlements and Applied Stresses for VCC Ground Treatment

CONCLUSIONS :

An innovative system of ground improvement for embankment support was employed for the Toll Plaza at the Second Severn Crossing Project. The adopted system incorporated Vibro Concrete Columns and a geogrid-reinforced granular platform and provided an effective solution for the embankment underlain by highly compressible peats and clays with negligible risk to the contract programme.

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ACKNOWLEDGEMENTS :

The Authors wish to thank Laing-GTM for permission to submit this Paper, and gratefully acknowledge the support of colleagues in Keller, Netlon, Halcrow-SEEE, and Laing-GTM.