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ELASTOPLASTIC ANALYSIS OF DIAMETRAL COMPRESSION TESTING: IMPLICATIONS FOR STRUCTURAL SAFETY AND ENGINEERING LIABILITY

ANÁLISE ELASTOPLÁSTICA DO ENSAIO DE COMPRESSÃO DIAMETRAL: IMPLICAÇÕES PARA A SEGURANÇA ESTRUTURAL E A RESPONSABILIDADE NA ENGENHARIA

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Abstract
Accurate tensile characterization of structural materials is critical for construction safety, technical standardization, and civil liability in the event of structural failures. Diametral compression testing, based on the formulation by Hondros (1959), is widely used to estimate indirect tensile strength under linear elastic assumptions. However, when applied to ductile structural steels, elastoplastic stress redistribution significantly alters the internal stress field, potentially leading to overestimation of effective tensile strength This study critically examines these limitations from a technical–legal perspective, demonstrating how uncritical use of purely elastic formulations can affect regulatory compliance and professional liability. A plastically corrected factor is proposed to align experimental practice, mechanical reality, and legal safety.

Keywords: Civil Liability. Structural Safety. Technical Standards. Diametral Compression Testing. Regulatory Compliance.

Resumo
A caracterização precisa da resistência à tração dos materiais estruturais é fundamental para a segurança na construção, a padronização técnica e a responsabilidade civil em caso de falhas estruturais. O ensaio de compressão diametral, baseado na formulação de Hondros (1959), é amplamente utilizado para estimar a resistência à tração indireta sob hipóteses de comportamento linear elástico. No entanto, quando aplicado a aços estruturais dúcteis, a redistribuição elastoplástica das tensões altera significativamente o campo de tensões interno, podendo conduzir à sobrestimação da resistência efetiva à tração. Este estudo examina criticamente essas limitações sob uma perspectiva técnico-jurídica, demonstrando como o uso não crítico de formulações puramente elásticas pode afetar a conformidade regulamentar e a responsabilidade profissional. Propõe-se um fator de correção plástica com o objetivo de alinhar a prática experimental, a realidade mecânica e os requisitos de segurança jurídica

Palavras-chave: *Responsabilidade Civil. Segurança Estrutura. Normas Técnica. Ensaio de Compressão Diametra. Conformidade Regulatória.*

1 INTRODUCTION

Structural safety is a fundamental component of the right to life and physical integrity, reflected in legal frameworks protecting individuals and property against structural failures (Silva & Almeida, 2020). In civil construction and metallic structures, precise determination of mechanical material properties is essential for correct design, member sizing, and collapse prevention.

Among experimental methods for estimating tensile strength—critical for assessing ductile failure mechanisms— Among experimental methods for estimating tensile strength—critical for assessing ductile failure mechanisms—diametral compression testing is widely used due to its relative simplicity and incorporation into international standards (Hondros, 1959. Li & Wong, 2013). Traditional diametral compression theory is based on linear elastic stress solutions, assuming the material remains purely elastic up to failure, with peak compressive load corresponding directly to maximum tensile stress at the disc center, assuming the material remains purely elastic up to failure, with peak compressive load corresponding directly to maximum tensile stress at the disc center. While reasonably accurate for brittle materials, this assumption is problematic for ductile steels, where plastic yielding precedes fracture, redistributing stresses and altering triaxiality (Mirzaei, Zehtab, & Maleki, 2015).

Recent studies confirm that classical assumptions may fail for medium- to high-strength steels, particularly when plastic zones are non-negligible or crack initiation occurs outside the disc center (Wang, Rossi, & Zhao, 2023. Bai & Wierzbicki, 2008). This has technical and legal implications, including misestimation of tensile strength and potential professional liability.

2 TECHNICAL BACKGROUND AND LIMITATIONS OF THE ELASTIC MODEL

According to the classical elastic solution for diametral compression, the maximum tensile stress at the disc center is predicted by the expression:

$$\sigma_t = 2P / (\pi D t) \qquad (1)$$

where P is the applied compressive load, D is the disc diameter, and t is the specimen thickness. This solution assumes homogeneity, isotropy, linear elasticity, and absence of prior plasticity. Beyond the yield point, Hooke’s law no longer applies. plastic zones develop, stress redistributes, and central tensile stress is reduced relative to the elastic prediction (Mirzaei *et al*., 2015).

For ductile structural steels, these effects can reduce the effective tensile stress by up to 30%, particularly in low- and medium-strength materials, highlighting the limitations of using purely elastic diametral compression predictions for design and safety assessment (Wang *et al*., 2023).

3 LEGAL IMPLICATIONS AND TECHNICAL LIABILITY

3.1 Regulatory compliance and professional duty

Technical standards are grounded in experimentally validated mechanical models and therefore carry a presumption of scientific legitimacy. However, this presumption is conditional: standards are valid only within the physical and methodological domains for which they were developed. In structural mechanics, most codified formulations—such as linear elastic solutions for the diametral compression testing—are derived under restrictive assumptions including homogeneity, isotropy, small strains, and purely elastic material behavior. When these assumptions are violated, the normative equation may no longer represent the actual stress state in the specimen.

For ductile structural steels, elastoplastic redistribution significantly modifies the internal stress field prior to fracture. The classical Hondros-type linear elastic solution assumes that the maximum tensile stress occurs at the disc center and scales directly with the applied load. Yet finite element simulations demonstrate that once yielding begins, stress relaxation and redistribution reduce the effective central tensile stress while increasing plastic dissipation in surrounding zones. Consequently, the direct application of the elastic formula may lead to a systematic overestimation of tensile strength.

From a regulatory standpoint, this discrepancy raises issues of compliance. Engineering regulations typically require not only adherence to standards, but also the competent and context-aware application of those standards. Professional duty extends beyond mechanical substitution into codified equations. it includes verification that the chosen model reflects the actual material behavior and loading regime. When engineers apply an elastic solution outside its validated range—without assessing plasticity effects or introducing correction factors—they risk breaching the obligation of due diligence.

In legal terms, negligence may arise when three elements converge:

- Foreseeability of error, given established knowledge of elastoplastic behavior in ductile steels.
- Deviation from accepted scientific practice, such as ignoring nonlinear analysis when warranted.
- Causal link to damage, if structural underperformance or failure can be traced to overstated tensile capacity.

As emphasized in the literature (Silva & Almeida, 2020), technical compliance is not merely formal adherence to a standard but requires scientifically justified application. Courts and regulatory bodies increasingly recognize that modern engineering competence includes understanding the limitations of simplified analytical models. Therefore, the absence of elastoplastic correction in diametral compression testing of ductile steels may expose practitioners to liability if the resulting design proves unsafe.

In this context, introducing a plastically corrected factor is not only a mechanical refinement but also a risk-mitigation measure. It aligns experimental interpretation with material reality, reinforces regulatory conformity, and strengthens the defensibility of engineering decisions in the event of forensic scrutiny.

3.2 Structural safety and consumer protection

Overestimating mechanical properties compromises design safety margins, increasing the risk of early yielding or catastrophic failure. Consumer protection frameworks and building codes presume that test methods conservatively estimate material performance. deviation may constitute legal liability. Solutions include:

- Updating technical standards to integrate elastoplastic effects.
- Periodic review of experimental protocols to reflect contemporary material behavior.

- Clear allocation of liability among designers, manufacturers, and testing laboratories.

4 PROPOSALS OF ELASTOPLASTIC CORRECTION

Finite element (FE) analyses of specimens under diametral compression with varying yield strengths reveal a clear dependence of stress redistribution on material ductility:

- Lower-strength steels (S355) develop larger plastic zones, resulting in significant redistribution of internal stresses across the disc. This leads to a reduction of the maximum tensile stress at the disc center compared to classical elastic predictions.
- High-strength steels (S690), with higher yield stress and lower ductility, exhibit more localized central plasticity, with less extensive stress redistribution.

Quantitative FE simulations indicate that the effective tensile stress at the disc center may be reduced by up to 30% relative to the classical elastic solution, particularly for low- and medium-strength steels (Mirzaei, Zehtab, & Maleki, 2015. Wang, Rossi, & Zhao, 2023).

To account for these elastoplastic effects, we propose a plastically corrected factor k_p , defined as:

$$\mathbf{k_p} = \boldsymbol{\sigma_t}^{FE} / \boldsymbol{\sigma_t}^{H} \qquad (2)$$

where,

- σ_t^{FE} is the maximum first principal tensile stress at the disc center, extracted from finite element simulations at the load corresponding to peak global reaction force .
- σ_t^{H} is the tensile stress predicted by the Hondros analytical solution for the same applied load.

This factor allows engineers and testing laboratories to adjust tensile strengths derived from diametral compression to account for material ductility, ensuring:

- Safer structural designs, with tensile estimates aligned with physical behavior

- Improved legal defensibility in professional liability contexts, as results explicitly consider plasticity
- Alignment with updated experimental protocols and international standards (ASTM D3967, ISO 1920-10)

Table 1

Typical Plastic Correction Factors (k_p)

Material	**Yield Strength σ_y (MPa)**	**k_p**
Mild steel (S355)	355	0.70
High-strength steel (S690)	690	0.90–1.0

a) Explanation of Table 1:

The plastic correction factors were obtained by comparing the maximum central tensile stress from elastoplastic FE simulations (σ_t^{FE}) with the classical elastic prediction ($\sigma^{elastic}$).

- Mild steel (S355): Plasticity develops diffusely, causing extensive stress redistribution. The effective central tensile stress is significantly lower than the elastic estimate, yielding a smaller correction factor (k_p=0.70).
- High-strength steel (S690): Plasticity is localized at the disc center, with limited stress redistribution. Consequently, the effective tensile stress remains close to the elastic prediction, giving a higher correction factor (k_p=0.90–1.0) (Mirzaei *et al.*, 2015).

This approach enhances design safety, aligns with legal expectations for professional diligence, and supports scientifically defensible material testing protocols.

To better illustrate the physical basis of the plastic correction factor k_p presented in Table 1, Figure 2 shows the distribution of plastic zones in specimens under diametral compression for mild (S355) and high-strength (S690) steels.

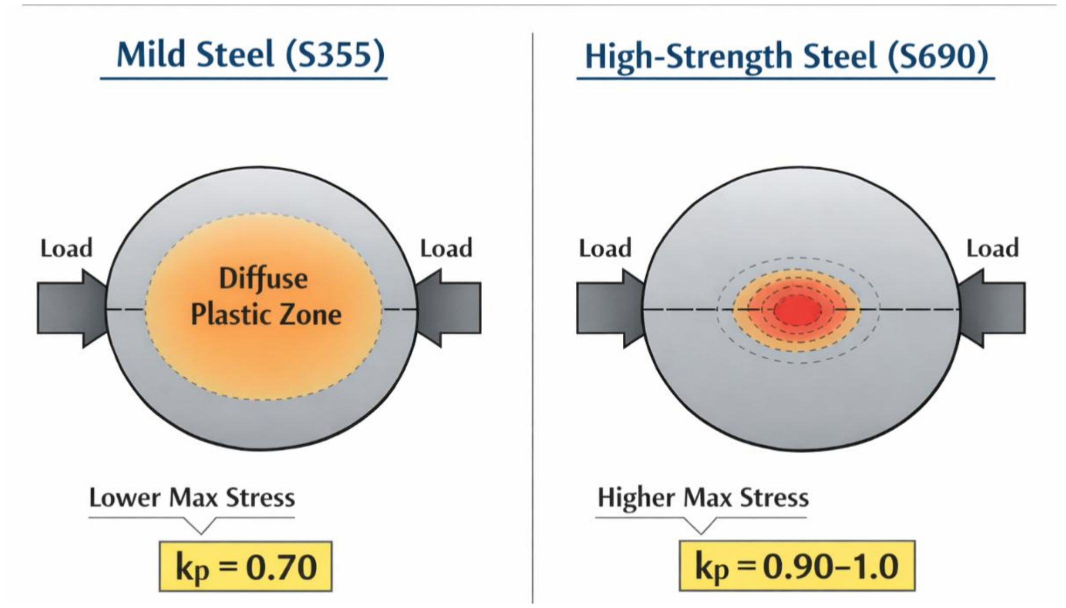
The figure highlights how material ductility affects the development and extent of plastic deformation under diametral loading

In mild steel, plasticity develops diffusely across the disc center, leading to significant stress redistribution and a lower effective central tensile stress. In contrast, high-strength steel exhibits localized central plasticity, with limited redistribution and a tensile stress closer to the classical elastic prediction.

This visual representation directly links the mechanical behavior of the material to the plastically corrected factor k_p, providing engineers and researchers with an intuitive understanding of how ductility influences the outcomes of diametral compression tests and reinforces both technical accuracy and legal defensibility.

Figure 1

Plastic Zones in Diametral Compression Specimens



- Left: Mild steel (S355) exhibits diffuse central plasticity, leading to substantial stress redistribution and a lower effective tensile stress (k_p=0.70).
- Right: High-strength steel (S690) shows localized plasticity at the disc center, with limited redistribution and a higher effective stress (k_p=0.90–1.0).
- Diametral compression is applied at the top and bottom of each disc (arrows). Plastic zones are highlighted in red/orange gradient to indicate plastic strain magnitude.

b) Obtention of Figure 1:

- Finite Element Modeling: Discs were simulated using elastoplastic material models with isotropic hardening, incorporating the yield stress, elastic modulus, and post-yield behavior of S355 and S690 steels.

- Loading: Diametral compression was applied until the maximum load was reached, reproducing the BDT test conditions.
- Plasticity Extraction: Regions exceeding the yield stress were highlighted, illustrating the extent and localization of plastic zones.
- Comparison Between Materials:
  - S355: Diffuse plasticity → lower central stress → smaller k_p
  - S690: Localized plasticity → central stress closer to elastic → higher k_p

5 DISCUSSION: ENGINEERING–LEGAL INTERFACE- DIAMETRAL COMPRESSION TESTING: MATERIAL, ENGINEERING, AND LEGAL INTERFACES

Diametral compression testing (Brazilian Disc Test) exemplifies the critical intersection of material science, structural engineering, and legal responsibility. Standard formulations based on linear elasticity are inherently valid only within the elastic domain. however, ductile steels frequently exceed this range under practical loading, exhibiting early yielding, stress redistribution, and plastic zone formation (Wang *et al*., 2023. Bai & Wierzbicki, 2008. Kumar *et al*., 2021). Finite element (FE) simulations provide quantitative insights into these elastoplastic effects, revealing their substantial impact on stress distribution, effective tensile strength, and fracture behavior (Li *et al*., 2022. Zhang *et al*., 2024).

5.1 Key implications for standards and practice

- Conditional Validity of Standards**:** Test methods must be applied strictly within their validated domain. The uncritical use of purely elastic diametral compression solutions for ductile steels risks overestimating tensile strength and may constitute professional negligence under regulatory scrutiny (Silva & Almeida, 2020. Marques *et al*., 2021).
- Dynamic Normative References: Advances in computational mechanics, damage-based modeling, and ductile fracture theory necessitate continuous updates of design codes, testing protocols, and standard operating procedures (Wang *et al*.,

2023. Li *et al*., 2022). Integrating elastoplastic correction factors ensures that experimental practice remains aligned with current scientific understanding.

- Predictable Structural Behavior as Legal Benchmark: Accurate material characterization, informed by elastoplastic simulations, provides a defensible basis for engineering due diligence. Regulatory authorities increasingly recognize that adherence to standards is insufficient if underlying material assumptions are violated. Properly adjusted test results thus mitigate potential liability claims (Kumar *et al*., 2021. Marques *et al*., 2021).

5.1.1 Integrating elastoplastic corrections

FE-based elastoplastic modeling allows classical linear elastic diametral compression solutions to be corrected for plasticity, capturing stress redistribution, plastic zone growth, and central stress reduction. The introduction of a plastically corrected factor k_p bridges the gap between experimental measurement, mechanical reality, and regulatory compliance, improving both structural reliability and litigation defense.

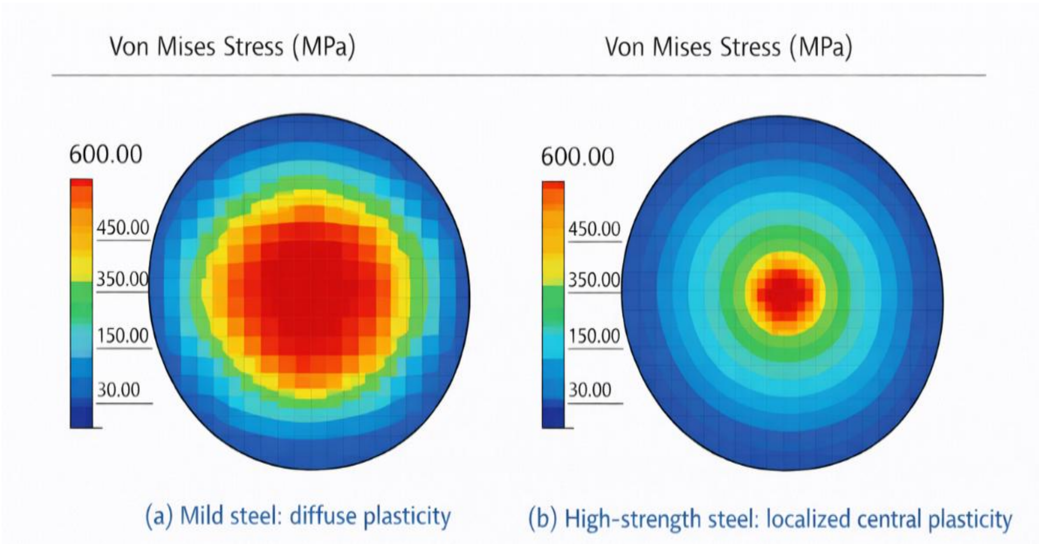
Figure 2 presents the FE prediction of Von Mises equivalent stress in S355 mild steel and S690 high-strength steel specimens under diametral compression. The results reveal markedly different elastoplastic behavior:

- (a) Mild Steel (S355): Yielding initiates early and spreads over a broad central region, producing diffuse plasticity and significant stress redistribution. Effective peak tensile stress at the disc center is reduced relative to the purely elastic solution.
- (b) High-Strength Steel (S690): Plasticity remains highly localized at the disc center, reflecting limited ductility and near-elastic behavior until fracture.

These simulations confirm that material strength and ductility directly affect stress redistribution and fracture patterns, underscoring the necessity of k_p corrections for physically accurate and legally defensible interpretations (Bai & Wierzbicki, 2008. Wang *et al*., 2023).

Figure 2

Von Mises Stress Distribution in Diametral Compression Specimens (FE Analysis)



6 CONCLUSIONS

The uncritical application of traditional elastic formulations for diametral compression to ductile structural steels can lead to a systematic overestimation of tensile strength, because the elastic solution does not account for plastic yielding, stress redistribution, and altered stress triaxiality. This technical shortcoming has direct consequences for structural safety: overestimated material strength may lead to insufficient design margins, early onset of plastic deformation, or unexpected service failures. In safety-critical structures, such miscalculations could compromise the integrity of load-bearing elements, posing a tangible risk to occupants and users.

From a legal perspective, this limitation affects multiple aspects of civil liability:

- Professional duty of care: Engineers are legally obligated to apply methods appropriately, considering the physical behavior of materials. Using linear elastic diametral compression predictions without correction in ductile steels may constitute negligence if it results in unsafe designs or structural failure.
- Compliance with standards: Technical standards presume proper application domains. Ignoring elastoplastic effects when interpreting diametral compression test results undermines the reliability of the method and may be considered a violation of regulatory expectations.

- Consumer protection and public safety: Overestimating tensile strength can reduce safety margins, potentially endangering end users and violating legal obligations to ensure structural reliability.

Implementing a plastically corrected factor k_p derived from elastoplastic finite element analysis or experimental calibration, aligns with the precautionary principle, which advocates for conservative design decisions in the face of scientific uncertainty. This approach ensures that structural predictions remain on the safe side, mitigating both technical and legal risks.

By integrating engineering judgment, numerical modeling, and legal awareness, the use of exemplifies responsible practice in structural engineering, where technical rigor directly supports regulatory compliance, professional liability mitigation, and societal protection. In essence, plastically corrected diametral compression interpretations bridge the gap between material science and legal accountability, reinforcing the engineer's role as both a technical expert and a guardian of public safety.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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