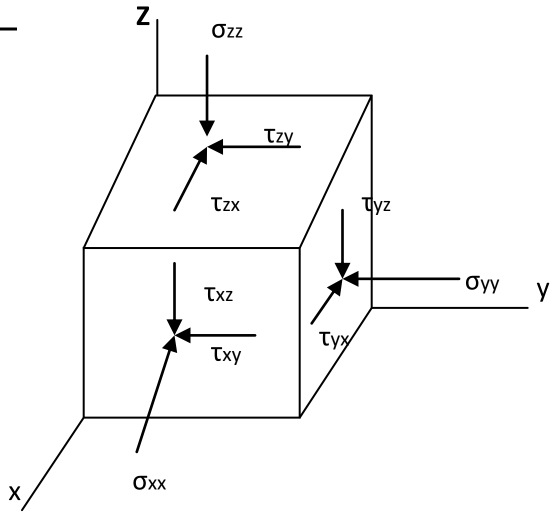
MEMORANDUM Certificate in Rock Mechanics: Paper 1 October 2010

Question 1

1.1



NB

1.Correct surfaces

2.Correct orientation

3.Correct direction

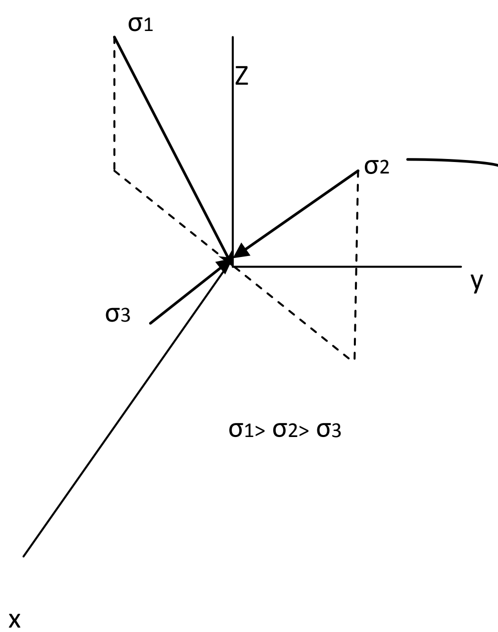
REFERENCE

Ryder & Jag

p118

Budavari p12

1.1.2



NB

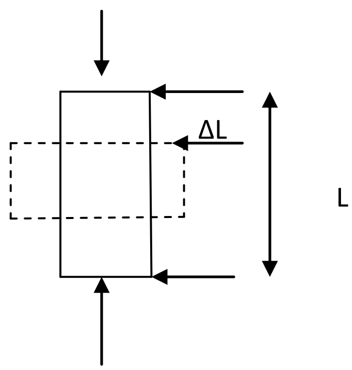
1. Perpendicular to each other
2. 3 x principal stresses
3. Any orientation acceptable as long as above is complied with.
4. Shear stress = 0

1.1.3

1.1.3.1 Normal strain =Caused by normal stress

Change size but not shape

Є =Change in length per unit Original length $\in = \frac{\Delta L}{L}$



Ryder & Jager P133,134 Spearing P17

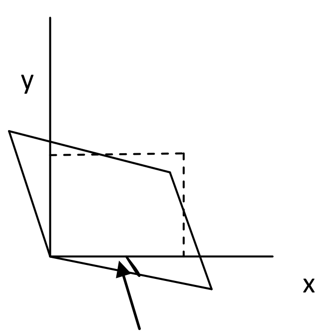
1.1.3.2 <u>Shear Strain</u>

Shear strain = Γ =½ x change in the original right angle

(Measured in radians)

= ½ γ

Shear stress results in shape changes but not the size



Ryder & Jager P133 135; Spearing P17

Budavari P13

1.1.3.3 Principal Strain

Principal strains are referred to when strain in mutually perpendicular directions exist at zero shearing strain. $\epsilon_1 > \epsilon_2 > \epsilon_3$

Brady & Brown P33

Budavari P14

1.2

1.2.1 Young's Modulus = Elastic Modulus (E) given by

Spearing P19

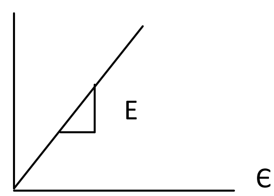
$$E = \frac{\sigma}{\varepsilon} \text{ (Hooke's Law in 1D)}$$

Ryder & Jager P148

Also called the "stiffness" of the material

Or the material's strengthening

Parameter



1.2.2 Modulus Of Rigidity = Shear Modulus (G)

Ryder & Jager p150

$$G = \frac{E}{2(1+v)} \qquad G = \frac{\tau_{xy}}{\gamma_{xy}} = \frac{\tau_{xy}}{2\Gamma_{xy}}$$

Ratio of Shear stress to shear strain

1.2.3 Bulk Modulus (k)

K = ratio of Hydrostatic Pressure to Volumetric strain it produces

Ryder&Jager P150

$$K = \frac{E}{3(1-2v)}$$

1.2 DEFORMATION:

Deformability expressed as Strain where

$$Strain_{normal} = \frac{\Delta Dimension}{Original\ dimension}$$

which is “Unit- less”, Elastic and might be recoverable.

DISPLACEMENT:

Movement expressed as a distance where

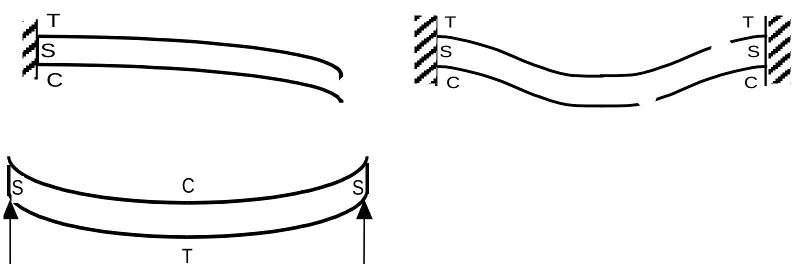
Displacement = $Position_{new}$ - $Position_{old}$ measured in (m).

Permanent

<u>Question 2</u>

2.1. ***Ryder&Jager P14***

2.1.1



2.1.2 (Question should refer to Deflection) ***Ryder&Jager P174***

γ = Unit weight = Density x9.81m.5^2

L = Beam length (m)

E = Lateral beam stiffness$^{(Pa)}$ (Young’s Modulus)

T = Beam thickness (m)

2.1.3

-Elastic beam theory assumes a beam with no weakness planes& assumes elastic Behaviour.

Ryder & Jager

P175

-In underground conditions it is known that the beam will consist of rock material That is not isotropic or homogeneous with large numbers of joints or stress fractures And which will not necessarily behave in a elastic manner only.

-Voussior – refers to the analysis of a 'broken-up' beams compared to 'solid' beams.

-As the VB bends, blocks kinematically 'stabilises" each other while joints open up, Beams separate from each other & additional loading of the beam can be catered for.

-Shear, crush & tensile failure can be suggested by VB analysis.

-Elastic beam theory can be used for a 1st estimation of deflections, stresses induced in the beam &possible failure.

-VB can then be used to further refine the analysis for beam failure mode.

2.1.4 Assume: The beam will behave elastically & the elastic beam theory & equations are appropriate to analyse this situation.

Vertical deflection is given by:

	Cantilever	Built-in both ends	Freely supported
Maximum deflection	$^{3}/_{2}\ \gamma L^{4} / Et^{2}$	$^{1}/_{32}\ \gamma L^{4} / Et^{2}$	$^{5}/_{32}\ \gamma L^{4} / Et^{2}$

Apply the appropriate equation to the correct beam example and calculate deflection.

2.1.4.1 Vertical deflection$_A$ $= \dfrac{(3/2)\ (26487kg/m^3)\ (4m)^4}{(20x10^9 Pa)(1m)^2}$

$= 1.986x10^{-6}(4^4/1^2)$ m

$= 0.00051$m

2.1.4.2 Vertical deflection$_B$ = 0.000013m

2.1.4.3 Vertical deflection$_C$ = 0.00023m

→Potential for failure: A→C→B

Question 3

3.1 $\sigma_{1,2} = ½(\sigma x+\sigma z) \pm ½\sqrt{(\sigma x-\sigma z)^2+4\tau xz^2}$

$=½(45x10^6+65x10^6) \pm \sqrt{(45x10^6 -65x10^6)^2+4(-15x106)^2}$

$= ½(110x10^6) \pm ½\sqrt{4.00x10^{14}+9.00x10^{14}}$

$= 55x10^6 \pm\ 18.028x10^6$ Pa

σ_1 =73.028MPa and σ_2 = 36.972MPa

$Tan2\theta= \dfrac{2\tau xz}{(\sigma_x-\sigma_z)} = \dfrac{2(-15x10^6)\ Pa}{(45x10^6- 65x10^6)Pa}$

$=- 30/-20$

$= 1.5$

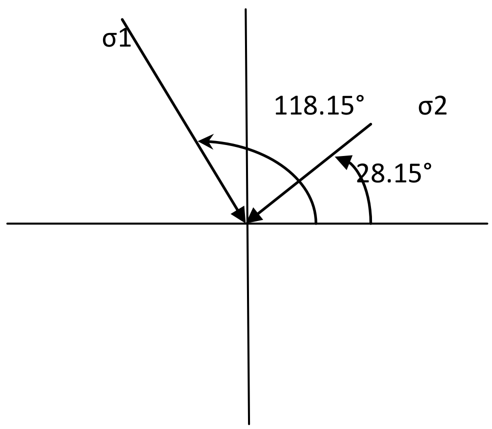
BUDAVARI P8

RYDER & JAGER P123

$2\theta 2 = 56.31°$ OR $2\theta 1 = 56.31° + 180°$

$\Theta 2 = 28.15°$ $= 236.31°$

$\Theta 1 = 118.15°$



3.2 $\epsilon_1 = (1/E)\ (\sigma_1 - v\sigma_2)$ Given a 2D body, assume plane stress , $\sigma 3 = 0$

$= (1/40x10^9)(73.028x10^6 - (0.18)(36.972x10^6))$

$= (1/40x10^9)(73,028x10^6 - 6,655x10^6)$

$= (1/40x10^9)(66,373x10^6)$

$= 0.0\ 0166$

RYDER & JAGER

P149

BUDAVARI

P19

$\epsilon_2 = (1/E)(\sigma_2 - v\sigma_1)$

$= (1/40x10^9)(36,972x10^6 - (0, 18)\ (73,028x10^6))$

$= (1/40x10^9)(36,972x10^6 - 13,145x10^6)$

$= (1/40x10^9)(23,827x10^6)$

$= 0.00059$

3.3 Stored energy= Volume x Strain energy Density

Q = Vol x W

Assume Plane strain i.e $\epsilon 3=0$ — ***RYDER & JAGER P153***

$W = ½ (\sigma_1\epsilon_1+\sigma_2\epsilon_2+\sigma_3\epsilon_3)$

= ½ ((73,028MPa)(0,00166)+(36,972Mpa(0,00059))

= ½ (143,039.96)KJ/m^3

= 71,519KJ/m^3

Volume = 5x5x1m3 (2D sample given)

= 25m3

Q = W x Volume

= 71,519KT/m3 x 25m3

= 1,788 MJ

3.4 Work done on a body is given by the product of the force to deform or displace the body → Work done =Fx S — ***Ryder & Jager P229***

-Elastic strain energy is the energy stored in a body due to the work done on it and is viewed as (½ Stress x Strain) integrated over the volume of the body

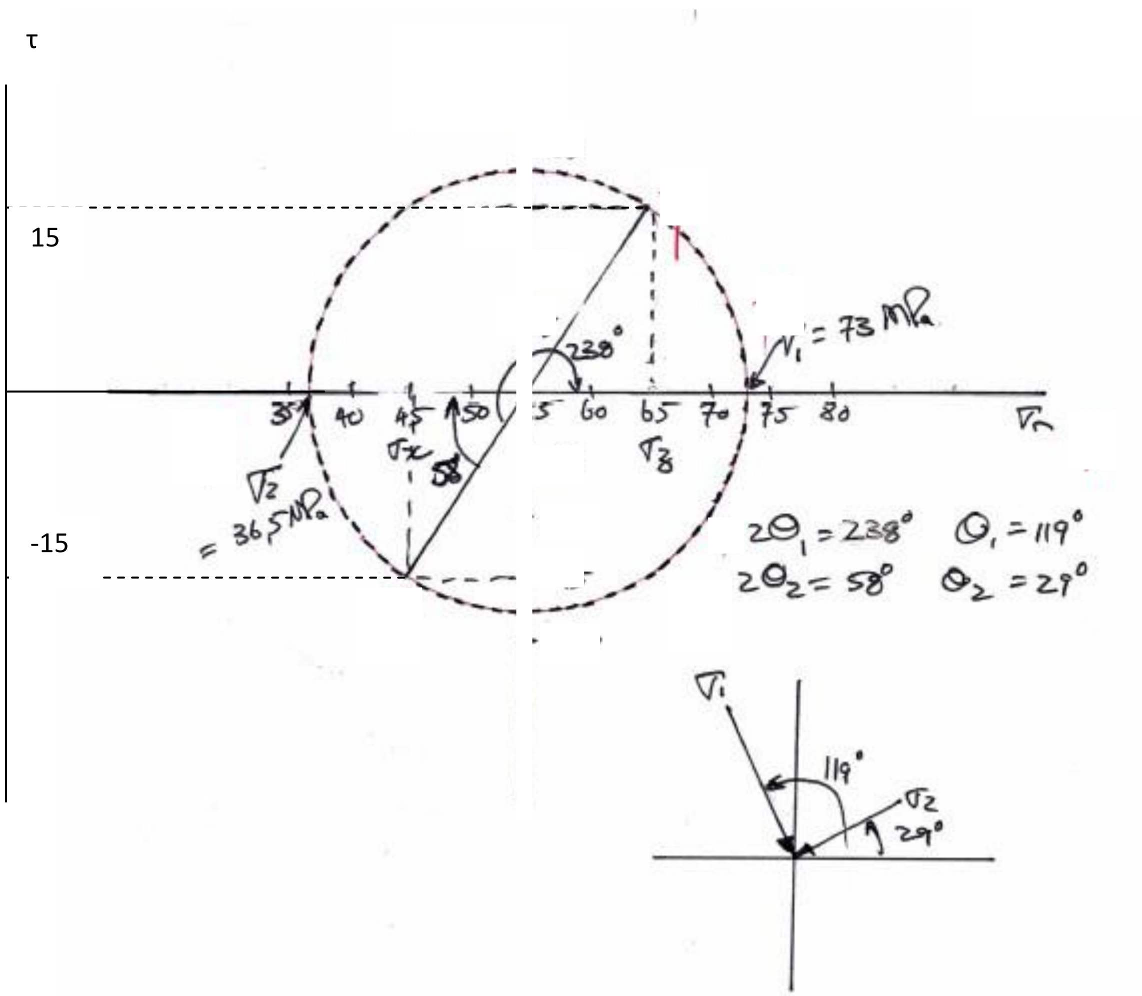
-ERR is a concept that measures the energy “unaccounted” for and is usually related to the accurence of seismic activity. The “unaccounted for energy” is that portion of the work done that is not stored (Elastically) within the body.

-The higher the Elastic Strain Energy stored in a body (Q), the higher/ larger the energy available for release through inter alia seismic events.

-Seismic event is defined as a ”sudden release of elastic strain energy”.

-*<u>Any other comments on energy stored or dissipated in the rock mass was accepted on merit.</u>*

3.5 ***RYDER & JAGER P125***



Same results as in 3.1, Results are confirmed.

Question 4

4.1 It is expected that the student should realize that the 'Rating" scales are large and that (e.g. UCS) a large range of strengths are related to the same "Rating Value". This defeats the objective of the Rating system. The student should place the values given within the "scales ranges" and select Most appropriate values.

(If not interpolated ratings –only 75% of marks)

Brady & Brown P78

UCS:

	<1 MPa	1 - 5MPa	5 - 25MPa	25-50MPa	50-100MPa	100-250MPa	>250MPa
Rating:	0	0-1	1-2	2-4	4-7	7-12	12-15

90 → 6 (Chrome)

180 → 10 (Pyroxenite)

RQD

<25%	25-50%	50-75%	75-90%	90-100%
3	3-8	8-13	13-17	17-20

35 → 5 (Chrome)

65 → 11 (Pyroxenite)

Joint Conditions

Chrome : 30

Pyroxenite : 25

Joint Spacings

Chrome : 20

Pyroxenite : 400→9

Groundwater

Chrome : 15

Pyroxenite : 15

STRIKE-AND-DIP ORIENTATIONS

Chrome : 0

Pyroxenite : 0

RMR_{CHROME}= 6 + 5 + 30 + 20 + 15 - 0 = 76

((7+8+30+20+15-0=80))(Using ratings as is in tables and not interpolating values)

$RMR_{PYROXENITE}$= 10 + 11 + 12 + 25 + 9 + 15 - 0 = 70

((12+13+25+10+15-0=75)) (Using ratings as is in table and not interpolating values)

4.2

$m=10.e^{(RMR-100/14)}$ $s=e^{(RMR-100/6)}$

Ryder &Jager P69

	m	**s**
CHROME:	1.8009 ((2.3965))	0.0183 ((0.0357))
PYROXENITE:	1.1732 ((1.6767))	0.0067 ((0.0155))

Brady & Brown P135

(Assume mί=10 for both rock types)

4.3 HOEK-BROWN : $\sigma 1=\sigma 3+\sqrt{s.\sigma_c^2+m.\sigma_c.\sigma_3}$

	σ_1	σ_3	m	s	σ_c	σ_{HB}	FAIL
CHROME	250	50	1.8009	0.0183	90	140.8	YES
PYROXENITE			1.1732	0.0067	180	153.8	YES

CHROME

$\sigma_1=\sigma_3+\sqrt{s.\sigma_c^2+m\sigma_c\sigma_3}$

$=50x10^6+\sqrt{(0.0183)(90x10^6)^2+(1.8009)(90x10^6)(50x10^6)}$

$=50x10^6+\sqrt{1.482x10^{14}+8.104x10^{15}}$

$=50x10^6+90.842x10^6$

=140.841MPa (155.2MPa using ratings as is)

PYROXENITE

$\sigma 1=\sigma 3+\sqrt{s.\sigma c^2+m.\sigma c.\sigma 3}$

$=50x10^6+\sqrt{(0.0067)(180x10^6)^2+(1.1732)(180x10^6)(50x10^6)}$

$=50x10^6+\sqrt{2.171x10^{14}+1.056x10^{16}}$

$=50x10^6+103.807x10^6$

=153.807MPa (174.9MPa using ratings as is)

4.4 K ≈ 0.3-0.51 x UCS

DRMS = UCS x (MRMR - RUCS/100)

K ≈ Design Rock Mass Strength NB:Student can suggest other methods, marks on merit

≈DRMS (from RMR ratings) | Brady&Brown P392,382

≈ 30% x UCS (Stacey) | Stacey P36,P117

≈ RMR x UCS (local application)

CHROME: k = 68MPa

Pyroxenite: k = 126MPa (RMRxUCS)

4.5 UCS=Unconfined uni-axial compressive strength where the

sample is void of any weakness planes

-By using and adapting the RMR ratings, the quality of the rock

mass is also catered for. The impact of joints & bedding on rock

mass strength is now included.

-Since k is the strength of 1m3 of rock,it will most likely have several

Weakness planes within the sample.

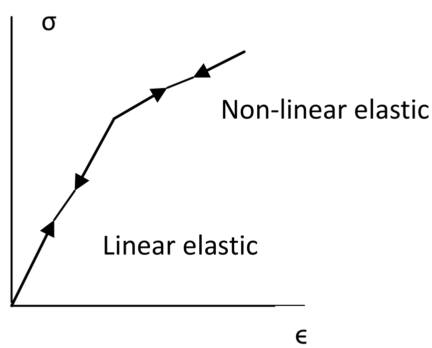
-By taking the UCS and downgrading this “intact” strength with the Rock Mass

Quality to get DRMS, a more appropriate rock mass strength value is determined.

Question 5

5.1

5.1.1 Elastic



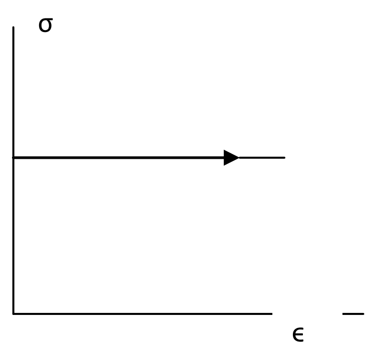
Ryder&Jager P83,147

Budavari P17

Arrows will indicate understanding of recoverable behaviour.

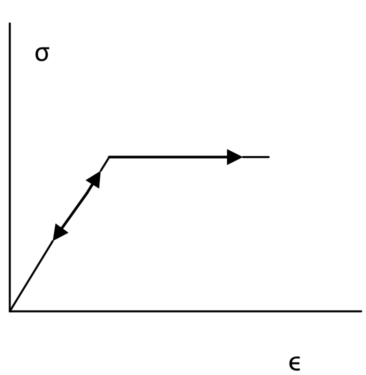
½ points if no arrows are shown.

5.1.2 Perfectly Plastic

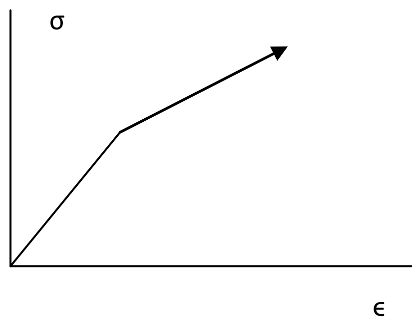


5.1.3 Elasto-Plastic

Brady & Brown P86

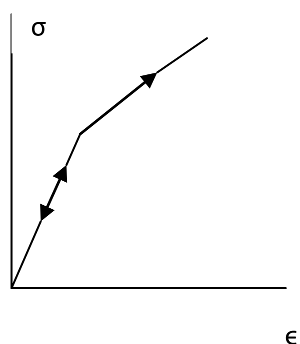


5.1.4 Ductile



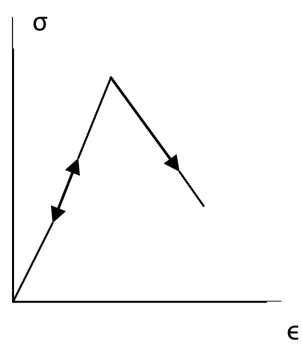
Permanent deformation without losing the ability to sustain load.

5.2



Strain “hardening”

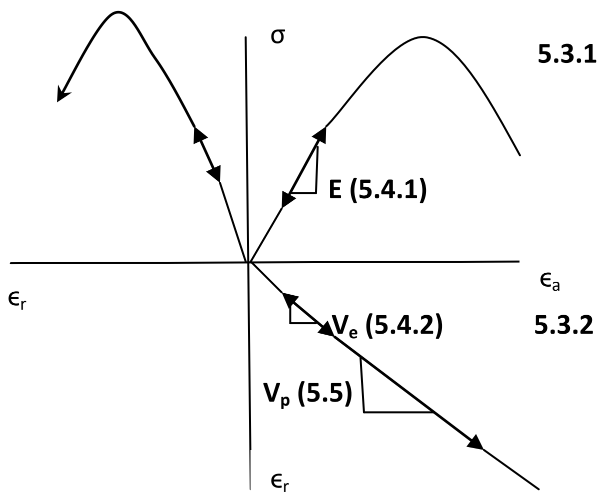
Any rock type that requires increase in stress to induce permanent and offer yield point.



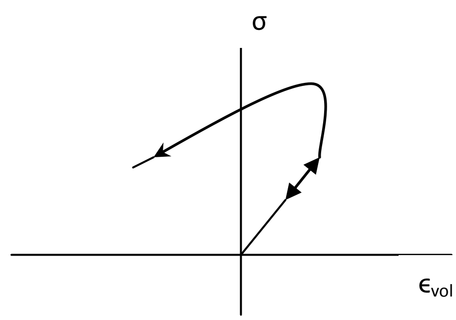
Strain “softening’

Any rock type that loses ability to sustain stress offer failure point.

5.3



5.3.3



Ryder & Jager P61

5.4 See graph in 5.3 (E and V_e)

5.5 See graph in 5.3 (V_p)

$$sin\varphi = \frac{2v_p - 1}{2v_p + 1}$$

Where ψ = Dilation angle

V_p = Slope of radial: axial strain graph at peak strength point.

REFERENCES

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2. Rock Mechanics for Underground Mining : Brady & Brown
3. Rock Engineering Practice for Tabular hard rock mines: Jager&Ryder
4. Handbook on Hard-Rock Strata Control :AIS Spearing
5. Textbook on Rock Mechanics for tabular hard rock mines: Ryder&Jager
6. Best Practice Rock Engineering Handbook for other Mines: Stacey E.T AL