INSTITUT ZA RUDARSTVO I METALURGIJU BOR YU ISSN: 1451-0162
KOMITET ZA PODZEMNU EKSPLOATACIJU MINERALNIH SIROVINA UDK: 622

UDK: 622.83:550.8.013(045)=861

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ODREĐIVANJE PARAMETARA SMICANJA STENA PO POVLAŠĆENIM RAVNIMA[**]

Izvod

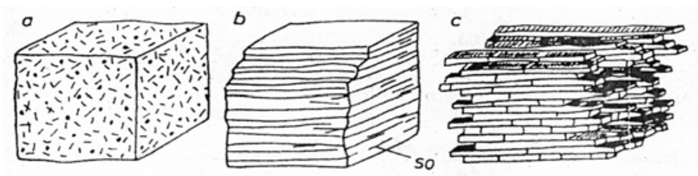
U ovom radu su prikazani rezultati ispitivanja otpornosti na smicanje u elastičnoj, anizotropnoj sredini u tri uzajamno normalna pravca. Istražno područje je transverzalno izotropan model, koga karakterišu konstantna fizičko-mehanička svojstva u različitim pravcima u ravni izotropije i različita svojstva u pravcima normalnim na ravan izotropije.

Ključne reči: *smicanje, anizotropna sredina, fizičko-mehanička svojstva, ravan izotropije.*

UVOD

S obzirom na raznolikost građe dela stenske mase i njenih svojstava na kojoj se izvode određeni građevinski objekti, teško je razraditi model koji opisuje svu složenost građe i naponsko-deformacijsko stanje. Takav model mora biti jednostavan, a dobijeni rezultati prihvatljivi.

Prvi korak istraživanja u području mehanike stena je razrada strukturnog modela koji odražava sve osobenosti građe dela stenske mase i njihova fizičko-mehanička i deformaciona svojstva, sl. 1.



Sl. 1. *Strukturni model*

a – neorijentisana izotropna zrnasta struktura
b – slojevita anizotropna struktura
c – škriljava anizotropna struktura

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[**] *Ovaj rad je proistekao iz Projekta broj 33021 „Istraživanje i praćenje promena naponsko deformacionog stanja u stenskom masivu“ in-situ“ oko podzemnih prostorija sa izradom modela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor“, koga finansira Ministarstvo za prosvetu i nauku Republike Srbije*

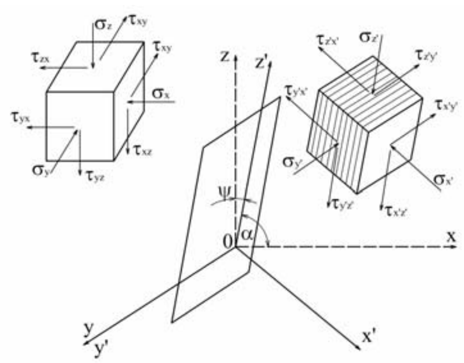
Na osnovu strukturnog stenskog modela moguće je razraditi takav geomehanički model stenske mase na koji se mogu primeniti numeričke analize metode konačnih elemenata pri rešavanju praktičnih zadataka pri temeljenju određenih građevinskih objekata.

Anizotropni elastični model stenske mase razlikuje se od izotropnog elastičnog modela što uzima u obzir izmenu svojstava masiva u različitim pravcima. U opštem slučaju [1] anizotropnu sredinu karakteriše 18 nezavisnih konstanti dok, poređenja radi, izotropnu sredinu karakterišu samo dve konstante (modul elastičnosti i koeficijent Poisson-a).

Najjednostavniji anizotropni model stenske mase je transverzalno-izotropni [3] (u prirodi su joj najbliži tankoslojni škriljci).

1. ŠKRILJAVA ANIZOTROPNA STRUKTURA PREGRADNOG MESTA H.E. „BRODAREVO 2“

Škriljci lokaliteta pregradnog mesta H.E. „Brodarevo 2“ su subvertikalne tankoslojne uslojenosti, koja se vrlo brzo na vazduhu razdvaja i prelazi u trošnu sredinu. Prema strukturnom modelu je škriljava anizotropna sredina. Ta sredina se karakteriše konstantnim fizičko-mehaničkim svojstvima u različitim pravcima u ravni izotropije poklapajući se sa ravni x’y’z’, sl. 2. i različitim svojstvima u pravcu ose x’, koja predstavlja osu simetrije elastične sredine.



Sl. 2. *Šema napona u transverzalno-izotropnoj sredini*

1.1. Priprema uzoraka škriljca za određivanje parametara otpora smicanju

Za definisanje parametara otpora smicanju škriljca (transverzalno izotropnog modela) u tri uzajamno okomita pravca neophodno je pripremiti 9 (devet) uzoraka dimenzija (8 x 8 x 8) [cm], koristeći Mor-Kulon-ov zakon, da rušenje stene nastupa po ravni najmanjeg otpora smicanju. Definisanje tog zakona je moguće sa minimum tri tačke:

$$\tau = c + \sigma_n \, tg\varphi \qquad (1)$$

τ - otpor smicanju po unapred definisanoj ravni

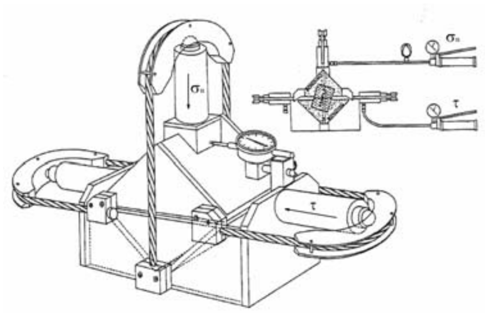
c – kohezija

σ_n - normalni napon

φ - ugao unutrašnjeg trenja

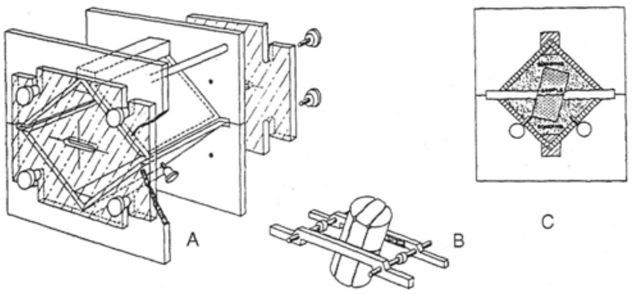
Pripremljeni uzorci škriljca se ubetoniraju u kalupima, sl. 5, i smeste u komoru za smicanje, sl. 3. i sl. 4. Betonirani uzorak škriljca smešten u komoru za smicanje pod pritiskom normalnog opterećenja σn se nalazi u troosnom stanju napona. Ravan po kojoj se izvodi smicanje opterećena je samo smičućim naponom jer je beton po toj ravni prekinut. Pomeranje pri smicanju se prati komparaterom tačnosti 10-2 [mm], a normalno opterećenje se drži konstantnim.

Takođe, postoje predlozi za izmenu pripreme, kao i metode za otkopavanje preostalih rezervi, imajući u vidu specifičnosti zaleganja rudnog tela Tilva Roš u nižim delovima [4], [5].



Sl. 3. *Izgled aparature za smicanje duž željene ravni*

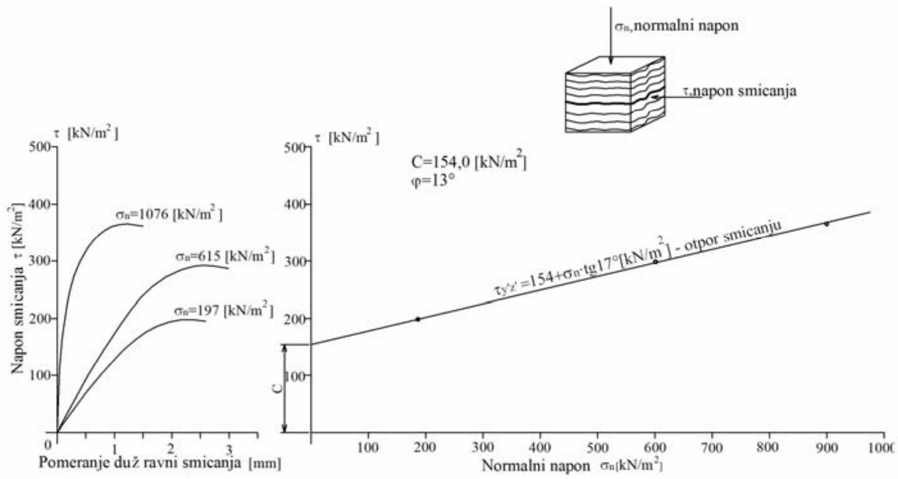
Sl. 4. *Aparatura za smicanje*



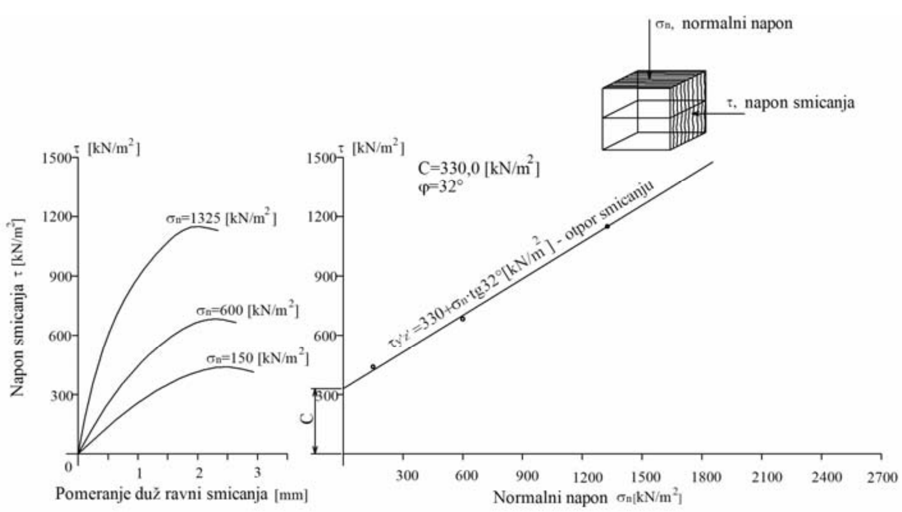
Sl. 5. *Pribor za orijentaciju uzorka i betoniranje*

1.2. Rezultati opita otpora smicanju u transverzalno izotropnoj sredini

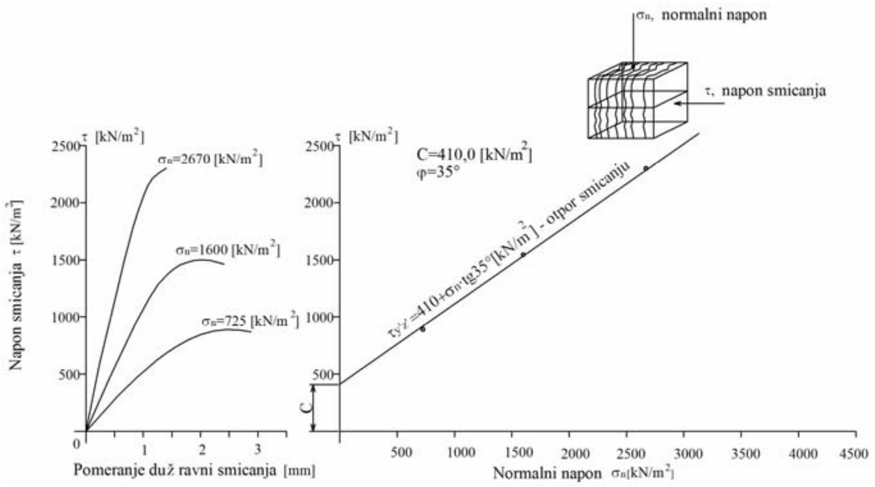
Na po tri uzorka škriljca definisani su parametri otpora smicanju duž tri međusobno normalna pravca. Dobijeni rezultati su prikazani dijagramski na sl. 6., 7. i 8.



Sl. 6. *Smicanje duž ravni škriljavosti* $\tau_{y'z'}$

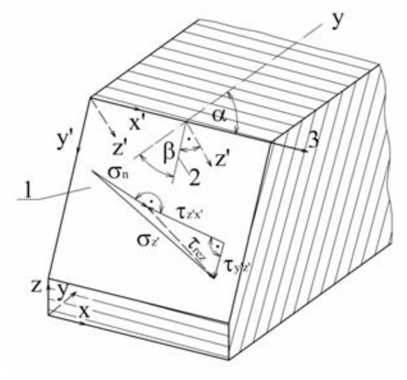


Sl. 7. *Smicanje u ravni* $\tau_{z'x'}$



Sl. 8. *Smicanje u ravni* $\tau_{y'x'}$

Nakon ove nesreće, eksploatacija rude bakra u borskoj Jami ograničena je na rudna tela Brezanik, sa proizvodnjom od oko 15.000 t mesečno i T, sa projektovanom proizvodnjom od 10.000 t rude mesečno. Rudno telo Borska reka još uvek je u fazi otvaranja.



Sl. 9. *Određivanje normalnog* σ_n *i smičućeg τrez. napona*

1 - ravan slojevitosti

2 - pravac pada

3 - pravac pružanja

U slučaju kao što je prikazano na sl. 9, osa z' je normalna na ravan slojevitosti. Veza sa nepokretnim koordinatnim sistemom u prostoru, ugao pružanja je α i pada β, sl. 9.

$l_1 = \sin\alpha$; $m_1 = \cos\alpha$

$l_2 = \cos\beta\cos\alpha$; $m_2 = -\cos\beta\sin\alpha$; $n_2 = -\sin\beta$

$l_3 = -\sin\beta\cos\alpha$; $m_3 = \sin\beta\sin\alpha$; $n_3 = -\cos\beta$

U koordinatnom sistemu x', y' i z', $\tau_{rez.}$ i σ_n se predstavljaju sledećim izrazima:

$$\tau_{rez.} = \sqrt{\tau_{y'z'}^2 + \tau_{z'x'}^2} \quad (2)$$

$$\sigma_n = \sigma_z^{'} \quad (3)$$

Smičući i normalni naponi se dobiju:

$$\begin{aligned} \tau_{y'z'} &= \sigma_x \cdot l_2 \cdot l_3 + \sigma_y \cdot m_2 m_3 + \\ &+ \sigma_z \cdot n_2 \cdot n_3 + \tau_{xy}(l_2 \cdot m_3 + l_3 \cdot m_2) + \\ &+ \tau_{yz}(m_2 \cdot n_3 + m_3 \cdot n_2) + \\ &+ \tau_{zx}(n_2 \cdot l_3 + n_3 \cdot l_2) \end{aligned} \quad (4)$$

$$\begin{aligned} \tau_{z'x'} &= \sigma_x \cdot l_3 \cdot l_1 + \sigma_y \cdot m_3 \cdot m_1 + \\ &+ \tau_{xy}(l_3 \cdot m_3 + l_3 \cdot m_1) + \tau_{yz} \cdot m_1 \cdot l_3 + \\ &+ \tau_{zx} \cdot n_3 \cdot l_1 \end{aligned} \quad (5)$$

$$\begin{aligned} \sigma_z^{'} &= \sigma_x \cdot l_3^2 + \sigma_y \cdot m_3^2 + \sigma_z \cdot n_3^2 + \\ &+ 2\tau_{xy} \cdot l_3 m_3 + 2\tau_{yz} \cdot m_3 n_3 + \\ &+ 2\tau_{yx} \cdot n_3 l_3 \end{aligned} \quad (6)$$

Pri razmatranju rušenja izazvanog naponom σts tj. naponom normalnim na ravan slojevitosti, a saglasno izrazu 3, primenjuje se sledeći kriterijum rušenja:

$$\sigma_n = -\sigma_{ts} \quad (7)$$

Ovde se mora naglasiti da za primenu numeričkih metoda naponsko-deformacijske analize za odabrani strukturni model (transverzalno izotropni), neophodna su još dodatna ispitivanja, koja bi se obavila na uzorcima reprezentativnog škriljca, a to su definisanje pomeranja u tri uzajamno okomita pravca pri jednoosnom opterećenju i definisanje parametara deformabilnosti u tri uzajamno normalne ravni.

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MINING AND METALLURGY INSTITUTE BOR YU ISSN: 1451-0162
COMMITTEE OF UNDERGROUND EXPLOITATION OF THE MINERAL DEPOSITS UDK: 622

UDK: 622.83:550.8.013(045)=20

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*Lidija Đurđevac Ignjatović**

DEFINING THE SHEAR STRENGTH PARAMETERS OF ROCKS ON PREFERENTIAL PLANES**

Abstract

The shear test results are presented in this work in the elastic, anisotropy environment in three mutually perpendicular directions. The research area is a transversely isotropic model, which is characterized with constant physical-mechanical properties in different directions in a isotropy plane and different properties in the directions perpendicular to the isotropy plane.

Key words: *shear test, anisotropy environment, physical-mechanical properties, plane of isotropy*

1. INTRODUCTION

Considering the diversity of rock mass structure and its properties on which the certain buildings are constructed, it is difficult to develop a model that describes a complexity of material structure and stress-strain state. Such model has to be simple, and the obtained results acceptable.

The first step of investigation in the field of rock mechanics is to develop a structural model that reflects all characteristics of the rock mass structure and their physical-mechanical properties and deformation, Figure 1.

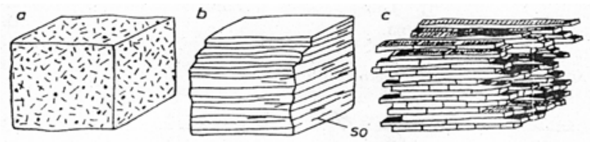

Figure 1. *Structural model*

a – non-oriented isotropic grain structure
b - layered anisotropic structures
c - schistose anisotropic structure

* *Mining and Metallurgy Institute Bor*

** *This paper is produced from the project no. 33021 "Researching and monitoring changes in stress-deformation condition of rock massif "in-situ" around undergraund facilities with development of model with special emphasis on Krivelj river tunnel and Bor pit", which is funded by means of the Ministry of Education and Science of the Republic of Serbia*

Based on the structural rock model, it is possible to develop such geomechanical model of the rock mass for applying the numerical analysis of finite element method in solving the practical problems in foundation of certain buildings.

Anisotropic elastic model of the rock mass is different from the isotropic elastic model which takes into account the properties of massive change in different directions. In general, [1] anisotropic environment is characterized by 18 independent constants, while, by comparison, an isotropic environment is characterized by only two constants (elastic modulus and the Poisson ratio).

The simplest model of an anisotropic rock mass is a transversely-isotropic [3] (in nature, the closest sample to this model is thin-layered shale).

1. THE SCHISTOSE ANISOTROPIC STRUCTURE FROM A PARTITION PLACE OF THE POWER PLANT "BRODAREVO 2"

Shales from a partition place of the Power Plant "Brodarevo 2" are thin-layered sub-vertical stratifications that are quickly separated in the air and transforms into a dilapidated environment. According to the structural model, it is a schistose anisotropic environment. This environment is characterized by constant physical and mechanical properties in different directions in the plane of isotropy coinciding with the plane x'y'z', Figure 2, and with various properties in the direction of x' axis, which is the axis of symmetry of the elastic environment.

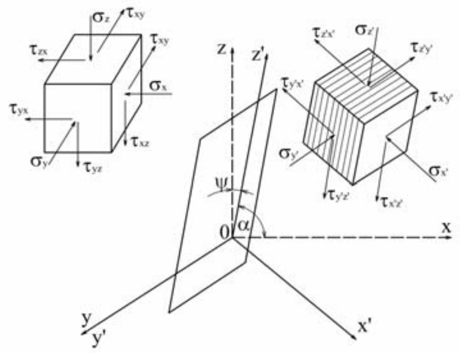

Fig. 2. *Stresses scheme in a transversely-isotropic environment*

1.1. Preparation of Shale Samples for Determination the Shear Resistance Parameters

For defining the parameters of shear resistance of shale (transversely isotropic model) in three mutually perpendicular directions, it is necessary to prepare 9 (nine) samples, size (8x8x8) [cm], using the More-Coulomb law, that the rock destruction happens in a plane of the lowest resistance to shear. Definition of the law is possible with minimum three points:

$$\tau = c + \sigma_n \, tg\varphi \qquad (1)$$

- τ, shear resistance of predefined plane
- C, cohesion
- σ_n, normal stress
- φ, angle of internal friction

The prepared shale samples are put into a wet concrete and then in molds, Figure 5, and placed in a chamber for shear, Figure 3 and 4. Concreted shale sample, placed in a chamber for pressure of normal shear stress σn, is in the triaxial stress state. The plane, along which which the shear stress is done, is loaded only with transverse stresses, as the concrete is interrupted at that level. Movement in shearing is monitored with comparator, accuracy 10-2 [mm], and the normal load is kept constant.

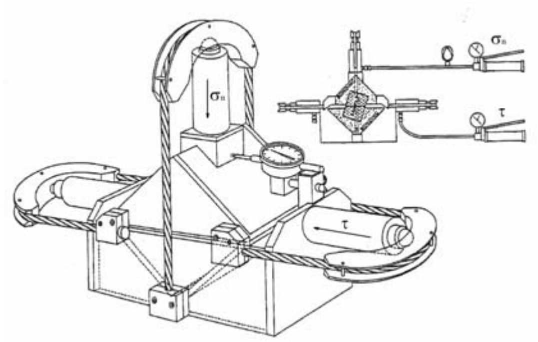

Fig. 3. *Apparatus for shearing along desired plane*

Fig. 4. *Apparatus for shearing*

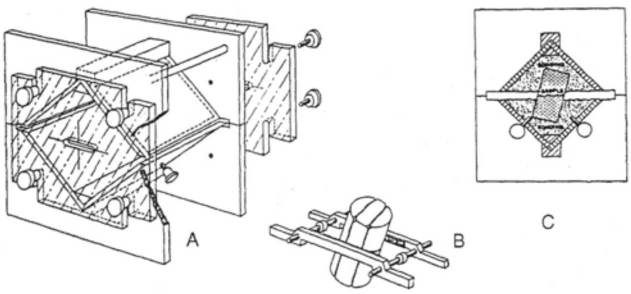

Fig. 5. *Tool for orientation and concrete of samples*

1.2. Results of Shear Resistance Experiment in a Transversely Isotropic Environment

Shearing parameters are defined on three samples of shale along three mutually perpendicular directions. The results are shown by diagrams in Figures 6, 7 and 8.

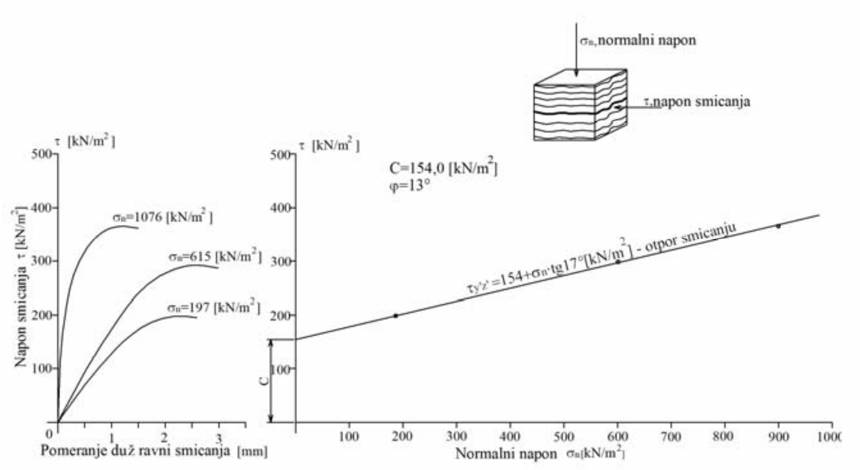

Fig. 6. *Shearing along schistose $\tau_{y'z'}$ plane*

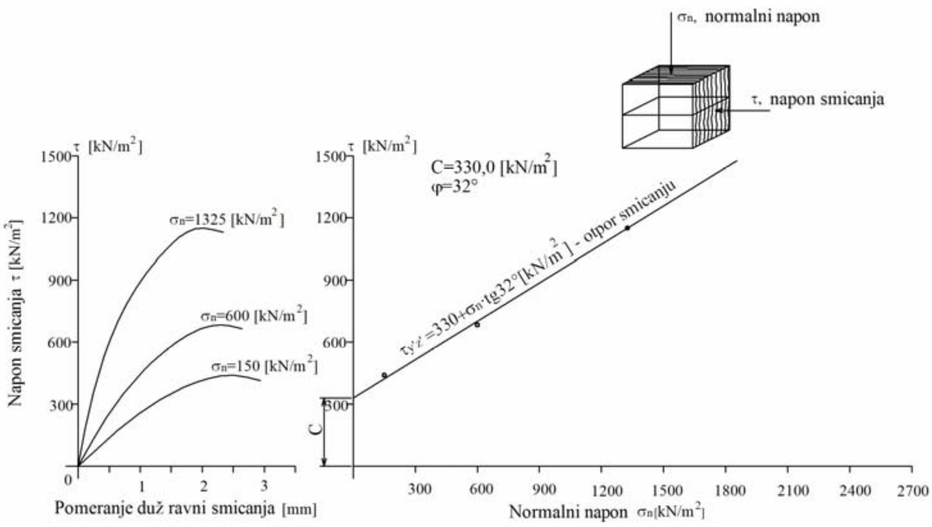

Fig. 7. *Shearing along $\tau_{z'x'}$ plane*

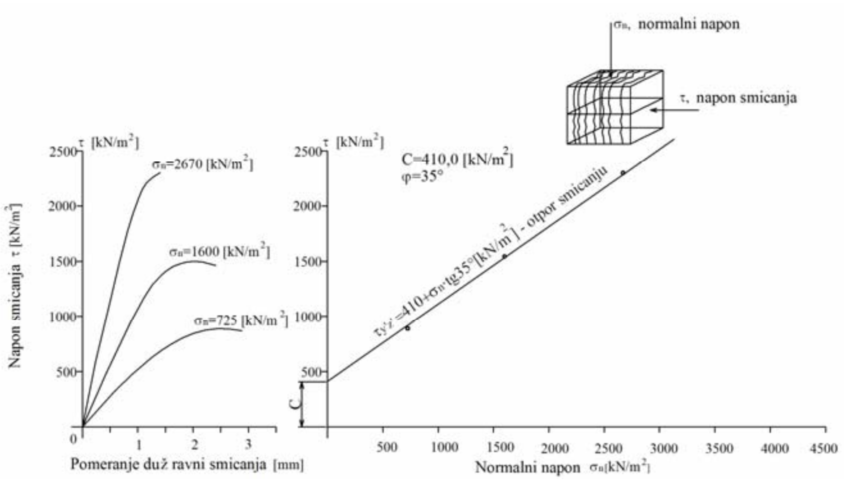

Fig. 8. *Shearing along $\tau_{y'x'}$ plane*

General case of determining the appropriate spatial stress state {σ}, shown in the system of coordinates x, y and z, has to be adapted to the local coordinate system x ', y' and z' and corresponding structure of tested rock, Figure 9.

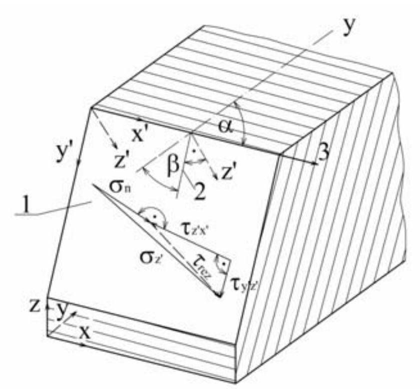

Fig. 9. *Determination of normal σ_n and shear τrez stress*

- 1, plane of stratification
- 2, direction of fall
- 3, strike direction.

In the case, as it shown in Figure 9, the axis z' is perpendicular to the plane of stratification. Connection with the fixed-space coordinate system is: the angle of strike direction α and angle of fall direction β, Figure 9.

$l_1 = \sin\alpha$; $m_1 = \cos\alpha$

$l_2 = \cos\beta\cos\alpha$; $m_2 = -\cos\beta\sin\alpha$; $n_2 = -\sin\beta$

$l_3 = -\sin\beta\cos\alpha$; $m_3 = \sin\beta\sin\alpha$; $n_3 = -\cos\beta$

Stresses τrez. i σn are shown in the coordinate system x’, y’ i z’ by the following expressions:

$$\tau_{rez.} = \sqrt{\tau^2_{y'z'} + \tau^2_{z'x'}} \quad (2)$$

$$\sigma_n = \sigma'_z \quad (3)$$

Shearing and normal stresses are obtained by the following equations:

$$\begin{aligned}\tau_{y'z'} &= \sigma_x \cdot l_2 \cdot l_3 + \sigma_y \cdot m_2 m_3 + \\ &+ \sigma_z \cdot n_2 \cdot n_3 + \tau_{xy}(l_2 \cdot m_3 + l_3 \cdot m_2) + \\ &+ \tau_{yz}(m_2 \cdot n_3 + m_3 \cdot n_2) + \\ &+ \tau_{zx}(n_2 \cdot l_3 + n_3 \cdot l_2)\end{aligned} \quad (4)$$

$$\begin{aligned}\tau_{z'x'} &= \sigma_x \cdot l_3 \cdot l_1 + \sigma_y \cdot m_3 \cdot m_1 + \\ &+ \tau_{xy}(l_3 \cdot m_3 + l_3 \cdot m_1) + \tau_{yz} \cdot m_1 \cdot l_3 + \\ &+ \tau_{zx} \cdot n_3 \cdot l_1\end{aligned} \quad (5)$$

$$\begin{aligned}\sigma'_z &= \sigma_x \cdot l_3^2 + \sigma_y \cdot m_3^2 + \sigma_z \cdot n_3^2 + \\ &+ 2\tau_{xy} \cdot l_3 m_3 + 2\tau_{yz} \cdot m_3 n_3 + \\ &+ 2\tau_{yx} \cdot n_3 l_3\end{aligned} \quad (6)$$

Considering the destruction caused by the σts stress, i.e. the stress normal on the plane of stratification, according to the expression 3, the following criteria of destruction is applied:

$$\sigma_n = -\sigma_{ts} \quad (7)$$

It must be emphasized that the additional tests are necessary for use the numerical methods for stress-strain analysis of selected structural model (transversely isotropic), which would be carried out on representative samples of shale, and those are defining the movement in three mutually perpendicular directions under uniaxial loading and defining the parameters of deformation in three mutually normal planes.

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