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Original article

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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ABSTRACT

Rock mechanical properties are essential input in many design applications in petroleum, mining, environmental and civil engineering. The most reliable source for these properties is the laboratory tests. Among these important rock mechanical properties are the tensile strength. Tensile strength can be measured directly and indirectly. For rocks, the indirect tensile test is the most convenient in terms of samples preparation, testing requirements, and availability of appropriate standards. The most common experimental method used to indirectly estimate tensile strength of rocks is called Brazilian indirect tensile test. 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 work is the investigation of potential modification of the Brazilian indirect tensile strength formula by the analysis of the relevant published laboratory data.

Based on the analysis performed in this study, using published laboratory measurements, the conventional Brazilian indirect tensile strength formula has been modified by the incorporation of Poisson's ratio effect ($BTS = 2(1-\nu)L/\pi Dt$). The modified Brazilian indirect tensile strength formula was validated using another set of published laboratory data for various rocks and rock-like geomaterials other than that used initially in the modification process. Direct tensile strength values have been estimated; for various types or rocks; using the modified Brazilian indirect tensile strength formula with an average error of estimate as low as 8% compared to 32.6% before correction. Therefore, the modified Brazilian indirect tensile strength formula ($BTS = 2(1-\nu)L/\pi Dt$) is very promising and suitable for most rocks and rock-like geomaterials having Poisson's ratio value lies between 0.10 and 0.45.

1. Introduction

The evaluation of rock mechanical properties is of great importance for petroleum, mining and civil engineering design projects as shown in Table 1. Rock mechanical properties include elastic modulus, Poisson's ratio, and rock strength (tensile strength, uniaxial compressive strength, and frictional properties). These rock properties can be estimated from laboratory standard tests or from in-situ (field) tests. When the rock samples are not available, well log and geophysical data can be used to predict the required mechanical parameters with less accuracy. To ensure accuracy and similarity, International standards (ISRM and ASTM) have been set and approved for all conventional mechanical tests.

To overcome errors may have been incorporated during laboratory or field tests, safety factors are normally utilized in all corresponding design applications based on the measured rock mechanical properties.

In average, tensile strength of rock is roughly equal to 10% of its compressive strength value. Thus, a rock is more likely to fail in tension than in compression (Gao, 2017). There are numerous tests for rock tensile strength measurement such as direct pull test, hollow cylinder test, sleeve fracturing test, Brazilian indirect tensile test, etc. (Matthew and Mark, 2014). The Brazilian indirect tensile test was invented in the 1940s by Brazilian and Japanese scholars (Matthew and Mark, 2014). Brazilian indirect tensile test is widely used due to its simplicity; in terms of test specimen's preparation and test conduction; amongst the most popular tension tests for rocks and rock-like geomaterials (Wang et al., 2004; Coviello

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Table 1
Application of rock mechanical properties in various engineering disciplines.

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, 2020).
Mining Engineering	Rock blasting, Drilling, Crushing and grinding, Deep mining hole stability, Ores extraction, Roof protection, Open pit mines, etc. (Zhang, 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).

et al., 2005; Aydin and Basu, 2006). There are two internationally approved standards of testing procedures for measuring the indirect tensile test, ISRM and ASTM, that have been suggested by International Society for Rock Mechanics (Bieniawski and Hawkes, 1978; ISRM, 1978) and by the American Society for Testing and Materials (ASTM, 2004), respectively. The Brazilian (splitting) tensile test is performed by compression with diametrically opposite concentrated loads on a rock specimen (disc) as shown in Fig. 1. The conventional Brazilian indirect tensile strength is calculated using the following conventional formula for isotropic, homogenous and linear elastic materials tested according to the above mentioned standards:

$$\mathrm{BTS} = \frac{2L}{\pi D t} \quad (1)$$

Where:

BTS = Maximum value of the Brazilian indirect tensile strength, MPa.

D = Test specimen diameter, m.

t = Test specimen thickness, m.

L = Applied axial load at failure, kN.

Eq. (1) has been derived based on stress analysis shown in Fig. 2 under conditions of line load contact (Fig. 1B) where the test specimen fails near the load points due to compressive stresses assuming isotropic, homogenous, and linear elastic behaviour of the tested material (Kennedy and Ronald Hudson, 1968). Line load means that the upper and lower compression machine platens (jaws) touch the test sample circumferential area by a line trace as shown in (Fig. 1B). Under line load conditions, it is assumed that the test sample split into approximately two identical halves with no compressional damage at the points of contact between the machine platens (compressional elements) and the test specimen. The experimental setups shown in Fig. 1 deliver different tensile strength values. If the curved loading setup is used, then Eq. (1) needs to be corrected (Li et al., 2013; Richards and Read, 2013). Several previous studies; related to the Brazilian tensile formula; have been performed to study the following issues:

1. The effect of test specimen thickness to diameter ratio on the measured tensile strength using Brazilian indirect tensile test.
2. The effect shape of contact between the test specimen and the compression elements during the Brazilian indirect tensile test.
3. The effect of beddings and laminations orientation on the Brazilian indirect tensile strength measurements.
4. The distribution of the tensile and compression stresses on the test specimen during the Brazilian indirect tensile test using numerical analysis and finite element analysis.
5. The relationship between tensile strength and uniaxial compressive strength and other rock properties.
6. The effect of loading rate on the values calculated by the Brazilian indirect tensile strength test.
7. The relationship between direct tensile strength and indirect tensile strength values of various types of rocks.

It is well known that tensile strength determined from direct (pull test) and indirect (Brazilian test) methods are rarely equivalent. Several researchers reported that the Brazilian indirect tensile test provides over estimated values when compared to the direct tensile test by up to ≈25% (i.e. DTS = 0.75BTS) (Kennedy and Ronald Hudson, 1968; Serati and Williams, 2019, Derek, 2014; Li et al., 2013). It is well known that direct pull test provides the most accurate tensile strength, while Brazilian indirect tensile strength test and confined direct tensile test provide overestimated values as shown in Fig. 3. In a recent study (Serati and Williams, 2019), the Brazilian indirect tensile strength formula (Eq. (1)) has been modified by the incorporation of thickness to diameter ratio (t/D) and Poisson's ratio (ν) as follows:

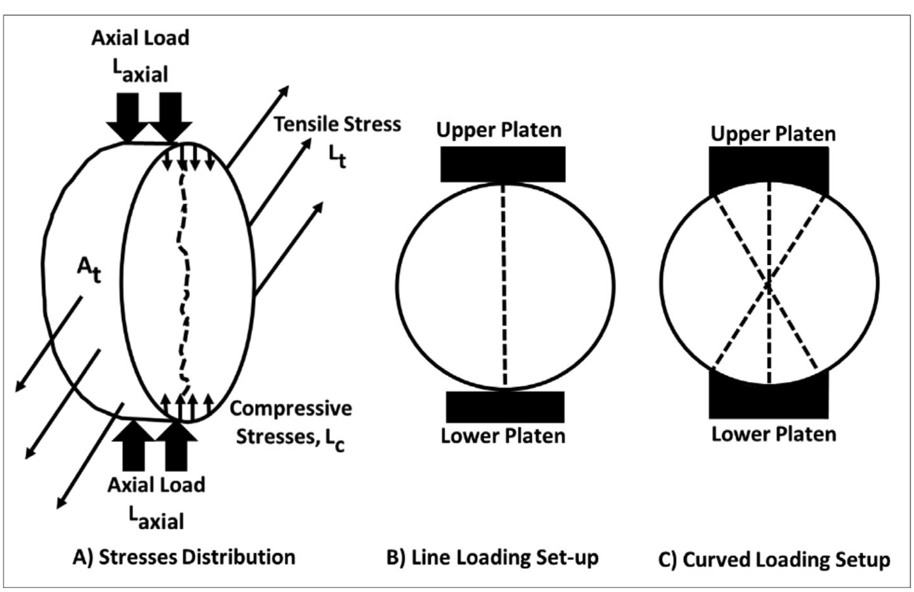

Fig. 1. Schematic diagram of the Brazilian tensile test.

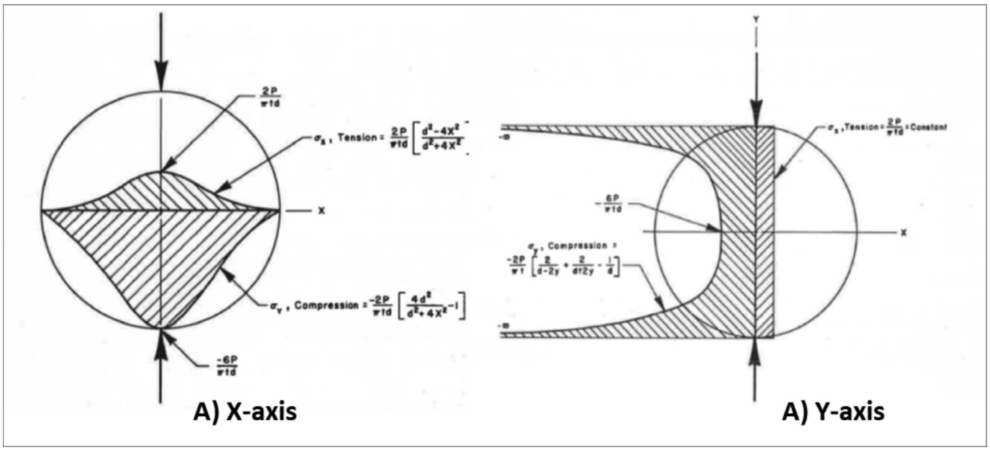

Fig. 2. BTS stress distribution on x- and y-axis (Serati and Williams, 2019).

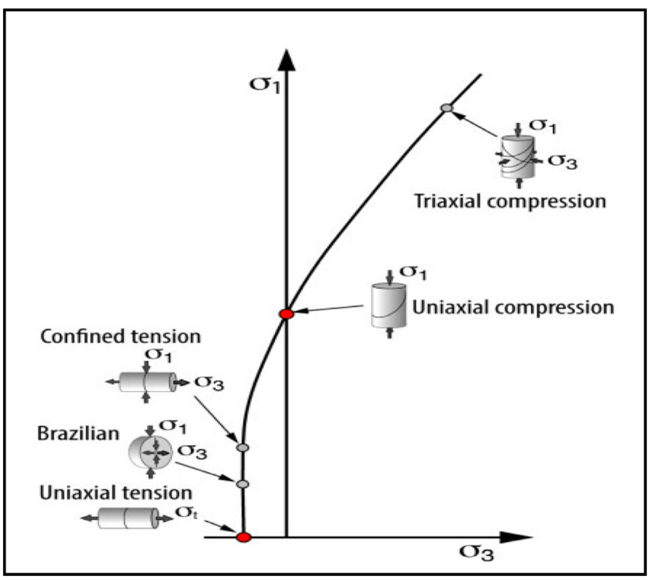

Fig. 3. Laboratory tests used to establish rock failure criteria (Derek, 2014).

$$BTS = \left(\frac{L}{D^2}\right)(4 - 0.15\nu)\left(0.2 + 1.7e^{\left(-5.5\frac{t}{D}\right)}\right) \quad (2)$$

Where:
ν = Poisson's ratio.

Eq. (2) has been developed based on laboratory measurements for granite and monzonite and it is mainly suitable for hard and brittle rocks and rock-like geomaterials.

Matthew and Mark (2014) reviewed the concepts and testing of the conventional Brazilian indirect tensile strength formula by introducing correction coefficients which exist when using the main rock types such that the factor (f) in Eq. (3) equal to 0.9 for metamorphic, 0.8 for igneous and 0.7 for sedimentary rocks.

$$DTS = f\,BTS \cdots \quad (3)$$

Zhang et al. (2018) concluded in their paper that the tensile strength estimated from the direct tensile test is normally lower than that estimated from the Brazilian test by a factor of 0.6 to 0.71 (i.e. the DTS/BTS ratio varied from 0.60 to 0.71). Briševac et al. (2015) concluded in their article that: "A large number of papers were made for the scientific purposes and did not have any practical application. Accordingly, there is actually a rather small number of papers which may be used to improve the Brazilian test. Therefore, it is necessary to determine more precisely the correction coefficients for the estimate of direct tensile strength by the Brazilian test for all types of materials, in order to obtain the optimum results" (Briševac et al., 2015).

The objective of this study is to develop a potential adjustment (correction) for the Brazilian indirect tensile strength formula by performing a comparison study between measured direct tensile strength (direct pull test) and measured indirect tensile strength (Brazilian test) using relevant literature experimental data for various types of rocks and rock-like geomaterials.

2. Methodology of the study

To achieve the above mentioned objective, the subsequent methodology has been followed in this study:

- Collecting and analyzing published data (BTS, DTS and Poisson's ratio) relevant to the objective of this study. Only data measured in accordance with ASTM or ISRM standards have been selected.
- Studying theory behind the Brazilian indirect tensile strength formula.
- Investigating the potential modification of the Brazilian indirect tensile strength formula for better estimation of the tensile strength.
- Validating the modified Brazilian indirect tensile strength formula using different set of experimental data from the literature.

3. Modification of the BTS formula

In addition to the theoretical background mentioned in the introduction on the historical development of the Brazilian indirect tensile test, this conventional formula (Eq. (1)) can be derived by another approach. At the maximum tensile strength conditions, the circumferential area of the two halves of the diametrically loaded test disc are subjected to induced tensile stresses. The circumferential area subjected to the tensile stress (A_t) can be calculated as follows (see Fig. 1A):

$$\text{Tensile Area} = 0.5\ (2\pi r\ t) = (\pi\ r\ t) = (\pi\ (D/2)\ t) \quad (4)$$

The general formula for Brazilian indirect tensile strength (Eq. (1)) can be obtained by dividing the applied diametrical load (L_{axial}) by the area subjected to tensile stress (Eq. (4)) as follows:

$$\text{Max.BTS} = \frac{L_{axial}}{\pi(D/2)t} = \frac{2L_{axial}}{\pi Dt} = \frac{0.636L_{axial}}{Dt} \tag{5}$$

Eq. (5) provides the maximum tensile strength value assuming the entire axial load is fully transformed to lateral tensile stress that created the fracture in the test sample (Fig. 1A) which is not applicable for all rock types (Kennedy and Ronald Hudson, 1968). For diametrically loaded rock disc, the applied and induced compressive ($L_{compressive}$) and tensile ($L_{tensile}$) stresses are governed by the following equation:

$$L_{axial} = L_{tensile} + L_{compressive} \tag{6}$$

The interpretation of Eq. (6) is that; for some kind of rocks; part of the applied axial (diametrical) load will be transformed to axial induced compressive stresses and the remaining load is transformed to the lateral induced tensile stresses as shown in Fig. 4 (Rocha and Wahrhaftig, 2016). Since Poisson's ratio controls the relationship between axial (longitudinal) and lateral strains, the compressional load ($L_{compressive}$) can be replaced by (νL_{axial}). Therefore, Eq. (6) can be transformed to the following form:

$$L_{tensile} = L_{axial} - \nu L_{axial} = (1-\nu)L_{axial} \tag{7}$$

The above hypothesis (Eq. (7)) is supported by Jianhong et al. (2009) in their study to estimate of the tensile elastic modulus using Brazilian disc by applying diametrically opposed concentrated loads in which they concluded that the axial compressive stress (σ_y) is about two times than the absolute value of the lateral tensile stress (σ_x) at the centre part of the Brazilian disc. Therefore, the tensile strain generated by the vertical compressive stress due to Poisson's effect (ν) must be considered.

However, the tensile strain contributed by the vertical compressive stress (σ_y) usually accounts for a small proportion of the total tensile strain, because Poisson's ratio usually is a small value of 0.1–0.45 for rocks. That is to say, the lateral tensile stress (σ_x) represents the majority in the total tensile strain. Therefore, a modified form of the conventional Brazilian indirect tensile strength formula (BTS) can be obtained as follows:

$$\text{BTS} = \frac{\text{Load}}{\text{Area}} = \frac{(1-\nu)L_{axial}}{\pi(D/2)t} = (1-\nu)\frac{0.636L_{axial}}{Dt}\cdots \tag{8}$$

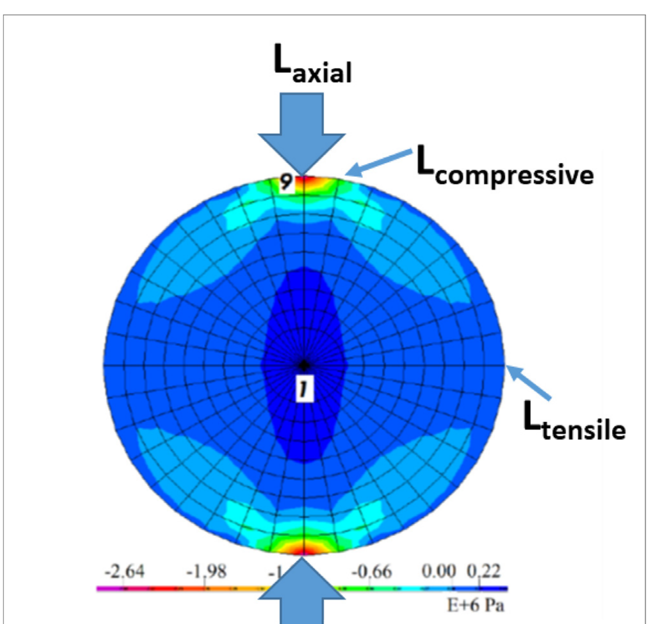

Fig. 4. Distribution of induced compressive and tensile induced stresses in the test specimen during BTS test (Rocha and Wahrhaftig, 2016).

The term (1−ν) in Eq. (8) is the correction factor proposed by this study for the modification of the conventional Brazilian indirect tensile strength formula. For rocks of small Poisson's ratio, Eq. (8) provides the maximum value for tensile strength and vice versa.

4. Verification of the modified BTS formula

The proposed modified Brazilian formula for indirect tensile strength estimation (Eq. (8)) has been verified by two different methods as follows:

4.1. Theoretical verification approach

Three hypothetical rocks types having Poisson's ratio equal to 0.01, 0.10 and 0.20 are inserted into Eq. (8) and the results are plotted in Fig. 5. It can be seen that rocks of small Poisson's' ratio has high tensile strength. While for rocks with moderate to high Poisson's ratio have a smaller tensile strength as indicated by the drop in the constant of the Brazilian indirect tensile formula from 0.636 to 0.509 for Poisson's ratio values of 0.01 and 0.2 respectively.

For case 1 shown in Fig. 5, the BTS constant has been found equal to 0.636 using tensile stress affected area (rhombus) within the test sample. A similar value (0.636) of the BTS constant has been estimated using the correction factor of Eq. (5) which given by (1−ν).

In previous studies, the compressional area is calculated based on visual inspection of the test sample after test termination. However, as shown in Fig. 5, the incorporation of Poisson's ratio effect into the conventional BTS formula (Eq. (8)) has been replaced this tedious inspection process. These results (see Fig. 5) are indicating that Eq. (8) is a promising modification for the conventional Brazilian indirect tensile strength formula. However; in the next section; related experimental data from the literature will be used for additional verification of the modified BTS formula (Eq. (8)).

4.2. Experimental verification approach

For additional verification of the modified Brazilian indirect tensile formula (Eq. (8)); developed in this study; laboratory data for direct and indirect (Brazilian) tensile strength for various types of rocks and rock like geomaterials have been collected and presented in Table 2. More than one hundred data pairs (BTS and DTS) have been collected from various literature resources did not contain even a single identical pair. Direct tensile strength and Brazilian indirect tensile strength data shown in Table 2 have been plotted as shown in Fig. 6. It is clear from Table 2 and Fig. 6 that the overall trend is showing that the measured Brazilian tensile strength provided a higher value when compared to the measured direct tensile strength.

Using data shown in Table 2, values of λ (measured BTS/measured DTS) have been plotted against calculated Poisson's ratio equivalent ($(\lambda-1)/\lambda$) as shown in Fig. 7.

λ values between 1.0 and 1.6 on the y-axis of Fig. 7 have been selected since they provide realistic Poisson's ratio values covering the normal range for common rock and rock-like geomaterials (0.10–4.5). Therefore, data in Table 2 that provided Poisson's ratio less than 0.10 or greater than 4.5 have been omitted in any analysis beyond this point. By this assumption, the remaining data (61 data pairs) have been used to plot Fig. 8. The average ratio (λ) of measured Brazilian tensile strength (MBTS) to measured direct tensile strength (MDTS) has been found equal to 1.49. This ratio has been transformed to Poisson's ratio as shown in Eq. (9).

$$\nu = \frac{(\lambda-1)}{\lambda} = \left\{\frac{\left[\left(\frac{MBTS}{MDTS}\right)-1\right]}{\left[\left(\frac{MBTS}{MDTS}\right)\right]}\right\} = 0.33\cdots \tag{9}$$

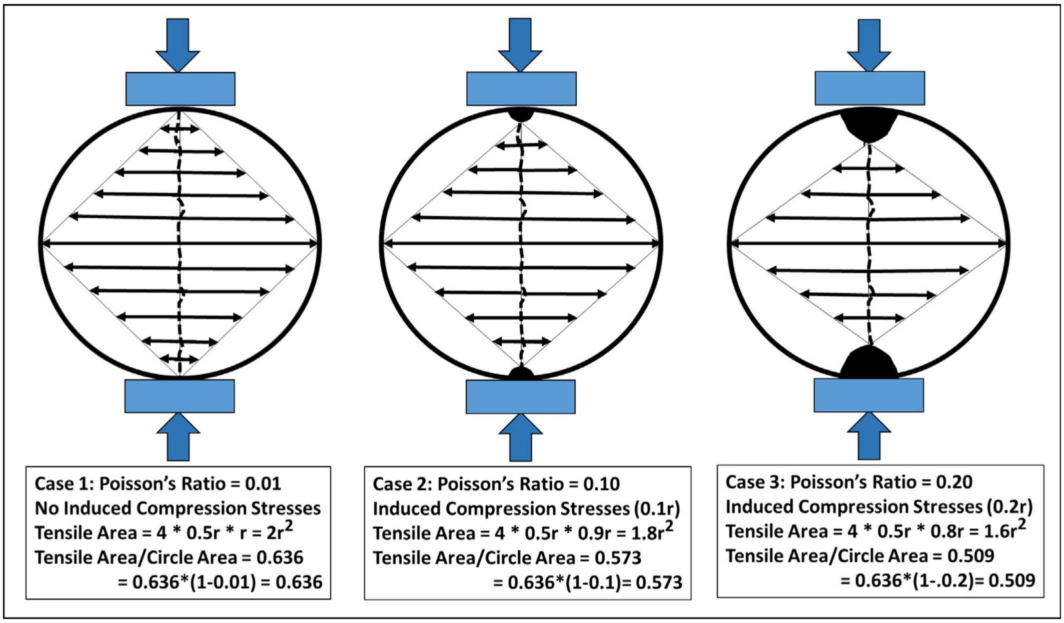

Fig. 5. Change in tensile area for three hypothetical rock of different Poisson's ratio.

Table 2
Measured direct and indirect tensile strength of various rock types.

DTS, MPa	BTS, MPa	DTS, MPa	BTS, MPa	DTS, MPa	BTS, MPa	DTS, MPa	BTS, MPa
Li et al. (2013)		Fuenkajorn et al. (2010)		Shengwen et al., 2019		Gong et al. (2019)	
13.30	11.8	3.59	3.72	8.81	9.30	4.50	4.60
Unlu and Yilmaz (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 et 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	Menschik (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	Demirdag 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	Demirdag et 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.

The calculated average value of Poisson's ratio for the investigated data has been found equal to 0.33 as shown in Eq. (9). Therefore, Eq. (10) represents the first step to improve the Brazilian indirect tensile strength.

$$BTS = \left(\frac{1}{\lambda}\right)\left(\frac{0.636L_{axial}}{Dt}\right)\cdots \quad (10)$$

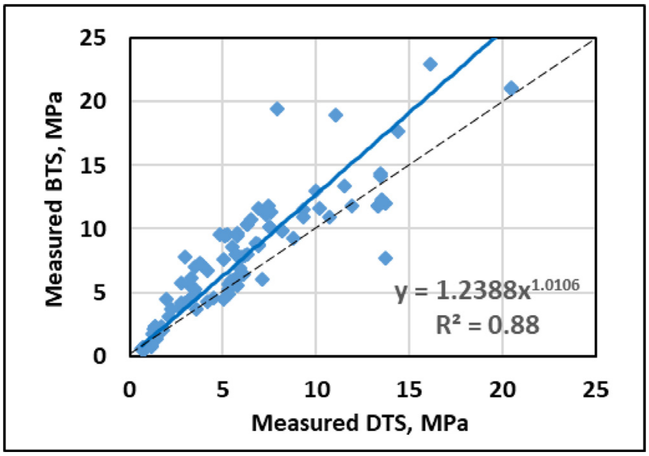

Fig. 6. Relationship between measured direct and indirect (Brazilian) tensile strength of various rock types.

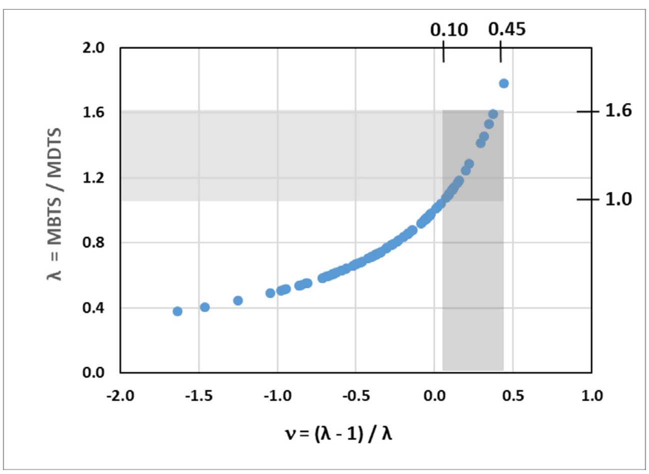

Fig. 7. Relationship between Poisson's ratio and λ = (BTS/DTS).

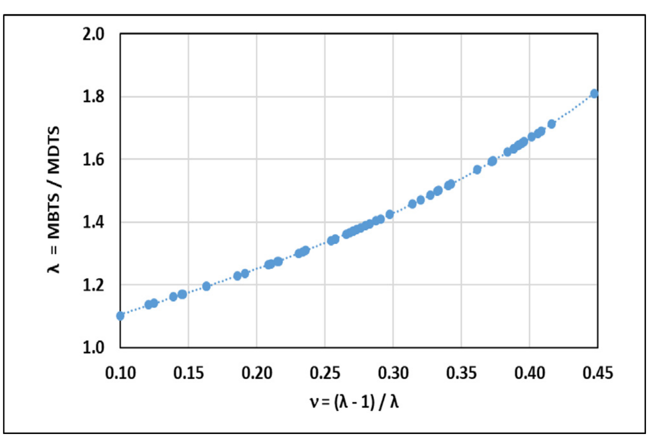

Fig. 8. Relationship between Poisson's ratio and λ = (BTS/DTS).

[Fig. 9](#) represents the plot of the measured DTS and BTS before correction. It can be observed; from Fig. 9; that the line fitting direct tensile strength and indirect tensile strength (Brazilian test) data before correction is diverged far from the 45-degree line indicating that Brazilian indirect tensile test provide overestimated values compared to the direct tensile strength test.

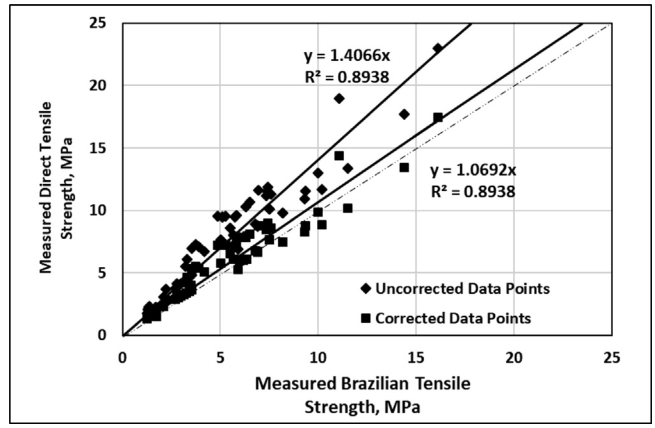

Fig. 9. Relationship between corrected and uncorrected BTS and DTS.

When values of the measured Brazilian indirect tensile strength have been corrected using λ values and Eq. (10), the data points have been moved closer to the 45-degree line indicating the success of the proposed BTS modification approach presented by this study (Eq. (10)).

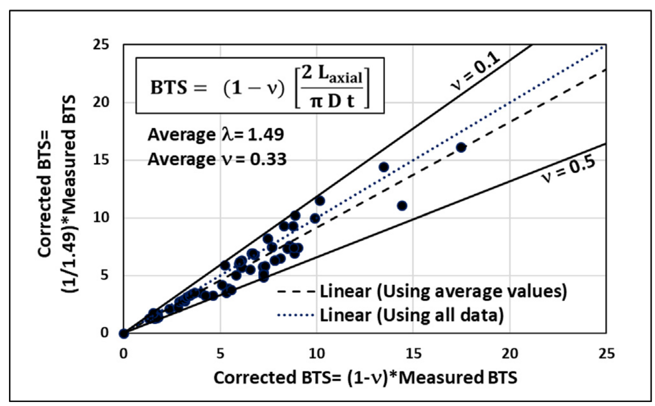

Fig. 10. Corrected BTS using λ and Poisson's ratio.

$$BTS = (1 - \nu)\left[\frac{2L_{axial}}{\pi Dt}\right] \cdots \quad (11)$$

If λ is replaced by Poisson's ratio (ν), Eq. (10) transforms to Eq. (11). The cross plot between corrected BTS data using λ and corrected BTS data using $(1-\nu)$ is presented in Fig. 10.

Fig. 10. Corrected BTS using λ and Poisson's ratio.

It can be observed from Fig. 10 that data points are located around the 45-degree line indicating that Eqs. (10) and (11) are identical. Therefore, $(1-\nu)$ can be considered as an appropriate correction factor as shown in Eq. (11). Therefore, realistic estimated values of the tensile strength of rocks and rock-like geomaterials can be estimated from the laboratory measured Brazilian indirect tensile strength using Eq. (11). The modified Brazilian indirect tensile strength formula (Eq. (11)) can be used if real Poisson's ratio is known. If real Poisson's ratio is not available, it can be estimated from published rock mechanical databases as shown in Table 3. To set boundaries for data shown in Fig. 10, ν = 0.1 and ν = 0.45 have been inserted into Eq. (11) and the result are the upper and the lower solid lines. It can be observed that all data used to develop Eq. (11) are located within these boundaries indicating that the process of developing Eq. (11) is successful.

Table 3
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

For further verification of the modified Brazilian indirect tensile strength formula (Eq. (11)), published laboratory data other than that presented in Table 2 have been used. The results are documented in Table 4.

It is clear that the modified Brazilian indirect tensile formula (Eq. (11)) provides reasonable correction for the measured Brazilian indirect tensile strength where the average error of estimate has been dropped from 32.6% to 8% for the investigated data presented in Table 4. Table 5 and Fig. 11 show a comparison between the modified Brazilian indirect tensile strength Eq. (11) and the modified Brazilian indirect tensile strength (Eq. (2)) by Serati and Williams (2019) using the same set of laboratory measured data.

It is clear that the term $(1-\nu)$ made the current modified Brazilian indirect tensile strength formula (Eq. (11)) dynamic enough to adjust its output according to rock Poisson's ratio value. On the other hand, Poisson's ratio in Serati et al. model has negligible effect as shown in Table 4 and Fig. 11.

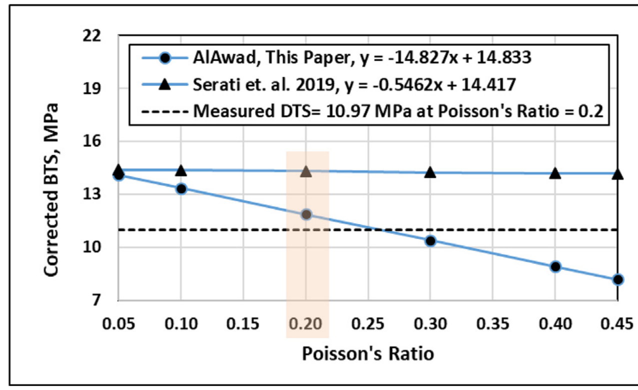

Fig. 11. Comparison between corrected Brazilian formulas (Eqs. (2) and (11)).

In another study, Serati et al. (2018) stated that "the induced tensile stress; at the centre of sample tested using the Brazilian indirect tensile strength test; is function of Poisson's ratio. If Poisson's ratio increases from 0 to 0.5, the tensile stress decreases in magnitude. Nevertheless, the sensitivity of the tensile stress to the Poisson's ratio is less noticeable compared to its variation to the change of t/D".

However, as shown in Fig. 11, and change in Poisson's ratio will notably affect the Brazilian indirect tensile strength calculated using Eq. (11) developed in this study. Therefore; based on the analysis conducted in this study; a promising modification of the Brazilian indirect tensile strength formula has been achieved. The modified Brazilian indirect tensile strength formula (Eq. (11)) is applicable for all types of rocks and rock-like geomaterials having Poisson's ratio in the range from 0.10 to 0.45. Although the analysis of this study has revealed the validity of the modified Brazilian indirect tensile strength formula developed in this study (Eq. (11)) more related data; similar to that shown in Table 4; are required for extra verification.

Table 4
Verification of the modified BTS formula (Eq. (11)).

Measured BTS, MPa	Measured DTS, MPa	Measured Poisson's ratio	Corrected BTS using Eq. (11)	Error	
				$\left(\frac{\lvert DTS-BTS\rvert}{DTS}*100\right)$ Before	$\left(\frac{\lvert DTS-CBTS\rvert}{DTS}*100\right)$ After
Jianhong et 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)					
8.8.0	6.90	0.22	6.864	27.5%	0.52%
Alehossein 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%

Table 5
Comparison between this study and Serati and Williams (2019).

Passion's ratio	BTS, MPa	DTS, MPa	Corrected BTS, MPa	
Data obtained from Alehossein and Boland (2004)			Eq. (2) Serati and Williams (2019)	Eq. (11) Current study
0.2	14.83 Error = 35.2%	10.97	14.31 Error = 30.5%	11.86 Error = 8.1%

5. Conclusions

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

1. 1 The conventional Brazilian indirect tensile strength formula provides overestimated values 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.
3. The modified Brazilian indirect tensile strength formula ($MBTS = 2(1-\nu)L/\pi Dt$) 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 into the modified Brazilian indirect tensile strength formula (Eq. (11)) developed by this study.
5. To get solid conclusion regarding the modified Brazilian indirect tensile strength formula (Eq. (11)) developed by this study, more related data are required for additional verification.

Declaration of Competing Interest

The author declares that he have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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