Silesian
University
of Technology

RESEARCH
UNIVERSITY
EXCELLENCE INITIATIVE
Ministry of Science
and Higher Education

A STUDY OF ROCK RESPONSE TO FAILURE IN THE CONTEXT OF THE BENDING PROPERTIES AND COMPARISON WITH UNIAXIAL TENSILE AND COMPRESSION BEHAVIOUR

24 - 27 May, 2022 / Kryvyi Rih, Ukraine

3rd International Conference on Sustainable Futures:
Environmental, Technological, Social and Economic Matters

BAgrSc, MSc, PhD **Krzysztof Tomiczek** / Asst. Prof.

Co-Coordinator 6.1. Priority SUT Research Sub-Area
POB6.1 Climate and Environmental Changes and Reduction of Air Pollution

Faculty of Mining, Safety Engineering and Industrial Automation
Department of Geoengineering and Raw Materials Extraction
Silesian University of Technology, Gliwice, Poland

Plan of presentation

1. ABSTRACT

The phenomenon of rock *bending* occurs during (all) underground exploitation, construction of underground excavations and tunnels, and even rising heading - shafts.

It is also common in building engineering, e.g., in the case of floors. Rocks and concretes as granular materials on the aggregate scale are fractured as a result of exceeding shear and tensile strength. In a complex state of stress - bending, crack propagation occurs from tensioned to compressed *fibres*.

Three-point bending tests of medium-grained *quasi* homogeneous and isotropic sandstone were tested for strength and deformation properties of rocks.

The *E* deformability modules for compressed and tensioned *fibres* as well as strains at failure were determined. The results of three-point bending were compared with the results of uniaxial compression and direct tension. Clear differences were found in the values of strengths, moduli of deformation and strains at failure.

2. INTRODUCTION. JUSTIFICATION OF THE SUBJECT.

A commonly used material constant describing the strength properties of rocks, but also concretes, composite granular materials and cohesive soils are the one- (and three-) axial compression strength. The use of this constants as a strength parameter is usually sufficient to solve most problems in the field of geomechanics, geotechnics and strength at the engineering level.

However, materials such as rocks and concrete are in fact fractured by shearing and/or tensioning, which already occur at the level of grain aggregates.

Compression and shear tests are in common use, while uniaxial tensile tests are much less common.

Failure of rocks is often due to *flexure*. Bending of rock layers occurs in the case of underground chamber roofs, mining excavations, tunnels and even rising headings at high horizontal stress values. Also in building engineering, the problem of bending of floors is key when designing ground-based and underground structures.

2. INTRODUCTION. JUSTIFICATION OF THE SUBJECT.

Bending tests of rock beams are (very) rare.

This is primarily due to the difficulty of obtaining and making rock samples with recommended accuracy, as well as the need to compare with the results of other strength tests, e.g., uniaxial tensile tests.

Although the phenomenon of rock damage and failure occurs in many cases as a result of their *flexure*, issues related to rock stability are solved primarily on the basis of compression and shear constants.

Similarly, in the numerical modelling the basic constants are already mentioned constants and constants related to shear strength such as cohesion c or angle of internal friction φ.

Few tests of rocks indicate, however, that bending strength σ_B should not be equated with tensile strength σ_T.

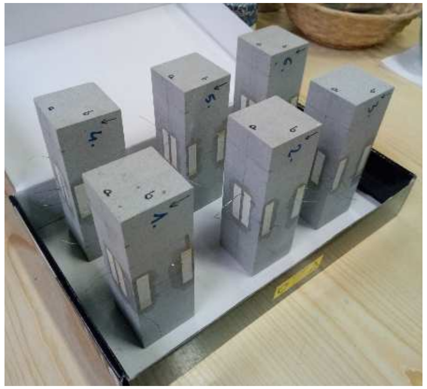
It also turns out that the properties of rock material subjected to bending are definitely different from that characteristic of rocks under compression or tension.

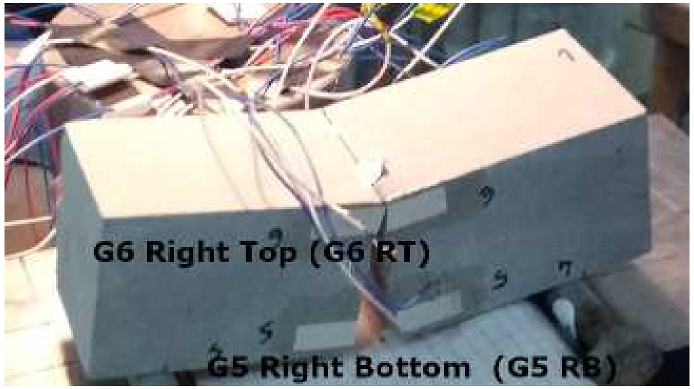
3. LABORATORY TESTS. MATERIALS AND METHODS.

Samples of medium-grained homogeneous and isotropic *Brenna* sandstone were tested. The properties of this sandstone have been well known as a result of self-research conducted in previous years.

***Brenna* sandstone is a medium-compactness light grey sandstone with a green, fine-grained shade with a random texture. A standard testing machine EDZ-40 was used for the tests. Cuboid samples with dimensions of 15×5×5cm (*h*×*a*×*b*) were made in accordance with the recommendations of the ISRM.**

Strains ε were measured by latticed strain gauges and by the strain gauge HBM bridge. A system of the 6 strain gauges glued in the middle of the sample height.





4. METHODOLOGY OF CALCULATION.

Some authors, e.g., Hobler, equate bending strength σ_B with tensile strength σ_T (in bending test) and state that σ_B is calculated:

$$\sigma_T (= \sigma_B) = \frac{2}{3} \cdot \frac{F \cdot l}{b \cdot h^2}, \text{ Pa}$$

where:

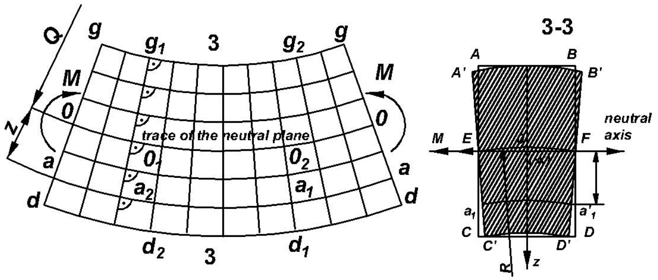
σ_T (=σ_B) - tensile strength determined in the three-point bending test, Pa,

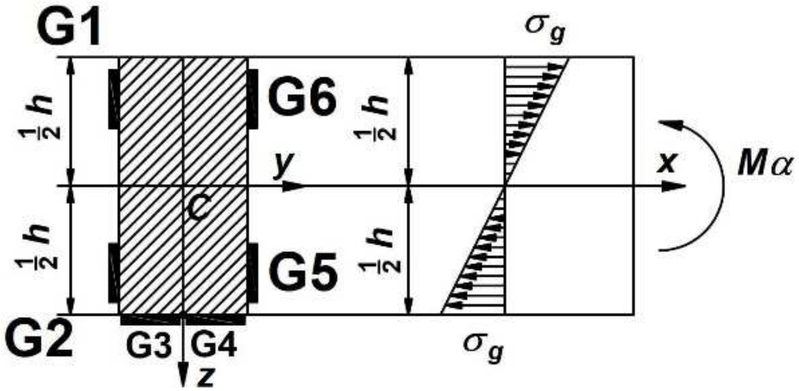
F- point load, N,

l - distance between supports, m,

h - beam height, m,

b - beam base (width), m.





Knowing the value of bending strength σ_B(=σ_x), one can determine the value of the elastic modulus E_b of tensile beam *fibres*.

$$E_b = \frac{\sigma_x \cdot \delta}{z}$$

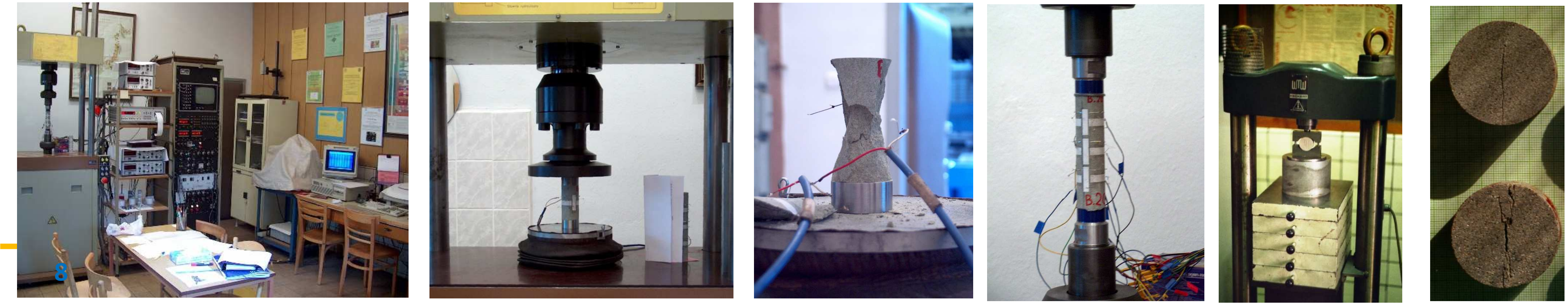
where:

E_b - modulus of elasticity of tensioned *fibres*, GPa,

$\sigma_x = \sigma_B$ – concurrently, (after Jastrzębski et al., 1985).

5. RESULTS OF LABORATORY TESTS.

The results of the *Brenna* sandstone bending tests were compared with the results of other tests self-carried out in previous years. *Brenna* sandstone has already been subjected to uniaxial compression, uniaxial tension and tensile tests using the *Brazilian* method.



Tab. 1. *Brenna* sandstone constants calculated on the basis of uniaxial compression, uniaxial tension and tensile *Brazilian* tests. Constant values calculated in the three-point bending test: ε_{xmax} - strains along the *x* axis (axial) at the failure, $\sigma_T(=\sigma_B)$ - tensile strength under the three-point bending test , E_b - modulus of elasticity of *fibres* under tensile stress along the *x* axis.

Uniaxial compression test *h*:*d*=2, *h*=84mm				Uniaxial tension test *h*:*d*=4, *h*=168mm				*Brazilian* test *h*:*d*=0.5, *h*=21mm		Three point bending test (1st series)			
Sample	σ_C	ε_{zmax}	E_c	Sample	σ_T	ε_{zmax}	E_T	Sample	σ_{TB}	Sample	ε_{xmax}	σ_B	E_b
No.	[MPa]	[%]	[GPa]	No.	[MPa]	[%]	[GPa]	No.	[MPa]	No.	[%]	[MPa]	[GPa]
B1	95.80	0.65	12.76	B20	3.15	0.07	4.89	B41	5.48	Bb21	-	8.98	-
B2	97.40	0.62	13.85	B21	3.54	0.09	4.13	B42	6.42	Bb22	0.16	9.16	5.67
B10	92.30	0.62	12.96	B23	3.63	0.08	4.46	B43	5.10	Bb23	0.17	10.14	5.98
B11	93.70	0.62	12.44	B30	2.74	0.04	6.65	B44	5.74	Bb24	0.16	9.34	5.75
B13	95.10	0.63	12.96	B31	2.84	0.09	3.93	B45	5.67	Bb25	0.17	9.00	5.37
Average	94.86	0.63	12.99	Average	3.18	0.07	4.81	Average	5.68	Bb26	0.17	9.29	5.32
										Average	0.17	9.32	5.62

5. RESULTS OF LABORATORY TESTS.

Comparing the values of strains at the failure strength obtained on the basis of three-point bending tests ε_x, and uniaxial compression and tensile ε_z, several interesting conclusions can be drawn:

- the absolute value of compressive strains of compressed *fibres* at the failure strength in the upper part of the sample under bending is lower than the value of tensile strains (tensioned *fibres*) in the bottom part of the beam; these values are 0.07% and 0.11% respectively; it means that in the case of rocks where is no symmetry of deformation (and probably stress values) relatively to the neutral axis, as described by theoretical solutions based on the mechanics of continuous and elastic media, the neutral axis is probably not the axis of symmetry of beam, and it is displaced upwards;
- all stress σ - strain ε characteristics of samples under bending, for both compression and tension *fibres*, are non-linear over the entire stress range. Such non-linear behaviour was characteristic of direct tensile tests, whereas in the uniaxial compression tests there were intervals of linear (elastic) behaviour.

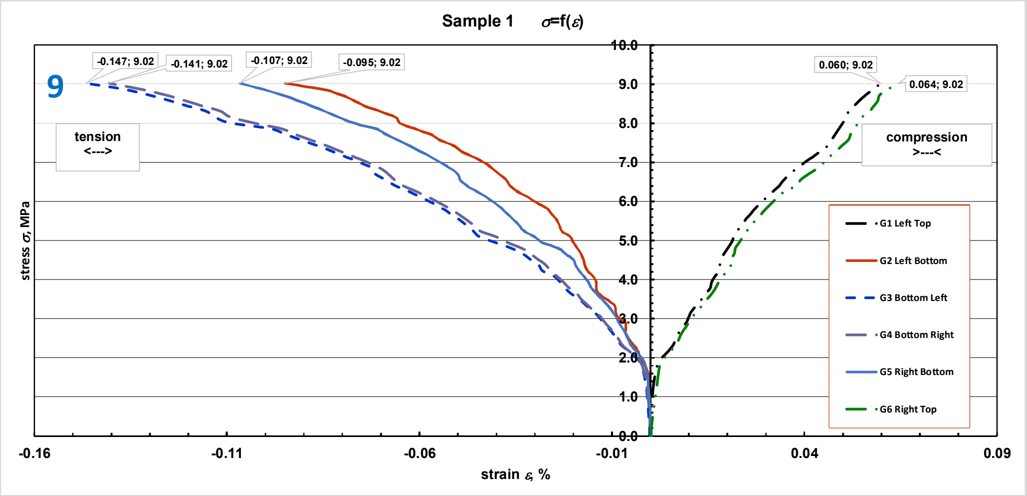
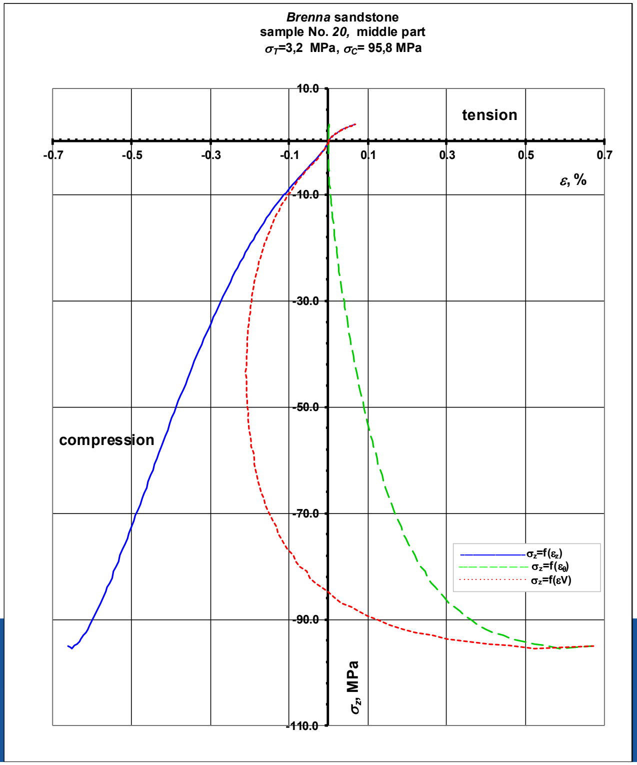


Fig. Comparing the values of strains at the failure strength obtained on the basis of three-point bending tests.

Fig. Typical characteristics of normal stress σ_z - strain ε of Brenna sandstone: comparison of the characteristics σ_z=f(ε) for uniaxial compression (left-bottom) and uniaxial tension (right-top)



6. CONCLUSIONS.

1. Rocks are granular materials. Mineral grains are bound by a *glue*. Their behaviour in the field of compressive stress is well known.

2. Shear and tensile tests are also carried out. Tensile tests are most often carried out by indirect methods, e.g., the *Brazilian* test. It is the properties of rocks (only) under uniaxial / direct tension conditions are most free of *faults* resulting from test *technology*.

3. However, rock damage and failure often occur when rock layers *bend*. Rock layers are always bent as a result of underground mining and excavations, chambers and tunnels. We also encounter the phenomenon of bending in the case of other granular materials, e.g., concrete.

4. Two series of tests were conducted on the deformation and strength properties of homogeneous and isotropic fine-grained *Brenna* sandstone under three-point bending conditions. It is well-described and known sandstone. In previous years, self-research was conducted on it, including uniaxial compression, direct tension and shear under compression tests.

5. The presented results of laboratory tests clearly indicate the differences between the values of constants calculated on the basis of three-point bending, direct tension and uniaxial compression tests. For the tested *Brenna* sandstone, these differences are very clear. The bending strength σ_B of about 9.5MPa is almost 3 times higher than the direct tension strength σ_T of about 3.2MPa and is 1/10 of the uniaxial compression strength σ_C.

6. CONCLUSIONS.

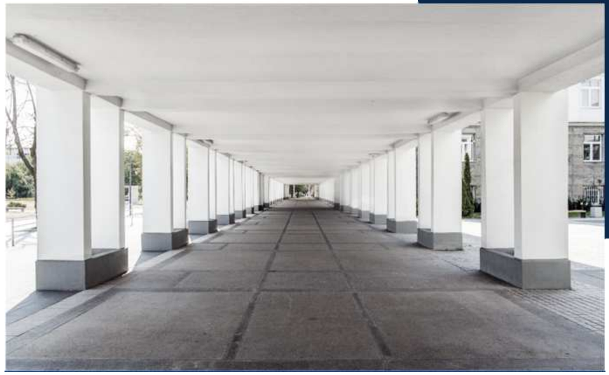
6. Differences also occur in the case of elastic / deformability moduli *E*. Under three-point bending, *E* is equal to: for tensioned *fibres* about 6.7GPa, and for compressed *fibres* 14.6GPa. For the same sandstone, the *E* values were equal: in uniaxial compression tests around 13.0GPa, and in direct tensile tests 4.8GPa. The deformability is therefore very different.

7. The stress σ - strains ε characteristics for both compressed and tensioned *fibres* of sandstone samples under bending were non-linear over the entire stress range. Until now, the properties of rocks under bending were most often equated with their properties under tensile conditions. As it results from the conducted tests, rocks in the conditions of a complex state of bending stress show different properties than those in compression and tension, and the failure occurs at different strains values.

8. These rock material properties are important, especially from the point of view of researching and forecasting the development of damage zones in the excavation ceilings and underground structures, mining excavations and tunnels, and in the description of the rock material during numerical analysis and simulations.

Acknowledgments: The research was carried out as part of the statutory work (No. 06/040/BK_19/0092 / BK265/RG-4/2019) of the Department of Geomechanics and Underground Construction, Faculty of Mining, Safety Engineering and Industrial Automation, Silesian University of Technology, Poland.

THANK YOU FOR YOUR ATTENTION!



CONTACT

BAgrSc, MSc, PhD
Krzysztof Tomiczek / Asst. Prof.

Faculty of Mining, Safety Engineering and Industrial Automation

Department of Geoengineering and Raw Materials Extraction

Silesian University of Technology

St. Akademicka 2, (r. No. 468)
PL-44-100 Gliwice, Poland

Phone
Ph.: +48 32 237 21 69
M.: +48 737 994 564 (or Viber)

E-mail
Krzysztof.Tomiczek@polsl.pl
Krzysztof.Tomiczek@aol.com

Follow me:
https://www.researchgate.net/profile/Krzysztof_Tomiczek

ORCID iDs
https://orcid.org/0000-0001-9227-310X