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COEFFICIENT OF THERMAL EXPANSION FOR FOUR BATCH DESIGNS AND ONE SOLID GRANITE SPECIMEN

by

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1.0 INTRODUCTION

The objective of this investigation was to determine the thermal expansion properties of the Glensanda aggregate and of portland cement concrete made with the aggregate. In addition, modulus of elasticity and compression tests strength were measured on concrete cylinders batched from concrete with the 1-1/2-in. nominal granite aggregate. The tests were performed at the request of Foster Yeoman Limited.

1.1 Batching

Batching of concrete was carried out using the mix proportions based upon the Texas Department of Highway and Public Transportation pavement design specifications. Three batches were made and mix designs are given as follows:

1.11 1-1/2-in. Nominal Granite

weight	pass	retained	%
41.5 lbs.	11/2-in.	3/4-in.	58
23.0 lbs.	3/4-in.	3/8-in.	32
7.5 lbs.	3/8-in.	No.4	10
72.0 lbs.			100

48 lbs. concrete sand
21 lbs. type III cement
10.5 lbs. water (0.5 w/c)

1.12 3/4-in. Nominal Granite

weight	pass	retained	%
41.5 lbs.	3/4-in.	3/8-in.	58
30.5 lbs.	3/8-in.	No. 4	42
72.0 lbs.			100

48 lbs. concrete sand
21 lbs. type III cement
10.5 lbs. water (0.5 w/c)

1.13 3/4-in. Norminal Limestone

weight	pass	retained	%
41.5 lbs.	3/4-in.	3/8-in.	58
30.5 lbs.	3/4-in.	No. 4	42
72.0 lbs.			100

48 lbs. concrete sand
21 lbs. type III cement
10.5 lbs. water (0.5 w/c)

1.2 A cubic foot volume of concrete was batched from each of the three mix designs and 3-in. by 3-in. by 16-in. beams were cast from them for thermal expansion testing. An additional one cubic foot batch of 1-1/2-in. nominal granite mix was needed for compressive strength and modulus of elasticity tests in the form of cylinders. All specimens were cured for seven days in the wetroom and dried in the oven for a duration of 24 hours then cooled over night before any tests were performed.

CONCRETE MIX DESIGN (CLASS C = 6 SACK)

1-1/2-in. Nominal Granite (1.5 G)(6-in. by 6-in. by 21-in. beam)

weight	pass	retained	%
	1-3/4-in.	1-1/2-in.	0
41.5 lbs.	1-1/2-in.	3/4-in.	58
23.0 lbs.	3/4-in.	3/8-in.	32
7.5 lbs.	3/8-in.	No. 4	10
72.0 lbs.			100

48.0 lbs concrete sand
21.0 lbs. type III cement
10.5 lbs. water (0.5 w/c)

3/4-in. Nominal Granite (0.75 G)

weight	pass	retained	%
	1-1/2-in.	3/4-in.	0
41.5 lbs.	3/4-in.	3/8-in.	58
30.5 lbs.	3/8-in.	No. 4	42
72.0 lbs.			100

48 lbs. concrete sand
21 lbs. type III cement
10.5 lbs. water (0.5 w/c)

3/4-in. Nominal Limestone (0.75 L)

weight	pass	retained	%
41.5 lbs.	1-1/2-in.	3/4-in.	0
	3/4-in.	3/8-in.	58
30.5 lbs.	3/8-in.	No.4	42
72.0 lbs.			100

48 lbs. concrete sand
21 lbs. type III cement
10.5 lbs. water (0.5 w/c)

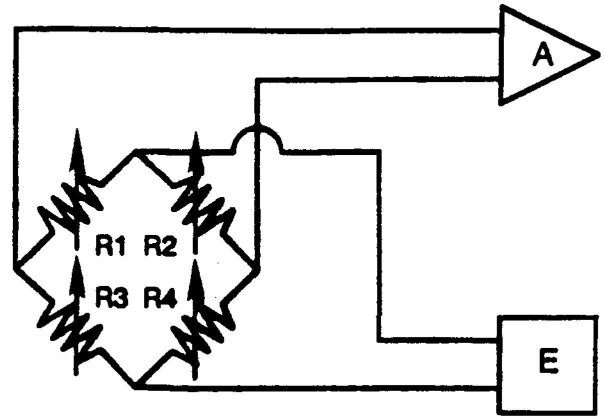
2.0 THERMAL EXPANSION TESTS OF GLENSANDA GRANITE CONCRETE

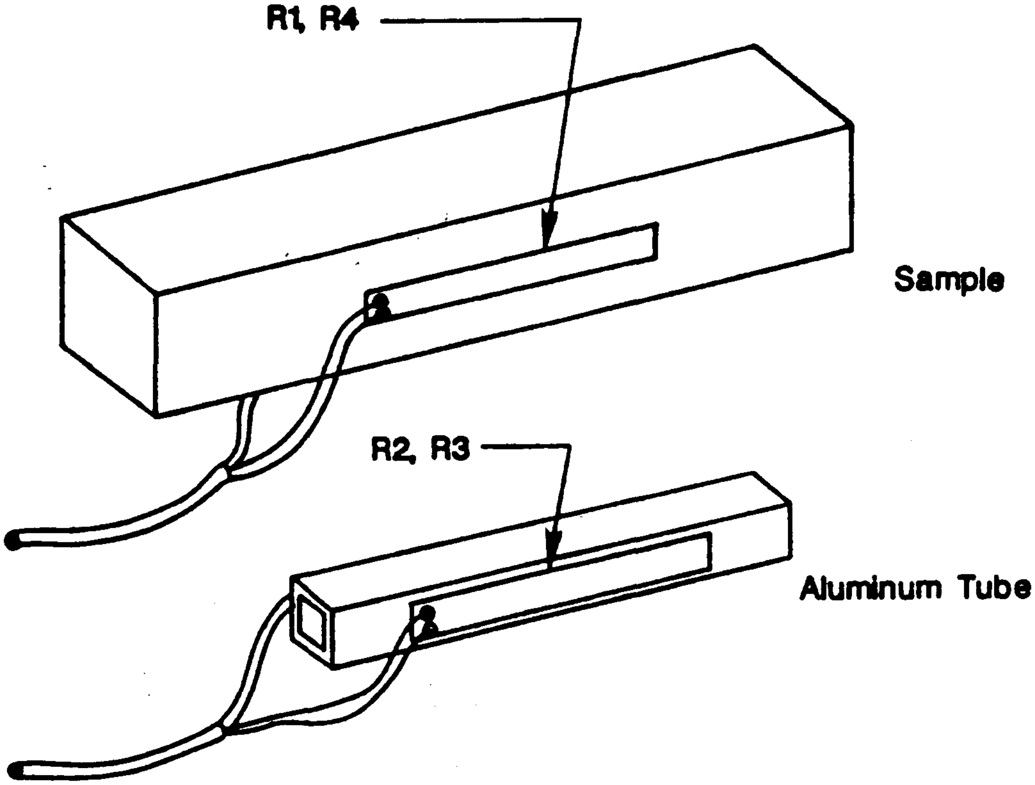
2.1 Procedure

The coefficients of thermal expansion for four different specimens were determined . Strain gages, identical in size, resistance, and gage factor were placed on opposite sides of the 3-in. by 3-in. by 16-in. beam. A full bridge configuration was used to compensate for temperature-induced conductivity changes in the gages. This was done by gaging an aluminum tube of known thermal expansion coefficient for alternate legs of the Wheatstone bridge. (Figs. 1a and 1b.)

R1 & R4 Mounted on Specimen

R2 & R3 Mounted on
Aluminum Tube





The strain gage determination of thermal expansion is based upon changes in electrical resistance of the gages. This change in resistance is due to the temperature-induced strains in the gage material and the temperature-induced strains of the specimen to which the gage is bonded, which accounts for most of the change in resistance. Additionally, however, a change in resistance can be attributed to a thermal electrical conductance shift in the metal alloy of the gage. These contributions are accounted for in the equations below.

$$\Delta/R = [\, \beta_G + (\alpha_s - \alpha_G)\, GF \,]\, \Delta T$$

where $\Delta R/R$ = unit resistance change

β_G = thermal coefficient of resistivity of strain gage material

$\alpha_s - \alpha_G$ = difference in thermal expansion coefficient between specimen and strain gage, respectively

GF = gage factor

ΔT = temperature change from arbitrary initia reference temperature

Then, since $\Delta R/F = GF \times \varepsilon$,

$$\varepsilon_{app(G/S)} = [\beta_G/GF + (\alpha_s - \alpha_G)]\, \Delta T \qquad \text{(A)}$$

where : $\varepsilon_{app\ (G/S)}$ = apparent strain output for strain gage alloy G on specimen material S

Similarly, for reference specimen R for which the coefficient of thermal expansion aR is already known.

$$\varepsilon_{app(G/R)} = [\ \beta_{G/GF} + (\alpha_R - \alpha_G)]\ \Delta T \qquad (B)$$

Subtracting Equation A from B, and rearranging

$$\alpha_s - \alpha_R = (\varepsilon_{app(G/S)} - \varepsilon_{app(G/R)}{}^{/\Delta T}$$

$$\therefore\ \alpha_s = (\varepsilon_{app(G/S)} - [\varepsilon_{app(G/R)/\Delta T}]\ \alpha^R$$

= thermal coefficient for the specimen

The thermal coefficient for the specimens data was then plotted and a straight-line, best-fit curve was drawn through the data points for each specimen. This was done for each specimen over the temperature range of 0 °F to 160 °F. The straight lines were overlaid to compare slopes for each specimen. The results are shown in Fig.1c.

2.2 Results

The coefficients of thermal expansion for the four different materials are as follows:

	α, X 10^{-6} in/in/°F
001.5 G: basic 6-sack concrete mix design using 1-1/2" crushed granite (ASTM No. 4) supplied by the sponsor	3.5
.75 G: Basic 6-sack concrete mix design using 3/4" crushed granite (ASTM No. 6) supplied by the sponsor	3.4

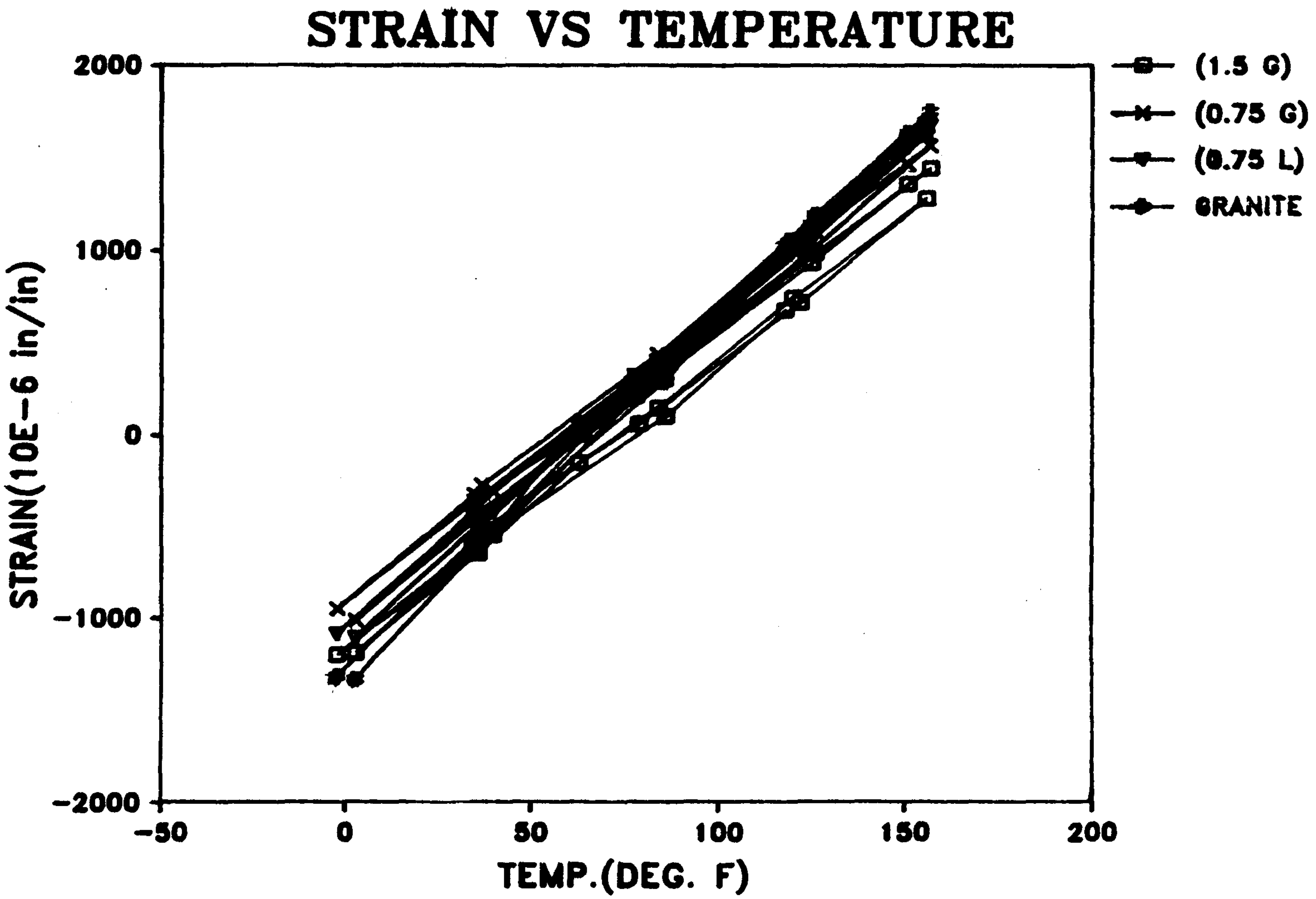

STRAIN VS TEMPERATURE
STRAIN(10E-6 in/in)
2000
1000
0
-1000
-2000
-50
0
50
100
150
200
TEMP.(DEG. F)
(1.5 G)
(0.75 G)
(0.75 L)
GRANITE

FIGURE 1 c

.75 L: Basic 6-sack concrete mix design using 3/4-in. crushed limestone supplied by Texas Crushed Stone	4.5
G. Rock: approx. 6-in. by 7-in. by 2-in. cut specimen from granite rock suplied by the sponsor	2.1

2.3 Conclusion

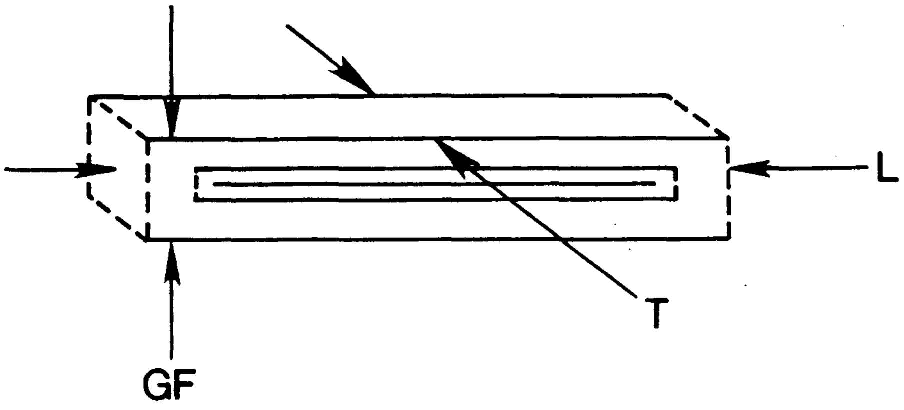
The coefficients of thermal expansion for the granite-aggregate concretes are about 25 percent lower than for limestone concrete. This is apparently due to the low coefficent for the granite rock.

STRAIN GAGES EMPLOYED
TML type PL-120-11
Length = 120 mm
Gage Factor = 2.13

DIMENSIONS

Sample	Gaged Face	Thickness	Length
1-1/2 G	5.75-in.	5.75-in.	18.75-in.
3/4 G	3	3	16
3/4 L	6 to 7.125	1.94	7.125
Drawn Aluminum Tubing	1	1	11.94

(hollow with 1/8-in. wall thickness)



3.0 COMPRESSION TESTING AND MODULUS OF ELASTICITY

3.1 Compressive Strength of Cylindrical Concrete Specimens

Compressive strength tests were conducted in accordance to the standard test method as specified in the ASTM manual (Designation: C39-81) cylindrical specimens of 6-in. by 12-in. were carefully aligned about the center of the loading pad and uninterrupted loadings were applied until failure was achieved. Loading rate was maintained at 20,000 lbs. per minute during testing and maximum load attained was recorded.

3.2 Procedure for modulus of elasticity

Modulus of elasticity tests were conducted on seven concrete cylinder specimens (6-in. by 12-in.) according to the standard test method specified in the ASTM manual (Designation: C 469-81). A companion was first loaded to failure using a compression loading machine to determine the approximate ultimate compressive strength for the batch. Forty percent of this ultimate strength was then used for establishing the modulus of elasticity values for each specimen. That is the stress at 40 percent of the ultimate load was divided by the strain at 40 percent of ultimate load.

A compressometer was used as the sensing device to measure the deformation of the specimens under loading. Two dial gages, each centered about midheight of the specimen, were used to measure the average deformation of two diametrically opposed gage lines. A long pivot rod was used to maintain a constant effective gage length of ten inches.

Specimens were loaded three times to a maximum of 40 percent of ultimate strength with no data recorded for the first loading. Deformation readings were taken for the two subseqsuent loading at a loading rate of 200,000 lbs. per minute. Deformations and applied loads were recorded, without interruption of loading at the following points:

(1). longitudinal strain of 50 millionths and
(2). applied load equal to 40% of ultimate load

These data were used to calculate the modulus of elasticity following the ASTM equation.

3.3 Results

The following modulus of elasticity and compressive strength test data were obtained from the respective tests performed on the seven concrete cylindrical specimens of 6-in. by12-in. Note that sample names were given to each specimen (sample A to G) in order to avoid confusion among specimens from the numerous data gathered.

Modulus of Elasticity

A $= 4.28 \times 10^6$ psi
B $= 4.19 \times 10^6$ psi
C $= 4.40 \times 10^6$ psi
D $= 4.57 \times 10^6$ psi

E = 5.69×10^6 psi

F = 4.62×10^6 psi

G = 3.98×10^6 psi

Average = $\underline{4.53 \times 10^6 \text{ psi}}$ = 4.53×10^3 ksi

(without E Average = 4.34×10^3 ksi)

Stress at failure

A = 5677 psi

B = 5890 psi

C = 6173 psi

D = 6296 psi

E = 4086 psi

F = 5837 psi

G = 5890 psi

Average = 5693 = 5.69 ksi

(without E Average = 5.96 ksi)

3.4 Conclusion

The compressive strengths of concrete cylinger specimens made with Glensanda granite conform to Texas State Department of Highway and Public Transportation minimum strength specification for six-sack mix design.

Also if the standard ACI modulus coefficient, 57,000 x $\sqrt{(f'_c)}$ is used the predicted modulus is virtually the same as the tested value.

APPENDIX

COMPANION SAMPLE TESTED TO ULTIMATE LOAD

ultimate load = 153,000 lbs

cross section area = 28.27 in.^{2}

compressive strength = 153,000/28.28 = 5,400 psi

40 percent ultimate load = 0.4 x 153,000 = 61,200 lbs

40 percent ultimate stress = 61,200/28.27 = 2,165 psi

According to ASTM

Modulus testing for cylinder specimens

Modulus E = (s_2-s_1)/(e_2-0.000050)

where

s_2 = stress at 40 percent ultimate stress

s_1 = stress at 50 millionth strain (0.000050)

e_2 = longifudinal strain produce by stress s_2

gage length l = 10 inches

= 0.000050

deflection at 0.00005 strain = 0.000050 x 10 = 0.0005 inch

Sample A

Stress at 40 percent ultimate stress s_2 = 61,200/28.27 = 2165 psi

average deflection at 40 percent ultimate stress = 0.0051 inch

strain at 40 percent ultimate stress ε_2 = 0.0051/10 = 0.00051

load at 0.00005 strain = 5500 lbs.

stress at 0.00005 strain s_1 = 5500/28.27 = 194.6 psi

Modulus $= (s_2 - s_1) / (\varepsilon_2 - \varepsilon_1)$

$= (2165 - 194.6)/(0.00051 - 0.00005)$

$= \underline{4.28 \times 10^6 \text{ psi}}$

load at failure = 160,500 lbs.

stress at failure = 160,500/28.27 = $\underline{5{,}677 \text{ psi}}$

Sample B

Stress at 40 percent ultimate stress s_2 = 2165 psi

average deflection at 40 percent ultimate stress = 0.0052 inch

strain at 0.00005 strain ε_2 = 0.0052/10 = 0.00052

load at 0.00005 strain = 5500 lbs.

stress at 0.00005 strain s_1 = 5500/28.27 = 194.6 psi

Modulus $= (s_2 - s_1)/(\varepsilon_2 - \varepsilon_1)$

$= (2165 - 194.6)/(0.00052 - 0.00005)$

$= \underline{4.19 \times 10^6 \text{ psi}}$

load at failure = 166,500 lbs.

stress at failure = 166,500/28.27 = 5890 psi

Sample C

stress at 40 percent ultimate stress s_2 = 2165 psi

average deflection at 40 percent ultimate stress = 0.0049 inch

strain at 40 percent ultimate stress ε_2 = 0.0049/10 = 0.00049

load at 0.00005 strain = 6500 lbs.

Sample D

stress at 40 percent ultimate stress s_2 = 2165 psi

average deflection at 40 percent ultimate stress = 0.0047 inch

strain at 40 percent ultimate stress ε_2 = 0.0047/10 = 0.00047

load at 0.00005 strain = 7000 lbs.

stress at 0.00005 strain s_1 = 7000/28.27 = 247.6 psi

Modulus $= (s_2-s_1)/(\varepsilon_2-\varepsilon_1)$

$= (2165 - 247.6)/(0.00047 - 0.00005)$

$= 4.57 \times 10^6$ psi

load at failure = 178,000 lbs.

stress at failure = 178,000/28.27 = 6296 psi

Sample E

stress at 40 percent ultimate stress s_2 = 2165 psi

average deflection at 40 percent ultimate stress = 0.0039 inch

strain at 40 percent ultimate stress ε_2 = 0.0039/10 = 0.00039

load at 0.00005 strain = 6500 lbs.

stress at 0.00005 strain = 6500/28.27 = 229.9 psi

Modulus $= (s_2 - s_1)/(\varepsilon_2 - \varepsilon_1)$

$= (2165 - 229.9)/(0.00039 - 0.00005)$

$= \underline{5.69 \times 10^6 \text{ psi}}$

load at failure =115,500 lbs.

stress at failure = 115,500/28.27 = 4086 psi

Sample F

stress at 40 percent ultimate stress s_2 = 2165 psi

average deflection at 40 percent ultimate stress = 0.0048 inch

strain at 40 percent ultimate stress ε_2 = 0.0048/10 = 0.00048

load at 0.00005 strain = 5000 lbs.

stress at 0.00005 strain s_1 = 5000/28.27 = 176.9 psi

Modulus $= (s_2 - s_1)/(\varepsilon_2 - \varepsilon_1)$

$= (2165 - 176.9)/(0.00048 - 0.00005)$

$= \underline{4.62 \times 10^6 \text{ psi}}$

load at failure = 165,000 lbs.
stress at failure = 165,000/28.27 = 5837 psi

Sample G

stress at 40 percent ultimate stress s_2 = 2165 psi
average deflection at 40 percent ultimate stress = 0.0055 inch
strain at 40 percent ultimate stress ε_2 = 0.0055/10 = 0.00055
load at 0.00005 strain = 5000 lbs.
stress at 0.00005 strain s_1 = 5000/28.27 = 176.9 psi

Modulus $= (s_2 - s_1)/(\varepsilon_2 - \varepsilon_1)$
$= (2165-176.9)/(0.00055 - 0.00005)$
$= 3.98 \times 10^6$ psi

load at failure = 166,500 lbs.
stress at failure = 166,500/28.27 = 5890 psi