Case History - Deflection of structures reinforced with materials of different stiffness

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ABSTRACT: Polymeric geogrid material was first used as reinforcement for permanent vertical reinforced soil retaining walls on Dewsbury Bypass (UK). Prior to the design of the Dewsbury walls a full scale trial wall was constructed to determine the suitability of geogrid reinforcement for long term usage. Comparative studies of the performance of geogrid reinforcement with glass fibre strip reinforcement and the influence of different fill materials on performance were undertaken. Following the successful completion of the trial wall the performance comparisons were continued during the construction of the permanent walls on the Bypass. The results of the studies provide a direct comparison of the influence of reinforcement stiffness on lateral strains together with the relevance of the properties of the fill. The importance of providing a method of accommodating the differential settlement between the wall facing and the fill was illustrated. The overall deflection characteristics of the walls on Dewsbury Bypass was a surprise with the base bearing pressure under the toe being minimal leading to the conclusion that the nature of the foundation is the dominant factor in determining horizontal strain in a reinforced soil wall. The implications of the wall movements on design at the Serviceability Limit State (SLS) are discussed.

1 INTRODUCTION

Polymeric geogrid material was first used as reinforcement for permanent vertical reinforced soil retaining walls on Dewsbury Bypass (UK). Prior to the design of the Dewsbury walls a full scale wall was constructed to determine the suitability of geogrid reinforcement for long term usage, Jones et al (1990). Comparative studies of the performance of geogrid reinforcement with glass fibre strip reinforcement and the influence of different fill materials on performance were undertaken. Following the successful completion of the trial wall the performance comparisons were continued during the construction of the permanent walls on the Bypass.

The fill materials used in the pre-design study were cohesionless fill and light weight pulverized fuel ash (PFA). Following the trial it was decided to construct the structures on Dewsbury Bypass with pulverized fuel ash fill. Both the geogrid and the glass fibre reinforcement were selected for use as reinforcements in separate structures. In one reinforced wall it was decided to use geogrid reinforcement in one half of the structure and to compare its performance with polyester strip reinforcement in the other half, all other details being the same. A notable feature of the reinforcements used in both the trial structure and the permanent reinforced walls was the significant differences in their relative stiffness. Construction of the walls was monitored closely with particular emphasis given to deflections/strains of the reinforcement, fill and overall structures.

2 TRIAL WALL

The trial wall constructed prior to the design of the Dewsbury Bypass walls was 6m high and 32m long. It was divided into 5 Bays to enable the following material combinations to be compared: frictional fill and glass fibre strip reinforcement; frictional fill and polymeric grid reinforcement; PFA fill and glass fibre reinforcement: PFA fill and polymeric grid reinforcement. The wall was designed for 37.5 units of HB surcharge loading, BS 5400 (1978), using the limit equilibrium method of analysis detailed in UK Department of Transport Technical memorandum BE3/78, (DoT 1978). This is the same method of analysis as that detailed in BS 8006 (1995) for extensible reinforcement. For comparison the spacing and density of the reinforcement in that part of the structure formed using conventional fill were kept the same as that detailed in the PFA section.

The facing of the structure consisted of vertical universal columns located at 1.2m centers resting on a mass concrete footing with prestressed concrete planks placed horizontally between the flanges of the columns to retain the fill.

2.1 *Trial wall construction*

The wall was constructed in accordance with Department of Transport specification and followed the following sequence:

1. Cast concrete footing 480 x 250mm deep
2. Place 300mm of drainage material
3. Erect and prop universal columns
4. Place precast concrete units together with 300mm vertical sand drain
5. PFA or frictional fill placed and compacted to the level of the first reinforcement
6. Place reinforcement
7. Repeat operations (1)-(7)

Intermediate construction operations included the removal of wedges supporting the bottom of the universal columns when the height of the fill reached 2m. The props supporting the universal columns were removed when the fill height reached 3m. Once the construction of the wall was complete a surcharge equivalent to full 45 HB units of load was applied, BS 5400 (1978).

3 FILL AND REINFORCEMENT MATERIALS

3.1 *Fill*

The PFA fill was conditioned hopper ash having an optimum moisture content of 30%; the material was delivered and used with a moisture content of 24-26 per cent. The frictional fill used in the trial structure was well graded good quality sandstone with a uniformity coefficient greater than 60; the material was delivered with a moisture content varying between 3-7.3 per cent. Details of the shear strength characteristics of the fill materials are shown in Table 1.

Table 1 Trial wall fill material properties

Fill material	γ kN/m^2	φ' degree	c' kN/m^2
Cohesionless sandstone	19.5	35	0
Pulverised fuel ash	15.2	32	30[a]

(a) A value of c' = 5 kN/m2 was used in design

3.2 *Reinforcement*

The geogrid reinforcement used in the trial wall was a uniaxial grid formed from high density polyethylene, the polymer used was classified by the code BS3412D-47-E-0.2-J. The glass fibre reinforcement used was formed from continuous filaments of E-glass roving embedded in a thermosetting polymer. The materials were combined to form an aligned fibre reinforcing strip in the form of a hairpin, the end connection being formed at the loop. Details of the performance characteristics of the reinforcements are shown in Table 2. Table 2 also provides details of the third reinforcement (polyester tape) used in the second trial conducted on Dewsbury Bypass.

Table 2 Reinforcing material properties

Reinforcement material	Width (mm)	Characteristic tensile strength [1] kN	Stiffness modulus kN/mm^2
Glass fibre strip	40 - 80	16 - 64	40
Polyethylene grid	1000	73	4.1
Polyester strap	90	50	9.8

[1] The design tensile strength used was 40% of the characteristic strength

3.3 *Reinforcement connections*

Two methods of connecting the geogrid reinforcement to the facing were studied. In the first a bodkin passed through the grid and was supported at its ends on lugs welded to the rear of the vertical columns. The amount of deflection which would occur in the bodkin under load and the amount of slackness inherent in the joint were considered to be critical to the forward movement of the facing. The deflection of the bodkin joint was investigated by direct observation through a series of 100mm diameter holes formed in the facing panels. The observations concluded that:

(a) a force of 0.25kN was required to remove slackness in the joint

(b) in-soil deflection of the connection under load was approximately 12mm.

The alternative fixing for the geogrid reinforcement was to have the grid pass through the facing in which case the bodkin was restrained by the front flanges of adjacent columns. Protection of the reinforcement, and as a means of accommodating the vertical settlement of the reinforcement relative to the facing, was achieved by the installation of compressible strips 12mm thick each side of the grid reinforcement located horizontally between the precast concrete facing units at each lift. The connection of the glass fiber strip reinforcement to the rear of the columns was by a sliding connection, Jones (1996).

4 MOVEMENTS OF THE STRUCTURE

A fixed reference point parallel but remote from the wall was established prior to the construction of the trial wall and movements of the facing and settlement of recorded. Forward (lateral) movements of the facing at the end of construction and after the application of the HB surcharge loading are shown in Table 3. Settlements of the facing are recorded in Table 4. The internal compaction of the fill and the differential settlement of the reinforcement relative to the vertical columns varied in the range 10-30mm with the maximum movement occurring in the lower third of the structure.

Table 3 Forward (lateral) movement and slope of the facing of the trial wall at end of construction and with the addition of HB surcharge ( )

Wall section	Top mm	Base mm	Slope
Granular/ glass strip	48 (60)	8 (11)	1:148 (1:120)
Granular/ geogrid	94 (111)	24 (29)	1:84 (!:72)
PFA/ geogrid rear fixing	127 (144)	40 (44)	1:68 (1:59)
PFA/ grid front fixing	120 (134)	23 (26)	1:61 (1:55)
Pfa/ glass strip	64 (72)	7 (10)	1:104 (1:95)

Table 4 Settlement of the wall

Fill/reinforcement type	Settlement of base (mm)	
	6m fill	HB surcharge
Granular/glass strip	40	65
Granular/geogrid	30	56
PFA/geogrid	16	24
PFA/glass strip	17	29

5 DEWSBURY BYPASS WALLS

Following the successful construction of the trial wall the design and construction details developed in the trial were specified in the contract for the construction of Dewsbury Bypass. In particular it was decided to use the light weight PFA fill as the foundation conditions at Dewsbury were poor. The Bypass was an inner highway constructed on land that had previously been used for housing and factories built circa 1840. The underlying soil was alluvium with a low bearing capacity. Improvement of the bearing capacity by dynamic compaction was not possible due to the closeness of the Bypass to prominent structures including the Town Hall. Four large reinforced fill walls were required to provide grade separation. One wall, (Wall1) was reinforced with glass fiber strip reinforcement and two walls, (Walls 2 and 3) with geogrid using the front fixing method for the geogrid reinforcement connections. The fourth wall, (Wall 4), which was of the same height as the initial trial wall, was divided into two equal sections one half being constructed with geogrid reinforcement, the other half being constructed with polyester straps, Table 2. The reason for the addition of polyester strap reinforcement was to extend the study of the influence of the form and stiffness of different reinforcing materials on the performance of reinforced soil structures.

5.1 *Wall movements at Dewsbury*

The lateral movements of the three walls reinforced with a single reinforcement type reflected the movements recorded in the equivalent bays of the trial wall. However, the two halves of the wall reinforced with both geogrid and polyester straps showed marked different lateral movements at the top of the structure. The half reinforced with the geogrid reinforcement showed a lateral movement at the top of the structure some 60-80mm greater than the half reinforced with polyester straps. The lateral movement of the polyester section was similar to that recoded by the PFA/glass strip section of the trial wall. The movement of the geogrid section was similar to the PFA/geogrid bay of the trial wall. Similarly, the differential settlement of the fill relative to the facing (10-40mm at the mid height) was of the same order of magnitude to that recorded at the trail wall.

There was one highly significant difference in the lateral movements of Wall 4 relative to the trial wall. The overall rotation of the structure was backwards such that it was possible to pass a hand under the front flanges of the vertical steel columns at the base. The reason for this backward rotation was the foundation conditions presented by the alluvium subsoil.

6 DISCUSSION

The maximum forward rotation of 1 in 55 in the trial wall occurred where PFA was used as fill with the geogrid reinforcement and the rear fixing. The minimum forward rotation of the trail wall occurred in the bay constructed with frictional fill and glass fibre reinforcement. It can be concluded that reinforcement stiffness has a major influence on lateral movement but it was not be apparent that frictional fill would produce less lateral strains than the light weight PFA fill, particularly as the latter has similar frictional properties as well as being cohesive. The vastly superior soil/reinforcement bond provided by geogrid reinforcement compared to strip or strap reinforcement had no influence on lateral strains.

Strain in the reinforcement is logically a function of the tensile strain in the reinforcement. The maximum reinforcement load (T_{max}) at any level in a reinforced soil structure can be taken as:

$T_{max} = K_a\sigma_v S_v$ for cohesionless fill
$= K_a\sigma_v S_v - 2c\sqrt{K_a} S_v$ for cohesive frictional fill

Where: $K_a = (1-\sin\varphi)/(1+\sin\varphi)$
σ_v = vertical stress
S_v = vertical spacing of reinforcement

The axial strain in the reinforcement, (ε), may be determined by:

$$\varepsilon = T_{max}/J_{\%}$$

Where: $J_{\%}$ = secant time and strain dependant stiffness

Assuming the material properties of the fill materials used in the trial wall and uniform distribution of load within the wall due to self weight, the design loads in the reinforcement for a unit section of the structure at mid height (3m) were;

T_{max} = 15.8kN for the section formed using sandstone fill
= 9.0kN for the section using PFA fill.

The computed tensions and the stiffness of the reinforcements, Table 2, suggest that those bays using sandstone fill should exhibit the greater lateral strains, however, the movements recorded showed the bays formed with PFA fill to be greater irrespective of the reinforcement used. It can be concluded that PFA fill has inherent greater strain characteristics than the sandstone fill even though the design loads required are less. The strain characteristics of fill alone are seldom considered in the design of reinforced soil structures. It would appear that this should be considered if accurate lateral strains are to be determined.

The results of the trail wall produced positive forward rotations. Adoption of identical design and construction details at Dewsbury produced significantly different results with conclusive evidence of backward rotation. This demonstrates that foundation conditions can be the dominant criteria in determining lateral strain of any structure. Failure to consider the foundation conditions in any situation other than conditions of a rigid foundation are likely to lead to the wrong conclusions regarding the serviceability strain conditions of reinforced soil structures.

The lateral strains of the walls on the Dewsbury Bypass had been anticipated and were of no consequence as the walls were provided with a masonry facing once all movements had ceased. The masonry facing was a design requirement to ensure that the walls remained in keeping with the surrounding buildings which were all constructed in masonry.

The use of reinforced soil for the retaining walls on Dewsbury Bypass provided savings over conventional designs which had been prepared of 46%. In 1988 the Dewsbury walls were the subject of an Institution of Civil Engineers award for excellence in design and execution.

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