Validation of the comparison between wide-width tensile test and static puncture test on geotextiles

A. Agosti
Caprino Veronese, Verona, Italy

D. Cazzuffi
Enel.Hydro, Milano, Italy

L. Mongiovì
University of Trento, Italy

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ABSTRACT: The results of the in-isolation wide-width tensile tests and the CBR puncture tests on nine types of polypropylene geotextiles are presented in order to validate the Cazzuffi's empirical formula that correlate the tensile load per unit width α_f and the maximum CBR puncture resistance F_p. The formula could be verified with proper hypothesis on stress distribution in breakage conditions. By introducing proper geometric coefficient it is possible to explain that the ratio (α_f / F_p) is close to ($1/2\pi$ r): this relationship is valid only for needle-punched nonwoven geotextiles.

1 INTRODUCTION

In this paper, the results of the in-isolation wide-width tensile tests (EN ISO 10319) and the CBR puncture tests (EN ISO 12236) on nine types of polypropylene geotextiles, are presented and discussed in order to validate the Cazzuffi's empirical formula:

$$\alpha_f \cong (1 / 2\pi\, r) \cdot F_p \qquad (1)$$

where: α_f (kN/m) = tensile load per unit width; r (m) = radius of the cylindrical metal plunger used in the CBR puncture test; F_p (kN) = the maximum CBR puncture resistance.

In Table 1 the nine types of PP geotextiles (of which six nonwoven geotextiles and three woven geotextiles) are listed with the main physical properties measured in laboratory.

2 COMPARISON BETWEEN WIDE-WIDTH AND STATIC PUNCTURE TESTS

Following the research developed by Cazzuffi et al. (1986), a correlation between the tensile load per unit width α_f (kN/m) and the maximum CBR puncture resistance F_p (kN) was studied.

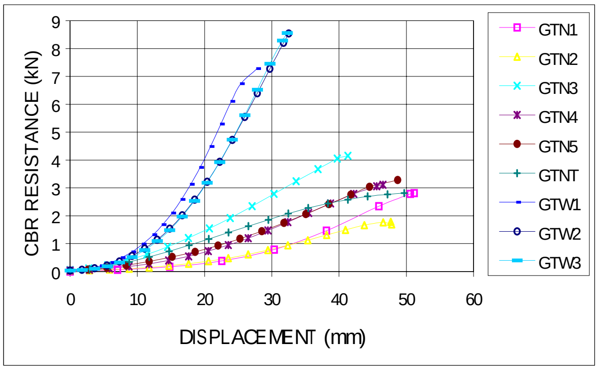

Figure 1. Results of the CBR puncture tests for the nine types of geotextiles (average curves).

The CBR puncture tests were developed according to the EN ISO 12236 standard (see also Murphy and Koerner, 1988): the results of these tests are illustrated in Figure 1.
The tensile tests were developed according to the EN ISO 10319 standard: the results of these tests are illustrated in Figure 2.

Table 1. The nine types of geotextiles tested in this research and their main physical properties measured in laboratory

TRADE NAME	SYMBOL	MANUFACTURER	MELTING POINT (° C)	MASS PER UNIT AREA (g/m^2)	NOMINAL THICKNESS (mm)
Geodren PP/S	GTN 1	Edilfloor	167.60	324.7	5.00
Ibigeo 300	GTN 2	Industrie Biagioli	163.83	298.5	3.08
Polyfelt TS 70	GTN 3	Polyfelt Ges.M.B.H.	164.20	339.7	2.75
Fibertex F43S	GTN 4	Fibertex	168.67	325.4	1.99
Thermofelt P/T2/300	GTN 5	Edilfloor	169.03	301.4	1.55
Typar 3857	GTNT	Du Pont De Nemours	164.20	294.3	0.76
Hate 6G/300/SA	GTW 1	Huesker Synthetics	167.67	335.0	1.31
Mac – Tex WP 300	GTW 2	Officine Maccaferri	168.60	319.4	1.03
Propex 6084	GTW 3	Amoco Fabrics	166.27	344.4	1.33

GTN: Needle-punched nonwoven geotextile
GTNT: Thermobonded nonwoven geotextile
GTW: Woven geotextile

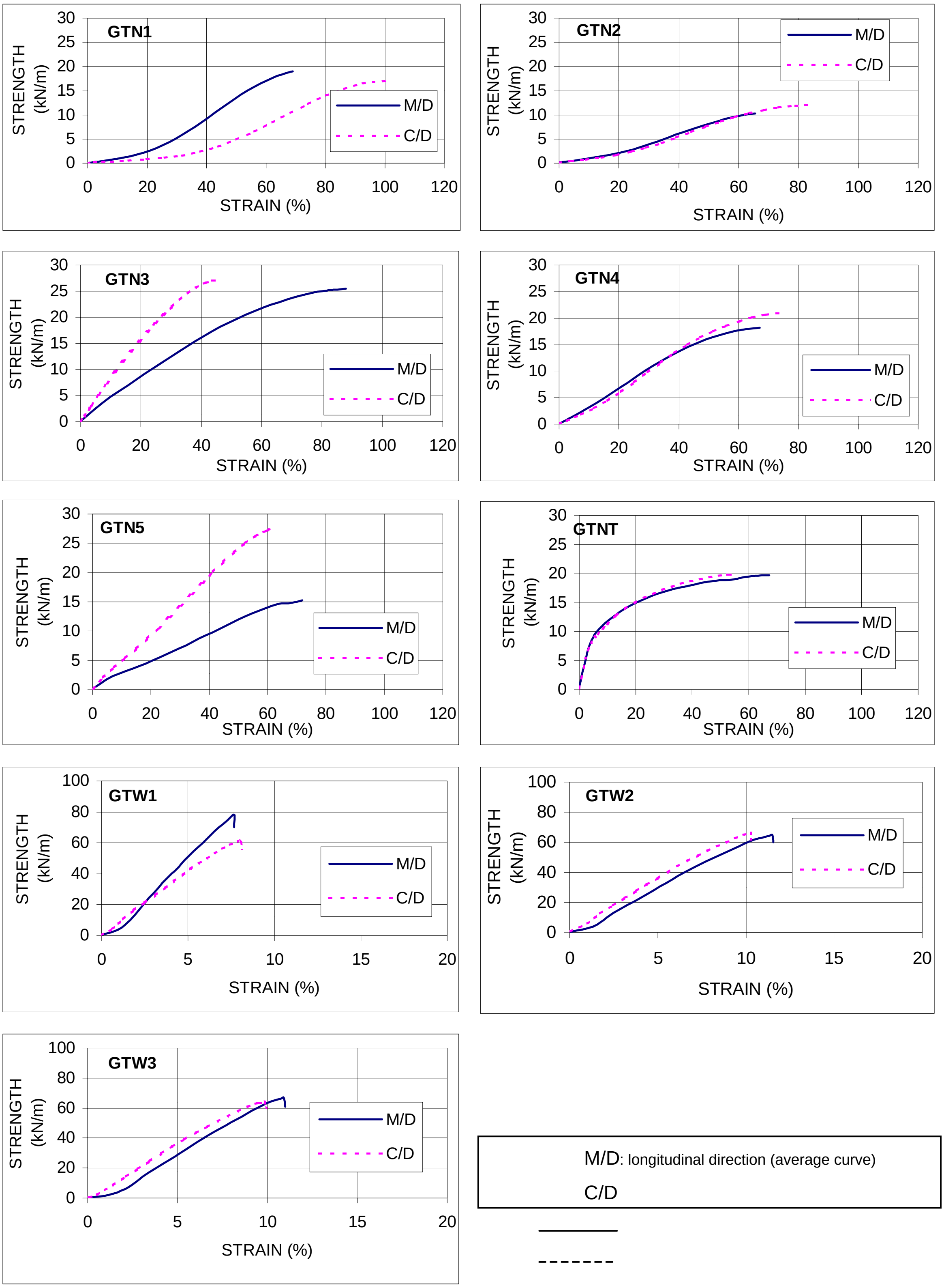

Figure 2. Results of the in-isolation wide-width tensile tests for the six types of nonwoven geotextiles (GTN 1, GTN 2, GTN 3, GTN 4, GTN 5, GTNT) and for the three types of woven geotextiles (GTW 1, GTW 2, GTW 3).

In Table 2 the results obtained in the two types of mechanical tests for the nine types of geotextiles, object of this research, are illustrated: for each tested geotextile, the values of the tensile load per unit width α_f (kN/m), as the mean of the values obtained in the two directions (M/D and C/D), the maximum CBR puncture resistance F_p (kN) and finally the ratio (α_f / F_p) are reported.

Table 2. Comparison between results obtained in wide-width tensile tests and CBR puncture tests

	α_f (kN/m)	F_p (kN)	α_f/F_p (m^{-1})
GTN 1	18.27	2.901	6.30
GTN 2	11.33	1.783	6.35
GTN 3	26.46	4.156	6.36
GTN 4	19.64	3.104	6.33
GTN 5	21.69	3.437	6.31
GTNT	19.74	2.810	7.02
GTW 1	69.92	7.284	9.60
GTW 2	65.53	8.538	7.67
GTW 3	65.65	8.556	7.67

3 VALIDATION OF THE CAZZUFFI'S EQUATION

At this point it has been tried to validate the Cazzuffi's empirical formula:

$$\alpha_f \cong (1 / 2\pi\, r) \cdot F_p \qquad (1)$$

where: $r = 25 \times 10^{-3}$ m, is the radius of the cylindrical metal plunger used in the CBR puncture test.
In fact, the ratio $(1 / 2\pi\, r) \cong 6.36\ m^{-1}$ seems rather close to the values obtained in the tests, see Table 2, in particular for the nonwoven geotextiles.
On the contrary, for the woven geotextiles, not considered by Cazzuffi et al. (1986), the values of the ratio (α_f / F_p) are distant from ($1 / 2\pi$ r) for all the three types of materials.
In Figure 3, the values of the ratio (α_f / F_p) vs. the mechanical isotropy degree (expressed in %) for all the tested types of geotextiles are reported.
The mechanical isotropy degree is defined as the ratio between the tensile strength per unit width in the main direction (M/D) and the tensile strength per unit width in the cross direction (C/D).
The exam of Figure 3 confirms the above mentioned correlation for all the types of needle-punched nonwoven geotextiles and, partially, for the thermobonded nonwoven geotextile: this correlation has been proved for nonwoven geotextiles apart from the grade of mechanical isotropy of the tested materials.

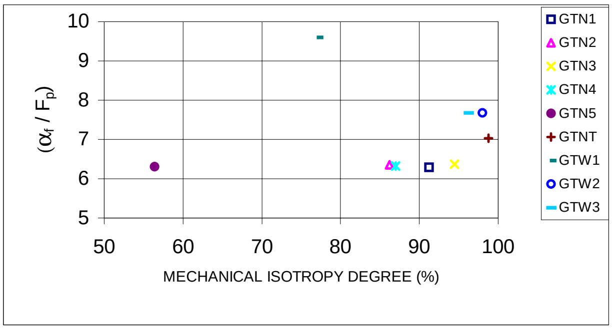

Figure 3. Values of the ratio (α_f / F_p) vs. the mechanical isotropy degree.

Before making other considerations, it is worth looking at the scheme of the in-isolation wide-width tensile test and the CBR puncture test, respectively.
On the basis of the in-isolation wide-width tensile test scheme, see Figure 4, it is possible to write the equation of the static equilibrium in vertical direction, underlying the present forces.

Figure 4. Scheme of the in-isolation wide-width tensile test.

In the in-isolation wide-width tensile test:

$$T_f = L' \cdot t_m \qquad (2)$$

with: T_f = the force applied to the wedge jaws; t_m = the medium force per unit of width valued on the span of length L' in breakage conditions and where T_f is expressed in kN, L' is expressed in m, t_m is expressed in kN/m (force per unit width).
According to the in-isolation wide-width tensile test, in conditions which are different from the breakage status, the stress distribution along the span L', is not uniform. Therefore, it is possible to consider the effective non-uniformity in the equation of the static equilibrium, Equation 2, introducing the corrective coefficient β, to show the real force in function of the maximum value t_{max}.

$$T_f = L' \cdot \beta\, t_{max} \qquad (3)$$

with: $\beta = t_m / t_{max}$

Yet in breakage conditions, in the in-isolation wide-width tensile test, it is possible assume that the behaviour of the material is plastic, endlessly ductile and that the breakage takes place just in the central area of the specimen, along the span L', for a value of t_m (kN/m) of the breakage load per unit width.
Therefore, in the breakage conditions, the stress distribution along the span L' could be considered uniform. By consequence the corrective coefficient β will have value 1.

Thus:

$$t_m = t_{max} \qquad (4)$$

and:

$$T_f = L' \cdot t_{max} \qquad (5)$$

In reality, there are not conditions of simple mono-axial tensile stress: in fact there are also cross stresses, which contribute to the breakage of the specimen. Nevertheless, in this approach, such cross stresses are not considered.
Therefore the tensile load per unit width α_f (expressed in kN/m) is:

$$\alpha_f = (L' \cdot t_{max}) / L = (L' / L) \cdot t_{max} \qquad (6)$$

In the CBR puncture test, referring to the Figure 5:

$$F_p = (2\pi\, r) \cdot t_{max} \cdot \text{sen}\,\theta \qquad (7)$$

with: F_p = maximum CBR puncture resistance; t_{max} = maximum tensile load per unit width, valued on the meridian, and where F_P is expressed in kN, t_{max} is expressed in kN/m (tensile load per unit width)
In the CBR puncture test it's possible assume that the break of the material takes place along the circonference 2π r, which defines the circular area of the specimen in contact with the plunger, and for a value of the plunger load equal to F_p (kN).

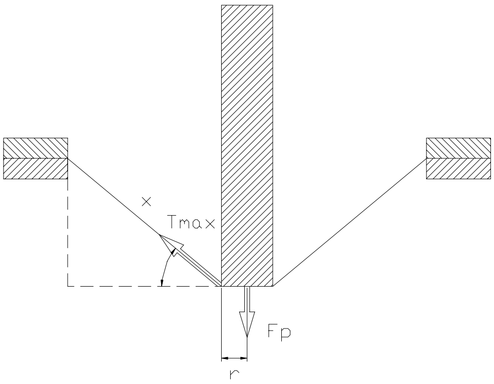

Figure 5. Scheme of the CBR puncture test.

In the CBR puncture test, the real state of stress implies the presence of normal stresses which act in circumferencial direction (along the parallels of the truncated cone surface of the specimen). These normal stresses influence the breakage system of the material, yet they are not considered since it was assumed that the fibers, in circumferencial direction, are "unbonded".

Therefore, considering the Equations 6 and 7, the equation proposed by Cazzuffi becomes:

$$\alpha_f / F_p = [(L' / L) \cdot t_{max}] / [(2\pi\, r) \cdot t_{max} \cdot \text{sen}\,\theta] \qquad (8)$$

At this point, with:

$\lambda = (L' / L)$ and: $\text{sen}\,\theta = \delta / x$

it is possible to write the Equation 8 as:

$$\alpha_f / F_p = [\lambda / (\delta/x)] \cdot (1 / 2\pi\, r) \qquad (9)$$

By consequence, λ and δ / x can be considered as proper geometric coefficients which characterize the breakage phase in the in-isolation wide-width tensile and in the CBR puncture tests, in every type of geotextiles.

In Table 3 the calculated values of coefficients λ and δ / x , based on experimental photographic measurements (see Agosti et al. 1999) made on four geotextiles (GTN 1, GTN 3, GTNT and GTW 2) rapresentative of the different types of tested geotextiles, are presented.

Table 3. Values of geometric coefficients λ and δ / x

	L_{base} (mm)	L' (mm)	λ (-)	δ (mm)	x (mm)	δ/x (-)
GTN 1 M/D	200	141.2	0.600	50.5	71.1	0.711
C/D	200	121.2	0.515	50.3	70.9	0.709
GTN 3 M/D	200	129.4	0.550	40.1	64.1	0.626
C/D	200	147.1	0.625	41.2	64.8	0.636
GTNT M/D	200	171.8	0.730	45.2	67.4	0.671
C/D	200	164.7	0.700	49.7	70.5	0.705
GTW 2 M/D	161	157.5	0.978	31.8	59.3	0.537
C/D	161	158.5	0.984	31.8	59.3	0.537

The values of λ and δ / x have been valued on specimens cutted along the same longitudinal band of the roll of geotextile in order to minimize the effect of non-homogeneity of the material.

Analyzing better the results, it is possible to see that the value of the geometrical coefficient λ rises in close relation with the level of stiffness of the considered sample. The stiffer the material, the higher is the value of λ: this is because the cross strain in breakage conditions in the central area is smaller.

This statement is evident for the thermobonded nonwoven geotextile (GTNT), as well as the woven geotextile (GTW 2). The value of coefficient λ is close to 1 in particular for the woven geotextile.

The opposite thesis can be made in relation to the values obtained for the ratio (δ/x), which tends to decrease as the material is stiffer.

In Table 4, the values of the ratio $\lambda / (\delta/x)$ and the values of the ratios (α_f/Fp), respectively obtained from Equation 9 and from experimental tests, are presented.

Table 4. Values of the ratio $\lambda/(\delta/x)$ and of the ratios (α_f/Fp)

	$\lambda/(\delta/x)$ (-)	α_f/F_p (from Equation 9) (m^{-1})	α_f/F_p (from tests) (m^{-1})
GTN 1 M/D	0.84	5.35	6.59
C/D	0.73	4.65	6.01
GTN 3 M/D	0.88	5.60	6.18
C/D	0.98	6.24	6.54
GTNT M/D	1.09	6.94	6.98
C/D	0.99	6.30	7.07
GTW 2 M/D	1.82	11.60	7.59
C/D	1.83	11.65	7.75

The equation of Cazzuffi could be verified, for nonwoven geotextiles, only for values of the ratio $\lambda / (\delta/x)$ close to 1 and , for woven geotextiles, only for values of the ratio $\lambda / (\delta/x)$ close to 1.2.

Therefore, it is possible to note that the adoption of geometric coefficients λ and (δ/x) in Equation 9 seems still unsatisfactory because the ratio $\lambda / (\delta/x)$ differs form the value 1 for the two types of needle-punched nonwoven geotextiles (GTN 1 and GTN 3) and from the value 1.2 for the woven geotextile (GTW 2); the ratio $\lambda / (\delta/x)$ is almost equal to 1 only for the thermobonded nonwoven geotextile (GTNT).

This can happen because there are some difficulties to measure λ, but it can be also because the hypothesis of breakage does not completely correspond to the reality, above all for the stress distribution and for the fact that the transversal and/or circumferencial stresses were not considered.

In conclusion, the Cazzuffi's formula could be justified by adopting a simple vertical equilibrium static scheme. Moreover, by introducing proper geometric coefficients λ and (δ/x), it is possible to explain that the ratio $(\alpha f / F_p)$ experimentally measured is close to $(1/2\pi\ r)$: nevertheless, more research data are needed in order to carefully determine the geometrical coefficients λ and (δ/x) for a wider variety of geosynthetics.

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