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Modification of the Brazilian Indirect Tensile Strength Formula for Better Estimation of the Tensile Strength of Rocks and Rock-like Geomaterials

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目录 Content

Introduction

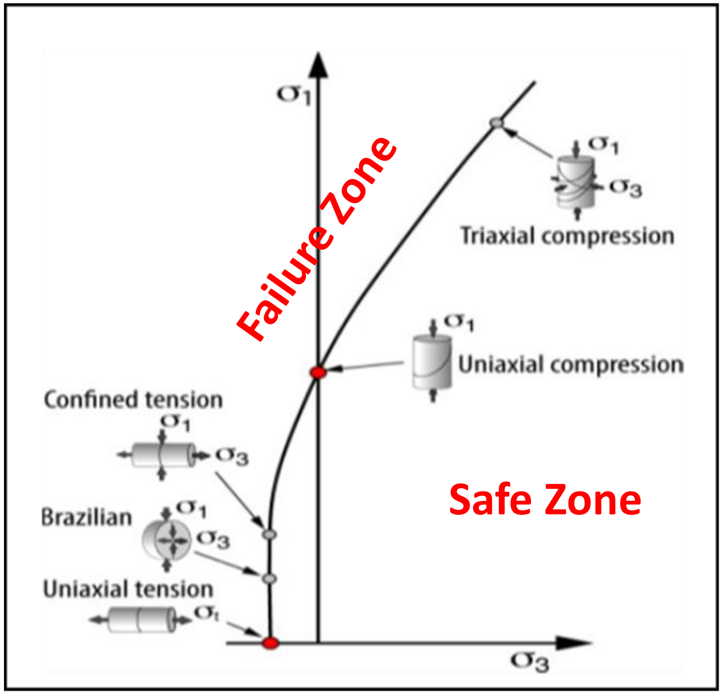
- Rock mechanical properties are essential input in many design applications in:

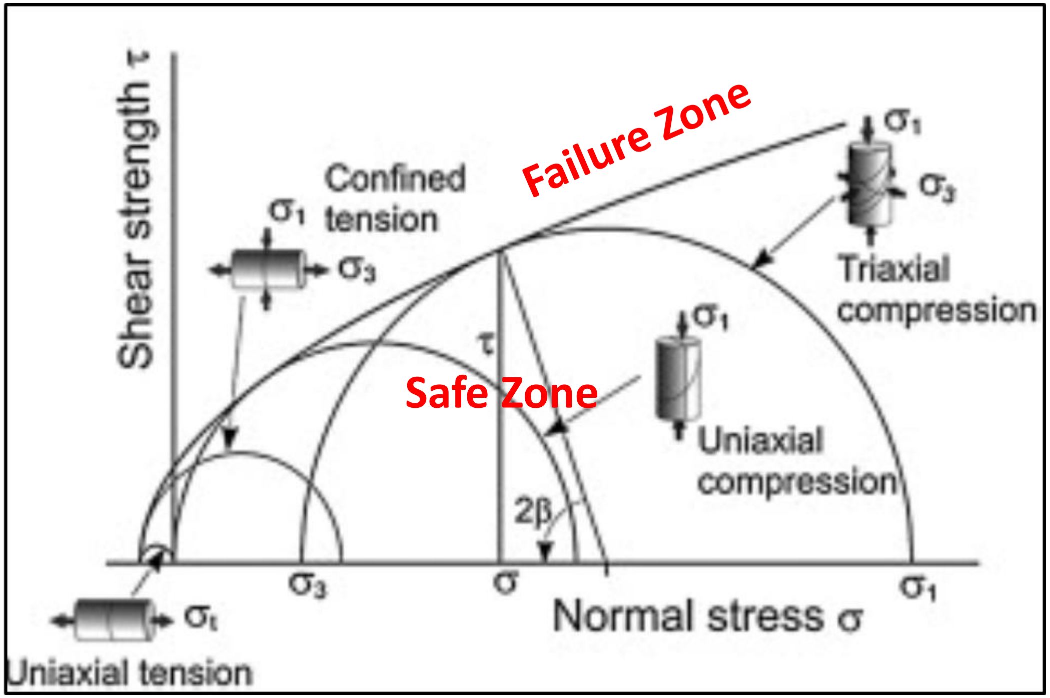
Petroleum and Natural Gas Engineering	Wellbore Stability, Drilling Rate Prediction, Hydraulic Fracturing, Sand Control and Mitigation, Well Cementing, Infill Drilling, Underground Storage, Geothermal Energy, etc. **(Musaed, 1998 and Musaed, 2020)**.
Mining Engineering	Rock Blasting, Drilling, Crushing and Grinding, Deep Mining Hole Stability, Ores Extraction, Roof Protection, Open Pit Mines, etc. **(Zongxian, 2017)**.
Civil and Environmental Engineering	Construction Materials, Tunnels, Slope Stability, Dams, Rock Bolting, Shafts, Underground Excavations, Road Cuts, Waste Repositories, etc. **(Hudson and Harrison, 2000)**.

- The most reliable source used for estimating rock mechanical properties is the laboratory tests.

Introduction

Laboratory tests used to establish rock failure criteria (Derek, 2014)





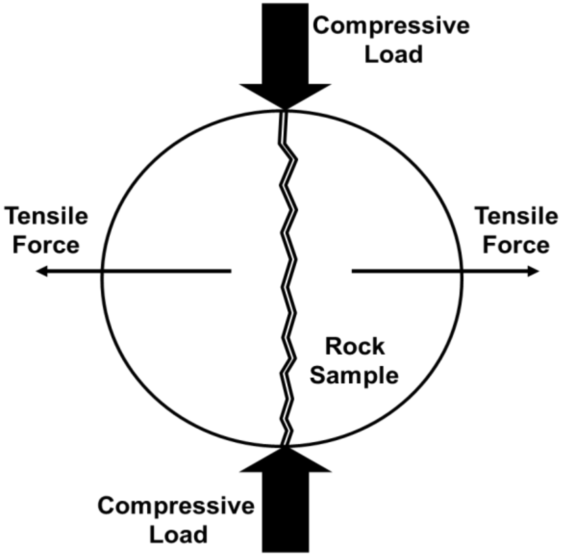
Introduction

- Among these important and critical rock mechanical properties is the tensile strength which can be measured directly (Pull test) and indirectly (Splitting Brazilian test).
- The Brazilian Indirect tensile test is the most convenient laboratory test in terms of:
  - Samples preparation (Cylindrical Disc with t=r)
  - Testing requirements (Equipment and Procedures)

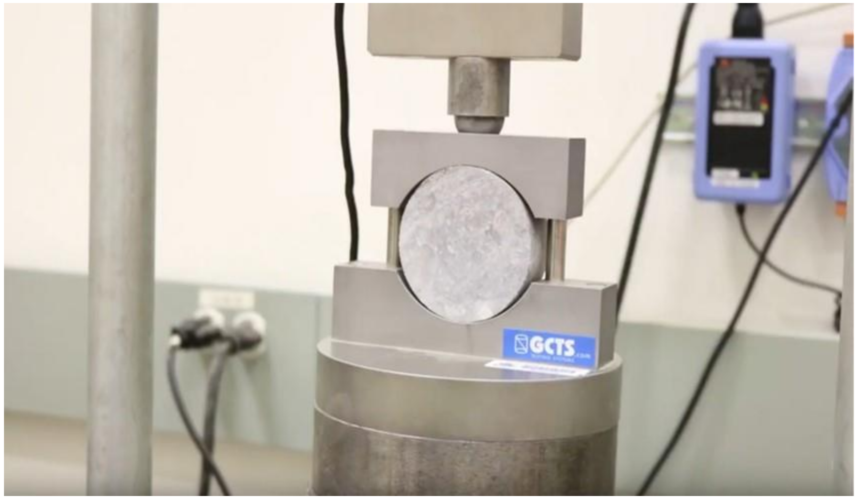
Introduction

The Brazilian Indirect Tensile Strength Test

$$BTS = \frac{2L}{\pi D t}$$



BTS = Brazilian indirect tensile strength, MPa.
D = Test specimen diameter, m.
t = Test specimen thickness, m.
L = Applied axial load at failure, kN.



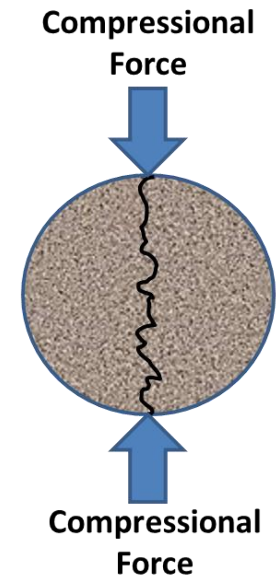
Objectives of the Study

- It is well documented in the literature that the Brazilian indirect tensile test provides over estimated tensile strength values compared to the direct tensile test.
- The objective of this study is the investigation of potential modification of the Brazilian indirect tensile strength formula by the analysis of the relevant published laboratory data.

Objectives of the Study

$$DTS < BTS$$

$$DTS = f * BTS$$

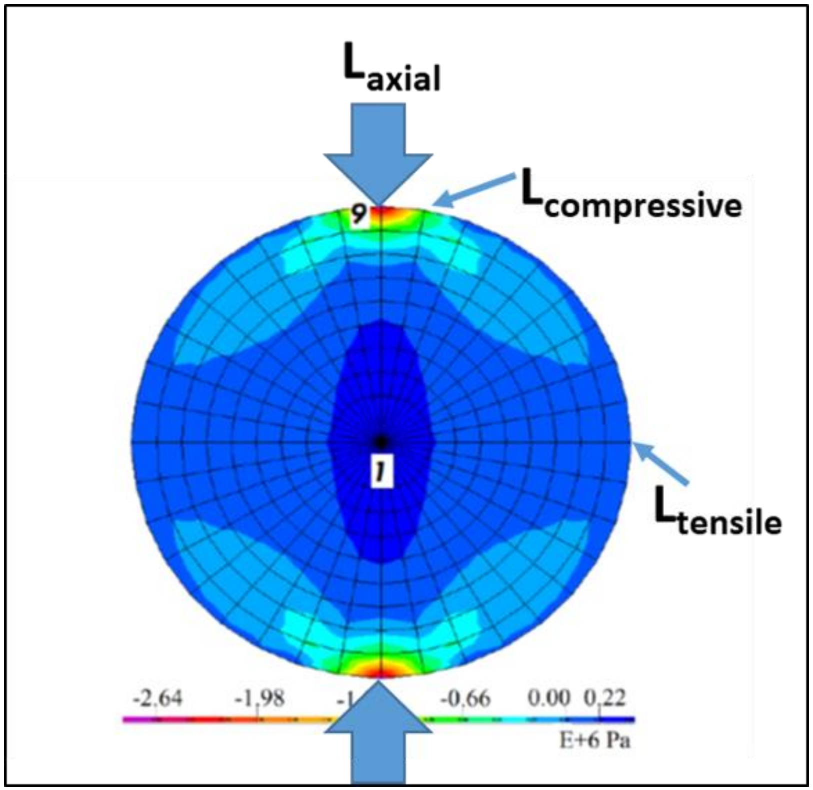


DTS = Direct Tensile Strength (Pull Test)

BTS = Brazilian Indirect Tensile Strength

f = Correction Factor (Less than 1.0)

Theoretical Background



$$BTS = \left[\frac{2\,L_{axial}}{\pi\,D\,t}\right]$$

Distribution of induced compressive and tensile induced stresses in the test specimen during BTS test (Rocha and Wahrhaftig, 2016)

Theoretical Background

Tensile Area = 0.5 (2 π r t) = (π r t) = (π (D/2) t)

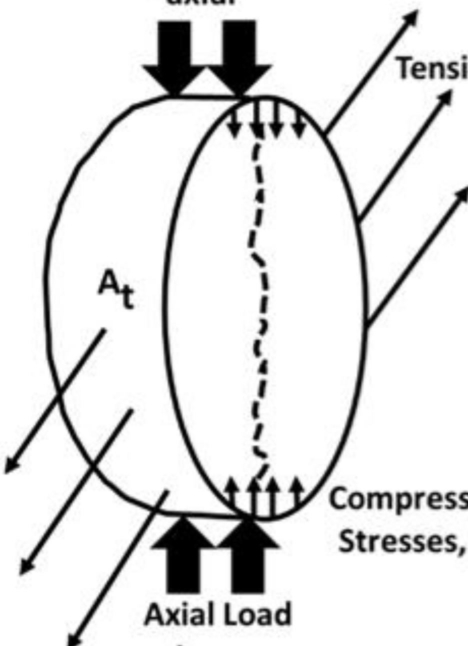
$$\text{Max. BTS} = \frac{L_{axial}}{\pi\,(D/2)\,t} = \frac{2\,L_{axial}}{\pi\,D\,t} = \frac{0.636\,L_{axial}}{D\,t}$$

$$L_{axial} = L_{tensile} + L_{compressive}$$

$$L_{tensile} = L_{axial} - \nu\,L_{axial} = (1-\nu)\,L_{axial}$$

$$\text{BTS} = \frac{\text{Load}}{\text{Area}} = \frac{(1-\nu)\,L_{axial}}{\pi\,(D/2)\,t} = (1-\nu)\frac{0.636\,L_{axial}}{D\,t}$$

$$\text{BTS} = (1-\nu)\left[\frac{2\,L_{axial}}{\pi\,D\,t}\right]$$



A) Stresses Distribution

Results and Discussion

$$BTS = \frac{2\,L_{axial}}{\pi\,D\,t}$$

Traditional BTS Equation

$$BTS = (1 - \nu)\left[\frac{2\,L_{axial}}{\pi\,D\,t}\right]$$

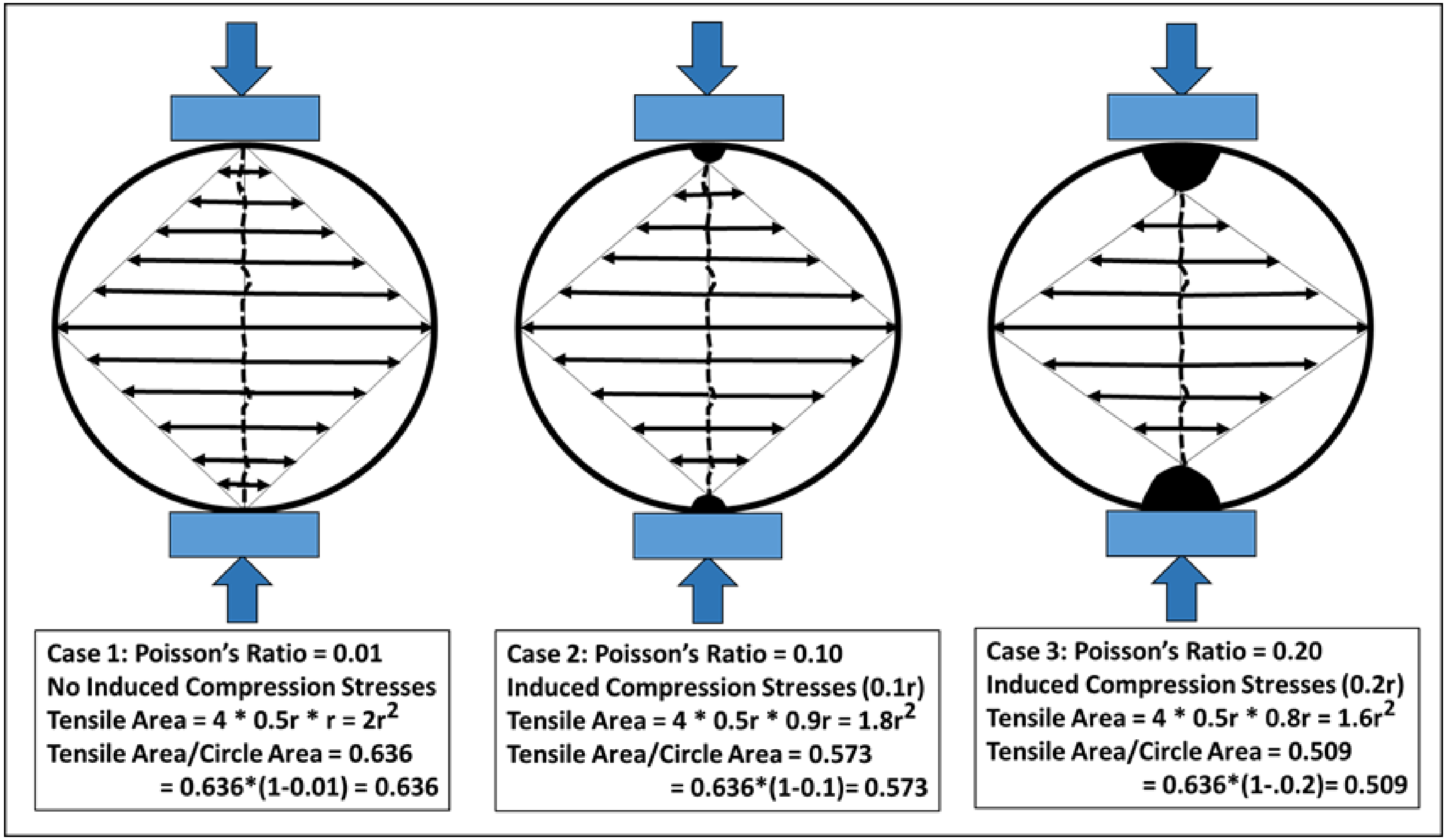
Modified BTS Equation

Correction Factor = $(1 - \nu)$

Results and Discussion

$$\text{Max. BTS} = \frac{2\ L_{axial}}{\pi\ D\ t} = \frac{0.636\ L_{axial}}{D\ t}$$

Change in tensile area for three hypothetical rock of different Poisson's ratio



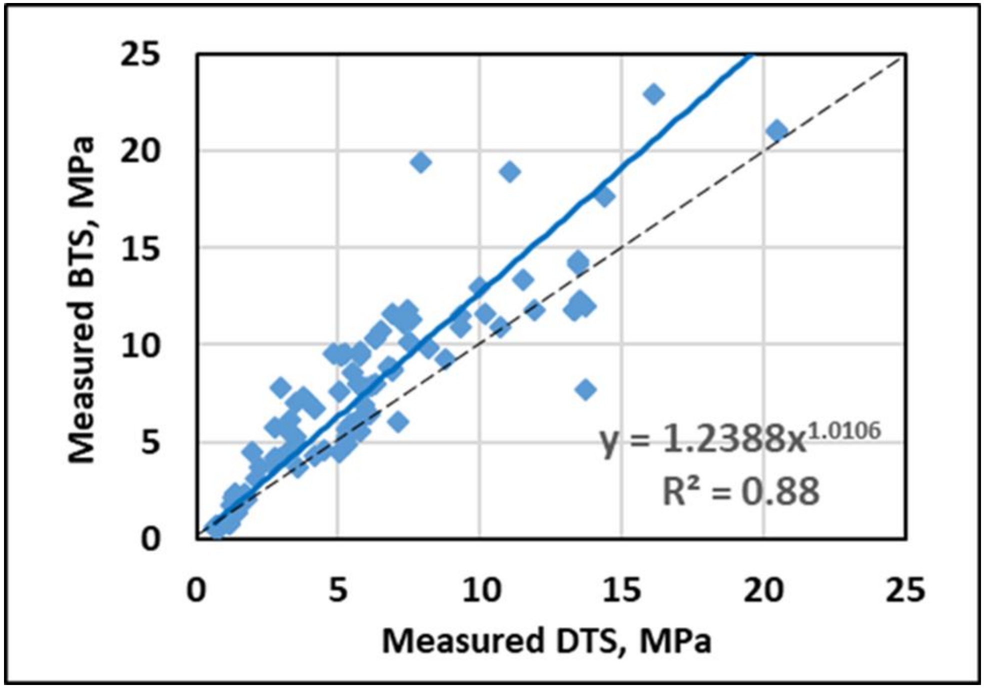
Results and Discussion

DTS, MPa	BTS, MPa	DTS, MPa	BTS, MPa	DTS, MPa	BTS, MPa	DTS, MPa	BTS, MPa
Diyuan, et al., 2013		Fuenkajorn and Klanphumeesri, 2010		Shengwen et al., 2019		Fengqiang et al., 2019	
13.30	11.8	3.59	3.72	8.81	9.30	4.50	4.60
Tugrul and Ozgur, 2014		4.15	4.28	11.50	13.35	5.30	5.20
6.90	8.80	5.79	5.56	3.75	7.30	6.10	6.40
Zalatko et al., 2015		5.79	6.27	5.75	9.45	5.30	5.60
2.96	7.80	10.72	10.95	6.00	7.83	6.00	6.40
5.27	9.54	13.53	12.27	10.20	11.65	6.20	7.90
Tufekci et al., 2016		13.48	14.17	7.44	11.85	Bernie at al., 2007	
13.72	12.0	2.10	3.09	5.30	4.85	0.70	0.60
6.90	8.72	3.50	5.25	2.24	3.70	8.20	9.80
13.45	14.34	5.45	5.93	14.41	17.7	6.30	10.30
5.86	6.21	6.94	11.60	16.12	22.95	7.50	10.10
20.5	21.05	9.33	11.54	Florian, 2015		5.10	9.50
1.75	1.99	5.04	4.49	7.90	19.46	13.30	11.80
1.42	1.29	11.06	18.95	Ghaffar et al., 2005		5.60	5.90
0.69	0.64	3.53	6.98	1.48	2.15	20.50	21.10
5.90	6.90	4.85	9.52	1.70	2.28	13.70	7.70
9.31	10.9	7.60	11.3	1.26	1.73	Servet et al., 2019	
6.33	8.02	1.18	0.77	1.39	2.34	7.39	11.58
6.49	10.68	0.79	0.56	1.28	2.08	2.77	4.15
7.50	10.1	0.66	0.53	1.34	2.26	Servet at al., 2019	
8.20	9.80	0.77	0.60	Richards and Read, 2013		5.68	8.01
6.30	10.3	1.15	0.79	0.86	0.54	7.34	11.16
13.3	11.8	3.59	3.72	2.80	5.72	5.81	9.62
5.60	5.90	4.15	4.28	2.00	4.50	5.04	7.64
7.10	6.00	Zhang et al., 2018					
5.70	8.00	2.72	3.79				
5.10	9.50	2.85	3.96				
3.90	7.10	2.99	4.13				
6.80	8.90	3.13	4.31				
4.20	6.70	3.27	4.48				
11.9	11.8	3.40	4.65				
10.0	13.0	3.54	4.82				
3.30	6.08						

DTS: Measured direct tensile strength

BTS: Measured indirect tensile strength

More than 100 Laboratory Tests Data For Various Types of Rocks



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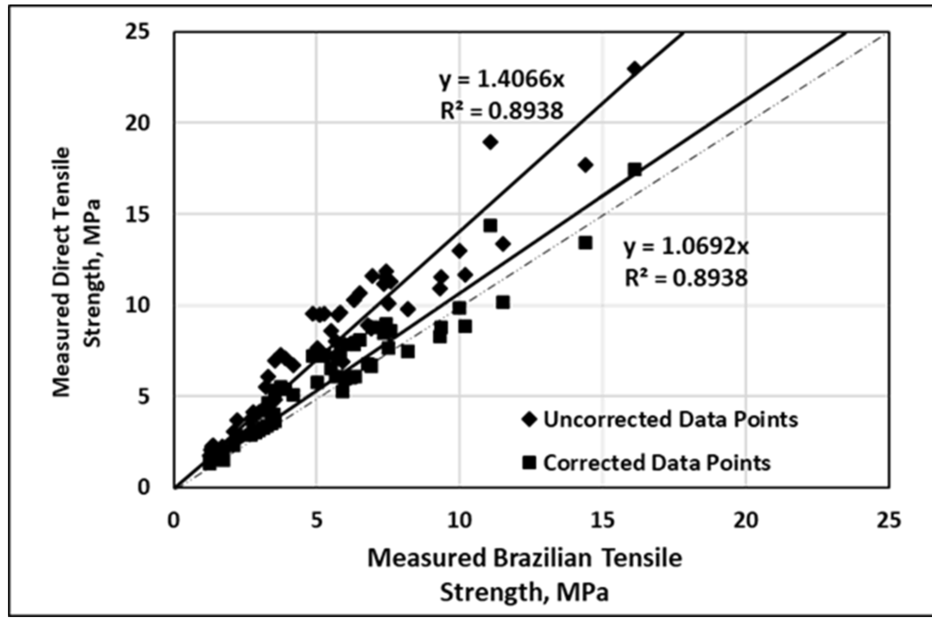
DTS: Measured direct tensile strength

BTS: Measured indirect tensile strength

$$BTS = \left(\frac{1}{\left[\left(\frac{MBTS}{MDTS} \right) \right]} \right) \left(\frac{2\ L_{axial}}{\pi\ D\ t} \right)$$



Results and Discussion

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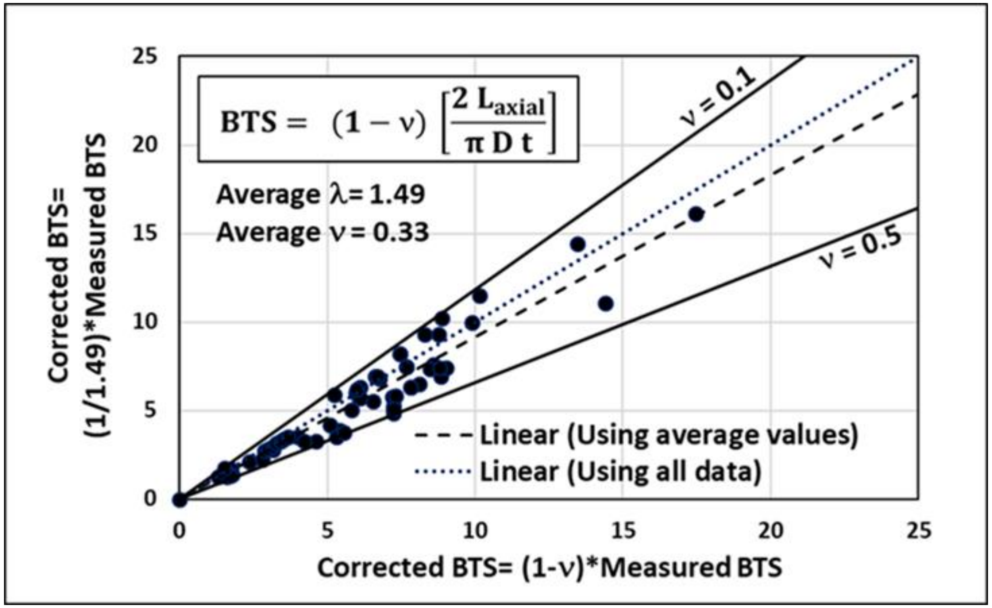
3.30	6.08						

DTS: Measured direct tensile strength

BTS: Measured indirect tensile strength

$$\frac{1}{\lambda} = \left\{ \frac{1}{\left[\left(\frac{MBTS}{MDTS}\right)\right]} \right\} = (1-\nu)$$



Results and Discussion

Poisson's ratio values for common rocks and concrete (Goodman, 1989)

Rock type	Passion's ratio	Rock type	Passion's ratio
Berea Sandstone	0.38	Quartz Mica Schist	0.31
Navajo Sandstone	0.46	Baraboo Quartzite	0.11
Tensleep Sandstone	0.11	Taconic Marble	0.25
Hackensack Siltstone	0.22	Cherokee Marble	0.25
Monticello Greywacke	0.08	Nevada Test Site Granite	0.22
Solenhoven Limestone	0.29	Pikes Peak Granite	0.18
Bedford Limestone	0.29	Cedar City Tantalite	0.17
Tavernalle Limestone	0.30	Nevada Test Site Basalt	0.32
Oneonta Dolomite	0.34	John Day Basalt	0.29
Lockport Dolomite	0.34	Nevada Test Site Tuff	0.29
Flaming George Shale	0.25	Concrete	0.15-0.25
Micaceous Shale	0.29	Chalk	0.35
Dworshak Dam Gneiss	0.34	Saturated clay	0.50

Results and Discussion

$$\mathbf{BTS} = \left(\frac{\mathbf{1}}{\left(\frac{\mathbf{MBTS}}{\mathbf{MDTS}}\right)}\right)\left(\frac{\mathbf{2\,L_{axial}}}{\boldsymbol{\pi}\,\mathbf{D\,t}}\right)$$

$$\mathbf{BTS} = (\mathbf{1} - \boldsymbol{\nu})\left[\frac{\mathbf{2\,L_{axial}}}{\boldsymbol{\pi}\,\mathbf{D\,t}}\right]$$

Results and Discussion

$$BTS = (1 - \nu)\left[\frac{2\,L_{axial}}{\pi\,D\,t}\right]$$

Measured BTS, MPa	Measured DTS, MPa	Measured Poisson's ratio	Corrected BTS, MPa	Error	
				Before $\left(\frac{\lvert DTS - BTS\rvert}{DTS} * 100\right)$	After $\left(\frac{\lvert DTS - CBTS\rvert}{DTS} * 100\right)$
Jianhong at al., 2009					
10.6	6.49	0.17	8.86	63.3%	36.5%
8.02	6.33	0.19	6.50	26.7%	2.7%
10.90	9.31	0.20	8.72	17.1%	6.3%
Shengwen et al., 2019					
8.80	6.90	0.22	6.864	27.5%	0.52%
Habib and Boland, 2004					
14.83	10.97	0.20	11.86	35.2%	8.1%
13.46	11.11	0.20	10.77	21.2%	3.1%
Patel and Martin, 2018					
11.60	8.59	0.26	8.580	35%	0.12%
Average				32.6%	8.2%

Conclusions

Based on the analysis and discussion performed in this study, the following conclusions are obtained:

1. The conventional Brazilian indirect tensile strength formula provides overestimated valued for the measured tensile strength if compared to the direct tensile strength test.
2. Incorporating the term (1-Poisson's ratio) into the conventional Brazilian indirect tensile strength formula provided more reasonable tensile strength values for most rocks and rock-like geomaterials having Poisson's ratio value between 0.10 and 0.45.

Conclusions

3. The modified Brazilian indirect tensile strength formula (MBTS= 2(1-ν)L/πDt) has been checked using published data and the average error of estimate between measured direct tensile strength and the corrected measured Brazilian indirect tensile strength was 8% compared to the 32.6% before correction.

4. If thickness to diameter ratio of the tested sample is not equal to 0.5, then any suitable correction term can be easily integrated with the modified Brazilian indirect tensile strength formula developed by this study.

Conclusions

5. To get solid conclusion regarding the modified Brazilian indirect tensile strength formula (MBTS= 2(1-ν)L/πDt) developed by this study, more related experimental data are required for additional verification.

$$\mathbf{BTS} = (1-\nu)\left[\frac{2\,L_{axial}}{\pi\,D\,t}\right]$$

Correction Factor

Thank You

Modification of the Brazilian Indirect Tensile Strength Formula for Better Estimation of the Tensile Strength of Rocks and Rock-like Geomaterials

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