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Editors:
Paulus P. Rahardjo
Adrin Tohari

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IMPORTANCE OF ELONGATION FACTOR IN DETERMINING GEOSYNTHETICS STIFFNESS FOR FINITE ELEMENT CALCULATION

GOUW Tjie-Liong [1]

ABSTRACT: The application of geosynthetics for reinforced earth, also known as mechanically stabilized earth, is gaining popularity in Indonesia. At the same time, many engineers have started using geotechnical finite element software in designing the geosynthetics reinforced earth. Unfortunately, many of them still do not know the importance of elongation factor in determination of the geosynthetics stiffness to be input into the finite element calculation. Some engineers even said that elongation of the geosynthetics need not be considered in selecting the right geosynthetics material, only the breaking strength and the type of geosynthetics need to be considered. Such misconception can lead to bad performance or even failure of the geosynthetics reinforced earth. This paper elaborates the importance of the elongation factor and the correct procedure in determining the stiffness of geosynthetics materials for finite element software input.

Keywords: Elongation, stiffness, geosynthetics, finite element analysis

INTRODUCTION

The application of geosynthetics for reinforcing earth embankment was first introduced in the second half of 1980s. It was successfully applied as reinforcement of road embankment underneath the Soediatmo toll road, the original highway toward Soekarno-Hatta International Airport of Jakarta, which was built on top of swampy lands. Since then, among other applications, it has been widely accepted as one of the alternatives to reinforce man-made slopes and retaining structures. As the computer technology advances, so does the geotechnical engineering software. To the author's knowledge commercial geotechnical finite element application came to Indonesian engineers in the mid of 1990s, and slowly gaining popularity since then. By now, many engineers have been using either Plaxis, Phase-2, Geo-Studio, Geo5 or other similar software.

In line with the widespread application of geosynthetics reinforced earth structures for road embankment, bridge approach, man-made slope, retaining structures, and other similar geotechnical structures, the need to utilize finite element software become more and more important in order to be able to design a performance based geotechnical structures. To make sure the stability and the movement of the geosynthetics reinforced structures fall within their safe and tolerable limit, one of the important inputs to the finite element software is the stiffness of the geosynthetics material in use. Unfortunately, the product specification of the geosynthetics materials, be it geogrids, geotextiles or geomembranes hardly provides such value. The worse thing is that the design engineer often does not know that the stiffness value varies with the allowable elongation of the geosynthetics. In a geotechnical forum, one asked: "In a geotextile catalog, we often presented with the elongation at break. What I do not understand is when we should adopt large elongation and when to take a small elongation". Many engineers answer that the elongation is not important! One even said: "I think elongation of the geotextile materials need not be considered in selecting the material. What important is its breaking strength.". And many of them just simply input its breaking strength (in kN per m run) as the stiffness of the selected geosynthetics material. This is definitely wrong! In light with the above erroneous approach, this paper explains the importance of elongation in the performance of geosynthetics reinforced soils structures and elaborates the right method to derive the stiffness of the geosynthetics material to be input into a geotechnical finite element software.

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[1] Senior Lecturer, Binus University, Jalan Syahdan No. 9, Jakarta 11480, Indonesia, gouw3183@binus.ac.id

GEOSYNTHETICS WORKING PRINCIPLE

Geosynthetics (geotextiles or geogrids), that are used as reinforcement, be it placed as a single sheet at the base of an embankment (Figure 1) or placed in layers to make reinforced earth wall (Figure 2), work by relying on their tensile strength. Under the earth pressures, the geosynthetics shall deform and subject to tension force. Subsequently, it will elongate as shown in Figure 3.

Figure 1. Geosynthetics reinforced embankment

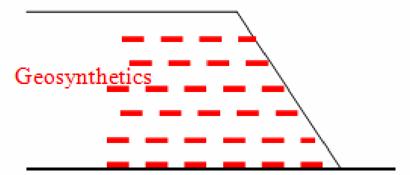


Figure 2. Geosynthetics Reinforced Earth

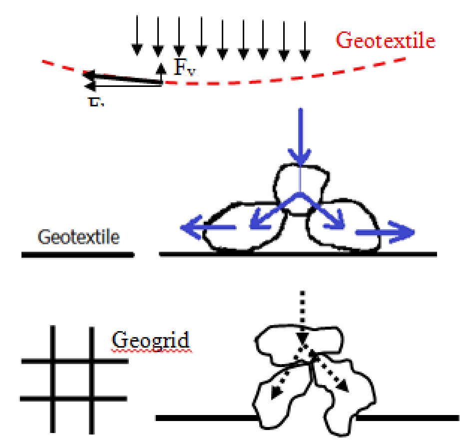
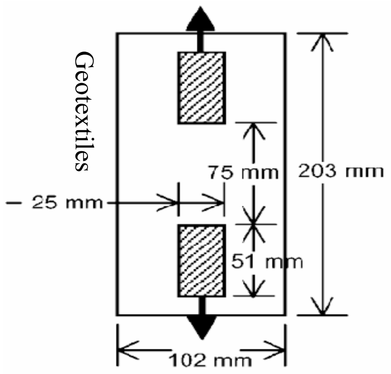


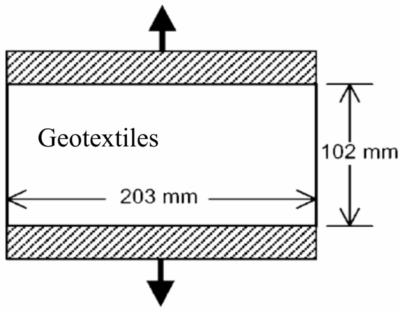
Figure 3. Geosynthetics reinforcement working principle

BREAKING STRENGTH & ITS ELONGATION

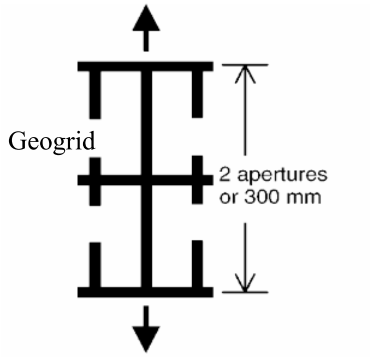
When geosynthetics are used as reinforcement, the most important property is their tensile breaking strength. To determine the tensile breaking strength, a relatively simple tension test is employed as shown in Figure 4. The test is performed by gripping the two ends of the geosynthetics specimen as shown and applying continuously increasing load until breaking (rupture) takes place. The load at rupture and the corresponding elongation are recorded. This tested rupture load is known as breaking or ultimate strength and is normally expressed in terms of a load per unit width (kN/m) rather than an actual stress since stress requires the material thickness, which is generally difficult to describe because it does not remain constant during tensile loading. The ultimate load also known as short term load capacity. The elongation is known as elongation at break and typically expressed as strain (%). A good product typically present the complete curve of test load (often expressed in % of ultimate strength) vs elongation (strain) as depicted in Figure 5.



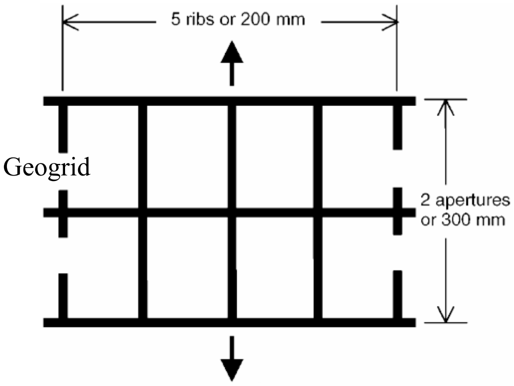
(a) Grab Tensile Test (ASTM D4632)



(b) Wide-width Tension Test (ASTM D 4595)



(c) Single Rib Test (ASTM D6637)



(d) Multi Ribs Test (ASTM D6637)

Figure 4. Geosynthetic Tension Test (after Sarsby, 2007)

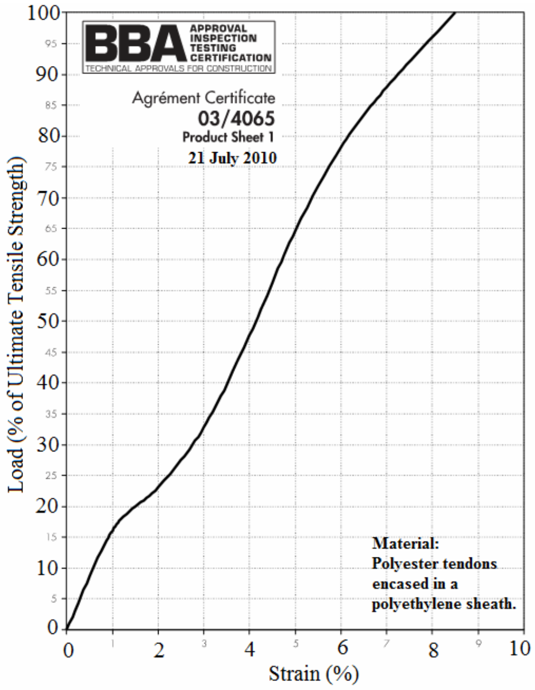


Figure 5. Example of Short Term “Stress”-Strain Curve of Geosynthetics (after Chamberlain & Cooper, 2010)

LONG TERM CREEP RUPTURE STRENGTH

Geosynthetics are typically made of polymeric materials and polymeric materials are elasto-visco-plastic materials which exhibit time dependent (creep) behavior, i.e. when subjected to a constant load, it deforms continuously as shown in Figure 6. Many manufactures and researchers have conducted the creep test on geosynthetics materials (Watts et al, 1998, McGown, 2000, Kaliakin et al, 2000). The result of the creep test is then typically plotted in a set of load vs strain curves with its time effect as schematically presented in Figure 7. This set of curves is known as isochronous curves. Figure 8 is an example of the isochronous curves for the same material of the short term strength curve presented in Figure 5.

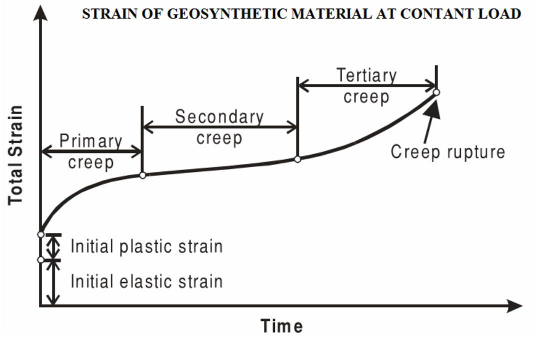


Figure 6. Idealized Creep Curve of geosynthetics at Constant Temperature (after McGown, 2000)

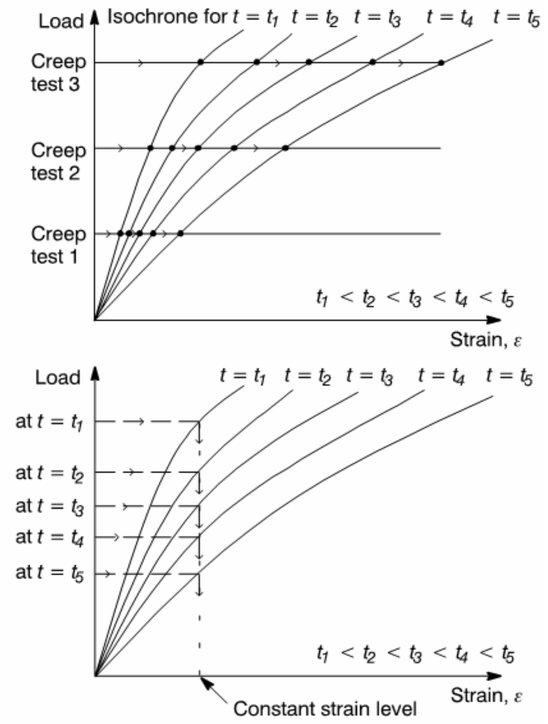


Figure 7. Typical Creep Isochronous Curve of Geosynthetics (after Kaliakin et al, 2000)

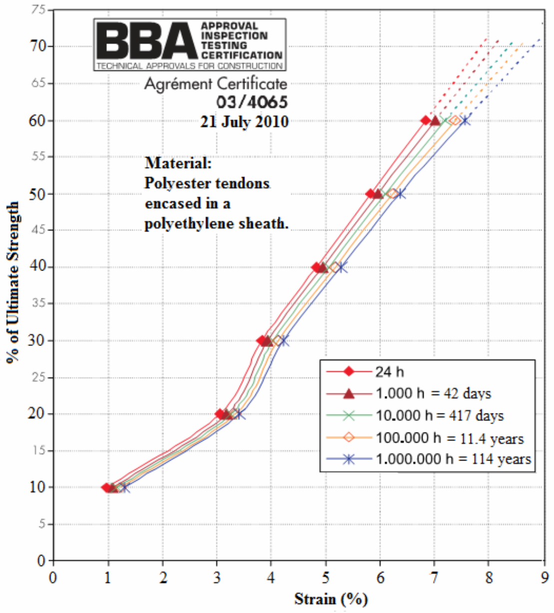


Figure 8. Example of Isochronous Curves (mod. after Chamberlain & Cooper, 2010)

It is clear that the strength of the geosynthetics degraded with time. The degradation of the strength is also often plotted as time vs % of ultimate strength as shown in Figure 9. When strain is not a limiting factor in the design of the geosynthetics reinforced soil, this time creep degradation curve (Figure 9) is used to determine the long term creep strength. If strain is the limiting factor then the long term creep strength is determined from the isochronous curves (Figure 8). Depending on polymer type and the manufacturing process, each geosynthetics have different long term creep performance, creep is more pronounced in polyethylene (PE) and polypropylene (PP) than in polyamide (PA) or polyester/polyethylene terephtalate (PET) as shown in Figure 10. Figure 11 presents the curves of geogrids made of polyethylene terephtalate (PET material).

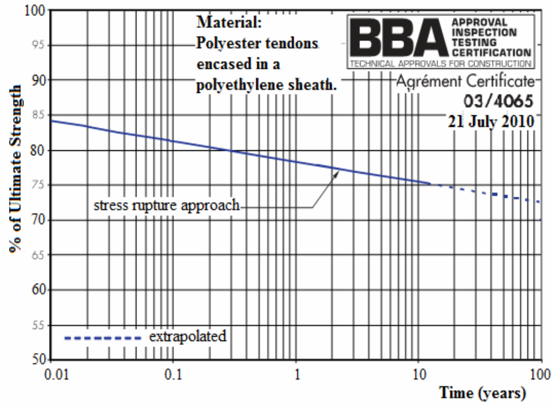
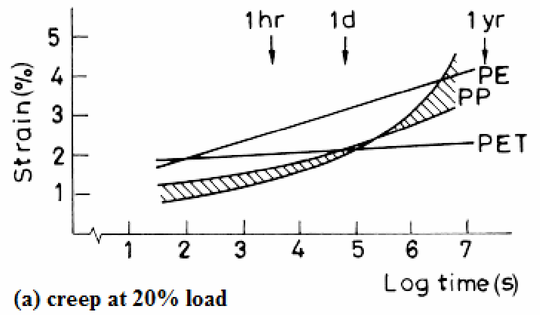
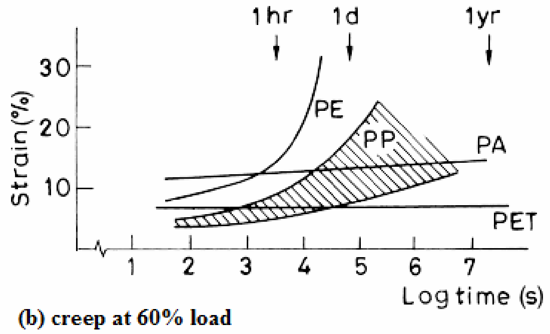


Figure 9. Time Creep Degradation Curve
(mod. after Chamberlain & Cooper, 2010)



(a) creep at 20% load



(b) creep at 60% load

Figure 10. Results of Creep Tests on Various Yarns of Different Polymers
(after den Hoedt, 1986; from Shukla and Yin, 2006)

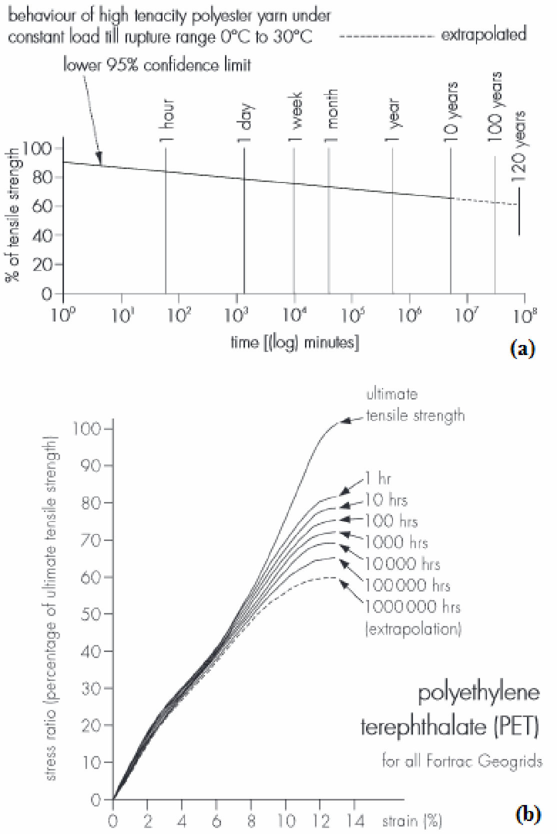


Figure 11. Time Creep Degradation & Isochronous Curve (after Chamberlain & Cooper, 2008)

DESIGN STRENGTH OF GEOSYNTHETICS

The allowable design (tensile) strength, Tall, of geosynthetics is determined through following equation (Koerner, 2005, Sarsby, 2007):

$$T_{all} = \frac{T_{ult}}{RF_{CR}xRF_{ID}xRFI_{CBD}xRF_{JOINT}} \qquad (1)$$

where:

T_{ult} = short term ultimate (breaking strength)
RF_{CR} = reduction factor due to creep
RF_{ID} = reduction factor for installation damage
RF_{CBD}= RF_{CD} x RF_{BD}
RF_{CD} = reduction factor for chemical damage
RF_{BD} = reduction factor for biological damage
RFjoint = reduction factor for joints/seams

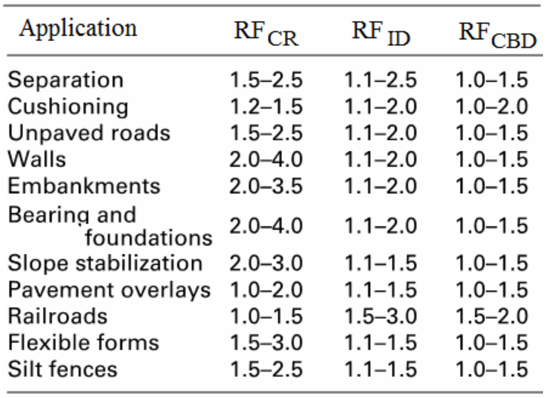
When strain is not an important factor in the design of the geogrids, i.e. for stress rupture design approach, the reduction factor due to creep (RF_{CR}) obtained from one over % of ultimate strength of the time creep degradation curve for the corresponding geosynthetics as typically shown in Figures 9 and 11a. As an example, for a design life of 50 years, Figure 9 gives creep strength of around

73% of ultimate strength, therefore, the RF_{CR}=1/0.73=1.37.

If strain is an important limiting factor where the maximum strain is generally limited to a certain percentage, then the isochronous curves is used to determine the creep reduction factor. For example, if design life of a structure is 50 years, and the limiting strain is 5%, Figure 8 gives creep strength in the order of 37.5%, which is translated into RF_{CR}=1/0.376=2.65.

Table 1 presents the recommended strength reduction factors (Koerner, 2005). The values of RF_{CR} in the table shall be used only when there is no creep reduction or creep isochronous curve available. The low end of the RF_{CR} range refers to applications which have relatively short service lifetimes and/or where creep deformations are not critical to the overall performance of the geosynthetics reinforced structures.

Table 1. Geosynthetics Strength Reduction Factors (after Koerner, 2005)



Application	RF_{CR}	RF_{ID}	RF_{CBD}
Separation	1.5–2.5	1.1–2.5	1.0–1.5
Cushioning	1.2–1.5	1.1–2.0	1.0–2.0
Unpaved roads	1.5–2.5	1.1–2.0	1.0–1.5
Walls	2.0–4.0	1.1–2.0	1.0–1.5
Embankments	2.0–3.5	1.1–2.0	1.0–1.5
Bearing and foundations	2.0–4.0	1.1–2.0	1.0–1.5
Slope stabilization	2.0–3.0	1.1–1.5	1.0–1.5
Pavement overlays	1.0–2.0	1.1–1.5	1.0–1.5
Railroads	1.0–1.5	1.5–3.0	1.5–2.0
Flexible forms	1.5–3.0	1.1–1.5	1.0–1.5
Silt fences	1.5–2.5	1.1–1.5	1.0–1.5

When there is joint in the geosynthetics reinforced soil structures, joint reduction factor, RF_{JOINT}, values can be taken within1.8 to 2.0.

STIFFNESS MODULUS OF GEOSYNTHETICS

In a country where the geosynthetics code of practice still not available, such as Indonesia, many geosynthetics brochures provided by the suppliers only gives the breaking strength and the elongation at break in numbers. To obtain the axial stiffness modulus of the geosynthetics, many engineers either simply input its breaking strength (in kN per m run) as the stiffness of the selected geosynthetics material or divide the breaking strength over the elongation at break. Obviously, those are not appropriate approach. The correct approach is presented below.

From the "stress" strain curve of the geosynthetics, it can be seen that the stiffness modulus of the geosynthetics is actually non linear. However, for practical purposes, a linear stiffness up to its allowable tensile stress is normally adopted, and is calculated as follows:

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{\sigma}{\varepsilon} = \frac{T_{all}}{A} \cdot \frac{1}{\varepsilon} \qquad (2)$$

hence:

$$EA = \frac{T_{all}}{\varepsilon} \qquad (3)$$

The allowable tensile strength of geosynthetics normally stated in load per unit width (kN/m), the EA values obtained is also in the unit of load per unit width (kN/m). So, the axial stiffness is obtained by dividing the allowable tensile strength of the geosynthetics by its corresponding (or allowable) strain. For a certain type of structures where deformation should be limited, the author takes the following limiting strain (note that wherever available the limiting strain given by local code of practice should be taken):

- Basal reinforced embankment: 6%
- Slope stabilization: 4 – 5%
- Retaining wall : 3 – 5%
- Bearing and foundation: 2%

Example of the axial stiffness calculation is given below:

- Given breaking strength of a geocomposite is, T_{ult} = 300 kN/m.
- For slope stabilization, design life 100 years
- Limiting strain = 5%
- RF_{CR} = 1/(37.5%) = 2.67 (from Figure 8)
- RF_{ID} = 1.10
- RF_{CBD} = 1.04
- No joint
- T_{all} = 300 / (2.67x1.10x1.04) ≈ 98.4 kN/m
- EA = 97.40/5% ≈ 2000 kN/m

In finite element analysis, for high slope stabilization application, rather than modeling the geosynthetics as elastic material, it is better to model it as elastoplastic material so that the tension force acting at the geosynthetics layers can be limited up to the allowed short term capacity (taking RF_{CR} = 1) calculated as follows:

$T_{all\text{-}short\ term}$ = 300 / (1x1.10x1.04) = 262 kN/m

CLOSSURES

The above shows that the performance of geosynthetics depends on its elongation or strain. The axial tension stiffness modulus of geosynthetics materials clearly depends on its elongation. Simply dividing the breaking strength with it is corresponding elongation to derive the stiffness is inappropriate. The proper procedure of deriving the geosynthetics axial stiffness must be through determination of the allowable tension capacity and its corresponding strain level as elaborated in the paper.

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