

LESSONS LEARNED FROM THE FAILURE OF A GEOTEXTILE REINFORCED RETAINING WALL FACING

by G.N. Richardson

ABSTRACT: During the fall of 1987, a geotextile reinforced retaining wall was constructed to provide vehicle access to the rear of a retail center. The wall has a maximum height of 13 feet and a length of 340 feet. The wall was constructed using a sand backfill reinforced with layers of a woven geotextile to form a wrapped faced fabric wall with a treated timber facing added for aesthetics. A separation failure of the timber facing occurred as the wall was reaching full height and as backfill was being placed on top of the wall. This paper presents details of the initial facing failure, the failure of a subsequent repair, and the final re-engineered connection that has proven successful. The paper concludes with a review of the current condition of the wall and its components six years after the initial failure.

KEYWORDS: Geotextile, Retaining Wall, Failure, Wall Facing, Field Observations

AUTHOR: G.N. Richardson, President, G.N. Richardson & Associates, 417 N. Boylan Ave., Raleigh, NC, 27603, Telephone: 1/919-828-0577, Telefax: 1/919-828-3899.

1 Introduction

This paper is an update of a previous published review of this wall failure (Richardson and Behr, 1988) and presents additional information that has come to the author's attention and a performance review of the wall after 6 years of service.

In the fall of 1987, Soil & Material Engineers was providing general geotechnical services for the construction of a small retail center being constructed in Raleigh, North Carolina. It had become obvious during the planning of this center that vehicle access to the rear of the center would be very limited. To ease access, the Raleigh office of Soil & Material Engineers was asked to design a retaining wall for the northern property line. The required wall would have a maximum height of 13 feet and a length exceeding 340 feet. The restricted space at the site limited the depth of the reinforced zone to less than 8 feet. This resulted in a wall aspect ratio (reinforcement length/wall height) of 0.60. The details of the wall geometry at maximum height are shown on Figure 1.

A cost comparison prepared for the developer showed that the least expensive wall alternative was a geotextile reinforced wall having a pressure treated timber face. Cost analysis showed that the geotextile wall could be constructed for approximately \$9.00 per square feet of wall facing. This was significantly less than commercial wall systems available at that time. Given the cost savings and the ability to build the wall using his own work force, the developer of the center preferred the design and construction of a timber faced geotextile wall.

2 Initial Design of Geotextile Reinforced Wall

Backfill for the wall had been selected during the costing phase and consisted of a man-made sand that was available from a local quarry. The 1200 yd³ of sand required for the wall were in fact supplied at near cost by the quarry because they did not meet NC-DOT specifications and as such could not be used on State projects. The off-spec sand was evaluated in the Soil & Material Engineers geotechnical laboratory in Raleigh and found to be relatively free draining in spite of having 20% fines. The in place sand would have an angle of internal friction, ϕ , of 35 degrees and a maximum total unit weight of 110 pcf (ASTM D698). In view of these properties, the off-spec sand was considered a suitable backfill material for the retaining wall.

The static design of the geotextile reinforced retaining wall considered global stability including sliding, overturning, and bearing capacity failure of the wall's toe. The sliding factor of safety was low, approximately 1.0, due to the low aspect ratio of the wall. However, the author has successfully designed and built actual walls with sliding factors of safety equal to one. In the laboratory, the author has built reinforced wall with sliding factors of safety less than one without a subsequent failure even when large seismic loads were applied.

The design of the geotextile reinforcement for internal stability followed essentially the simple equivalent fluid method proposed for steel reinforcement by Lee et al. (1973) and adapted to geotextiles by Bell et al. (1983). The lateral fluid pressures acting on the back of the wall are calculated using an active earth pressure coefficient. For a low wall such as this, it is common to use a uniform vertical spacing, length, and strength of reinforcement. Using a constant vertical spacing, the maximum stress in the reinforcement will occur near the bottom of the wall. This force must be resisted by the tensile strength of the reinforcement itself and the frictional bond of the reinforcement to the backfill sand. The internal factors of safety for the initial wall were greater than 3.0 and are acceptable.

The author prepared the design of a geotextile rolled faced retaining wall to which a timber facing would be added. The 'detail' of this attachment was left to be designed by the staff engineer responsible for the project.

3 Wall Facing Connection Failures

3.1 Facing Attachment Failure Number 1

The initial construction of the wall was begun in the fall of 1987. The timber facing was to be attached to the wrapped faced geotextile wall using the detail shown on Figure 2. The geotextile reinforcement was vertically spaced approximately the height of four 6x6 facing timbers or approximately 24 inches. A single treated timber 2x4 was nailed from behind the geotextile into the timber facing at the top of each backfill lift. The lower 2x4 at each lift had been omitted by the contractor. Post-failure inspection showed that 16 penny nails were used at approximately 30 inch spacing to secure the 2x2 attaching the facing.

As the final soil surcharge was being placed atop the wall, a significant bulge developed in the facing. Workers were cleared from the vicinity of the wall and a cursory inspection made that same day. The following morning the timber facing of the wall was found nearly completely collapsed and lying on the ground in front of the geotextile wall, Figure 3. The geotextile wall itself was stable and not damaged by the collapse of the facing.

A close inspection of the geotextile wall showed that the attachment 2x4 had been placed at the top of each lift and that each lift of the wrapped faced geotextile wall had 'bulged' as successive lifts were constructed. Placing a straight edge on the face of the wall showed that the nails attaching the timber face to the 2x4s had been progressively pulled out as the face of each lift bulged, e.g. the nails were not strong enough in tension to resist the lateral earth pressures applied to the face, Figure 4. Eventually the nails on the lower lifts pulled out and the wall facing began to bulge. This nail pullout failure progressively moved upward and led to the eventual total collapse.

Lessons Learned:

- The wall facing attachment 2x4s placed immediately above each layer of geotextile reinforcement to limit bulging of the wrapped face is critical to the performance of the initially designed connection..
- The wall facing attachment 2x4s should have been attached to the wall facing using a connection designed for tension. This would include the use of bolts placed through the facing with bolts and washers on both ends. Nails are designed for shear and are not intended to be placed in tension.
- As the vertical spacing of the geotextile increases, the tendency for bulging of the facing elements increases. The impact of the vertical spacing of reinforcement on the performance of face elements should be evaluated.

3.2 Facing Attachment Failure Number 2

The failure of the connection between the geotextile wrapped faced wall and the timber facing left a stable geotextile wall that required a facing. Alternatives facings included driving rebar into the wall to support a wire mesh gunite facing and construction of a free standing timber wall that was tied to the geotextile wall. The architect for the project felt that the gunite wall would be objectionable in appearance so the free standing timber wall was selected.

The timber facing was reconstructed 12 inches from the geotextile wall and attached to it by means of metal strips as shown on Figure 7. These strips were secured to the back of the timber facing and the existing 2x4 strip behind the geotextile face with galvanized 16 penny nails. Note that the space between the timber facing was intended to be left empty. The author does not know how the metal strips were designed.

Shortly before completion of the wall, the Raleigh region experienced a major rainstorm that turned into an ice storm. Sometime after this storm, a significant bulge in the timber facing was again observed. Closer inspection showed that the metal strips had failed, Figure 8, allowing the timber facing to collapse, Figure 7. Failure of was determined to have been the result of a combination of unusual weather conditions; driving rain that then turned into a severe ice storm. The driving rain produced runoff that quickly saturated the fill behind the wall and continued to flow behind the wall due to several run on conditions. Workers at the retail center indicated that the ice storm then quickly covered the wall with a sheet of ice which prevented the drainage of water accumulating behind the facing. Ultimately, the water level built up behind the facing and created lateral pressures larger than the metal straps could resist.

Lessons Learned

- Discrete drains should be provided in all retaining walls including those that appear to have a pervious face.

4 Redesign of Timber Faced Geotextile Reinforced Wall

4.1 Facing Attachment Alternative Three

Once again, the failure of the facing connection left the facing collapsed at the foot of the wall and a stable and intact geotextile wall. It was at this point the author was called in to the project to redesign the wall facing attachment. While the wrapped face geotextile wall was intact, I opted to have the structure removed and to start with a fresh design. As before, the architect for the project required the use of the timber facing.

The redesign of the geotextile reinforced wall began with a laboratory evaluation of alternative methods of connecting the geotextile to the facing. The goal was to develop a connection that would develop the full tensile strength of the geotextile. Figure 8 shows laboratory testing of the final connection detail. The construction of this connection is shown in greater detail on Figures 9 and 10. All nails and rebar are used in shear in the revised connection.

4.2 Revised Design of Geotextile Reinforcement

In addition to revising the geotextile-facing connection detail, the vertical spacing of the geotextile was reduced to 12 inches to limit potential bulging of the facing between the attachment points for the geotextile, Figure 10. This reduction provided a direct attachment to one face of each 6x6 facing panel of the geotextile reinforcement. Candidly, the vertical spacing was reduced because the cost of the additional geotextile was less than the cost of a laboratory study to evaluate potential bulging in the original design.

The wall was reconstructed using AMOCO 2002 geotextile as reinforcement. Using the revised design, the retaining wall was reconstructed in February of 1988 and remains in service.

5 Summary

It is important to point out that the failures reviewed in this article were not specifically related to the performance of the geotextile reinforced soil block. At no time was there concern that the reinforced soil block would collapse. In fact, it proved to be more difficult that anticipated to remove the first reinforced soil block. Each layer had to be individually removed using a large tracked backhoe.

The connection of any reinforcement media to a facing system should receive a evaluation equal to that give the design of the reinforced soil backfill. The use of laboratory tests to confirm the tensile strength of the connection is highly recommended. Additionally, the impact of the vertical spacing of the reinforcement on potential bulging of face elements should be considered.

Monitoring points established and annually checked by the author have shown no lateral displacement of the wall to date. Visual inspection of the facing indicates no deterioration of the timber, and no soil loss is apparent on the top of the wall.

6 References

Richardson, G.N. and Behr, L.H., 1988, "Geotextile-Reinforced Wall: Failure and Remedy," Geotechnical Fabrics Report, IFAI, Vol. 6, No.4, pp. 14-18.

Lee, K.L., Adams, B.D., and Vagneron, J.J., 1973, "Reinforced Earth retaining Walls," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol.99, No.SM10, pp. 745-764.

Bell, J.R., Stilley, A.N., and Vandre, B., 1975,"Fabric Retained Earth Walls," Proc. 13th Engineering Geology and Soils Engineering Symposium, moscow, ID.

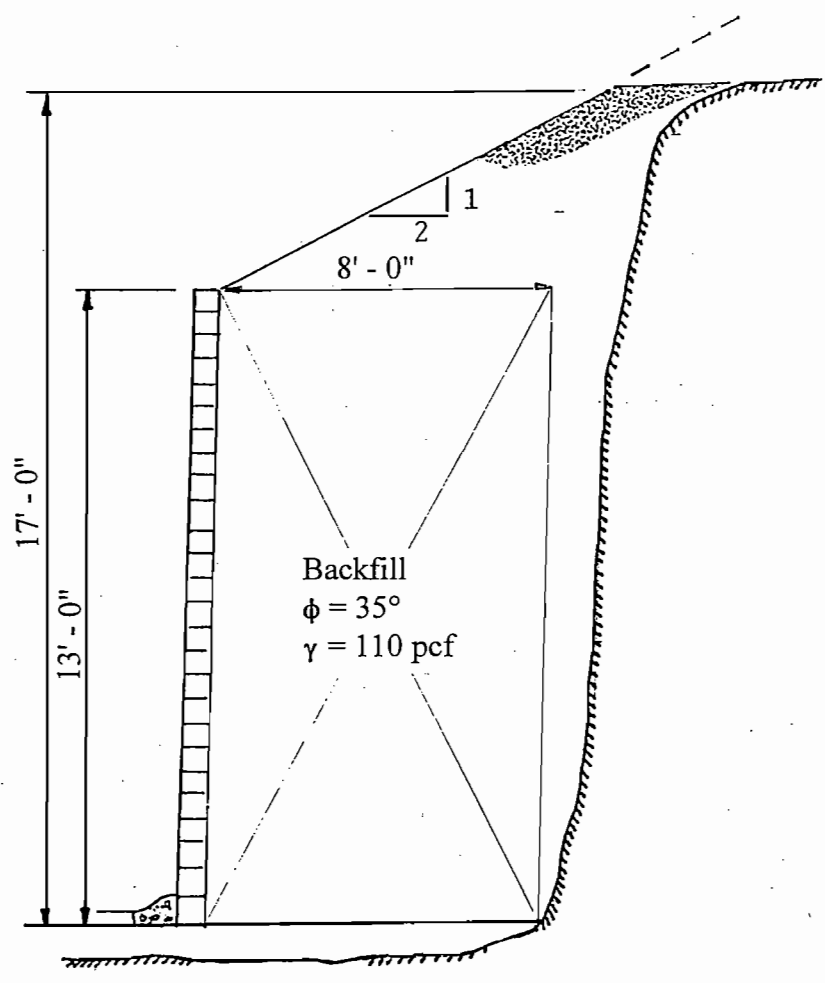


Figure 1 Maximum Design Wall Section

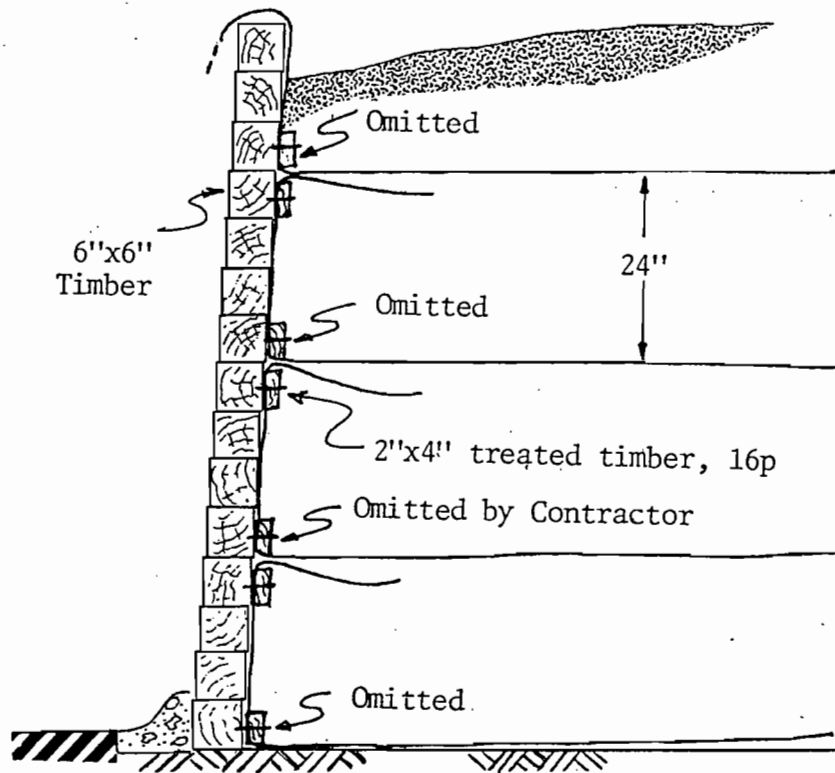


Figure 2 Initial Wall Section - Reinforcement and Connection



Figure 3 Collapse of Facing - Original Wall

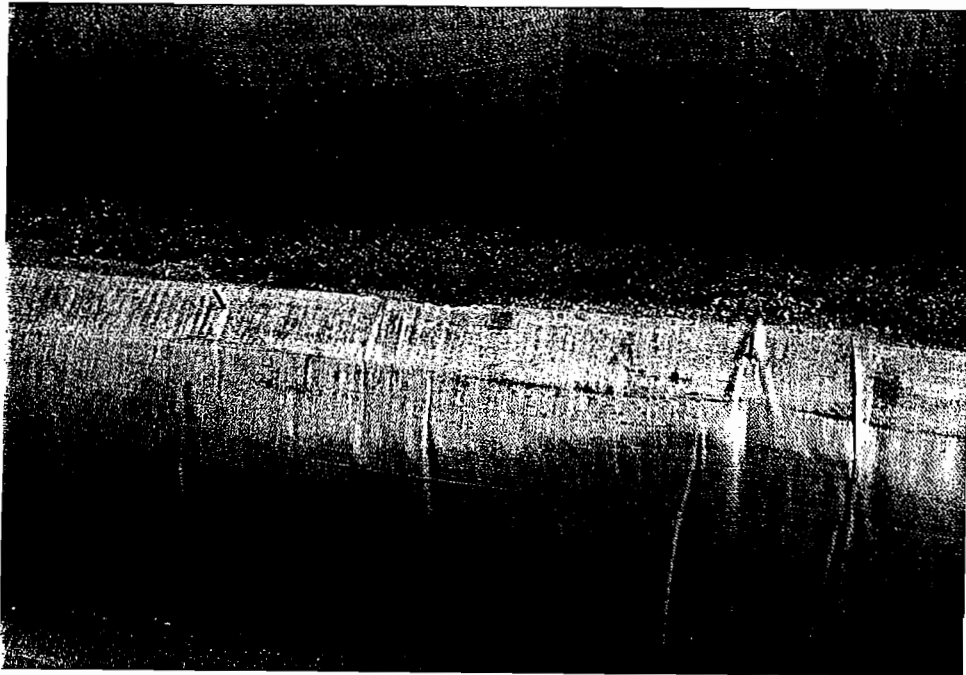


Figure 4 Limited Attachment of Facing - Original Wall

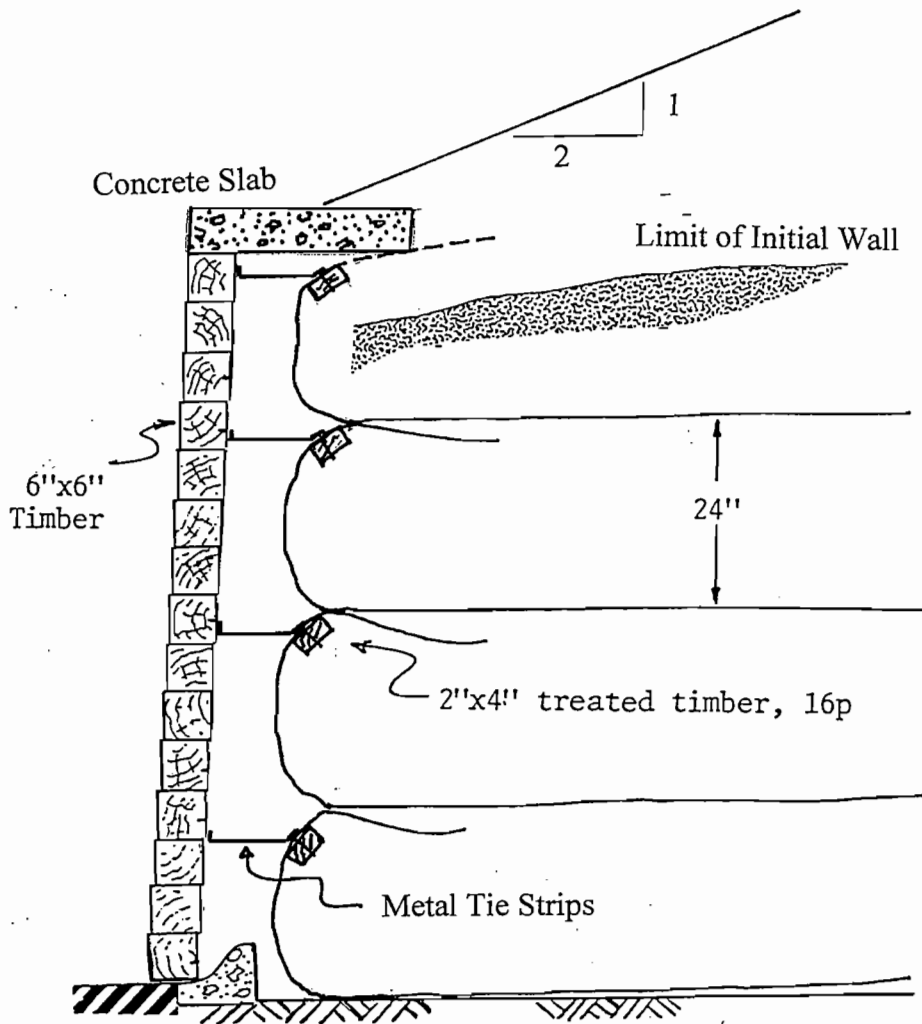


Figure 5 Free Standing Wall Facing

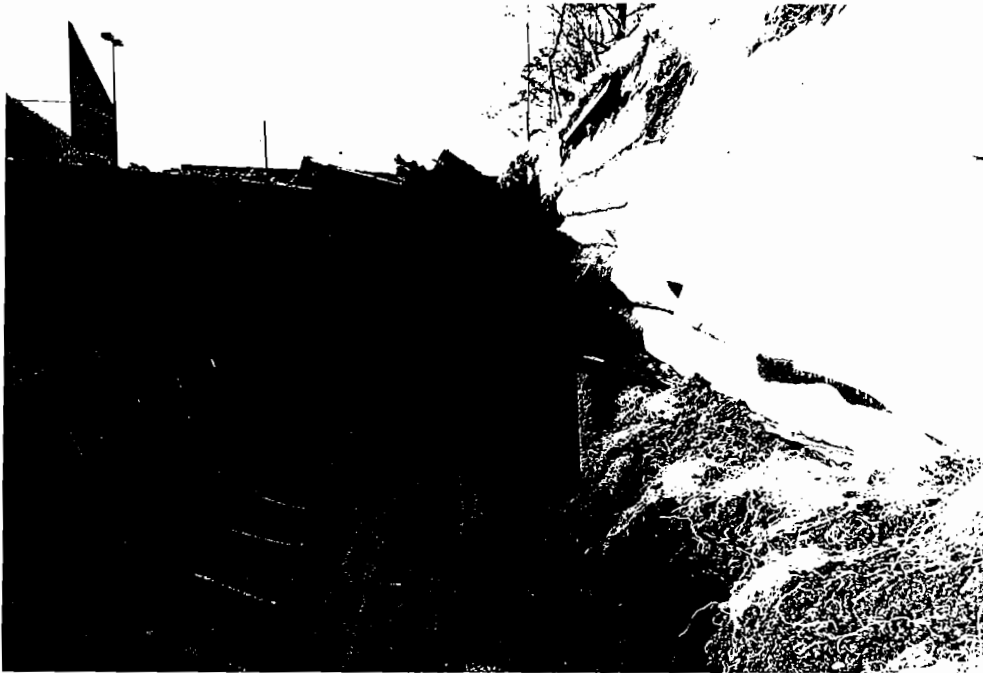


Figure 6 Failure of Metal Tie Strips

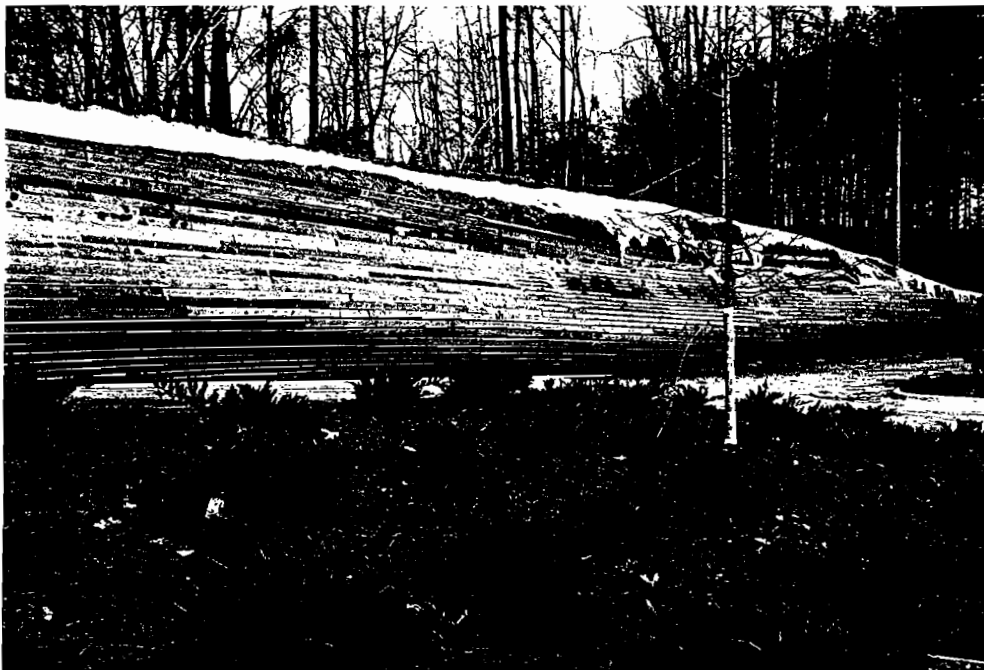


Figure 7 Collapse of Free Standing Timber Face

Figure 8 Laboratory Testing of Revised Facing Connection

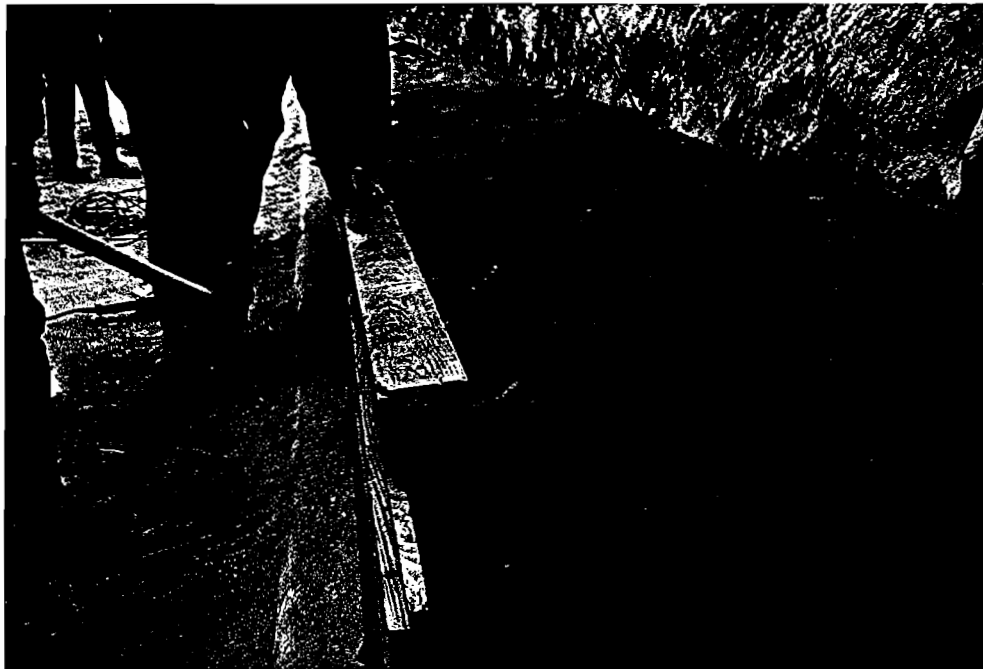


Figure 9 Construction of Revised Geotextile/Facing Connection

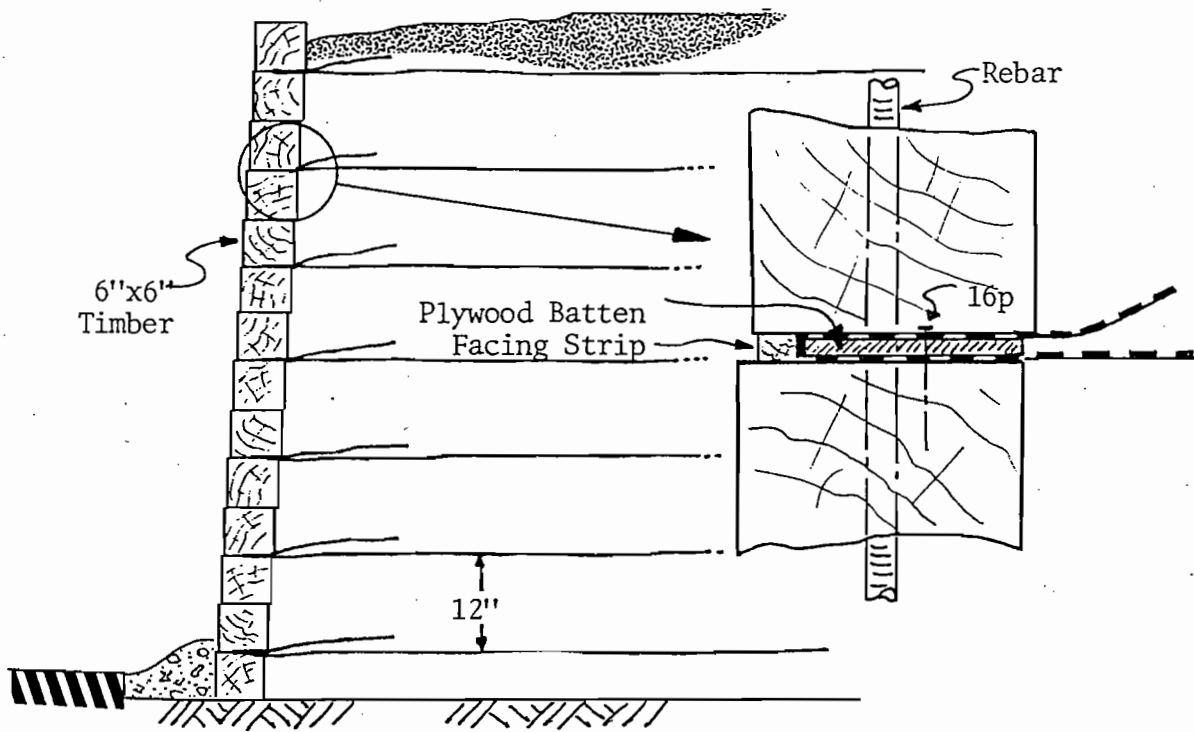


Figure 10 Section of Revised Geotextile Reinforced Retaining Wall