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NUMERICAL MODELLING OF GEOSYNTHETIC REINFORCEMENTS – SIMPLE CONSTITUTIVE MODELS ALLOWING FOR DURABILITY

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Abstract. *Numerical models, particularly using the finite element method, are becoming increasingly popular, for example to assist the design of geosynthetic reinforced soil structures and/or analyse their performance. Geosynthetics are often represented by a stiffness (and sometimes a tensile strength). As durability is key for the design and performance of geosynthetics, representing their response using non-linear constitutive models allowing for durability is essential. Thus, it is important to understand how damage may influence the load-strain response and how such changes can influence design tensile properties. Recent research work on this topic is summarised, highlighting how simple hyperbolic-based constitutive models can be used to represent the tensile response of geosynthetics, for both their as-received and damaged conditions. The model parameters have physical meaning and can be linked to the material tensile properties. The approach adopted allows estimating the model parameters after damage from model parameters of undamaged samples and reduction factors for the damage agent or mechanism considered. This approach has large potential for application in geotechnical design, as estimated constitutive models allowing for durability may be implemented in software, e.g., using finite element method, and lead to more realistic designs.*

1 CONSTITUTIVE MODELS FOR GEOSYNTHETICS

Geosynthetics exhibit mechanical behaviour that is a combination of typical responses of elastic solids, viscous liquids, and plastics, primarily temperature dependent (McGown et al., 2004). Constitutive models depend on polymer type, temperature and load conditions, strain rate, load direction, and stress confinement. The tensile force-strain response of geosynthetics is complex, can be highly non-linear, and is affected by damage and degradation (durability aspects). Often, constitutive models for geosynthetics are phenomenological, as they rely on curve fitting of experimental data to estimate model parameters. Bathurst and Kaliakin (2005) distinguish simple mathematical models, polynomial models, rheological, hyperbolic-based models, models based on the isochrone concept, elastic-viscoplastic, elastoplastic-viscoplastic, and bounding surface models.

Polynomial models and hyperbolic-based models (Equations 1 and 2) have been used to fit the short-term tensile response of geosynthetics. Equation 1 refers to a hyperbolic shape, while Equation 2 combines a hyperbola for low strains and an exponential function for high strains, to capture a stiffening response of some geosynthetics. Herein: tensile load per unit width (*T*), tensile strain (ε), model parameters (*a*, *b*, and *c*), strain at maximum load (ε_{max}).

$$T = \frac{\varepsilon}{a + b\varepsilon} \tag{1}$$

$$T = \frac{\varepsilon}{a + 2b\varepsilon} + \frac{1}{2b} e^{-c(\varepsilon - \varepsilon_{max})^2} \tag{2}$$

2 METHODOLOGY

Recent research work on this topic is summarized, highlighting how simple constitutive models can be used to represent the tensile response of geosynthetics. The approach adopted included: 1) obtaining tensile experimental data for intact and damaged geosynthetics; 2) fitting data with polynomial and hyperbolic-based models; 3) estimating model parameters; 4) investigating links between model parameters and material properties.

The main objective was to implement simple relations to estimate model parameters for damaged samples from tensile properties of reference and damaged materials. The geosynthetics studied included geotextiles, geogrids, and reinforcement geocomposites; the damage induced encompassed: i) mechanical damage; ii) abrasion damage; iii) sequential mechanical and abrasion damage; iv) field installation damage; v) natural weathering; vi) artificial weathering. The work summarised has been reported by: Paula and Pinho-Lopes (2018a), Paula and Pinho-Lopes (2018b), Paula and Pinho-Lopes (2021), Lombardi et al. (2022), Carneiro et al. (2023), Lombardi et al. (2023a) and Lombardi et al. (2023b).

3 CONSTITUTIVE MODEL AND ESTIMATES OF MODEL PARAMETERS

3.1 As-received geosynthetics

The constitutive models analysed (polynomial and hyperbolic-based) can fit experimental data for as-received (intact) samples well; confirmed by statistical analysis of the goodness of fit. Model parameters of polynomial equations have no physical meaning. Parameters of hyperbolic-based models may be associated with the tensile properties of geosynthetics (Liu and Ling, 2007). Initial work (e.g., Paula and Pinho-Lopes, 2021) led to the adoption of adjustment coefficients, to calibrate such relationships. Although some authors argue that C_T is a material constant, the results showed a different trend (particularly after damage).

Equation 3 (Liu and Ling, 2007) relates model parameter *a* to the initial tangent stiffness (J_i). Equation 4 (Lombardi et al., 2023b), obtained from Equation 3 ($\varepsilon \rightarrow \varepsilon_{max}$), relates model parameter *b* to: tensile strength (T_{max}), strain at maximum load (ε_{max}) and model parameter *a*. Equation 4 (Lombardi et al., 2023b) is derived from Equation 2 applying boundary conditions and relates model parameter *c* to ε_{max} and parameters *a* and *b*.

$$a = \frac{1}{J_i} \tag{3}$$

$$b = \frac{-aT_{max} + 2\varepsilon_{max} + \sqrt{4\varepsilon_{max}{}^2 + a^2 T_{max}{}^2}}{4\varepsilon_{max} T_{max}} \tag{4}$$

$$c = \frac{-\ln\left(\frac{2b\varepsilon_i}{a + 2b\varepsilon_i}\right)}{(\varepsilon_i - \varepsilon_{max})^2} \tag{5}$$

3.2 Damaged geosynthetics

The constitutive models for damaged geosynthetics showed similar trends to the undamaged materials. As all models analysed are phenomenological, they can accurately reproduce the force-strain response after damage. The hyperbolic-based model parameters (a_d, b_d and c_d) were estimated from curve fitting. These parameters can be estimated from Equations 3 to 5 using the tensile properties exhibited by the damaged geosynthetics: initial stiffness, $J_{i,d}$; tensile strength, $T_{max,d}$; corresponding strain, $\varepsilon_{max,d}$.

If the damage induced does not alter the shape of the tensile force-strain curve, estimating model parameters after damage is likely to be possible. Thus, simple relations to estimate model parameters for damaged samples were explored, using tensile properties of as-received, reference, samples ($J_{i,r}$, $T_{max,r}$, $\varepsilon_{max,r}$) and of damaged samples ($J_{i,d}$, $T_{max,d}$, $\varepsilon_{max,d}$). For that, reduction factors for J_i, T_{max} and ε_{max} after damage were used. The reduction factor for property X (R_X) is the ratio of the values of property X after damage (X_d) to that of the reference sample (X_r). The most recent and promising relations obtained refer to applying Equations 3 to 5 to obtain estimates of tensile properties of damaged geosynthetic ($J_{i,de}$, $T_{max,de}$, $\varepsilon_{max,de}$), using mean values of reference properties ($J_{i,r}$, $T_{max,r}$, $\varepsilon_{max,r}$) and reduction (scaling) factors ($R_{Ji,d}$, $R_{T,d}$, $R_{\varepsilon,d}$).

4 CONCLUSIONS

Simple hyperbolic-based models can qualitatively describe the tensile load-strain response of geosynthetics, both undamaged and damaged, either mechanical damage (in laboratory and under real conditions), abrasion damage, sequential mechanical and abrasion damage, and weathering (natural and artificial). Hyperbolic-based models are the most promising, as they allow describing the load-strain curves of most geosynthetics studied (before and after damage) only from their tensile properties: J_i, T_{max} and ε_{max}. Regardless of the type of damage, if there are no changes to the shape on the force-strain curve, hyperbolic-based models can describe the tensile response of damaged samples using data from undamaged samples and scaling factors.

The proposed process can be summarized as:

1. Characterise the full tensile response of a chosen geosynthetic (reference sample).
2. Use curve fitting to approximate that response by a hyperbolic-based equation and derive the corresponding model parameters (a_r, b_r, c_r); alternatively, these can be related to J_i, T_{max} and ε_{max} using Equations 3 to 5.
3. Obtain reduction factors for J_i, T_{max} and ε_{max} after damage (using laboratory or field tests, or from the literature, depending on the context): R_{Ji}, R_{Tmax}, $R_{\varepsilon max}$.
4. Estimate model parameters for the damaged sample ($a_{d,e}$, $b_{d,e}$, $c_{d,e}$) using the proposed equations (Equations 3 to 5) and mean values of undamaged tensile properties ($J_{i,r}$, $T_{max,r}$ and $\varepsilon_{max,r}$) and reduction (scaling) factors ($R_{Ji,d}$, $R_{T,d}$, $R_{\varepsilon,d}$)
5. Implement the estimated hyperbolic equation for the damaged sample on numerical software.

This approach allows estimating the response of damaged samples using tensile tests results of both reference and damaged samples. It contributes to defining simple constitutive models allowing for durability, which can be implemented in geotechnical software. Ultimately, more realistic responses of geosynthetics will be used in design.

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