DESIGN AND CONSTRUCTION OF A BLOCK FACED REINFORCED EARTH WALL AT CHEPSTOW: CASE STUDY

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Abstract: Regrading of ground at a site in Chepstow for construction of large industrial units necessitated cutting into the existing sloping ground by up to 7m. It was also necessary to provide a visual/landscaped screen in excess of 2m above this necessitating some form of ground retention system in excess of 9m high.

Various options were considered for ensuring long term stability of the ground around the perimeter particularly as land take was restricted. Options considered included crib walling and reinforced earth. A solution utilising a dry laid concrete block facing system by Allan Block with Huesker geogrid reinforcement was determined as the most appropriate system based on visual and economic grounds.

The reinforced earth solution comprised a wall constructed at 84 degrees to the horizontal ranging in height between about 3m and 9m and in excess of 700m long. The Allan Block Facing System is well established in the USA where it was developed. However this scheme is one of the first utilising this system in the UK. This paper presents a review of the design process together with commentary on the construction of the reinforced earth wall.

The paper considers particular aspects of the design with comparison between American design procedures and British Standards and reference to ground conditions, internal and global stability, geogrid strength and interaction between geogrids and the wall facing units. In addition the paper outlines some of the main construction issues particularly relating to earthworks, performance of earthworks materials, earthworks testing and construction sequence. Also discussed are some of the difficulties encountered during the construction of the reinforced earth wall.

Keywords: case study, clay, compaction, construction, geogrid, reinforced earth.

INTRODUCTION

The location of this case study is a site of two large retail distribution warehouses in Chepstow, South Wales. The site originally comprised open fields sited on ground that generally sloped gently down from north to south with an elevation ranging between about 12m OD and 20m OD. The proposed development for the site was for two large warehouses necessitating forming a level building platform on the site resulting in the need for a substantial ground retaining system around the northern part of the site. The retaining system adopted was a reinforced earth wall using a dry laid block facing system.

SUMMARY OF GROUND CONDITIONS

The geology beneath the site consists of a typical weathered profile of the Mercia Mudstone of Triassic Age. A ground investigation to explore the ground conditions was undertaken in September 2002. This comprised 22 mechanically excavated trial pits and three rotary core boreholes. The trial pit investigation generally proved the ground conditions to comprise a cover of topsoil and turf over firm to stiff sandy clay and silts with occasional clasts of very weak mudstone/siltstone. (Mercia Mudstone Group Grade IV). The clays and silts typically graded into stiff to very stiff clays with some to many clasts of weak mudstone (Mercia Mudstone Group Grade III). The very stiff clays graded into weak closely fissured mudstone with a little clay matrix (Mercia Mudstone Group Grades II and III). Generally Mercia Mudstone Group Grade II and III material was within about 2m of the original ground level. The deeper boreholes proved a similar weathering profile and that the mudstones become less weathered with less clay generally with Mercia Mudstone Group Grade II being within between about 3m and 4m of the original ground level. Based on the results of the ground investigation it was evident that ground water was present within the Mercia Mudstone Group II material at an elevation of about 10m OD.

DEVELOPMENT PROPOSALS

The development proposed for the site was to create a level platform at an elevation of 10.8m OD for the construction of two substantial warehouse buildings covering a floor area of 32000m². This necessitated cutting into the existing ground slope to a depth up to a maximum of about 8m. In addition a planning requirement was to ensure that the roof ridgeline of the buildings were screened by an earthworks bund with a crest level of 22m OD.

To maximise the area available for building construction and useable yard/car parking, the area to the north would need to be retained as steep as possible. Several options of retaining structure were considered including crib walling gabions and reinforced earth.

It was eventually decided that the most cost effective option that would achieve the desired finish was a block faced reinforced earth wall. The system used was the Allan Block system incorporating Fortrac Geogrids. The Allan Block system is a hollow dry laid block with a free draining angular stone placed in the hollow part of the block. There is no positive locking system for the geogrids. The pull out resistance for the geogrids relies on frictional resistance between the grids the blocks and the granular infill. This block system has been used extensively in America for many large reinforced earth walls but has not been used on any major reinforced earth walls in the UK. This project is the first of its kind in the UK.

Because of the extensive earthworks involving a significant volume of cut it was important to use site dug material for the fill to the reinforced earth. It was apparent from the ground investigation that the Mercia Mudstone arising from the earthworks would be either mostly clay with some gravel size clasts of intact mudstone or weathered mudstone comprising weak and very weak mudstone and siltstone gravel and cobble size fragments within a silty clay matrix. In terms of the Department for Transport Specification for Highway Works (SHW) these materials would generally be within Class 7C wet cohesive fill to reinforced earth. However the inclusion of mudstone within the material would make it unsuitable in terms of the SHW suitability criteria . However the economics of not using the clays and mudstones would have had a significant impact on the cost of the works particularly as the reinforced earth wall was to be 750m long and up to 9m high which would have required an extensive amount of imported fill and disposal of unsuitable material. In consideration of this and the characteristics of the clay and mudstone arising from the earthworks it was decided to use the clay and mudstone as fill to the reinforced earth.

SUMMARY OF DESIGN

For design reference was made to CIRIA Report C510 Engineering in Mercia Mudstone. Based on this and the Ground Investigation data the following design parameters were use in design.

Table 1 Summary of Geotechnical Parameters Used In Design

Material	**Bulk Unit Weight** (kN/m^3)	**Drained Shear Strength**		**Undrained Shear Strength**	
		Angle of Friction ϕ' (^{o})	Cohesion c' (kN/m^2)	Angle of Friction ϕ_u (^{o})	Cohesion c_u (kN/m^2)
Intact Clay	20	28	0	0	70
Intact Mudstone	22	32	0	10	200
Intact Siltstone	22	35	0	10	200
Clay Fill	19	27	0	0	60
Mudstone/Siltstone Clay	20	30	0	0	70

Large diameter shear box tests were also undertaken on samples of clay fill and mudstone/siltstone fill to confirm the adopted design parameters for these materials. The results of shear box testing showed that the drained angle of friction for the clay and mudstone fill was likely to be well in excess of the parameters used in the design.

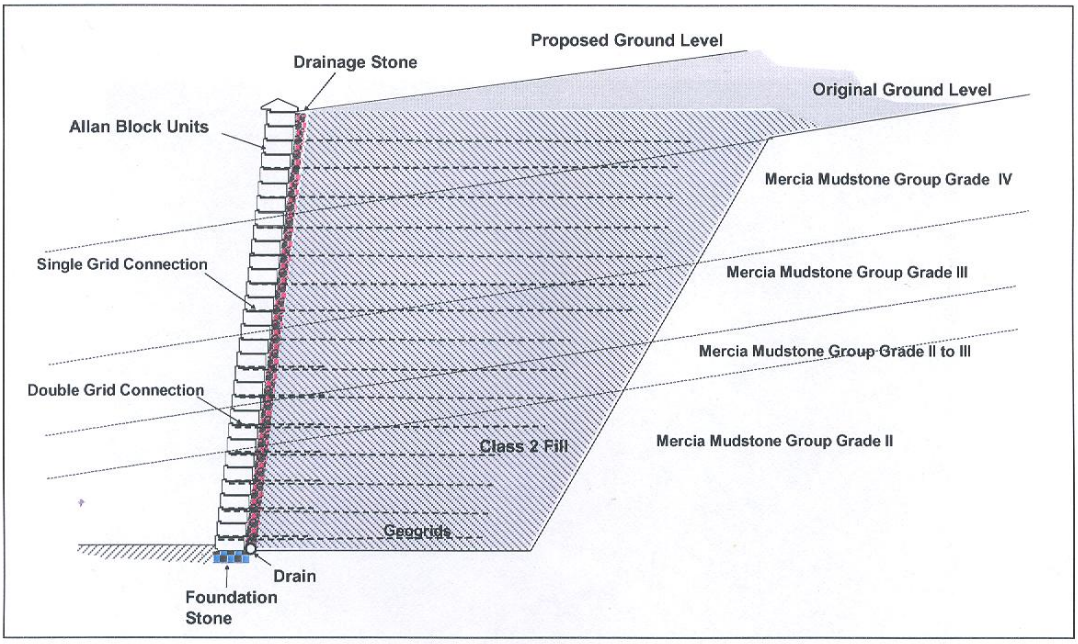

Figure 1. A typical section through the site showing the geological model and typical reinforced earth wall layout.

The design (Figure 1) was undertaken by Peter Brett Associates in general accordance with BS 8006: 1995 Strengthened/ Reinforced Soils and Other Fills. The method adopted was use of the tieback wedge method utilising an Excel Spreadsheet to determine the required geogrid strength, lengths and vertical spacing for internal stability. The spreadsheet was also used to assess factors of safety against bearing capacity failure. Based on guidance in BS

8006 the required connection capacity of the connection between the geogrids and the wall facing blocks was determined.

To check the sliding resistance and global stability GGU stability Software was used. In addition to the design in accordance with BS 8006 the Allan Block software supplied by the manufacturer was used as a check of the design. The Allan Block software however is based on American standards particularly Task Force 27, In Situ Soil Improvement Techniques, "Design Guidelines For Use Of Extensible Reinforcement For Mechanically Stabilised Earth Walls in Permanent Applications" AASHTO-AGC-ARTBA, AASHTO, Washington DC 1990 which typically adopts the principals of a Coherent Gravity Wall using single Factors of safety for limiting Eqilibrium. Though there were some differences between the American methods and designs based on British Standards there was a reasonable agreement between the output for each method.

One of the principal differences was in the estimation of the required pull out resistance at the facing connection. The BS tends to be conservative in this respect and the values determined from this process were used for determining the connection requirements.

Tests have been performed in America to determine working pull out capacity for the differing grades of geogrid. These have been performed by both Allan Block and Huesker. Based on these it is apparent that for the high pull out capacity a double layer of geogrid gives higher working capacities than a single connection. Figure 2 shows typical results for single layer pull out capacity and figure 3 shows typical results for double layer connections. These tests were undertaken in America and therefore the graphs presented are in imperial units.

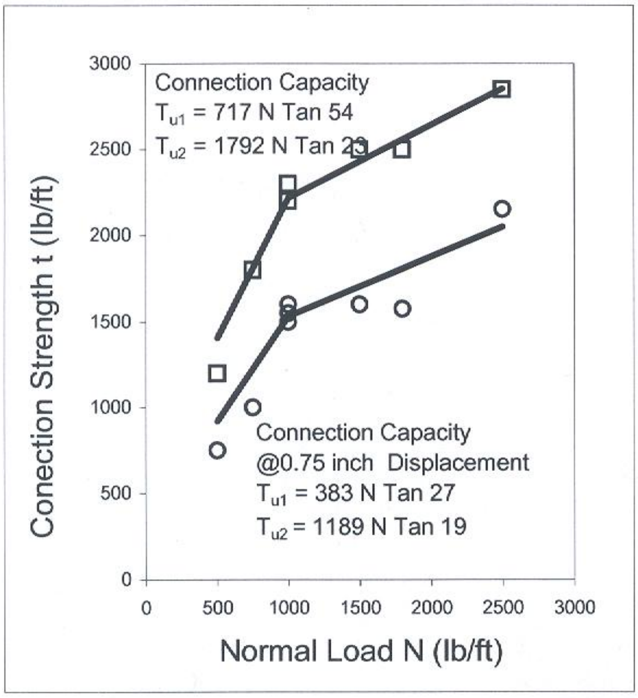

Figure 2. Connection Strength For Single Connection of Fortrac 35 Geogrid

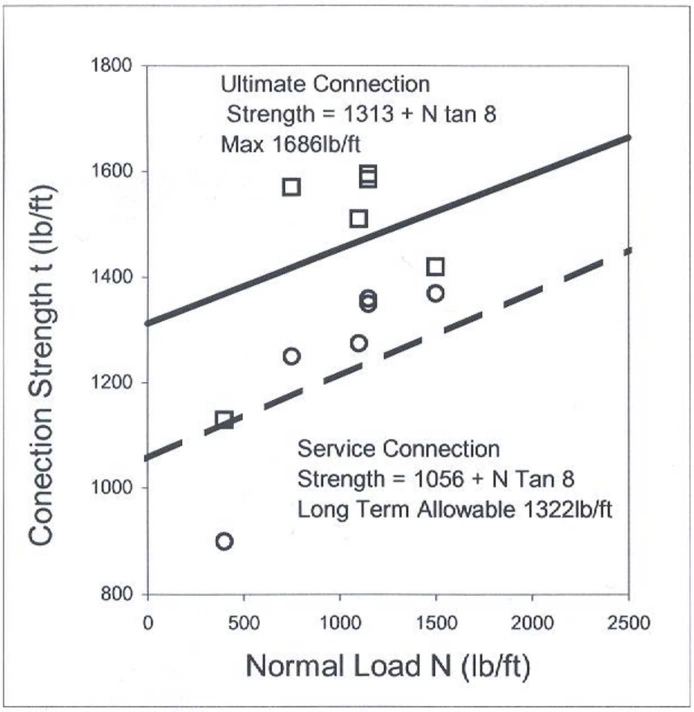

Figure 3. Connection Strength For Double Connection of Fortrac 35 Geogrid

EARTHWORKS AND REINFORCED EARTH CONSTRUCTION

Bulk Earthworks were commenced in September 2007 to form the level area below the proposed building footprints. This produced a significant cut slope around the area of the proposed reinforced earth wall. The cut slope confirmed anticipated ground conditions with a typical weathered profile of the Mercia Mudstone At formation level the Mercia Mudstone comprised a moderately weak to moderately strong blocky siltstone/mudstone which in places was difficult to excavate. In respect of the good formation there was no particular concern with bearing capacity. In addition the excavated mudstone was good material for re-use in the reinforced earth construction.

The construction of the reinforced earth wall commenced in late October 2007. Once the bulk earthworks were completed a Class 803 Type 1 fill was placed along the line of the reinforced earth wall facing blocks to produce a level foundation for the first row of Allan Blocks. It was important to ensure that the foundation was level within very tight tolerances particularly in view of the length and height of the structure so that there would be no unsightly variations in the block coursing. Figures 4 shows the bulk earthworks and the start of the reinforced earth construction. Figure 5 shows the double layer Geogrid connection.

Figure 4. Showing Bulk Excavation

Figure 5. Showing Double Geogrid Connection

As with all earthworks adequate compaction of the soil is critical to the performance of the earthworks and any associated structures. The specification for the construction of the reinforced earth wall included acceptance criteria based on moisture content and end product in situ density. In addition the method of compaction was also specified based on the guidance in SHW. The method of compaction specified was for 4 passes of a Bomag 120 roller for a layer thickness no greater than 175mm for the bulk fill away from the face of the reinforced earth. Close to the face a plate compactor was used so as not to affect the face blocks. During construction the moisture content of the fill material at source was determined on site using a microwave method. Though there may be some variability in the moisture content results determined by this method of test it is considered to give results that are within about plus or minus 2% of the actual moisture content. In this respect it is considered to give a reasonable level of confidence that material arriving on site to be included in the earthworks are most likely to be with in acceptance criteria before the material is placed. When results indicated that the moisture content was likely to be outside acceptance limits either earthworks were put on hold until the fill material became acceptable or an alternative source was identified that was within acceptance limits. Figure 6 show the placement and compaction of the fill material.

Figure 6. Laying and Compaction of Fill

Figure 7. Commencement of Wall Construction

In addition to the site determinations of moisture content the in situ dry density and moisture content were determined at a frequency once per 500m^3. A Nuclear Density Meter was used for this and every 10 sets of tests the nuclear density meter was recalibrated against sand replacement tests. When the results of either the site moisture content tests or the in situ testing indicated that the fill material as placed and compacted it the fill was removed or scarified to allow the layer to dry and be recompacted.

The filling of the reinforced earth commenced in November 2008 (Figure 7), during the first few weeks the weather was particularly good for this time of year and construction progressed well with no particular problems. The only problem in the first month was with one batch of Allan Block which had not been cast particularly well resulting on some minor flaws in the finish that led to some minor misalignment of the blocks. This was easily rectified on site by breaking off the small blemishes so that the blocks could be laid correctly. No further problems were encountered with the block facing once this problem was sorted.

The main problem encountered during the reinforced earth construction was the deterioration of the fill at source due to very wet weather and the fill becoming too wet for adequate compaction to be achieved. Generally when wet weather was forecast earthworks were suspended to allow the fill to dry out. In addition the compacted fill was sealed up to prevent this deteriorating. Once the weather became dryer the upper surface of the placed fill was removed generally to a thickness of at least 150mm to remove any softened fill and remove any potential weak layer that could potentially be a slip surface.

During wet weather it was also important to control surface water run-off so that excessive water would not flow over the surface of the fill and the face of the reinforced earth.

Immediately at the rear of the block facing units a minimum 300mm of free draining fill comprising Class 6N was placed to mitigate the potential for water pressures to build up immediately to the rear of the facing units. In addition because of the dry laying of the blocks water could also percolate through the face. However during even the wettest conditions there was never any real sign of water percolating though the facing units indicating that the Class 6I fill was acting as a good drainage. As well as providing drainage the Class 6I granular fill was more easily compacted and far less moisture sensitive allowing good compaction of the material immediately to the rear of the facing units.

As the reinforced earth was constructed there was a need to provide an adequate safety rail along the face to mitigate the risk of falling form the face. Several options were considered for this but in the end a scaffold system was adopted with the scaffold attached to the facing units using expanding anchored drilled into the blocks(Figure 8). An area of completed wall is shown in Figure 9.

Figure 8. Wall Partly Built Showing Safety Barrier

Figure 9. Area of Completed Wall

CONCLUSION

The Allan Block system of facing steep reinforced earth walls has proved very successful for the reinforced earth wall at Chepstow. It was identified as the most cost effective solution and produced a good finish which was important on a wall of this size as any slight misalignments would be very noticeable. Though the contractor had experience of reinforced earth construction they had never built using the Allan Block System and they found it very easy to work with and produced an excellent end product. The weather was the factor that influenced the construction most and though it would have been much easier using a granular fill that would be less moisture sensitive this would have required a significant removal of fill off site and import of other fill which not only would have had a significant impact on the cost but would also have been less sustainable.

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