The history and development of incremental block wall systems utilising geogrid reinforcement

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ABSTRACT: Civil engineers have endeavored to develop a practical, attractive and economical reinforced soil facing system. Concrete is often the favoured material to use and many branded products are now available. This paper will record some of the steps in development taken to achieve the necessary flexibility, durability and cost effectiveness in the systems available. Several types of facing unit will be analysed to help understand the features required to be accepted in the market place. In order for these systems to be accepted engineers must be satisfied that they are suitable for the purpose intended and several criteria need investigation, such as: Durability, crushing strength, manufacturing tolerances, buildability, interlocking capability, fire resistance, pull-out strength. The requirements for an incremental block wall system, to achieve official independent approval, necessary for use in Highway schemes will be investigated. … Special attention should be paid to the face/geogrid connection in order to maximise the available safe design strength. Also some of the difficulties encountered during construction and the building methods developed in response will be examined.

1 INTRODUCTION

Unreinforced incremental concrete units are becoming broadly accepted for use as a facing to reinforced soil retaining structures. The ease and speed of construction of this type of facing may lead to cost savings over conventional retaining wall designs whilst allowing a variety of surface finishes to be achieved.

Due to the critical nature and long design life of reinforced soil retaining walls and bridge abutments constructed using such systems, concerns are often expressed during design approval regarding the components of the system. The quality and durability of the facing units as well as the geogrid soil reinforcement must be assessed and in particular the connection strength between the two.

The history and development of connection systems which enable a high percentage of short-term reinforcement strength to be mobilised at the geogrid/face will be examined. The development of practical mechanical connection systems allows incremental concrete unit faced reinforced soil structures to be economically designed, in compliance with European and other design code requirements, without a reduction in grid design strength to account for the lower connection strength achievable in early frictional connection systems.

Numerous designs of segmental blocks are available throughout the world. The ease and speed of construction of these dry-laid blocks may lead to considerable cost savings over conventional retaining wall designs whilst the variety of surface finishes available permits the colour and texture of adjacent structures to be matched. Some of the systems permit the construction of horizontal curves of relatively tight radius, both external and internal, a feature which is very difficult to achieve with most other forms of construction and can result in very attractive and elegant structures.

2 HISTORY

2.1 *Full height panels*

The use of geogrids in reinforced soil structures started to become accepted in the early 1980's with the development of high density polyethylene orientated uniaxial materials. Design and test methods were in their infancy with most of the knowledge of reinforced soil surrounding the use of steel strips. The first examples of geogrid structures tended to use full height precast concrete panels to form the face.

The limit to what safe design strength was to be used in the design was the strength of connection developed at the junction with the face. As a response to this critical requirement, starter lengths of the geogrid were cast into the rear face of the face panel at the appropriate level. The layers of geogrid reinforcement were then connected using the bodkin method, (fig. 1), allowing a 100% efficiency connection.

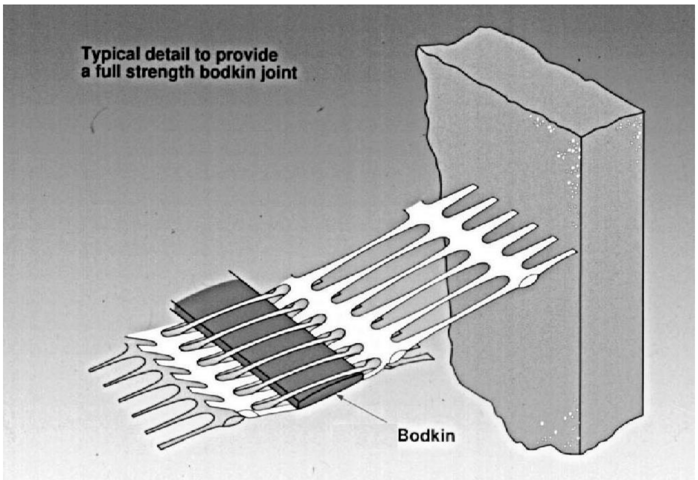

Figure 1. Polymer bodkin connection

Systems utilising full height concrete panels and bodkin connections have won independent approval for use in critical retaining walls and bridge abutments where high strength and a 120 year design life is a requirement (BBA Certificates No. 99/R108 and 99/R109, 1999). The system of using full height concrete panel worked well and continues to be used in projects today.

However, every project has different parameters to design to; height, soils, foundation conditions, hydrostatic pressures etc. Each scheme in question would possibly require a unique set of panels, requiring new moulds. Add to this the transport cost and the system, although still valid may become less economically attractive when compared to other systems.

2.2 *Incremental Panels*

To avoid the tailor-made approach with full height panels, smaller units using the same connection detail were manufactured in geometric shapes which were designed to lock together. One such system utilised hexagonal panels 1.5 metres across, with starter lengths of geogrid reinforcement cast into the rear face. The panels (fig. 2) are craned into position and clamped during the backfilling operation.

Figure 2. Incremental panel wall

Although attractive and slightly more cost effective in terms of manufacture, the system requires cranage to handle heavy units and remains inflexible in aesthetic terms.

2.3 *Incremental concrete unit*

Further development of the incremental idea led to the design and manufacture of concrete units resembling blocks rather than panels. The geometry being such that there is sufficient depth to allow the unit self stability when positioned. Early examples still took advantage of the cast-in tail and the bodkin connection (fig. 3).

Figure 3. Large incremental unit using cast-in geogrid

However, the size of the unit still dictated the use of mechanical plant for lifting and placing. This mass of unit was necessary to resist the force applied during construction when removing slack from the bodkin joint. In addition, it was a disadvantage to have to cast in a geogrid tail during manufacture.

Concrete units similar to the previous one were designed and manufactured to connect to the grid via a slot connection at the rear (fig. 4).

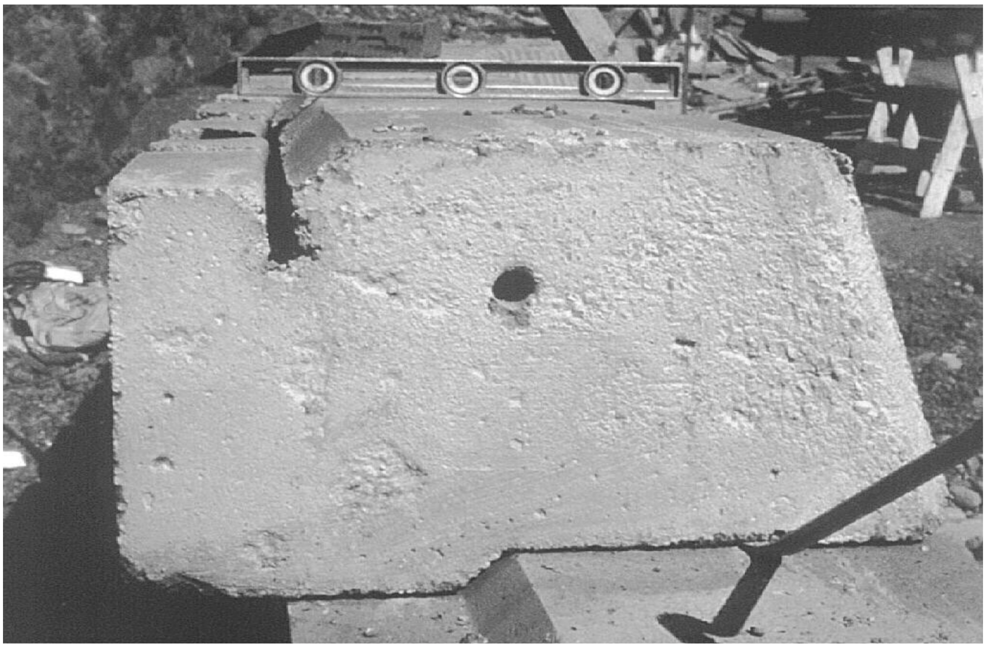

Figure 4. Large incremental block with cast-in slot for geogrid connection

The geogrid was tucked into the slot at the upper rear corner and then located and fixed when the next unit is placed. Once again the unit relies largely on its shear mass for stability and the anchorage of the grid. This time no bodkin connection, but an anchorage relying on normal pressure and some degree of shear resistance in the slot. The mass of the unit necessitated mechanical lifting making delivery and placement a time consuming and a costly business.

What engineers started to look for was a walling system which incorporated the benefits of reinforced soil such as economy and ease of construction with a mass produced, lightweight, attractive facing unit.

2.4 *Purpose made precast concrete incremental wall systems*

The first proprietary precast concrete systems were designed principally as mass retaining walls for structures up to 2 metres in height. The mass produced unreinforced units were more easily handled, typically around 50kg per unit or less (a two man lift with lifting devices).

The units were produced from steel moulds in purpose built precasting machines, using a semi dry mix. After rapid curing these types of unit could be palletised and transported easily to site in bulk.

The units produced attractive walls but the market penetration was limited to low height architectural structures and the larger structural/civils market was still beyond reach.

The chance of using these incremental wall systems with newly developing geosynthetics in the mid 1980s, opened up a whole new opportunity which stimulated huge growth of the market.

2.5 *The early years*

The first segmental block systems developed in the 1980's (Bathurst, Simac, 1994) relied almost entirely upon friction between the soil reinforcing material and the blocks to transfer facing connection loads between the two components.

Some systems however, relied upon a combination of load transfer mechanisms:

- grid to block friction

- interlock with drainage stone placed within and around the blocks
- mechanical transfer onto load bearing pins or concrete shear keys

The use of such wall systems was principally developed in the USA where the increasing use of segmental blocks lead to the development of design and test standards by the NCMA, 1997.

The aforementioned methods of connection to the facing unit lead to varying face/grid connection strengths (depending on the geogrid/facing unit combinations), one such method is illustrated (fig. 5).

Figure 5. Geogrid connected to face locked together by the use of fibreglass location pins and drainage medium.

Assessment of a particular wall system for a project, requires knowledge of the connection strength between the reinforcement and the block, under the range of normal pressures which will be experienced in-service. With the principal market for hard faced retaining walls being in the 1-8m height range, the influence of normal pressure on the available connection strength of frictional connection systems is significant. To overcome this potential problem, mechanical connection systems were developed to provide a high level of load transfer at the grid-block connection and the transfer of horizontal shear loads between adjacent blocks. The advent of these systems meant that for the first time the facing unit and soil reinforcement were being developed as one, rather than bringing together two independent components not necessarily designed to work together.

Nevertheless, a system of the type illustrated in figure 5 continues to be widely used worldwide and has won independent approval for use in highways structures BBA Certificate 98/R103, 1997.

3 THE ARRIVAL OF PURPOSE DESIGNED MECHANICAL CONNECTION WALL SYSTEMS

3.1 *The early days*

To make an impact in the marketplace, it was recognised that any new system being developed should have the following features:

- High grid/face connection strength
- Low weight for easy handling
- A range of finishes available

- Ability to negotiate horizontal curves
- Competitive price
- Ease of construction

Much of the early work concentrated on connection strength resulting in several methods which were later dismissed and superceded (fig, 6 and fig. 7).

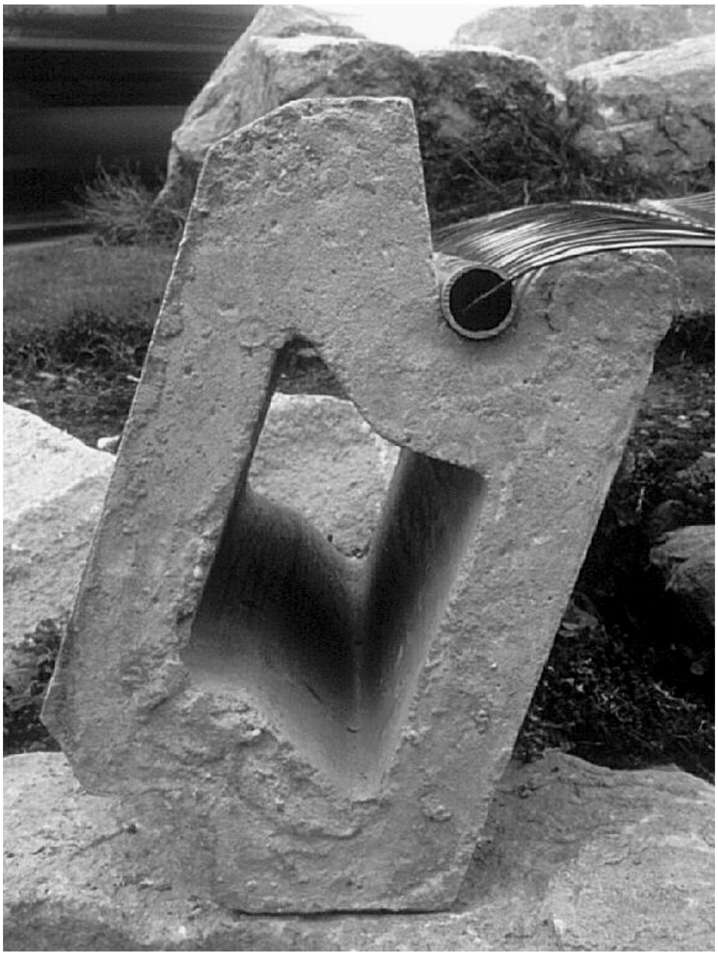

Figure 6. Tubular steel connector with hollow section block

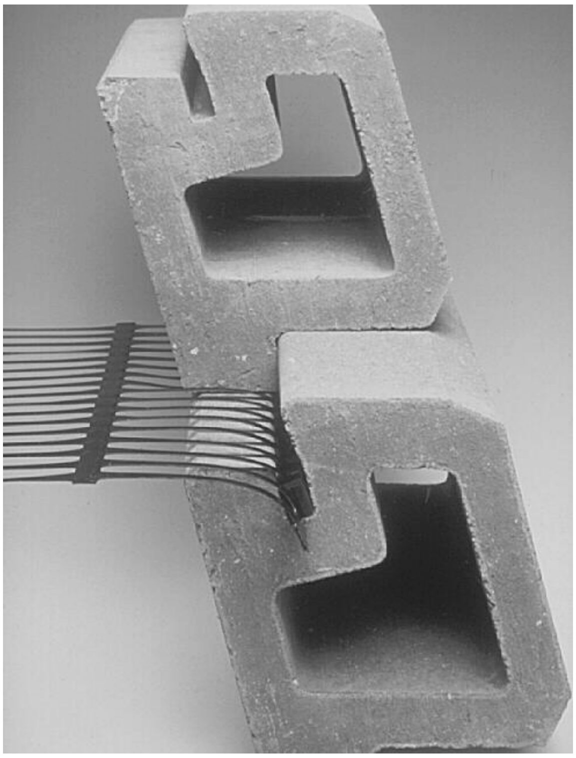

Figure 7. Hollow section block and polymer connector

These two development units are similar in that they have a hollow section to achieve low weight and the geogrid is located in a recess. This location method gives good connection strength but the reliance on a tight fit of the connector into the recess, limits construction to straights only.

3.2 *Further development and into production*

The drive to achieve the features highlighted in 3.1 lead to the mass production of the geogrid and facing system illustrated in figure 8.

Figure 8. Concrete 'finger' connector set into longitudinal recess

Development of the concrete finger unit gave very high connection strength between face unit and geogrid plus high shear load transfer. The available space in the recess forward of the finger unit allows some articulation of the facing units which permits construction of horizontal curves. The facing units themselves weigh around 25kg, significantly less than the early gravity units. However, by spanning across the horizontal joint between blocks, such a system is only suitable for straight walls or long-radius curves. Thus the ability to achieve the tight radius curves, often regarded as one of the most important features of segmental walls, is lost.
Nonetheless. this system has also achieved independent approval for use for use in highways structures with a 120 year design life (BBA Certificate 97/R094, 1997).

3.3 *Development of polymer connectors*

To provide high connection strength, a polymeric connector has been developed (fig. 9) which is suitable for use with a wide range of different segmental units. The connector can tolerate small differences in the transverse pitch of the geogrid ribs by the use of flexible links every third aperture.

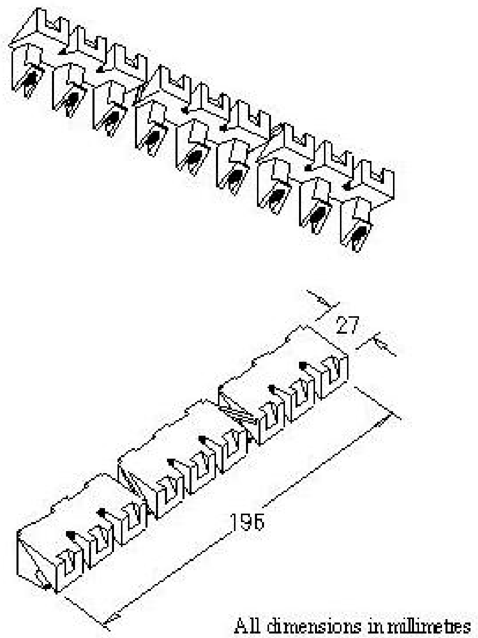

Figure 9. Polymer connector

The polymeric connector system is suitable to fit a range of facing units, providing the upper surface has or can be modified to accept a recess into which the of polymer grid connector can sit. Figures 10 shows a block with pins acting as the shear key which can utilise the connection system developed, whilst at the same time permitting tight horizontal curvature of the facing.

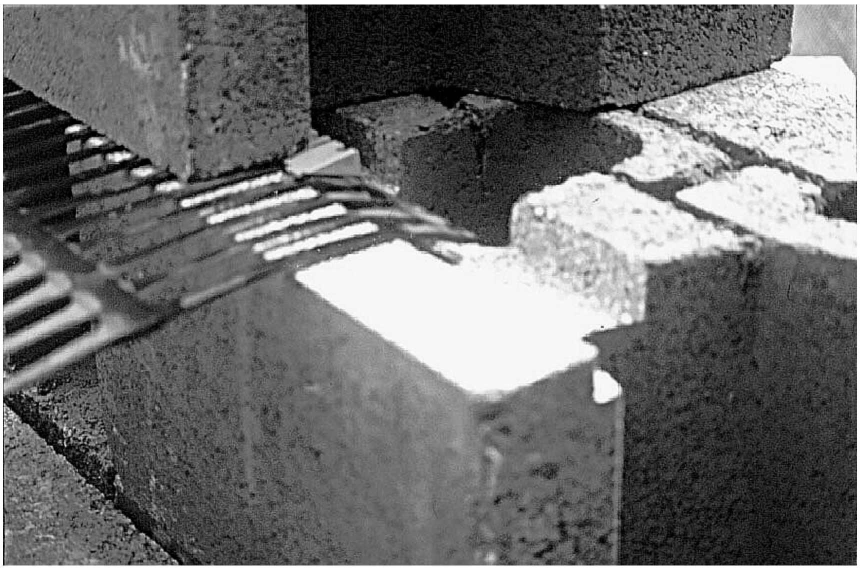

Figure 10. Polymer grid connector in segmental block with fibreglass pin shear keys

To utilise the features of the polymeric connector in a lighter weight segmental block, systems have been developed. These systems rely on a concrete downstand to provide shear load transfer between blocks when located into the recess in the top of the block below. To maintain the vertical alignment of the wall the system provides concrete to grid contact under the shear key and on the top rear surface of the block (fig. 11).

Figure 11. Shear connection facing unit with polymer geogrid connection

This feature enables just one connector and block design to be suitable for a range of geogrid thickness', whilst ensuring overlying blocks sit level on the longitudinal geogrid ribs. The design of this block developed coupled with the polymeric connector permits small radius curves to be constructed down to 1.8 metres while maintaining high connection strength (fig. 12).

Figure 12. Construction of a horizontal curve

4 TESTING AND APPROVAL

4.1 *Connection testing*

In many countries, the design standards for permanent reinforced soil retaining walls requires that a high proportion of the grid design strength is available at the connection, between the reinforcement and the facing. In the UK, the Code of Practice for reinforced soil, BS 8006, 1995, requires that the available connection strength is 70-100% of the design strength of the reinforcement, depending on the vertical position of the reinforcement in the structure. In practice this means that the available connection strength governs the grid design strength and therefore the higher the design connection strength, the lower the reinforcement cost per unit of face area. Consequently a connection system which provides a high connection design strength, even at low normal pressures, is desirable

Laboratory tests for connection strength are generally short-term tests. However, whilst it is the long-term strength available at the connection which is important for design, BS 8006 gives no guidance how long-term connection strength should be calculated. The approach to this problem adopted in the UK, is to determine a short-term connection efficiency relative to the short-term tensile strength of the reinforcement and apply this connection efficiency to the creep limited strength of the geogrid. To calculate this correctly requires wide-width tensile tests to be undertaken on control samples of the reinforcing grid using the same sample size, equipment and strain rate as for the connection tests. Once a short-term connection efficiency has been established this can be applied to the long-term creep limited strength of the geogrid to calculate the long-term connection strength.

Geogrid to facing unit connection tests have been carried out using the industry standard method NCMA SRWU-1, 1997. In addition the effects of installation damage and chemical attack to the reinforcement within the facing need to be accounted for.

4.2 *Fire testing*

To gain approval for use in highways structures it is also necessary to prove the integrity of the system under the simulated conditions of a high temperature fire, at the face. Typically this may be caused by a road traffic accident with a subsequent high intensity fire fuelled by petroleum or diesel. Generally, concerns centre on the reduction in connection strength between the geogrid and face/connector unit, due to elevated temperatures and penetration by fire into the joints between adjacent blocks. Also the concrete facing unit must remain unaffected. Such tests should be carried out in accordance with the appropriate method BS476, 1987.

In order to simulate this condition, a representative panel of the wall facing (1m x 1m) complete with geogrid located in the rear, is constructed within a concrete frame which forms one end of a gas furnace test rig. During construction of the wall thermocouples are fixed to the grid and blocks in order to record temperature throughout the test (fig. 13).

Figure 13. 1m x 1m. unit ready to be offered up to the furnace

The fire test has a duration of 30 minutes with furnace temperature raised from ambient to 861^0C. Exposed wide width samples are tested and compared with control. Residual strength should not be significantly lower if reductions in overall design strength of the geogrid are not to be made.

4.3 *Quality of facing units*

The facing units for proprietary systems are generally produced from an automated factory process using a semi-dry concrete mix. As such several checks must be carried out as part of this manufacturing process in order to ensure quality of construction.

These systems rely on the concrete units being dry bedded, therefore the tolerance on the blocks must be consistently in the +/-2mm range which has come to be the accepted industry standard in the UK. The concrete should achieve a 28 day crushing strength of 30Mpa to ensure long term stability. Water absorption should be a maximum of 6%. Where the facing units are required to be bedded in aggressive soils the need for sulfate resisting cement should be assessed.

Facing units having shear load transfer and polymer connectors' have gained approval for use in highway walls and bridge abutments BBA Certificate 00/R122, 2000.

5 DISCUSSION

The use of reinforced soil incremental block walls has grown dramatically from its inception in the early 1980's. Starting life as modified gravity systems, purpose designed systems have been developed. For any construction method to become widely accepted it must satisfy several criteria;

- Durability
- Strength
- Independent approval
- Aesthetically appropriate
- Economical

However it is the last of these which often first attracts the designer. It has been broadly accepted by civil engineers that the technique of reinforced soil produces an economical design, hence it's growing acceptance. The cost of geosynthetic reinforced soil incremental block walls has been compared with several other structure types including, reinforced concrete, modular/crib walls and concrete paneled steel reinforced soil, Koerner et al, 1998. The results of the survey are summarised in figure 14.

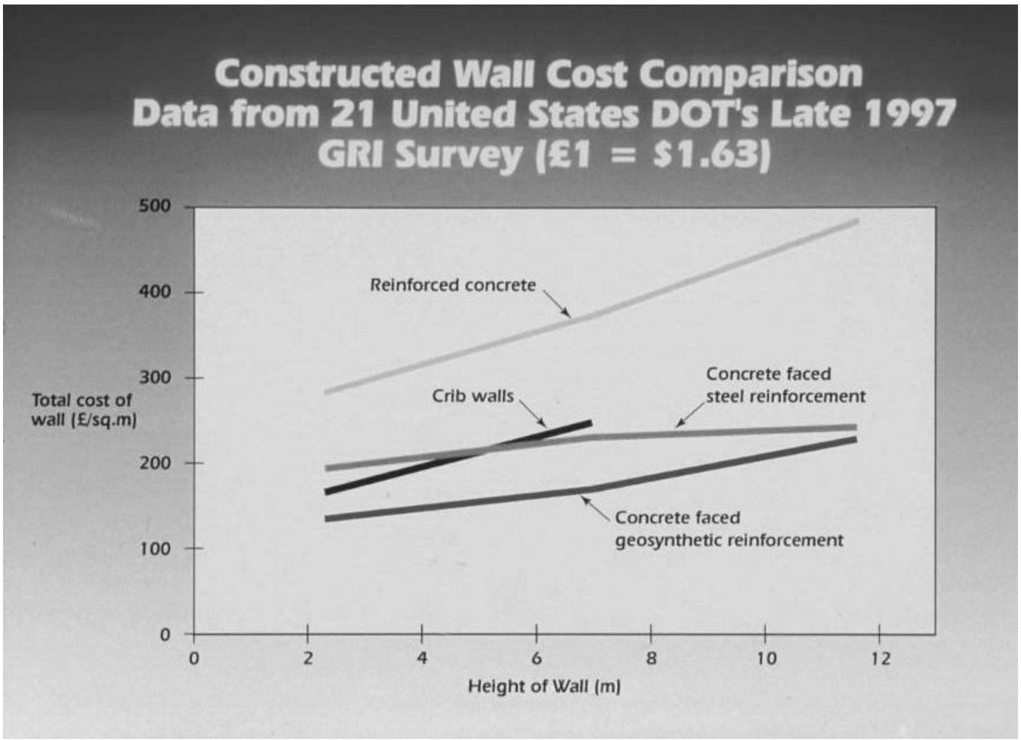

Figure 14 Results of cost comparison survey

Concrete faced geosynthetic structures were shown to be lower cost than any of the commonly used alternatives for highways structures and interestingly less than 50% of the cost of reinforced concrete structures.

6 FURTHER DEVELOPMENT OF THE TECHNIQUE

Designers wishing to take advantage of the flexibility and economy of these systems are often faced with need to provide a face to the structure which is compatible with the surroundings. Planning approval for schemes will often hinge on retaining structures being faced with brickwork or masonry to match in with existing surrounding structures and buildings.

With this in mind facing units have been developed to accept a stainless steel tie for an external single skin face to be subsequently attached. These ties are inserted during construction and may be adjusted vertically to fit in with course height of the facing to be attached (fig. 15)

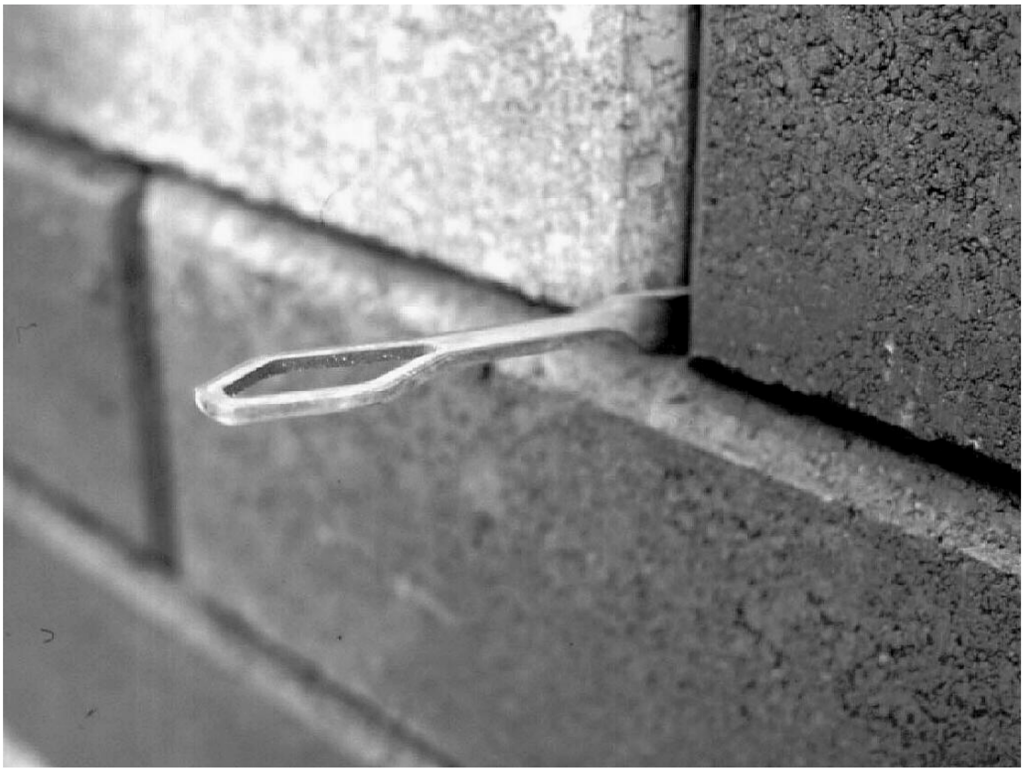

Figure 15 Stainless steel tie fitted into facing unit

When post constructional strain has taken place the architectural finish may be applied (figure 16) making sure that vertical expansion joints are included as required. The technique allows further choice of finish for the wall, whilst still remaining economically competitive.

Figure 16. A brick fascia is often chosen to face up the structure

7 CONSTRUCTION TECHNIQUE

The first course of blocks is best laid onto an in-situ concrete strip footing. Using a C30/20 mix this leveling pad is not considered part of the structure, but should be viewed as a method of ensuring true line and level for the base units of the facing. To further assist and to ensure accuracy, it recommended that the first course also be bedded on mortar and checked using a string line and spirit level.

Subsequent courses of facing units should always be placed onto a clean surface. The presence of even very small pieces of aggregate in the joints will have a detrimental effect on the appearance of the finished structure.

When connecting the geogrid to the face at the appropriate level it is vital that all slack is taken out of the joint. Any play here may manifest itself as forward movement of the face as the load from the soil fill behind is applied.

It is also important to avoid the use of heavy plant (mass per metre width < 1300kg and a total mass<1000kg) within 2 metres of the rear of the face during construction. The lightweight nature of modern facing units may leave them susceptible to forward rotation during construction. The presence of a pea gravel drainage layer behind the face helps in this regard.

The top course of facing units is often placed using a proprietary adhesive. This helps resist the upper courses being kicked off after completion.

8 CONCLUSIONS

- Geogrid reinforced soil walls with incremental block facing have been proven to be an economic method of providing structures in all application areas.

- The wealth of research and development work over the last 20 years have demonstrated that a high grid to facing unit connection strength is a vital feature for designers and to gain independent approval.

- The development of the polymer connector system has allowed
  - high connection strength
  - construction of tight horizontal curves
  - high block to block shear continuity through pin or shear key connection.

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