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A Study on Engineering Properties of Rocks around Bangalore Area

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Introduction

In this investigation a study is made on the rocks around Bangalore area 12° 50' to 13° 15' N latitude. The rocks of the area are being used as masonry stone, decorative stone, paving stones, flooring material and as slabs for various purposes. In addition they are used in large quanitities as aggregates for road and concrete. Though they are being used so extensively for varying purposes, there has been no attempt to have their engineering properties assessed in a systamatic manner, especially in correlating with their original petrological characteristics.

It becomes necessary to establish a correlation between the geological characteristics viz: Mineral content and character, lithological characteristics, weathering on engineering behaviour through a systematic study of their compressive strength, flexural strength, shear strength, elastic constants and durability tests. A study of the megascopic and microscopic characteristics of these rocks indicate the colour, texture, and composition of the constituent minerals present in them.

The rocks have been collected from several quarries located around Bangalore. These quarries have been indicated as A, B, C, D, E, F and G as given in Table 1 and shown in Fig. 1.

The rock specimens were investigated for compressive strength, shear strength, flexural strength, impact resistance abrassive resistance, water absorption and porosity. In addition, an attempt has been made to evalute the elastic modulus and poission's ratio of rocks under uniaxial compression.

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TABLE 1

Location of the quarry and textural classification of the rocks

Symbol Designation	Location Details	Textural Classification of Rocks
A	Avalahally quarry	Fine grained gneissic granite
B	Banashankri quarry	Medium grained gneissic granite
C	Bettalsoor quarry	Coarse grained gneissic granite
D	Bettahalli quarry	Coarse grained gneissic
E	Haralur quarry	Fine grained gneissic granite
F	Hudi quarry	Fine grained gneiss
G	Karithimmanahalli quarry	Coarse grained gneissic granite

Compressive strength of rock is influenced by their texture particularly the coarseness of the grains. Fine grained rocks are stronger than coarse grained sedimentary rocks. (Krynine and Judd, 1957). Crystallinity plays an important part in igneous and metamorphic rocks as they have strong interlocking texture. The highest compressive strength is obtained where the Cementing medium is quartz. The presence of cracks, seams and fissures influence the compressive strength of rocks. A theory that may be found to be a good representation of the strength of brittle rocks is Griffith's theory (Griffith, 1925). This theory postulates that the presence of microscopic cracks within the material produces concentration of stresses around these boundaries. If the principal stress is tension and normal to the cracks, the tensile stress will be created at the end of cracks. If the principal stress is compression then tension is produced in a direction at right angles to the direction of compressive load.

Crushed Rock may be used as an aggregate for road pavement, mixed with cement or bitumen. These aggregates will be subjected to impact and abrassion by construction equipment and traffic during the service life of road. Weathering brings about the deterioration and degradation. This degradation is dependent on the minerological composition of the parent rock from which the aggregate is derived. So it becomes essential to correlate the physico-mechanical properies like hardness, toughness, durability with the lithological and minerological characteristics of rocks.

Standard test procedures as per Indian standards are followed for the evaluation of the aggregates for the engineering properties. Megascopic examination of these rocks are done through usual Indian procedure.

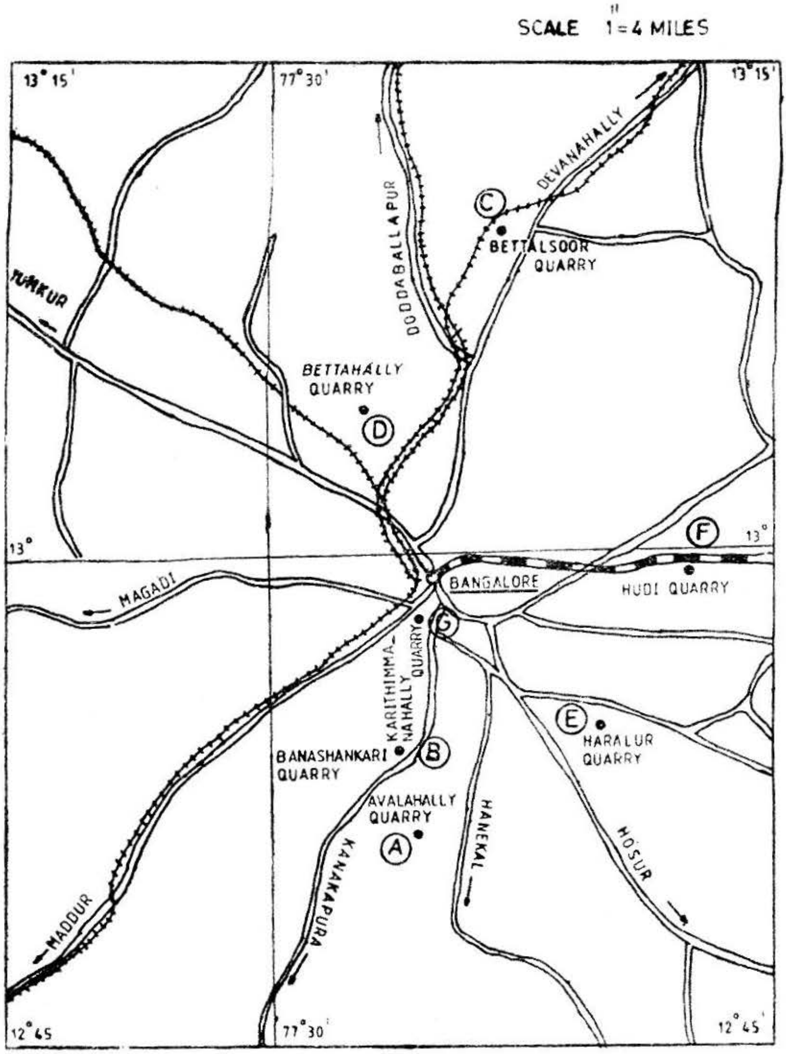


FIGURE 1 Locations map of quarries of Bangalore Area

Microscopic examination has been carried out with Zeiss petrological microscope. The modal analysis is done on mechanical stage and by actual counting.

Geology of Bangalore Area

Bangalore area is a part of metamorphic complex of Karnataka region. The main lithological components of the area are Gneiss, Granitoids, Migmatities (Vidya Shankar 1981). Amphibolites occur as enclaves within these lithologies.

Topography of the Area

The area has visible undulatory topography. The area of investigation includes within it the Bangalore Metropolis and mofussil area. The topography of the metropolis area is almost plain whereas the mofussil area is characterised by visible undulatory ground. On an average the topography of the area rise to 915 meters above MSL.

Nature of Outcrop

Outcrop of raising dimensions are explored and scattered all over the area. The metropolis have low mounds, whereas mofussil areas have large outcrops. The quarries that have been established on these outcrops expose fresh rocks although they are weathered on their surfaces.

Petrological Characteristics of the Rocks

The mega and micro character of these rocks have been studied. They show certain common characteristics. All of them are grey in colour. Battalsoor rocks are more lighter in colour. Structurally they are gneissic granites to grantic gneisses. In the former the gneissic banding is more megascopically visible. They are commonly constituted of quartz, orthoclase, plagioclase and Biotites. The modal composition is given in Table 3. In the table the total of orthoclase and plagioclase is given and other accessory minerals have not been recorded as they do not influence the rock properties. Table 2 gives the detailed petrological description of the lithologies individually.

Experimental Investigations

Through a preliminary recconaitory survey Seven Quarries were selected to represent both metropolis and mofussil areas around Bangalore as indicated in Table 1. The specimens from the locations were extracted as per Indian standard significations. These specimens were polished and the shapes selected for testing are cylinders, cubes and beams.

Petrographical Examination

Thin sections of the rock specimens were prepared and examined under microscope. The modal analysis is done as per swift's automatic scale. The megascopic analysis of petrography and lithology is done on irregular field specimens.

Engineering Properties

(*a*) *Porosity*: Determination of the true specific gravity (G_1) and apparent specific gravity (G_2) is done as per IS 1124—1974.

(*b*) *Compression Test*: (1121—Part I—1974) The tests are conducted

TABLE 2

Classification of rocks, on megascopic and microscopic examination Class of Rock : Metamorphic

Location Symbol*	Type of rock	Colour	Structure	Texture	Constituents	Remarks
A	Gneissic	Grey	Shows rough gneissic banding	Completely crystalline, crystalloblastic, fine grained.	Quartz, orthoclase, microcline and biotite.	Quartz is anhedral, feldspars and biotite are subhedral ; quartz shows a strain shadow and high crushing.
B	Gneissic	Grey	Shows very vague gneissic banding.	Medium grained crystalloblastic.	Quartz, microcline, orthoclase and biotite.	Quartz is anhedral, feldspars and biotite are subhedral. Biotite shows a little alteration, quartz shows high crushing.
C	More granitic than gneissic	White	Shows no conspicuous gneissic banding almost granite.	Very much coarse grained more crystalloblastic.	Quartz, orthoclase, very little of microcline and biotite.	Quartz is anhedral, feldspars and biotite are subhedral. Feldspar shows alteration. Biotite is less altered.
D	Gneiss	Dark grey	Visible gneissic structures.	Highly coarse grained, crystalloblastic.	Quartz, orthoclase, a little of microcline, biotite.	Quartz is crushed, shows high strain shadow, Much of biotite is altered to chlorite. Unaltered biotite is subhedral.
E	Gneiss	Dark grey	Characteristic Gneissose structure.	Crystalloblastic, Fine grained.	Quartz, orthoclase, and biotite.	Quartz is anhedral, shows shadow. Orthoclase is subhedral. Biotite is not much altered subhedral.

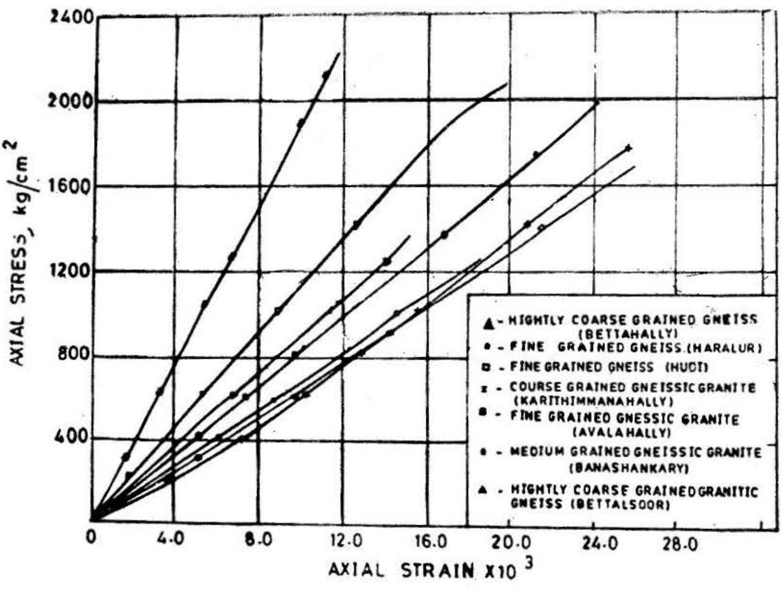
F	Gneiss (Contorted)	Dark grey	Gneissic with contorted banding.	Crystalloblastic, Fine grained.	Quartz, orthoclase plagioclase, and biotite.	Quartz is highly crushed and shows strain shadows of metamorphism. Orthoclase is subhedral. Biotite is present as lamellar mineral, and at many places altered into chlorite.
G	Gneissic granite.	Grey	Not very much visible gneissic banding.	More crystalloblastic coarse grained.	Quartz, orthoclase microcline, a little of plagioclase. Biotite is also present.	Quartz is anhedral, feldspars and biottite are subhedral crystals. Quartz show a strain shadow and high crushing.

TABLE 3

Modal Mineral constituents of lithologies

Location	Quartz %	Feldspar %	Biotite %
A	48.2	46.50	5.30
B	53.0	39.20	7.80
C	53.5	36.00	10.50
D	51.5	34.20	14.30
E	51.0	37.00	12.00
F	58.0	33.60	8.41
G	50.5	35.00	14.50

This has been obtained by using the mechanical stage and actually counting the mineral grains on a known area of thin section of the rock observed under petrological microscope.



FIGURES 2 Stress V_s strain curves for rock specimens

on 7.1 cm cubes. Three typical specimens from each quarry are tested for uniaxial compression at slow speeds under a 200 ton testing machine. Stress strain curves are plotted for each of these specimens.

(c) *Bending Tests*: (IS 1121 Part II 1974) The tests were conducted on the specimens of size 20 cm × 5 cms × 5 cms. The length of the specimen between the supports is 15 cms. A knife edge load is applied to the specimen at the Centre.

$$\text{Flexural Strength} = \frac{3WL}{2bd^2}$$

W = load at failure, L = length between the supports, b = width of the beam, d = depth of the beam. Load vs deflection curves are plotted for each of these specimens.

(d) *Shear Strength*: (IS 1121 Part IV—1974) The test is conducted on a 5 cm sq. cross section beam with a special arrangement for inducing single shear.

(e) *Tensile Test*: (IS 1121 Part III—1974) To determine the tensile strength, split tests were conducted on 4 cms cube as per the procedure given by Karol Koulos (1968). The specimen is placed diagonally between the loading plattens and the load is applied. The specimen splits diagonally, inducing tension on the failure plane.

$$ft = \frac{0.5187\,P}{a^2} \quad \text{Karol Koulos 1968}$$

a = side of the cube, p = load at split, ft = tensile strength

(f) *Durability Tests*: (IS 1126—1974) 3 cm cube specimens dried in oven for 24 hours at 105°C and then air cooled. They are immersed in 14% sodium sulphate solution for 16 to 18 hours at room temperature and then air cooled for half an hour. They are again dried at 105° in oven for 4 hours. They are removed and cooled to room temperature. The test is continued for 30 cycles. At the end of the 30 cycles they are weighed and the loss in weight expressed as a percentage of original weight is recorded as durability value.

(g) *Abrassion Test*: The test is conducted on 7.1 cms cube using Dory's abrassion test as per standard procedure. The loss in weight and coefficient of hardness are determined for each of the specimens.

(h) *Impact Test*: The test is conducted on polished right cylinders of 2.5 cms dia and 2.5 cms height in page impact testing machine. The number of blows causing failure is taken as a measure of resistance.

(i) *Poisson's Ratio and Youngs Modulus*: The deformation are measured for the specimen under uniaxial compression using strain gauges. Strain gauges are fixed vertically and horizontally. The

TABLE 4a

Engineering properties of the rocks investigated

Location	Specific Gravity		Porosity* $\left(\frac{G_1-G_2}{G_1}\right)\times 100$ (%)	Durability** test (loss of weight %)	Weathering** test (increase in absorption %)	Toughness**	Coefficient** of abrasion
	True Sp. Gr. (G_1)	Apparent (G_2)					
A	2.682	2.600	3.060	0.39	0.910	11.00	15.99
B	2.733	2.625	3.840	0.44	0.820	10.00	17.88
C	2.724	2.620	3.680	0.57	0.780	9.00	18.06
D	2.720	2.710	0.360	0.51	0.440	9.00	16.48
E	2.755	2.690	1.650	0.52	0.193	7.00	15.28
F	2.745	2.650	3.460	0.37	0.037	11.00	17.16
G	2.710	2.680	1.100	0.25	0.060	7.00	17.23

*Average of three specimens.
**All these tests were conducted as per IS 1121-1126 and 1706, Indian Standard tests for building stones.

TABLE 4b

Engineering properties of the rocks investigated

Location	Compressive* strength (kg/cm²)+	Flexural* strength (kg/cm²)	Shear* Strength (kg/cm²)	Tensile strength (kg/cm²)	Young's Modulus 'E' kg/cm² × 10^5		Poisson's ratio
					Using dial gauge	Using strain gauge	μ
A	1878.30	187.30	190.25	91.50	2.00	4.50	0.515
B	1653.41	189.70	199.70	79.93	1.00	8.00	0.140
C	2116.67	156.00	189.40	52.70	1.01	15.00	0.175
D	1287.86	162.00	179.25	84.70	0.86	—	—
E	1065.95	185.70	186.90	91.50	1.12	10.00	0.264
F	1798.50	183.00	186.50	71.20	0.89	6.70	0.182
G	1341.22	188.70	208.00	59.43	0.78	10.00	0.330

*Average of three specimens.
+All the failures occured along the line of action of load. Failure line is along the grain boundries.

strains are measured using a Wheatstone Bridge. By plotting the stress strain curves, the tangent modules '*E*' is evaluated. The poisson's ratio is measured as a ratio of horizontal strain to vertical strain. The results are tabulated in Tables 4*a* and 4*b*.

Discussions and Test Results

Mega-Micro Structure Analysis of Rocks

Modal analysis conducted on the microsections and results shown in Table 3 indicate that the main constituents of the gneissic granite and banded gneisses consists of quartz, feldspar and mica. The quartz is more predominant and biotite being least. This variation of the mineral composition from location to location has a strong influence on the strength properties.

The foliations are found to be clearer in gneisses than in the gneissic granites. It is peculiar to note that the foliations found in gneisses around Bangalore are vertical. Foliations in gneisses influence the strength properties of the rocks.

Uniaxial Compression

All rock specimens show explosive type of failure, indicating the brittleness of the rocks. At the beginning of the stress-strain curve, the non-elastic behaviour was predominent. This is indicated by the dispersal of the plotted points. The dispersal of the points is more for specimens loaded with their foliations being vertical. The possible explanation for this inelastic behaviour at the beginning is due to the closure of the grain boundary cracks and pores after which the rock becomes compact and shows a stress-strain behaviour more or like a straight line.

In the tests on the rock specimen under unaxial compression, three types of failure were observed:

(*i*) Complete crushing of the specimen

(*ii*) Vertical split

(*iii*) Inclined failure

Complete crushing is due to the uniform stress distribution within the specimen and most of the gneissic granites failed by this nature. Gneisses failed by cracking vertically. This may be due to the extension of the micro cracks.

Young's Modulus and Poisson's Ratio

Young's modulus of the rocks tested are found to be stress dependent.

From Fig. 3, it can be inferred that the *E*-value is small at lower stresses and increases as the stresses are increased. Strains are measured using both dialgauges and strain gauges. Generally dialgauges have shown higher strains than measured by strain gauges. Hence the *E* modulus calculated by both methods differ widely as given in table 4*b*.

Bending

The bending tests on the rock specimens tested show a low flexural strength and the failure is sudden, justifying brittle nature. The rocks with coarse grained structure (from locations C and D) show lesser strength (Table 4*b*) where inter granular bond is weaker than the fine grained specimens. *From Fig. 4 it is seen that deflections increase with the load and the* rate of increase decrease after 50% of its maximum deflection.

Tensile Strength

The tensile strength of rock specimens were conducted by split tests. The tensile strength values are given in Table 4*b*.

According to Griffith the ratio of the compression to tension is 8.0. Fairhurst (1964) has shown that this ratio is 11.5:1 for discs tested in diagonal compression (Brazillian test). But it is observed in the present study that this ratio varies from 20:1 to 11:1. The tensile strength of the

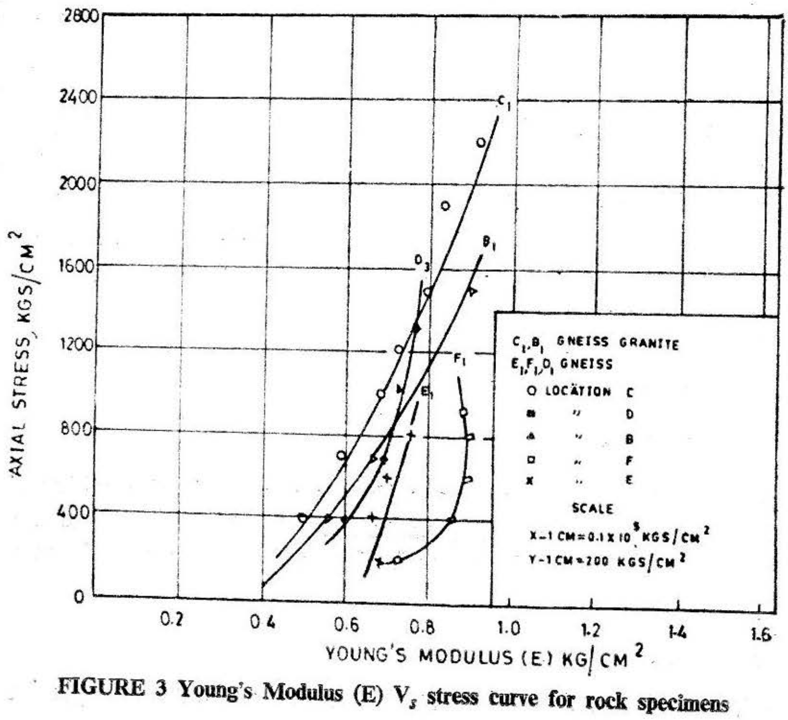
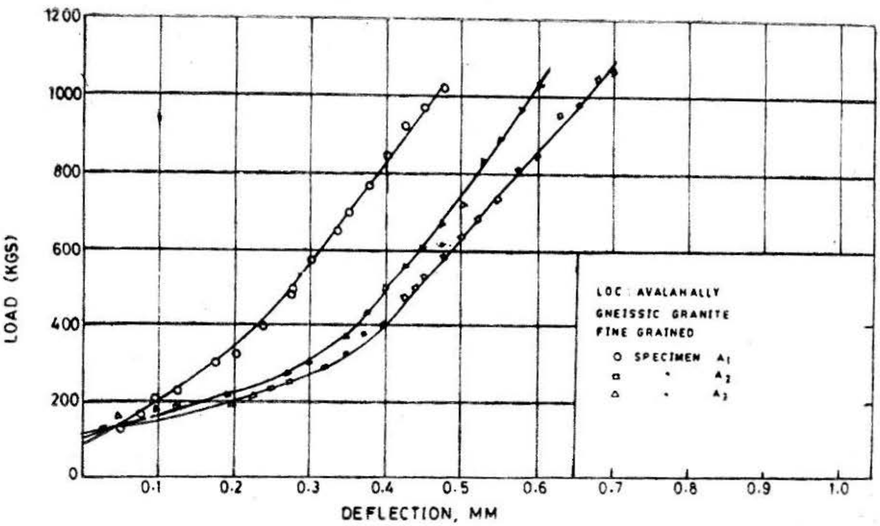


FIGURE 3 Young's Modulus (E) V_s stress curve for rock specimens



FIGCRE 4 Load V_s deflection curves for bending test on Rock specimen

specimens from locations *C* and *G* show less strength than the other specimens, probably due to coarse grained texture and limited grain contacts under tension.

Shear Strength

From the Table 4*b*, it is observed that the difference in shear strength of gneissic granites and gneissic rock specimens is not too great. It can be inferred that the type of surface of failure and friction along the surface play a vital role in deriving the shear strength than the type of formation itself. It can be deduced that rocks having similar minerological composition exhibit more or less same shear strength.

Conclusions

1. The rocks of the area under study is generally gneissic in character, but even the gneissic banding show clear visible variations. However the Northern part of Bettalsoor is more granitic in nature as the gneissic structure megascopically is nonvisible.

2. The most common characteristic of the constituent minerals of these rocks is that all of them have only quartz, orthoclase, plagioclase and biotite. Orthoclase is dominent over plagioclase. Therefore the feldspars together are taken into consideration for assessing the engineering properties. The accessary minerals are not considered. The rocks from locations *B*, *C*, *D* and *F* have more quartz in their composition and in others *i.e*. at locations *A* and *E*, the proportion of feldspar and quartz are almost same. The rocks of location *G* show that quartz is more dominent over feldspar.

3. The textural variation is also visible clearly in these rocks. It is only in rocks of location *C*, it is found to be more granitic in condition. The textures of the rocks from locations of *A*, *E* and *F* are fine grained and that of location *B* is medium grained. Incase of rocks of location *C*, *D* and *G* they are coarse grained. These textural variation certainly reflect in the variation of the engineering properties as can be seen from the curves in Figs 2, 3 and 4.

4. There is considerable variation in strength under uniaxial compression between gneissic granites and gneisses though the minerological composition is same. The extensive foliations in gneisses are the weak planes. From this it is clear that gneissic foliations are the controlling factor in determining the strength of rock.

5. Highly coarse grained textured rock is weak in tension and bending as given in Figs 3 and 4. Where as the shear strength is not affected by either texture or foliation.

6. Young's Modulus '*E*' is found to be strongly dependent on the stress and increases with load at low stress levels. This is further more evidenced by the dependance of the '*E*' value on the grain size of the constituent minerals. From Fig 3 it can be inferred that gneisses behave more non-linearly than the gneissic granites as indicated by the curves of *E* vs axial stress.

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