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Creep behaviour of model fabric reinforced brick faced earth retaining walls

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ABSTRACT: The paper describes a study of the extension of creep of model fabric reinforced brick faced earth retaining walls. This type of wall construction combines the reinforced earth techniques with a conventional brick wall. The study was carried out on walls 300 mm high, 240 mm wide, with good foundation grounds, and reinforced with short sheets of a non-woven fabric "Vilene-312" used as interfacing in dressmaking. The walls were built, backfilled and then surcharged. During the creep tests the surcharge was left for a long period of time and both wall deflection and reinforcement deformation were measured during that period.

Both the deflections and the tensile stresses generated after the first five minutes are significant and they become more significant as the load level increases. However creep does not seems to be a major problem. Results also show evidence that the system became stiffer while the time was passing and therefore creep effect is more important when the load is applied immediately after construction than same time later.

1 - INTRODUCTION

When inextensible reinforcement materials such as steel are used in reinforced earth walls, the creep is not considered an important matter, as creep does not have an important role in steel behaviour. However, the use of polymer materials has grown in recent years, and as they suffer considerable creep, this may now be an important parameter to be considered in the behaviour of reinforced earth structures. It cannot be forgotten that reinforced earth structures have usually a long design life and large movements will be unacceptable as they might be detected by the public who will then receive a psychological feeling of unsafety.

Creep may be defined as being the time-dependent deformation which occurs under a constant sustained load as distinguished from the deformation which occurs immediately when the load is applied. Creep is strong interrelated with relaxation that is the reduction in tensile stress under constant deformation. When a material is subjected to an increment of load the resulting deformation can in general be represented by the curve shown in Fig. 1 (Kabir, 1988, Shrestha and Bell, 1982). It consists of four parts: an instantaneous deformation e_0 which occurs on the application of the stress; a primary creep region, where the deformation continues but at decreasing rate; this is followed by a secondary creep region, representing a nearly constant creep rate; and finally the last stage where the creep occurs at a rapidly increasing rate and ends eventually with failure of the material.

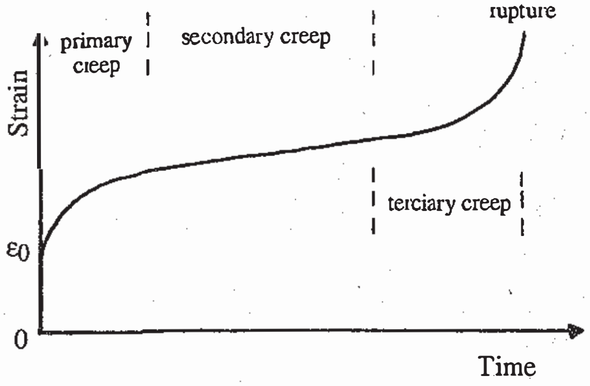

Fig. 1 - Typical strain-time behaviour of a material

There are many factors that may contribute to creep of reinforced retaining walls, the main ones being the creep and relaxation of the reinforcement material, and the creep of the soil.

The objective of this series of tests was to measured the extension of creep of model brick face reinforced earth retaining walls. This type of wall construction combines the reinforced earth techniques with a conventional brick wall: the reinforcement is extended into the backfill from the face of the wall and is anchored into the bed joints of the brickwork. This study was done on walls 300 mm high, 240 mm wide, built on rigid foundations The walls were reinforced with short sheets of a non-woven fabric "Vilene-312" used as interfacing in dressmaking. The reinforcement was 12 cm long, spaced every 4 brick courses.

Thirty minute preliminary creep tests carried out on prototype walls by Walsh (1987) revealed that most of the wall deflection was produced within the first five minutes after the application of the load increment and the deflection rate was already very low. Walsh found that the reinforced walls tended to creep when surcharged, and that this tendency increased as the load level increase. The same behaviour was also observed in the model tests during this investigation, were the surcharge was left for a long period of time.

2 - INFLUENCING FACTORS

Creep of reinforced earth retaining walls is believe to result mainly from a rearrangement of the structure to a different stress situation due to creep of their components. This rearrangement results in a new stress distribution which itself may affect the creep behaviour of the components. This process is therefore interactive. The factors that most affect the creep behaviour of reinforced earth retaining walls are thought to be the creep of the reinforcing material and the creep of the soil

The effect of the load system may appear to be another cause of creep. However, as the load was applied almost instantaneously and it remained constant during the creep tests this cause was not considered important.

2.1 - Reinforcement material

Reinforcement materials made from polymers are expected to demonstrate a behaviour comparable to these when loaded over long periods of time, i.e. being generally time, temperature and stress - level dependent. It is known (Nielson, 1963) that the creep properties of a polymer are very dependent on the temperature and of the stress level. According to Nielson, the effect of the stress level is more pronounced in crystalline polymers of which polyethylene and polypropylene are examples.

Although the strength and deformation properties of the reinforcement materials are largely determined by the specific polymer or polymers they are made of, the manufacturing process has a very pronounced effect on such characteristics, according to Ingold (1982), Koerner et al (1980), Finnigan (1977), McGown et al (1982) and Sims (1977). Especially for non-woven fabrics creep is dominated by structural effects rather than by properties of the material itself (Finnigan, 1977, McGown et al, 1982 and Sims, 1977). Finnigan (1977) even pointed out that as a first approximation the creep effect can be reduced by reducing the complexity of the fabric structure.

Shrestha and Bell (1982), conducted some tests to study the creep behaviour of six different types of geotextiles. Each geotextile was tested under two different load levels, each being applied for twenty hours. Creep was shown to be very dependent on the load for two polypropylene continuous filament geotextiles (non-woven needlepunched and non-woven heat bonded). In contrast to these, the load level didn't seem to be as important for the remaining geotextiles: staple filament polypropylene (non-woven needlepunched), monofilament polypropylene (woven), slit film (woven with needlepunched nap) and a continuous filament polyester (non-woven resin bonded). The lowest creep was measured on the two last geotextiles cited.

Matichard et al (1990), performed several tests on polyester and polypropylene, with the respective structures being non-woven needlepunched, non-woven heat-bounded and woven. The aim of the tests was to study the creep behaviour according to the polymer and structure, the load, temperature and confining pressure. They reached the following conclusions on the creep behaviour:

1. the shape of the strain-time curves are little influenced by the structure and the predominant element is the polymer itself (however, it is important to mention that the results show that for similar load levels the strains measured do vary with the structure, and for both polymers it decreases when the structure varies respectively from non-woven needle punched of continuous fibers to non-woven heat bounded of continuous fibers to woven).
2. it is strongly influenced by the load level on polypropylene geotextiles but very little on polyester ones.
3. it is affected in some geotextiles by the application of a small confining pressure.
4. the creep behaviour is described by equation 1.1 (the creep parameters are presented in their paper for some of the geotextiles tested).

Koerner et al (1980), report tests on six different geotextiles. They describe the creep behaviour of these geotextiles by means of an equation 1.2 given bellow. The values of the equation constants for each geotextile are given in their publication.

Kabir (1988), conducted several creep tests on fou types of geotextile, including a melt bonded non-woven (Terram 1000), a needlepunched non-wover (Bidim U24), a woven (Lotrax 16/15) and composite geotextile (Propex 6067). The tests were performed at several different loads but at constan temperature and relative humidity. Each load wa applied and sustained for at least 1000 hours. The stress-strain-time behaviour was described by equation 1.1, whose constant parameters for the different geotextiles are listed in the paper.

Some work has been done to provide a method for predicting the creep behaviour using existing mathematical methods. Three different approaches have been made:

1. Based on principles of rheology (e. g. Shresthe and Bell, 1982);
2. Based on a rate process theory (e. g. Shresthe and Bell, 1982);
3. Based on a curve-fit technique (Matichard et al (1990) used equation 1.1 developed by Findley, Lay and Onaram (1976) as reported by Kabir; Shrestha and Bell (1982) and Koerner (1980) used equation 1.2, similar to the one used for clays by Singh and Mitchell (1968); Kabir (1988) and Finnigan (1977) used equation 1.3).

$$\varepsilon(t,p) = \varepsilon_{t=0}(p) + \varepsilon_{+}(p)t^{n} \qquad 1.1$$

where e(t,p) = total strain at time t and load p; n = constant, function of the material; $\varepsilon_{t=0} = \mu_{1}p + \mu_{2}p^{2} + \mu_{3}p^{3}$; $\varepsilon_{+} = w_{1}p + w_{2}p^{2} + w_{3}p^{3}$; μ, w = constants.

$$\varepsilon(t,p) = A\, e^{aD}\, (t_1/t)^{m} \qquad 1.2$$

where $\varepsilon(t,p)$ = strain rate at time t and deviator stress D; t_1 = unit of time; m, a, A = constants.

$$\varepsilon = \varepsilon_{t=0} + b_c \log_{10}(10t) \qquad 1.3$$

where ε = total strain at time t; $\varepsilon_{t=0}$ = initial strain; b_c = creep coefficient.

Shrestha and Bell (1982) analysed the creep behaviour either by using a four-element rheological model whose constants were calculated based on the rate process theory and by using the equation 1.2. They concluded that the former method offered a better fit to experimental data (obtained in 20 hours tests) than the latter one.

Kabir in 1988 concluded that equation 1.1 was versatile and proved to be suitable for all four types of geotextile when tested for as long as 1000 hours.

Matichard et al in 1990 reports that equation 1.1 gives good agreement to the total strain observed during the creep tests when lasting for 360 hours.

However, more important than the differences of behaviour obtained by the different methods may be the fact that most of these studies were conducted under laboratory conditions without including the effect of the soil-reinforcement interaction. The frictional effect of the soil both in the direction of the load and by restricting contraction in the transverse direction may well have an important rule in the creep behaviour. McGown et al (1982) subjected to creep testing unconfined and confined in-soil samples of two non-woven geotextiles (a melt bonded Terram 1000 and a needlepunched Bidim U24). Both materials showed a significant reduction in long term strains when they were confined in-soil.

2.2 - Soil

Some studies have been undertaken in order to investigate the creep behaviour of cohesive soils (as those reported by Sing and Mitchell, 1968), but as yet no studies have been reported on the creep of granular soils. It is usually assumed that a cohesionless mass reach the equilibrium almost instantaneously with the application of the load.

Rowe (1962) in his stress-dilatancy theory does mention that a certain time is required for the sand reach the equilibrium under a constant load. He comments that while for low loads a few minutes are necessary to achieve equilibrium, when the load is increased to near the peak strength, many days may be needed.

Jones (1989) reported some creep effect while testing laterally loaded piles in sand. For low loads the deflection was generated almost simultaneously with the application of the load, but as the load increased, more and more time was necessary for the pile to stabilise. She added that in some cases, as the load increased, the pile did not stabilise for quite a considerable time, as the sand appeared to "creep".

3 - TEST PROCEDURE

A total of three similar walls were tested in order to study the creep behaviour of the model brick faced reinforced earth retaining walls. The walls were built in the test tank, backfilled and then surcharged. The surcharge was left for a long period of time (until the deflection stayed constant over a period of about 3 days) and both wall deflection and reinforcement deformation were measured during that period.

In the first test the creep was studied immediately after the backfill was completed, therefore without a surcharge being applied (height of backfill = 0.3 m). In the second test the load was first kept constant at 1.0 m equivalent height of backfilll. When the deflection was found to be constant, the load was increased progressively up to 1.3 m and the deflections measured again until they became constant over a period of 3 days. This procedure was repeated at 1.6 load level. In the last test the creep behaviour was studied at a load level of 1.6 m. The wall deflection was measured by a LVDT situated 2 cm from the top of the wall.

4 - RESULTS

The deflection of the top of the wall as a function of time is presented in Figs. 2 and 3 for the different levels of load and the deformation of the reinforcing layers as a function of time (for the load level of 1.0 m) is plotted in Fig. 4. In the short term most of the movement occurred indeed within the first five minutes after the application of the load increment. Most of the deformation of the reinforcement (and therefore the tensile stresses) are also induced within the first five minutes. Five minutes seems therefore to be a good compromise taking into account the increment of deflection and tensile stresses already generated and the laboratory testing time consuming for the great majority of the test programms.

It can be seen that the shapes of the creep curves obtained are in general as would be expected, convex-up as the creep rate decreases with time. The first part of the curves shows a high rate that slowly decreases with time (primary creep). This is followed by a constant rate phase (secondary creep). In none of the tests performed was the tertiary creep observed and none of the walls showed signals of failure or collapse either.

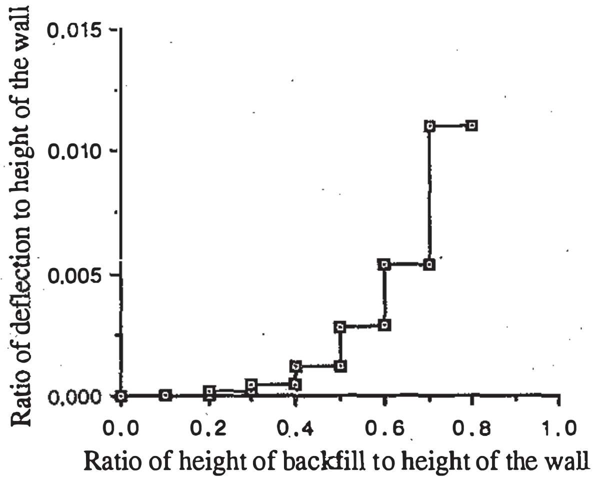

Fig. 2 - Wall deflection vs time (30 min. test)

However, over a long term, both the deflections and the tensile stresses generated after those five minutes are significant and they become more significant as the load level increases. In the thirth test the wall deflection was monitored over a total period of about 3 months. Although the deflection seemed to have stop increasing at the end of the first month it still continued increasing for another month after which no further increments were registered. While in the first testing month the total creep deflection (defined herein as the deflection suffered by the wall after five minutes of the application of the load increment) measured was 1.73 mm, in the second month it was just 0.35 mm. It can be observed that increasing the load level not only increases the deflection but it takes longer for the system to stabilise as well.

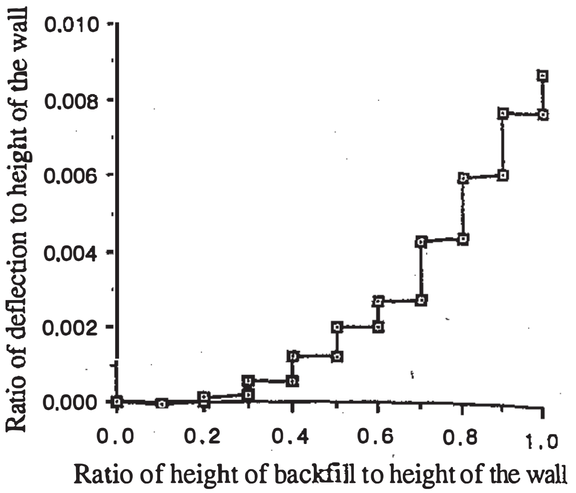

Fig. 3 - Wall deflection vs time

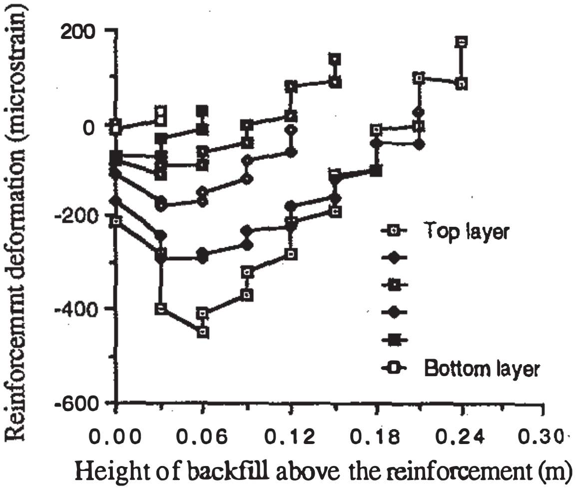

Fig. 4 - Reinforcement deformation vs time

If the creep deflection is plotted against the logarithm of time (Fig. 5) the behaviour appears to be linear in the early stages but later it shows an apparent upturn and it becomes slightly concave-up although this is not a real acceleration as it is due to the logarithmic scale. Later still the curve became convex-up as the creep rate approaches zero. This type of behaviour is also observed on the reinforcement when the creep deformation (defined as the deformation suffered by the reinforcement after the first five minutes of the application of the load increment) is plotted against the logarithm of time.

In Fig. 6 the log of the creep deflection is plotted against the log of time. This was done as an attempt to describe the creep behaviour of the reinforced earth retaining walls by using equation 1.1 which was reported by several researchers, including Kabir (1988) and Matichard et al (1990), to be a good equation to describe the creep of the viscoelastic materials.

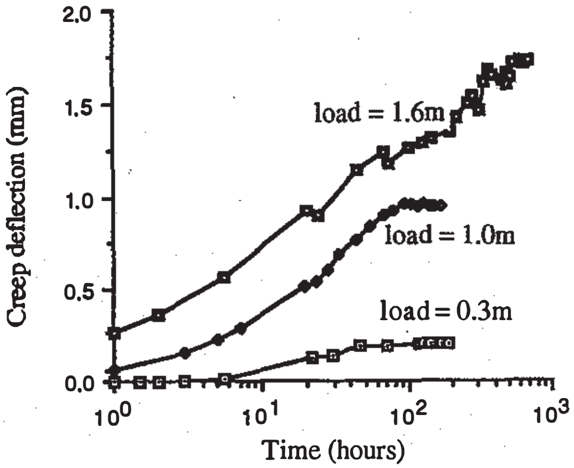

Fig. 5 - Creep deflection vs log time

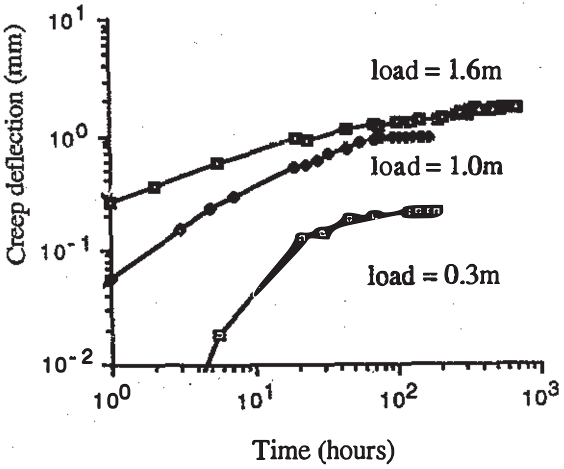

Fig. 6 - Log creep deflection vs log time

Rearranging equation 1.1 and taking logarithms gives, for a particular load level:

$$\log(\varepsilon - \varepsilon_{t=0}) = \log \varepsilon_{+} + n \log(t) \qquad 1.4$$

By plotting the creep deflection ($\varepsilon - \varepsilon_{t=0}$) at a logarithmic scale against the logarithm of time it should be possible to determine n (the slope) and ε_{+} (the intercept value at unit time). n was found to be constant for each material and independent of stresses by Kabir (1988), Findley et al (1976) and Matichard et al (1990).

Fig. 6 shows curves that seems to be approximately represented by two straight line portions and for each a different value of n can be quoted. This figure shows that n varies not only with log time but also with load level. Therefore, the creep behaviour recorded in the present investigation can not be described by Equation 1.1. Equation 1.2 presents the same problem as m (slope of log time vs log strain rate response) is not a constant but a variable. Equation 1.3 does not seem to be suitable neither, as the creep curves in a $\log_{10}$ (10 x time) are similar to those of Fig. 5, hence b_c is shown to be not a constant but a variable dependent of the time. The characterization of the creep behaviour of the reinforcement material by using the described equations does not seem possible neither, for the same reasons.

In Fig. 7 the creep deflection (deflection suffered by the wall after five minutes of the application of the load increment) is plotted against the load (height of backfill), for the different tests performed. For the second test the creep deflection at the 1.3 m and 1.6 m load levels was added. This was considered to be the sum of the creep deflection measured at that load level with the creep deflection measured at lower load levels in the same test (e.g. total creep deflection (l=1.3 m) = creep deflection (l=1.3 m) + creep deflection (l=1.0 m)). In the thirth test it was considered the creep deflection at the end of the first month. This figure shows that the relationship between creep deflection and the load level seems to be represented by a smooth curve and that creep increases with load level. The curve can be described by the following equation:

$$\delta_c = 0.6816\, p + 0.2461\, p^2 \qquad 1.5$$

where δ_c = creep deflection (mm); p = load level (m of backfill).

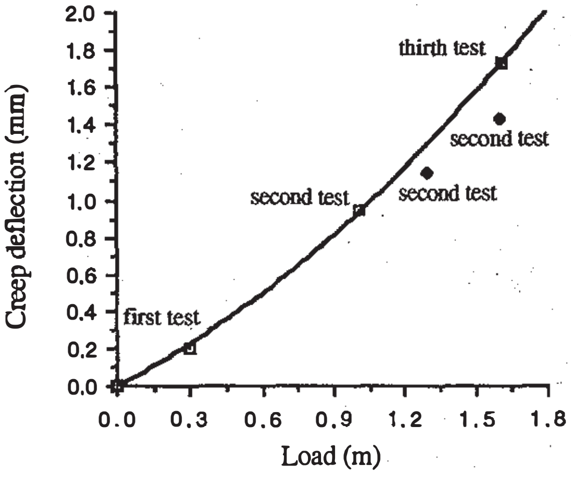

Fig. 7 - Creep deflection vs load level

The points corresponding to load levels of 1.3 m and 1.6 m (of the second test) are slightly below the curve defined by the other tests, probably because the system has became stiffer with time. Further evidence of this stiffness of the system can be observed in Fig. 6 by comparison of the different slopes.

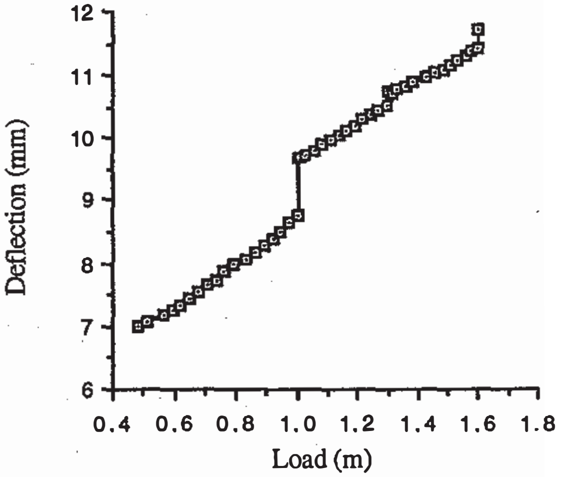

Fig. 8 - Deflections on surcharge (second test)

5 - CONCLUSIONS

The results obtained confirm that in laboratory studies it is reasonable to take the measurements five minutes after the application of the load increment but in a life design, a long term behaviour should be taken into account. However creep does not seems to be a major problem.

The small number of creep tests performed does not allow an accurate prediction of the deflection that the reinforced earth retaining walls would experience due to creep (i. e., after the first five minutes of the application of the load increment). Some scatter was obtained on the wall deflection on the previous series of tests and therefore the same may be expected in these tests. For this reason it would not be prudent to predict the creep deflection of the wall and more tests need to be performed in order to provide an accurate representation of the creep behaviour.

None of the equations suggested to describe the creep behaviour of materials seems to be suitable on the present investigation (both for wall deflections and for the reinforcement). However, the creep deflection expected for this particular wall under a specific load may be predicted approximately by taking into account the relationship between creep deflection and load level described by Equation 1.5.

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