Fifth Australia-New Zealand
Conference on Geomechanics
Sydney, 22-23 August 1988

Prevention of Loss of Backfill through Gaps Between Retaining Wall Elements

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SUMMARY Loss of backfill through joints or gaps between retaining wall elements can be observed in various types of structures, such as crib walls, gabions and systems with face panels attached to soil reinforcement strips or meshes. A solution to this problem which is gaining in acceptance is the placement of geotextiles across these gaps or openings. Criteria with respect to the mechanical and hydraulic properties of the geotextiles can be established. Problems arise with assessing the durability of the typical synthetic fabric used, particularly in relation to UV-radiation (which may penetrate through the gaps) and possible high alkalinity adjacent to fresh concrete. Potential problems are illustrated by a case study of a Reinforced Earth wall built with sand backfill which showed signs of backfill loss.

1 INTRODUCTION

Loss of backfill through structural openings in earth retaining structures is not a new phenomena. It can be observed in traditional retaining walls with joints and drainage holes. The significance of this problem has increased due to the growing use of retaining walls of elemental construction, such as Reinforced Earth, crib walls, gabions and other systems. A similar problem exists with the loss of soil through mats and rip-rap placed for bank and shore protection.

If Australia follows the trend from overseas, many new elemental wall construction systems will be introduced here in the next decade. With the adoption of new wall construction methods and materials there is not only the danger of unknown long term performance, but also of neglecting basic geotechnical principles, such as appropriate backfill selection and consideration of filter criteria.

This paper reviews design criteria for granular and synthetic filters. It then reports the observed loss of backfill from a Reinforced Earth structure, discusses remedial measures and gives guidelines for the functional selection of synthetic materials for use in elemental wall construction.

2 GRANULAR FILTER PERFORMANCE CRITERIA

Well accepted filter criteria for granular materials include the 1955 guidelines from the Corps of Engineers, U.S. Army, which suggest the following grain size relationships (e.g., as quoted by Lambe and Whitman, 1969):

$$\frac{D_{15}\text{ Filter}}{D_{85}\text{ Soil}} < 5 \qquad (1)$$

$$\frac{D_{15}\text{ Filter}}{D_{15}\text{ Soil}} < 20 \qquad (2)$$

$$\frac{D_{50}\text{ Filter}}{D_{50}\text{ Soil}} < 25 \qquad (3)$$

D_{15}, D_{50}, D_{85} are the diameters corresponding to 15, 50 and 85% passing, as read off a grain size distribution diagram. If these relationships are satisfied, no significant migration of soil fines into the filter and drainage layer should occur.

The first and second of the above criteria ensure two performance aspects: The granular filter should be significantly more permeable (say 10 times more) than the soil it is supposed to protect, but not too much more, otherwise its voids would be large enough to pass large particles from that soil. The third equation has been termed the uniformity requirement and relates to the shape of the grain size distribution curves of filter and base soil.

Special criteria have been developed for fill adjacent to holes and slots. The Corps of Engineers proposed for slot openings:

$$\frac{D_{85}\text{ Filter}}{\text{Slot Width}} > 2 \qquad (4)$$

Although developed for slotted pipes and screens, this formula could assist in the selection of filter material behind gaps between retaining wall face elements.

3 SYNTHETIC FILTER PERFORMANCE CRITERIA

The use of synthetic woven and non-woven fabrics as filters is more involved than appears at first sight. Geotextile filters are much thinner than conventional granular filters. Determining a representative size and distribution of the fabric pores is considerably more difficult than measuring the grain size of a soil. Geotextiles do have advantages compared to soil filters: they have tensile strength, are very consistent in quality, easily handled and generally cheaper than a granular filter material.

Installing a fabric across gaps does mean we rely on its mechancial strength as well as its hydraulic properties. Continuous immersion, exposure to UV-radiation or extreme chemical influence means it is also necessary to closely evaluate geotextile durability.

3.1 Hydraulic Criteria

Behind the wall face the geotextile fulfills two hydraulic functions: filtration and drainage.

Similar to the formulations applying to granular filters, geotextile filter design criteria also relate to adequare filter flow capacity (permeability criterion) and prevention of continuing soil particle migration or "piping" (retention criterion). Several different criteria have been proposed, as discussed by Lawson (1982), Hoare (1982) and others.

According to Giroud (1982) the permeability criterion can be formulated in terms of the respective coefficients of permeability k (= flow per unit area per unit gradient) of the soil and the fabric:

$$k_n > 0.1\ k_{soil} \qquad (5)$$

where k_n represents the permeability for flow normal to the fabric. The problem with this expression is that the determination of k_n requires a representative thickness for the fabric, which is difficult to obtain.

Another approach (Lawson, 1986) to the permeability criterion compares a grain size indicator, such as D_{15}, to a representative pore size O, usually O_{90}, determined by dry sieving sand or glass beads of known size through the fabric. A value of $O_{90} = 0.2$ mm would mean that 90% of particles with a diameter of 0.2 mm are retained on the fabric after a specified period of shaking. Lawson gives as a general rule:

$$O_{90} > C\ D_n \qquad (6)$$

where C is a constant which may vary depending on n (the percentage passing) and the soil type involved. Specifically, the following relationship is finding increasing acceptance:

$$O_{90} > D_{15} \qquad (7)$$

As a general retention criterion, Lawson (1986) suggests:

$$O_{90} < C\ D_n \qquad (8)$$

The following may serve as a reasonable rule:

$$O_{90} < D_{85} \qquad (9)$$

This criterion may be further enhanced by incorporating factors related to the uniformity and relative density of the soil to be protected (Giroud, 1982) or by introducing additional criteria for other percentages, n.

Where wall backfill is not subject to stringent selection criteria, filter textiles may also be subject to clogging (intrusion of fines into the fabric structure) and blinding or blocking (accumulation of fines at the soil-fabric boundary).

Laboratory permeater tests on specific soil-geotextile systems, such as developed by the U.S. Corps of Engineers, allow measurement of the gradient increase near the clogging fabric. This value, divided by the normal gradient in the soil (after flow has stabilised), is termed the gradient ratio. The clogging criterion proposes that the gradient ratio GR should be less than 3 in such a filtration test in order to ensure satisfactory performance in the field:

$$G < 3 \qquad (10)$$

The gradient ratio test appears most useful for evaluating the performaces of woven monofilament fabrics in combination with granular soils. For other materials long term flow tests are advised, as recommended by Halse et al (1987).

The permeability and retention criteria may be complemented by stating minimum flow requirements normal to the fabric and within the plane of the fabric.

3.2 Mechanical Criteria

A geotextile placed across gaps between structural elements acts as a tensioned membrane, resisting the earth pressure of the backfill.

Two tests are often used to given an indication of the bridging capacity of a fabric. In the Mullen Burst strength test (ASTM D3786), a fabric sample is clamped against a rubber membrane over a circular opening of 30 mm diameter. The membrane is hydraulically extended until failure of the geotextile occurs. With exception of the lightest non-wovens and some knitted fabrics, burst strength of commonly used fabrics exceed 1300 kPa. This means that unless the fabric has been subject to degradation, there is certainly enough strength available to bridge across a 30 mm joint in a retaining wall. For gaps up to 50 mm width, the measurements in a CBR plunger test (SAA Draft Standard) may be more appropriate. Extrapolation to greater widths may need special testing.

3.3 Durability

In applications such as behind retaining walls, fabrics are intended to serve for the expected life of the particular structure. The potential to resist long term influences by a large number of damaging stress conditions and deleterious environmental factors is termed durability. Durability is usually expressed in terms of reduction of initial fabric properties, such as strength, elongation at break, permeability and transmissivity. This section reviews damaging environmental factors, published test results and performance data.

3.3.1 Environmental Factors

UV-stability is important because fabrics are exposed to direct sunlight during constructions and by light reaching the fabrics through the joints in the wall face. Just how much light can reach the fabric inside the structures is a matter of speculation. Degradation due to UV-radiation is potentially the most severe durability problem because it affects all polymers, albeit to a different degree.

Other factors that should be considered include:

- Chemical Reaction - particularly adjacent to concrete panels where alkaline moisture conditions may prevail.

- Water - either strength reductions due to hydrolysis with continuous immersion or the effect of wetting and drying on filtration and drainage characteristics.

- Thermal Stability - loss of strength or changes in deformation properties due to changes in temperature have been reported.

- Biological Stability - deleterious effects due to micro-organisms are unlikely to be serious, though fresh or sea water may promote their growth which could affect the filtration capacity.

- Abrasion Resistance - is really only likely to be of importance for a short time during construction.

3.3.2 Laboratory Tests & Field Performance

Durability tests in controlled (laboratory) conditions allow comparison between various fibre materials and fabric structures. The accelerated aging (or weathering) tests aim at predicting long term fabric properties; however, it has proved difficult to relate laboratory performance to changes occurring in the field, where there is going to be multitude of variables. For example, when trying to relate times of UV-radiation in the laboratory to equivalent exposure in the field, many additional factors should ideally be taken into account: geographic location, radiation angle, temperature, humidity, rainfall, wind, air pollution etc.

Test results from different sources are not always in agreement, often due to different procedures employed. There is little information available regarding durability of these materials. Where fabric samples have been recovered from the field, it is often uncertain whether properties measured show the effect of aging only, damage during sampling or treatment during construction. Therefore the discussion soon becomes restricted to the most prominent synthetics, namely Polyesters (PES), Polypropylene (PE) and Polyamides or Nylons (PA).

3.3.2.1 Laboratory Irradiation & Outdoor Exposure

A study by Sotton and Leclercq (1982) found that exposure to light degraded the surface fibres of a fabric by the combined effect of photons, oxygen, humidity and temperature, leading to fibre rupture and rupture of bonded joints (points of needle punching or welding). This means: the thicker the fabric, the less the overall loss in strength due to UV-radiation. These authors also quote information which indicates that the "half-life" (time taken to lose 50% of a characteristic - e.g. resistance to rupture) of geotextiles may vary from 300 to 1500 hours for 18-75 kLy energy irradiations, equivalent to 3 to 12 months exposure to weather in continental Europe. One kLy (kilo-Langley) is 1 kcal/cm² irradiated energy. Australia has a rating from about 100 kLy in Tasmania to 200 kLy in central and northern regions.

Raumann (1982) conducted a comprehensive program of outdoor exposure tests in the U.S.A. As far as strength and elongation retained after exposure is concerned, best performance over one year was obtained from woven monofil PP fabrics and needled (non-woven) PES geotextiles. These retained at least 50% of the strength and 50% elongation. Woven PES fabrics were not used in these tests. Intermediate performers included PP non-wovens and woven slit film fabrics; some of these fabrics deteriorated completely within the 8 to 24 week test period. Raumann's results clearly show that type of polymer and fabric structure strongly affect a geotextile's longer term performance.

Risseeuw (1984) compared woven fabrics consisting of aramide, PES, PA and PP. Best results, after free exposure to the weather in the Eurpopean lowlands, was shown by PES wovens: 80% residual strength after 40 weeks exposure; strength was reduced by at least twice as much for the other woven fabrics.

Schneider (1985) quotes results from exposure tests carried out in Queensland (Rocklea and Claredale) on thick PP wovens: some 40% of the original strength was retained after 48 weeks of weathering. These fabrics were UV-stabilised, a treatment which has been shown to be very effective, at least initially.

3.3.2.2 Alkaline Media

Schneider (1985) presented data which indicates that PES fabrics show significant deterioration in a high concentration (15%) lime solution: a reduction to 25% of the initial strength within 12 months. PP fabrics subjected to similar treatment retained 90% original strength. Schneider claims that fabrics placed against concrete may be subjected to pH-values around 12.

EMPA, the Swiss materials testing organisation, assessed alkali-resistance by using lower concentrations and shorter times of immersion. According to Report No. 11 11660 (1984), Bidim 24 (PES) was submerged for 15 days in a 0.1m Na_2CO_3 (pH 11.6) at 50° Celsius and also in a $Ca(OH)_2$ solution (10g/l, giving a pH of 12.5) at 25°. No statistically significant reduction in tensile strength was observed.

3.3.2.3 Seawater

In one of the earliest investigations of the effect of seawater, Haliburton et al (1978) immersed several fabrics in artificial seawater for a six week period and found that some materials lost as much as 30% of their original strength, while other fabrics of similar construction, and with the same type of fibre, experienced no strength loss at all. Relatively inconsistent results like these do not seem to be substantiated by the newer tests in real seawater. More recent results, such as presented by Sotton and Leclercq (1982) reported less than 10% loss in strength after immersion for up to two years.

4 CASE STUDY: LOSS OF BACKFILL FROM A REINFORCED EARTH WALL

Loss of sand backfill from the Reinforced Earth (RE) walls at the Bondi Junction Bypass in eastern Sydney was observed in 1984, some seven years after construction. This wall was designed at a time when it was not common practice to use geotextiles for prevention of this type of loss. Instead a polyurethane foam was used which evidence now suggests may have degraded with time. A systematic investigation was carried out by

Reinforced Earth Pty. Ltd. and remedial measures were developed. The problem was evident from sand accumulated at the base of the wall. At no stage was there any danger of partial collapse of the wall or damage to the pavement supported by the retaining wall.

4.1 Typical Design and Construction Details

The RE walls at Bondi Junction range in height from 1.9 to 8.5 m. The four walls support a 6 lane bypass road and the face panels are 180 mm thick unreinforced concrete. The design life for the structure is 100 years. Cast in-situ reinforced concrete parapets integral with the pavement were provided along the entire length of the walls. Surface drainage is collected via gully pits at approximate 50 m spacing. The water drains down downpipes passing vertically through the RE block and then horizontally out under the toe.
The vertical joint filler between the panels was a polyurethane open cell foam of 50 x 50 mm section. As was the standard erection technique, the foam was pushed into the rear of the vertical joint prior to placing the select backfill. The horizontal joint filler was a resinbonded corkboard, 100 mm wide and 20 mm thick. The cork was placed on top of the concrete facing panels prior to the next row of panels being placed.

4.2 Select Backfill

A significant proportion of the backfill consists of well graded sand and gravel with some crushed sandstone. Electrochemical testing indicated: ph values between 5 and 6, chloride contents ranging from 18 to 30 ppm and resistivity varying between 6000 and 12000 ohm.cm.

4.3 Observed Loss of Backfill

Generally the RE wall is in very good condition. There is no visible horizontal movement of the panels or signs of significant settlement. The vertical joint separation ranges from approximately 5 to 20 mm with an average of 15 mm. Near the toe the horizontal joint separation varies from about 0 to 20 mm, with an average 3 mm; close to the top of the wall, the gaps vary from 0 to 20 mm, average of 7 mm.

It was observed that during heavy rainfall large flows of water emanate from various points in the wall and flow down the face of the panels, often carrying sand particles. Wind action was also observed to carry sand away from the joints.

Records by the owner, the Department of Main Roads of N.S.W., indicated that there had been problems with the road drainage downpipes that pass through the total height of the backfill: breaks had occurred, allowing access of water into the backfill.

4.3.1 External Measurements

Displaced fill deposited in front of the wall was measured at weekly intervals at 39 separate control points. The displaced sand collected at any particular point varied from 0 to 3 kg per week with an average of 0.1 kg per week. There appeared to be some correlation between rainfall and measured material loss. Assuming the average recorded loss will continue for 100 years, the potential total loss could reach 4% of the constructed RE block volume.

Using a 12 mm diameter spring loaded steel bar, systematic "penetration" tests were carried out in order to evaluate the horizontal extent of the cavities formed behind the panels. It was found that the voids are not continuous and penetrations to a depth of 0 to 550 mm, with an average of about 80 mm were noted.

4.3.2. Visual Inspection of Cavities Using Fibre Optics

An Olympus Fibroscope with a high powered light source was used to observe the shape of the voids behind the panels. Although it was not practical to measure the actual size of the cavities, it could be confirmed that they were not continuous, neither vertically or horizontally. In some of the voids ants, bees and cockroaches were observed to be in habitation.

5.4 Possible Causes of Backfill Loss

It was observed that the backfill loss has been through the vertical joints. At many locations, the foam installed during construction was no longer effective in sealing the joints. It had either been degraded; pushed out under hydrostatic pressure, eaten by insects or had not been installed properly in the first place.

The primary mechanism of backfill loss is transport by water flow. As the entire upper surface of the walls is sealed, the most likely source of the water is a leaking drainage system or open joints in the concrete parapet at the top.

Wind action and vibrations due to traffic are thought to be contributing factors to the cause of backfill loss.

4.5 Remedial Measures

The following options for repair or replacement of the joint sealants were considered:
a. Pushing polyurethane open cell foam into the vertical joints.
b. Filling the vertical joints with gun-grade waterproof sealant.
c. Filling the vertical joints with bitumen impregnated polyurethan foam.
d. Filling of the short horizontal joints where backfill is collecting, with "Sista" polyurethane foam.

Option D was chosen. The "Sista" foam, when it comes into contact with air, expands to 60 times its original volume and thus provides a very effective barrier against further backfill loss. It also has good adhesion to concrete surfaces.

5 PROPOSED SELECTION OF FABRICS FOR ELEMENTAL WALLS

If the conditions are not favourable for the development of a natural filter, then a durable synthetic filter could be provided. Based on the preceding discussions and the case study, it is suggested that the selection of fabric for the prevention of backfill loss should proceed along the following steps:

Step (1): Given the grain size distribution of the backfill material, determine the range of suitable fabric pore sizes, based on the established filter criteria.

Step (2): Determine the minimum strength of fabric required to withstand expected earth pressures without significant creep, e.g., by relating the estimated earth pressure to burst strength.

Step (3): Decide whether in-plane drainage is a desirable function. If so, estimate the required flow capacity and minimum transmissivity required from the fabric.

Step (4): Maximize durability by selecting the appropriate polymer material and fabric structure. In order to do that, it is necessary to establish the relative importance of the most deleterious factors affecting fabrics behind wall face panels: UV-stability and resistance against the alkalinity adjacent to concrete panels. Presently available information seems to indicate that for the same fabric structure, PES appears to have better UV-resistance, but is susceptiable to moisture, while PP seems to perform better in an alkaline environment.

Step (5): Based on the above steps, choose a fabric and attempt to estimate its longevity. To do this in a rational way, it should be determined just how much light reaches the fabric through the gap, and what long term pH will be established. In the absence of real measurements, any estimate of life expectancy can only be a guess.

With respect to UV-stability, it could be assumed that a fabric exposed to 100% of 100 kLy radiated energy loses 50% of its original strength in one year, for PES fibres, and in six months for stabilized PP fibres. One could then further guess that only say, 5% or 10% of the outside light reaches the fabric in the case of a Reinforced Earth type wall and that the relationship between age and retained strength is linear. The life expectancy could then simply be related to the strength reserve of the fabric after installation. (Note: most recently Schneider and Groh (1987) produced results which seem to indicate that the rate of degradation in UV-light may diminish with time, producing a straight line on a semi-log graph).

Evaluating longevity for an alkaline environment is even more controversial, because estimates of relevant pH-values range from 9 to 12.5 and higher and laboratory test results show considerable variations. As a rough guess, it appears appropriate to assume a strength loss of 5% at pH 9, and 20% at pH 12 over a one year period. To obtain an estimate of real field performance it would also seem reasonable to consider that the alkilinity of the moisture in the fabric and soil adjacent to concrete reduces with time due to seepage. However no information about this effect is readily available.

The above considerations indicate, that for so-called permanent structures, those with a life expectancy of 70 to 100 years, the synthetic filters may present a weak point, possibly requiring periodic remedial work. In contrast to road pavements and revetments, the general expectancy for retaining wall structures is that little or no maintenance should be required. This may be true for traditional retaining walls (e.g., gravity walls) but is unlikely to hold for elemental walls, particularly crib and gabion construction and possibly reinforced earth.

6 CONCLUSIONS

As the elemental wall construction methods are increasingly gaining acceptance, the problems of loss of backfill through joints and other structural openings is becoming more important.

Traditional granular filter materials which may prevent backfill loss through seepage and other factors may be replaced economically by geotextiles. Adequate filtration and strength criteria exist for the selection of a proper type of fabric. A problem exists in respect to predicting the durability of fabrics. Synthetic materials can degrade, as illustrated by the problems encountered with a Reinforced Earth wall, where the synthetic foam sealing the joints was not able to prevent small backfill losses due to unexpected seepage flows and other factors. In the case described, the cavities formed were filled and joints resealed with expanding polyurethane foam.

With the present state of knowledge, it cannot be guaranteed that synthetic filter materials can prevent backfill losses for the design life (>70 years) of "permanent" retaining structures, particuularly where UV-radiation can penetrate the joints and where unfavourable alkaline conditions exists. Remedial measures are, however, not only possible, but also relatively cheap.

7 REFERENCES

EMPA (Eidgenossische Materialprufungs- und Versuchsanstalt) (1984). Untersuchungsbericht No. 11'11660, Nov. 1984.

Giroud, J.P. (1982). Filter Criteria for Geotextiles. Proc. Second International Conference on Geotextiles, Las Vegas, Vol.1, pp. 103-108.

Haliburton, T.A., Anglin, C.C., and Lawmaster, J.D., (1978). Testing of geotechnical fabrics for use as reinforcement. Geotechnical Testing Journal, ASTM, Vol. 1, No. 4, pp. 203-212.

Halse, Y., Koerner, R.M., and Lord, A.E., Jr. (1987). Filtration properties of geotextiles under long term testing. Proc. ASCE/PennDOT Tech. Seminar, Hershey, PA, April 14/15.

Hoare, D.J. (1982). Synthetic Fabrics as Soil Filters - A Review. Journal Geotechnical Engineering Div., ASCE, Vol. 108, GT10, pp. 1230-1245.

Lambe, T.W., and Whitman, R.V., (1969. Soil Mechanics. John Wiley and Sons, Inc.

Lawson, C.R. (1982). Filter Criteria for Geotextiles: Relevance and Use. J.of the Geotechnical Div., ASCE, Vol. 108, No. GT10 (Oct.), pp. 1300-1317.

Lawson, C.R. (1986). Geotextile Filter Criteria for Tropical Residual Soils. Proc. Third Int. Conf. on Geotextiles, Vienna, Vol. 2, pp 557-562.

Raumann, G., Outdoor exposure tests of geotextiles. Proc. Second Int. Conf. on Geotextiles, Las Vegas, August, 1982, Vol. 2, pp. 541-546.

Risseeuw, P. (1984). Long term behaviour of heavy -duty reinforcing mats/structural elements in earthworks. Proc. Geotextile Technology '84, London, April 1984, A Construction Industry International Conference.

Schneider, H, and Groh, M. (1987). An analysis of the durability problems of geotextiles. Proc. Geosynthetic '87 Conference, New Orleans, U.S.A., pp. 434-441.

Schneider, H. (1985). Durability of geotextiles. A report produced by Chemie Linz AG.

Sotton, M., and Leclercq, B. (1982). Geotextiles and aging tests. Proc. Second Int. Conf. on Geotextiles, Las Vegas, August, 1982, Vol. 2, pp. 559-564