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GEOTEXTILE REINFORCED SOIL WALLS IN A TIDAL ENVIRONMENT

OUVRAGE DE SOUTENEMENT EN TERRE RENFORCE PAR UN GEOTEXTILE DANS UNE ZONE A MAREES

GEOTEXTILVERSTÄRKTE STÜTZKONSTRUKTIONEN UNTER DEM EINFLUSS DER GEZEITEN

The currently accepted design methods for geotextile reinforced soil walls are closely based on those developed for walls using metallic soil reinforcement. By applying these methods to geotextiles, which have a lower tensile stiffness, the interaction between strain and tensile force in the reinforcement is not fully taken into account. To examine this aspect three geotextile reinforced soil walls were instrumented, two of which were in a tidal environment. It was observed that there was no decrease in lateral pressure at high tide. Although this might at first appear to contradict the principle of effective stress, a simple hypothesis explaining this behaviour is presented. As this hypothesis could have serious implications for the adherence safety factor of geotextile reinforced soil walls in a tidal environment it is suggested that these walls be designed with caution.

Die Entwurfsmethoden, die heutzutage fuer geotextile Stuetzwaende verwendet werden, sind denen aehnlich die man fuer Waende aus bewertem Boden verwendt die mit Metallstreifen gestaerkt sind. Wenn man diese Methoden an Geotextilien anwendet die eine geringere Dehnbarkeit haben, wird die Zusammenarbeit zwischen der Zugbeanspruchung und der Dehnungskraft nicht voellig in Betracht gezogen. Um diesen Aspekt zu untersuchen, wurden drei Stuetzwaende aus geotextiler bewerter Erde mit Instrumenten versehen; zwei von diesen Waenden waren in einer Umgebung wo sich Gezeiten befanden. Es wurde beobachtet dass bei dem hoechsten Wasserpegel sich keinen abbau des Seitwaertsdruck ergab. Obwohl es zuerst erscheint dass dies das Prinzip des effectiven Stresses wiederspricht, wird hier eine enifache Hypothese dieses Phaenomen dargestellt. Da diese Hypethese bedeutsam sien koennte fuer den festhaltungs Sicherheitsfaktor von Stuetzwaenden aus geotextiler bewehrter Erde, wird hier vorgeschlagen dass diese Waende mit Vorsicht entwarfen werden.

INTRODUCTION

When the design methods for reinforced soil retaining walls first became established, only metal strip reinforcement was thought to be suitable for this application. The subsequent development of geotextiles with a high tensile stiffness has provided alternative forms of reinforcement which are particulary attractive for sites where corrosion problems might be anticipated.

Although the tensile stiffnesses of these special geotextiles are high in comparison with other geotextiles they are not compatible with that of metallic strip reinforcement as shown in figure 1. This figure compares the tensile stiffness of a high strength soil reinforcement geotextile strip (Paraweb 5t) with steel strip soil reinforcement, both at their typical spacing in a reinforced soil wall. A standard grade woven geotextile (Lotrak 16/15) and a standard grade nonwoven geotextile (Terram 1000) are also shown on this figure.

Despite the difference in tensile stiffness between geotextile and metal strips used for soil reinforcement, basically the same design method is used for both materials. Often the only difference in design is the inclusion of checks and limits on the theoretical elongation of the reinforcement when geotextiles are used. However, as there must be interaction between the load and the strain in the reinforcement it would seem logical to expect a different strain distribution in the geotextile strips which should lead to different values of tensile force.

In practice, the design methods for reinforced soil walls appear to be cautious and in some national

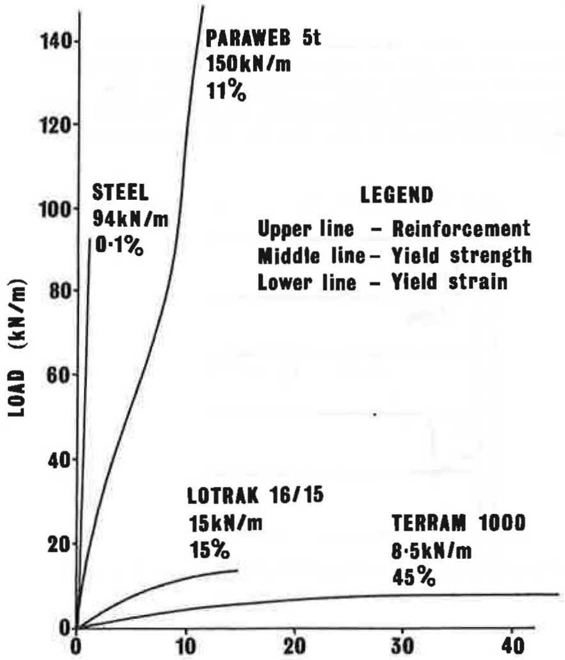

Figure 1. Tensile stiffness of Paraweb in perspective.

standards (1) do not take into account the beneficial effect of the precast flexible facing on both the lateral pressure distribution and the limited extent of the potential failure zone. This, combined with cautious elongation calculations, has tended to lead to unrecognised high factors of safety in geotextile reinforced soil walls. Under these conditions the behaviour of the geotextile soil reinforcement appears to be very similar to that of steel reinforcement strips.

The main difference detected from a programme of instrumenting these structures is that the peak lateral loads at low tide remain locked into the geotextile soil reinforcement at high tide. This behaviour has serious implications for the adherence safety factor at high tide if the other factors leading to an underestimate of the safety factor are not present or the design method has been modified to take them fully into account. This paper therefore concentrates on the adherence safety factor at high tide for a geotextile reinforced soil wall in a tidal environment.

ADHERENCE DESIGN

The adherence design of a reinforced soil wall involves comparing the lateral earth pressure acting on the face of the wall to the frictional bond between the reinforcement strips and the backfilled soil. The frictional bond anchoring the wall face to the fill is assumed to develop only on the reinforcement length beyond the potential failure surface. In the UK (2), this failure surface is assumed to be a simple inclined plane which in the case of walls with either a uniform surcharge or no surcharge together with no point, line, strip or horizontal loads, forms a classical Coulomb failure wedge (figure 2). In France the failure surface is assumed to be a logarithmic spiral (3) which for calculations is simplified to a bi-linear surface (figure 3).

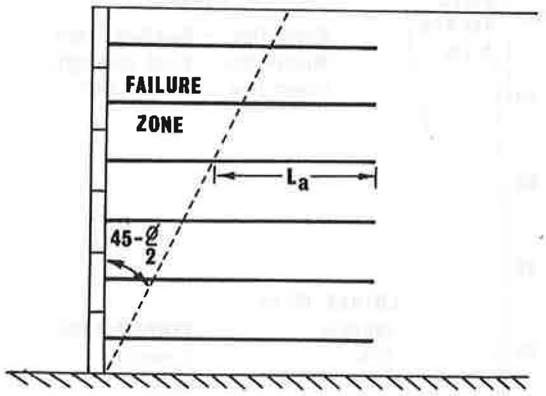

Figure 2. British failure wedge.

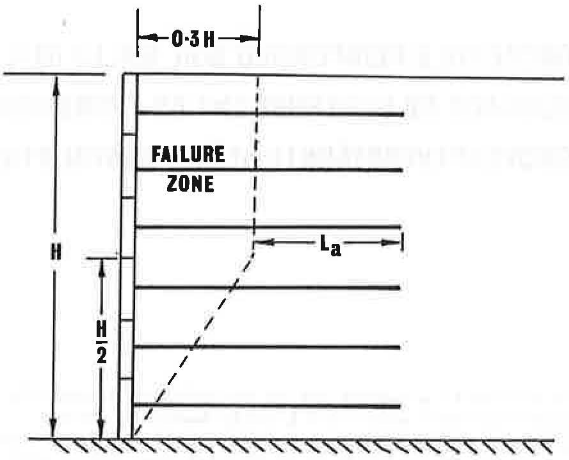

Figure 3. French failure zone.

The lateral earth pressure tending to pull-out the reinforcement strips is taken as the total lateral active earth pressure modified according to the appropriate national design code. In the UK this will include an additional force due to the overturning moment from the fill behind the reinforced zone (2), whereas in France the earth pressure coefficient is assumed to vary linearly between the at-rest earth pressure coefficient at the top of the wall to the active earth pressure coefficient at a depth of 6m. These two different methods of incorporating an additional lateral pressure help to compensate for the stresses induced by compaction, which are usually ignored. If for illustrative purposes these comparatively small additional lateral loads are discounted, then the total lateral force, P, is given by:-

$$P = K_a \gamma H^2 / 2$$

where H is the height of the wall, and
γ is the bulk unit weight of the reinforced soil.

The frictional force on a single reinforcing strip, F, is given by:-

$$F = 2 L_a \gamma h b \mu$$

where L_a is the active length of reinforcement,
b is the width of the reinforcement.
μ is the coefficient of surface friction.

Hence the adherence safety factor is equal to $\Sigma F / P$

TIDAL ADHERENCE DESIGN

For a wall in a tidal environment, the low tide conditions are the same as for a reinforced soil wall on dry land and the above equations apply. During high tide part of the reinforced soil mass is submerged and therefore is affected by the Archimedes bouyancy effect or the principle of effective stress. In the simplest case, with the tide level at the top of the wall, the effective frictional bond, F', is reduced to:-

$$F' = 2 L_a \gamma' h b \mu$$

where γ' is the bouyant unit weight of the reinforced soil mass

In theory the effective lateral pressure, P', is reduced to:-

$$P' = K_a \gamma' H^2/2$$

As the term γ' appears in both the expression for the lateral pressure and the expression for the frictional bond, the adherence safety factor would at first sight appear to be unaffected by the presence of a tidal water table. However, as shown later, this appears to ignore the relationship between stress and strain in the reinforcement strips.

INSTRUMENTED RETAINING WALLS

Three geotextile reinforced soil retaining walls were monitored as part of a research programme into the behaviour of these structures. Two of these walls were 4m and 8m high and constructed in a tidal environment. The other retaining wall was 2.5m high and constructed on dry land. In each case the soil reinforcement was a high strength geotextile strip manufactured by ICI and known as Paraweb (4). This is a composite polymer strip consisting of cores of aligned high tenacity polyester filaments encased within a polyethylene sheath. The aligned polyester filaments give this geotextile strip a comparitively high tensile stiffness and good creep properties, whereas the polyethylene casing gives it a high resistance to environmental attack. It is claimed that the combination of these properties gives Paraweb a working life in excess of 120 years in most natural soils (5). Although replacing convential metal strip soil reinforcement with this high strength geotextile strip avoids the potential problem of corrosion, its tensile stiffness is somewhat different from steel, as shown in figure 1.

Among the instruments installed to monitor the behaviour of these walls were load cells used at the connection points between the soil reinforcement strips and the facing panels. Each facing panel has either six or eight reinforcing strips attached to it. In the 4m high retaining wall the load cells were installed at the connection points in the four corners of one of the lowest facing panels together with one load cell near the centre of the panel. In the 8m high wall, which was constructed afterwards, it was decided to instrument each connection point for a full height section of the wall, one panel wide.

The readings from the load cells indicate that in the upper part of the wall the lateral pressure is close to that for active earth pressure conditions and near the base of the wall it is significantly below this theoretical load (figure 4). The theoretical load indicated in this figure is simply the active earth pressure without any allowance for overturning moments or compaction. This behaviour was evident both during and after construction (figures 4 and 5 respectively). A tendancy for the connector loads to slowly redistribute across each panel while the total load remained fairly consistent was also observed as indicated in figure 5, particularly for the panel at a depth of 4m. Comparing figures 5 and 7 appears to indicate a slow increase in the lateral pressures with time.

It is thought that the low lateral pressures at the

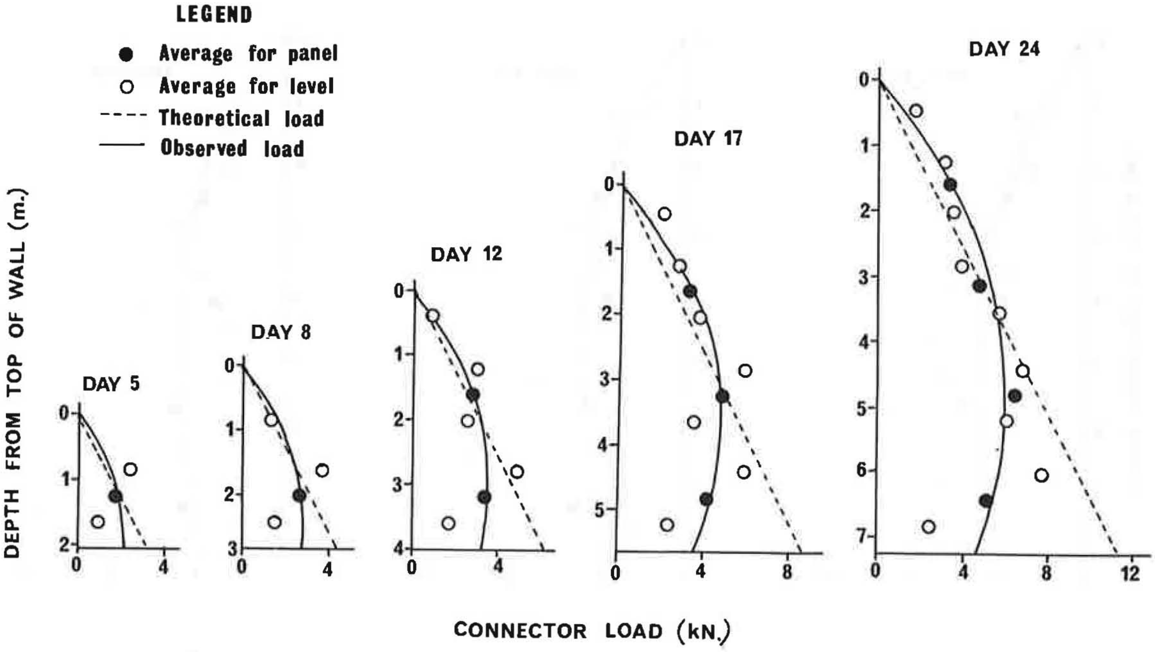

Figure 4. Lateral loads during construction.

base of the walls are probably the result of base restraint together with arching from the base to the top of the walls due to the flexible nature of the interlocking facing unit system and also the sequence of of construction. This behaviour is benificial because it it increases the safety factors above the values predicted by theory. The redistribution of loads between the connection points on a panel could well be the result of small rotations of the facing panels possibly originating from variations in the initial taughtness of the individual reinforcement strips when they were first placed. This again does not appear to be an area for concern as over-stressing any individual reinforcement strip is likely to stretch it more than the other strips, causing a redistribution of load back to the other less strained reinforcement strips.

However one potentially hazardous aspect of the walls' behaviour pattern was observed, namely the failure of the connector loads to reduce at high tide. This was first noted in the 4m high wall and was subsequently confirmed in the 8m high wall as shown in figure 6. When figures 5 and 6 are compared it is evident that there is little or no reduction in lateral pressure at high tide. Standpipe readings indicated that the walls were free-draining and no loads were due to an inbalance in the water level through the wall. The failure of the connector loads and the lateral pressure to reduce at high tide must therefore be due to some other factor.

ADHERENCE SAFETY FACTOR

The fact that peak low tide loads remain locked into the wall during the tidal cycle means that in the worst possible case, with the water table at the top of the wall, the lateral pressure would remain unchanged and equal to P . However, the Archimedes buoyancy effect is still present and will reduce the effective unit weight of the fill to γ' and hence reduces the effective weight holding the reinforcement strips in place. The frictional anchor bond is therefore reduced to F' .The combination of these two factors should therefore reduce the adherence safety factor in the ratio γ'/γ , causing this safety factor to be about half that predicted by the currently accepted design theories.

TIDAL BEHAVIOUR HYPOTHESIS

The observed tendancy for the peak loads occuring at low tide to remain locked into geotextile reinforced soil walls at high tide has not been reported for reinforced soil retaining walls using metal strip reinforcement. This might indicate that either this phenomen is limited to walls with geotextile reinforcement, or else the enviromental difficulties have so far prevented the successful instrumentation of metal strip reinforced soil walls in a tidal environment. If this behaviour pattern is limited to walls with geotextile soil reinforcement, then it is most likely that this arises from the lower tensile stiffness of geotextile soil reinforcement.

For convential earth pressure theories to remain applicable in the case of a geotextile reinforced soil retaining wall, then it must be possible for a compatible reduction in reinforcement strain to accompany any theoretical reduction in lateral pressure at high tide. The relationship between load in the reinforcement and its strain makes it impossible for one to reduce without a corresponding decrease in the

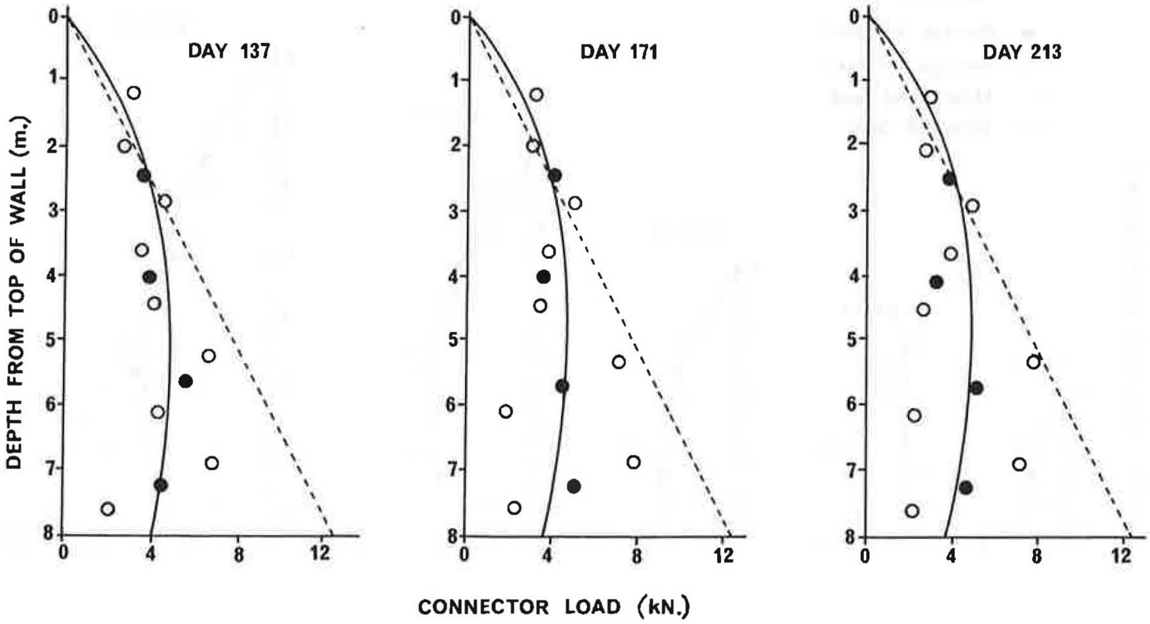

Figure 5. Lateral loads after construction at low tide.

other.

If a reduction of lateral load of the magitude suggested by conventional theory took place this should therefore be associated with a significant contraction in the reinforcement length, resulting in the movement of the facing panels towards the fill material. However if such movement were to take place, then the earth pressure coefficient would increase from the active earth pressure coefficient towards the passive earth pressure coefficient. The passive earth pressure coefficient for the granular fill usually used in reinforced soil walls is so high that it could not be fully induced under these circumstances. The increased lateral pressure due to a change in the earth pressure coefficient can not exceed the initial restraining force in the reinforcement strips, otherwise the facing panels would then start to move outwards. For movement of the facing to cease there must be equilibrium between the lateral earth pressure and reinforcement tension. This places an upper limit on the induced passive pressure at high tide since it can not exceed the active earth pressure previously existing at low tide.

It therefore appears that the lateral earth pressure coefficient rises during high tide as a result of small movements of the facing panel which cause any pressure reduction from the buoyancy effect to be cancelled out as equilibrium of the lateral forces is re-established.

MODEL TESTS

A series of model tests is currently being undertaken at Queen Mary College to determine whether the hypothesis that there is a reduction in the adherence safety factor due to the presence of a tidal water level is correct. The procedure being adopted is to first establish the collapse heights for model geotextile reinforced soil walls in dry conditions for different reinforcement configurations. When this height has been satisfactorily established the model is then reconstructed to a height just below the collapse height, with an adherence safety factor of just over 1.0 in dry conditions. The model tank is then slowly flooded and a record kept of the water level which induces collapse. Although this work is still in progress it is hoped to be able to report the results shortly.

RECOMMENDATIONS

As the results from the instrumentation of two geotextile reinforced soil retaining walls in a tidal environment seem to imply that the adherence safety factor could be reduced by a factor of as much as 2 due to the presence of a high water level it is recommended that these walls be designed with caution. Fortunately the existing design methods seem to ignore other aspects helping to increase the true adherence safety factor. As a consequence of these aspects tending to partially counter-balance the tidal effect it would appear that the current methods of calculating the adherence safety factors are often adequate in practice. However, if the design procedure were amended to take into account the beneficial aspects while ignoring the effect of a high tidal level on the adherence safety factor, this might prove hazardous.

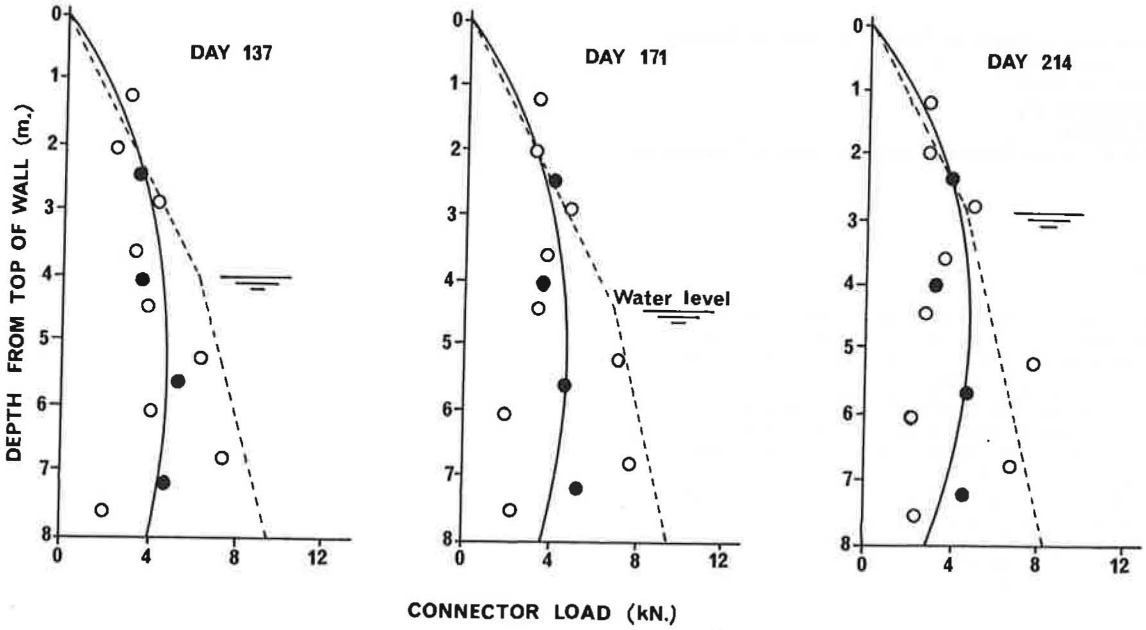

Figure 6. Lateral loads at high tide.

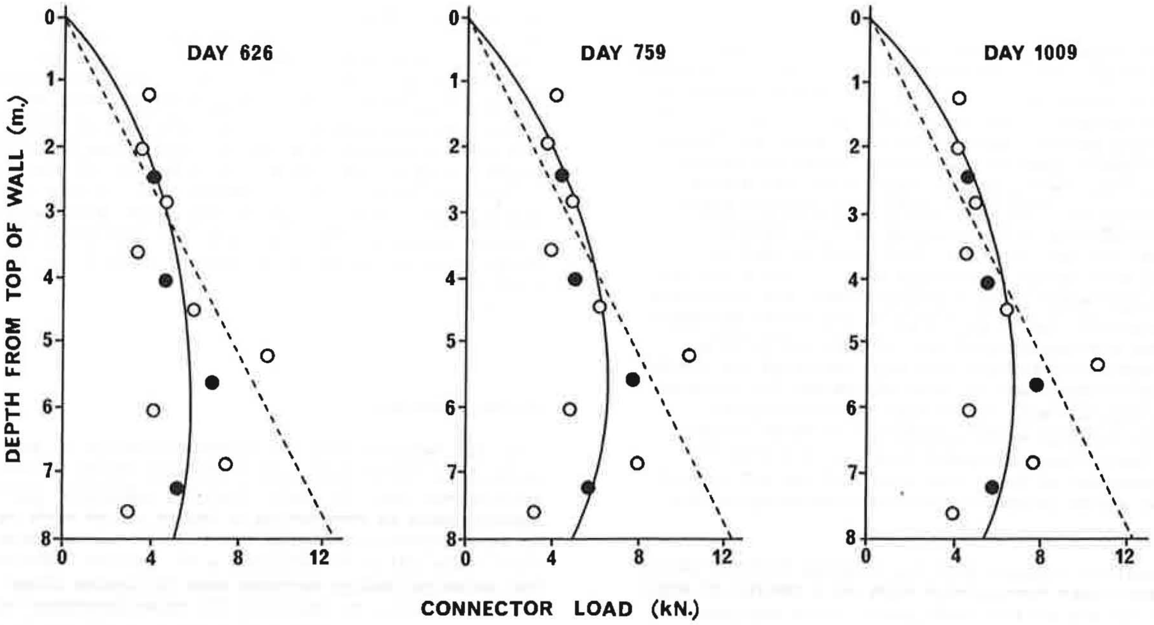

Figure 7. Lateral loads after construction.

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