SPLIT CYLINDER TEST FOR TENSION STRENGTH OF CONCRETE

by

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Traditionally certain operations such as the removal of centering under forms and application of loads to concrete pavement have been controlled by the modulus of rupture determined by 6" x 6" - 30" test beams. As the molding, curing, and handling of the 6" x 6" x 30" beam specimen are more difficult than 6" cylinders, replacing the flexure test with a split cylinder test could be desirable. This project was intended to establish the desirability of such a change. The questions to be answered included:

1) Does tensile strength correlate with flexure modulus? Such a correlation is crucial if past experience is to continue as a basis for decisions concerning construction.

2) Is the inherent variability of tension tests greater or less than that of flexure tests? Deviation of test results determines the number of tests required for a specified degree of confidence.

3) Does the change in age of concrete reflect a change in tensile strength comparable to the change in flexure modulus?

Procedure

A number of beams and cylinders were molded of Class "F" concrete (See Appendix P. 6) and tested at ages 4, 7, 11, and 14 days. Since all the beams and cylinders were not mixed in one batch, each set of beams and cylinders were not exactly identical in composition. As a result any significant increase in strength of concrete with age was hidden by the scatter of the test results (Fig. 1). Data from tests using this procedure will be typical of the results obtained from tests done using beams and cylinders made from different ready-mix truck loads of a specific concrete mix. Samples of concrete obtained from different ready-mix trucks will not be identical, just as the four sets of beams and cylinders used in this research effort were not identical.

Using several batches to make all the beams and cylinders needed for the study proved to be somewhat fruitless in terms of finding the relation between flexure modulus and tensile strength with age. To eliminate a portion of the variation among the beams and cylinders used in the study, a second group of beams and cylinders was made from single batches of class "F" and "A" concrete. Plotting the data collected from this second group of beams and cylinders, (Figs. 2a and 2b), shows a significant increase in strength of concrete with age whether measured by flexure modulus or by tension stress.

In addition, it is apparent from inspection of (Figs. 3a and 3b) that the flexure modulus is approximately equal to 100 psi more than the tensile strength. The modulus of rupture of the beam test is the value of tensile stress in the beam formula $S = \frac{Mc}{I}$. This computation assumes that a plane cross-section remains plane during bending (Fig. 5a). At early ages there is substantial yield in the concrete and the idealized tensile stress calculated differs from the true tensile stress actually present at the extreme fiber (Fig. 5b). These tests showed that as the concrete cured the tensile stress became a greater portion of the computed stress in flexure. This indicates that the modulus of elasticity increased and less yielding or plastic flow occurred before failure.

An equal number of cylinders were cast in steel and cardboard molds. Test data has been plotted in Figs. (2a and 2b). No difference appears in magnitude of the results or scatter.

It is readily apparent in Figures (2a and 2b) that the variability of strength found by beam breaks is greater than that found by split cylinder tests. A portion of this difference in variability of the two methods of testing can be attributed to the difference in quality of the test loading used. The cylinders were split in a 300,000-pound Rhiel machine capable of applying a constant loading. The beams were broken in a hand operated portable beam machine with no provision for control of the loading rate.

The greater portion of the difference in scatter can be explained by a very basic principle of quality control of continuous materials. Numerous studies (See References P. 5) have shown that the smaller the test quantity the greater the variability. That is, the probability of selecting a cubic inch of material sharply different from the median material is far greater than for selecting a cubic foot.

In flexure tests, only the material at the extreme surfaces of the beam is stressed critically (Fig. 6b). In split cylinder tests all of the material at the median plane is subjected to the ultimate stress (Fig. 6a). A small amount of low or high quality material located at the surface of the beam will have a greater effect on the test result than the same amount of material in the cylinder.

Procedures for rodding uniformly the entire volume of the beam are much more difficult to formulate and carry out than for cylinders. An added factor may well involve curing. The beam test is affected sharply by surface concrete whereas the cylinder test is more directly oriented toward internal concrete.

Logistically the preparation, handling and testing of beam samples are more demanding than for cylinders. The beam molds are more susceptable to damage and the labor of moving a 110-pound plus beam in 40-pound plus mold is far greater than the handling of a 30-pound plus cylinder with a 10-pound plus mold. With labor representing the major portion of the costs, eliminating use of beams will result in a savings.

Recommendations

It is evident from the work done in this study that it would be advantageous to replace the flexure test with the split cylinder test. The split cylinder test provides a more dependable means of testing concrete and facilitates the logistics of the operation. It is also possible to replace the steel cylinder molds with cardboard molds without appreciable change in results.

References:

1. Bertholf, W.M., "The Effect of Increment Weight on Sampling Accuracy", ASTM STP No. 242, Symposium on Bulk Sampling, p. 27, 1958.

2. Cordon, William A., "Size and Number of Samples and Statistical Considerations in Sampling, ASTM STP No. 169. Significance of Test and Properties of Concrete and Concrete Aggregates, p. 14, 1955.

3. Miller-Warden Associates, "Effects of Different Methods of Stockpiling Aggregates, Interim Report", National Cooperative Highway Research Program Report No. 5, 1964.

4. Miller-Warden Associates, "Effects of Different Methods of Stockpiling and Handling Aggregates", National Cooperative Highway Research Program Report No. 46, 1967.

5. Orning, A. A., "Coat Sampling Problems", ASTM STP No. 119, Symposium on Bulk Sampling, p. 30 and p. 32, 1951.

APPENDIX

Mix

a) Class "F" Concrete

Coarse Aggregate

Type	-	Broken Stone
Source	-	Balf, Newington
Combination	-	60% of 3/4" size & 40% of 1/2" size
Absorption	-	1.12%
Wear	-	O.K.

Fine Aggregate

Type	-	Natural Sand
Source	-	DeSiato, Eagleville
Fineness Modulus	-	2.60
Absorption	-	0.95%

b/^{b}o: .65 Cement Factor: 7.0 Sacks/cu yd: Estimated Air,%: 5%

Batch:

Cement (P)	-	658 lb (+29 lbs for Truck Mix)
Water	-	34 gal .02 change in b/^{b}o
Coarse Aggregate 3/4"	-	1060 lb ± 55 lb
1/2"	-	700 lb
Fine Aggregate	-	1360 lb ∓ 50 lb (+60 lbs. for Truck Mix)
Admixture	-	Maintain Air between 5% & 7%
Mortar Volume (Chace Air Indicator)	-	17.0 cu.ft.

b) Class "A" Pavement

Coarse Aggregate

Type	-	Broken Stone
Source	-	Balf, Newington
Combination	-	50% of 1-1/4" size & 50% of 1/2" size
Absorption	-	1.12%
Wear	-	O.K.

Fine Aggregate

Type	-	Natural Sand
Source	-	DeSiato, Eagleville
Fineness Modulus	-	2.60
Absorption	-	0.95

b/^{b}o: .75 Cement Factor: 6.5 Sacks/cu yd: Estimated Air,%: 4%

Batch:

Cement (P)	-	611 lb (+32 lbs. for Truck Mix)
Water	-	33 gal .02 change in b/b_o
Coarse Aggregate 1-1/4"	-	1070 lb ± 55 lb
1/2"	-	1070 lb
Fine Aggregate	-	1110 lb ∓ 50 lb (+60 lbs. for Truck Mix)
Admixture	-	Maintain Air between 4% & 6%
Mortar Volume (Chace Air Indicator)	-	15.0 cu. ft.

Molding

The beams and cylinders were each rodded 25 times per layer.

~~The beams were filled in two layers and the cylinders in three.~~

Curing

First 24 hours - wet burlap

Thereafter - Horn-cure

Testing

The beam flexure test followed specifications for AASHTO T97.

The split cylinder test followed specifications for ASTM C-496.

c) Illustrations

(Fig. 1) Strength of Class "F" Concrete at Various Ages (Group 1)

(Fig. 2a) Strength of Class "F" Concrete at Various Ages (Group 2)

(Fig. 2b) Strength of Class "A" Concrete at Various Ages (Group 2)

(Fig. 3a) Ratio of Tension Stress to Modulus of Rupture at Various Stress Levels

(Fig. 3b) Relation of Tension Stress to Modulus of Rupture

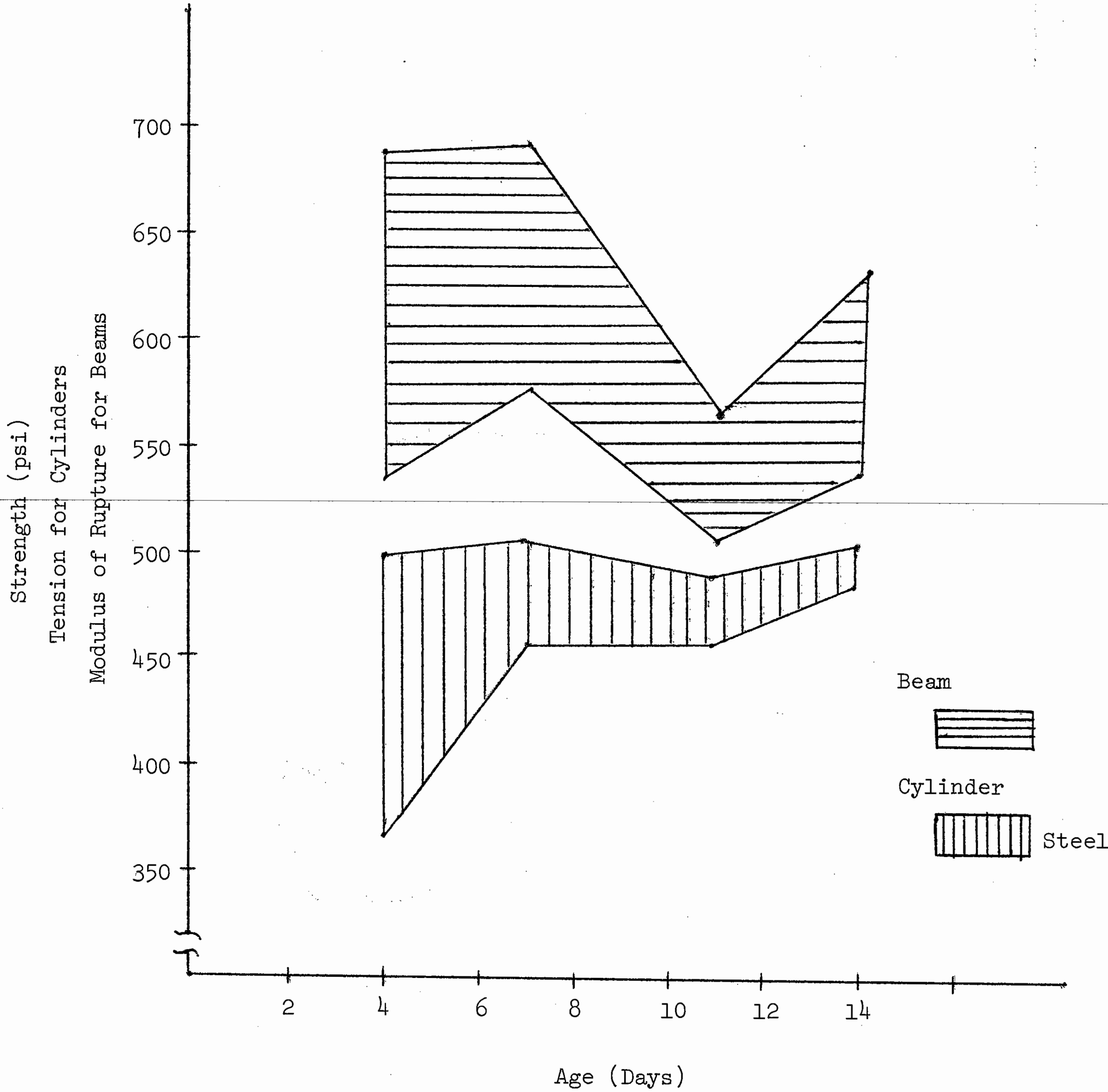
(Fig. 4a) Modulus of Rupture vs. Tensile Strength of Class "F" Concrete

(Fig. 4b) Modulus of Rupture vs. Tensile Strength of Class "A" Concrete

(Fig. 5) Stress Distribution for Beams

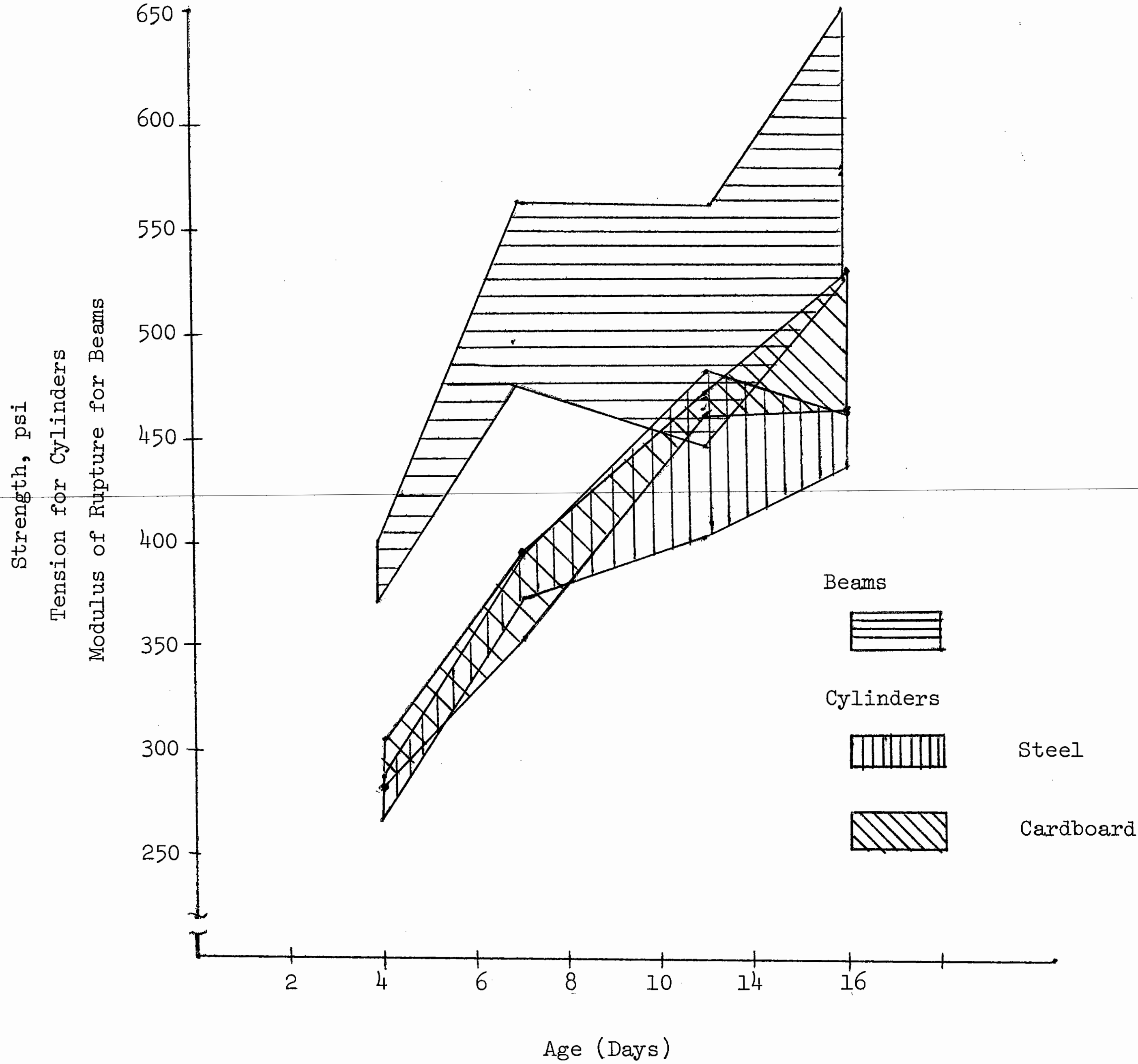
(Fig. 6) Stress Distribution for Cylinders vs. Stress Distribution for Beams

d) Tables



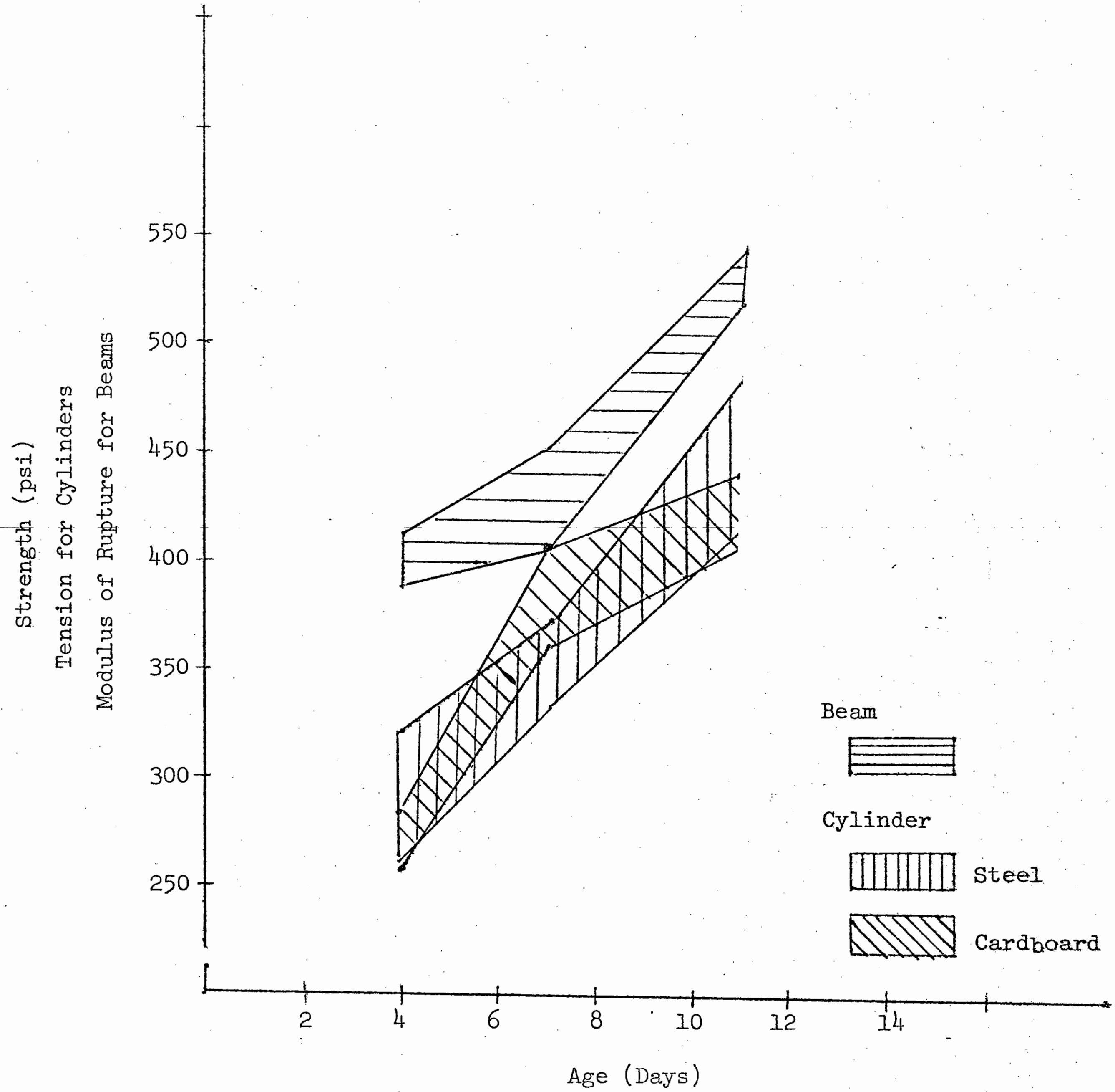
(Fig. 1) STRENGTH OF CLASS "F" CONCRETE AT VARIOUS AGES

(GROUP 1)



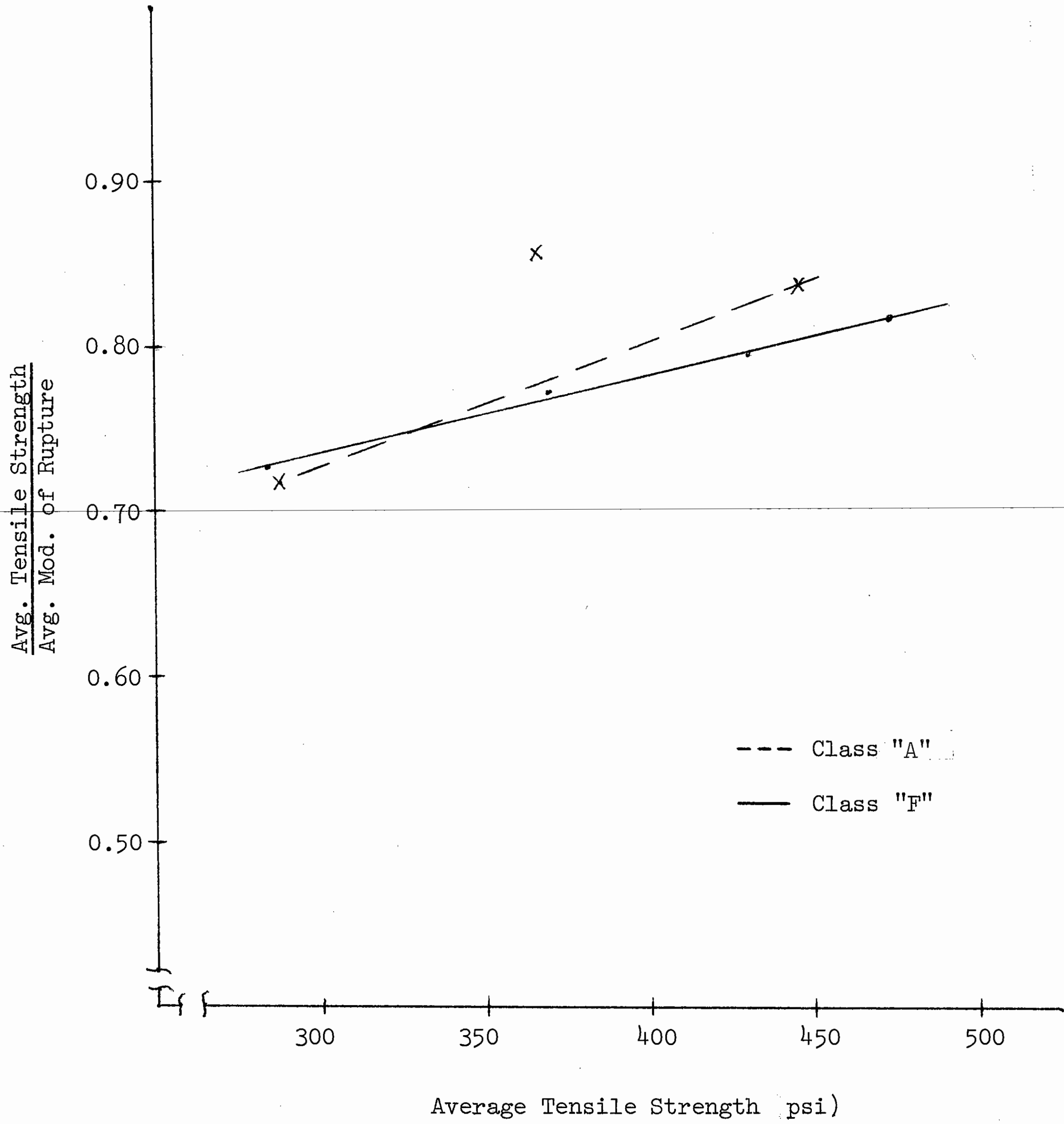
(Fig. 2a) STRENGTH OF CLASS "F" CONCRETE AT VARIOUS AGES

(GROUP 2)

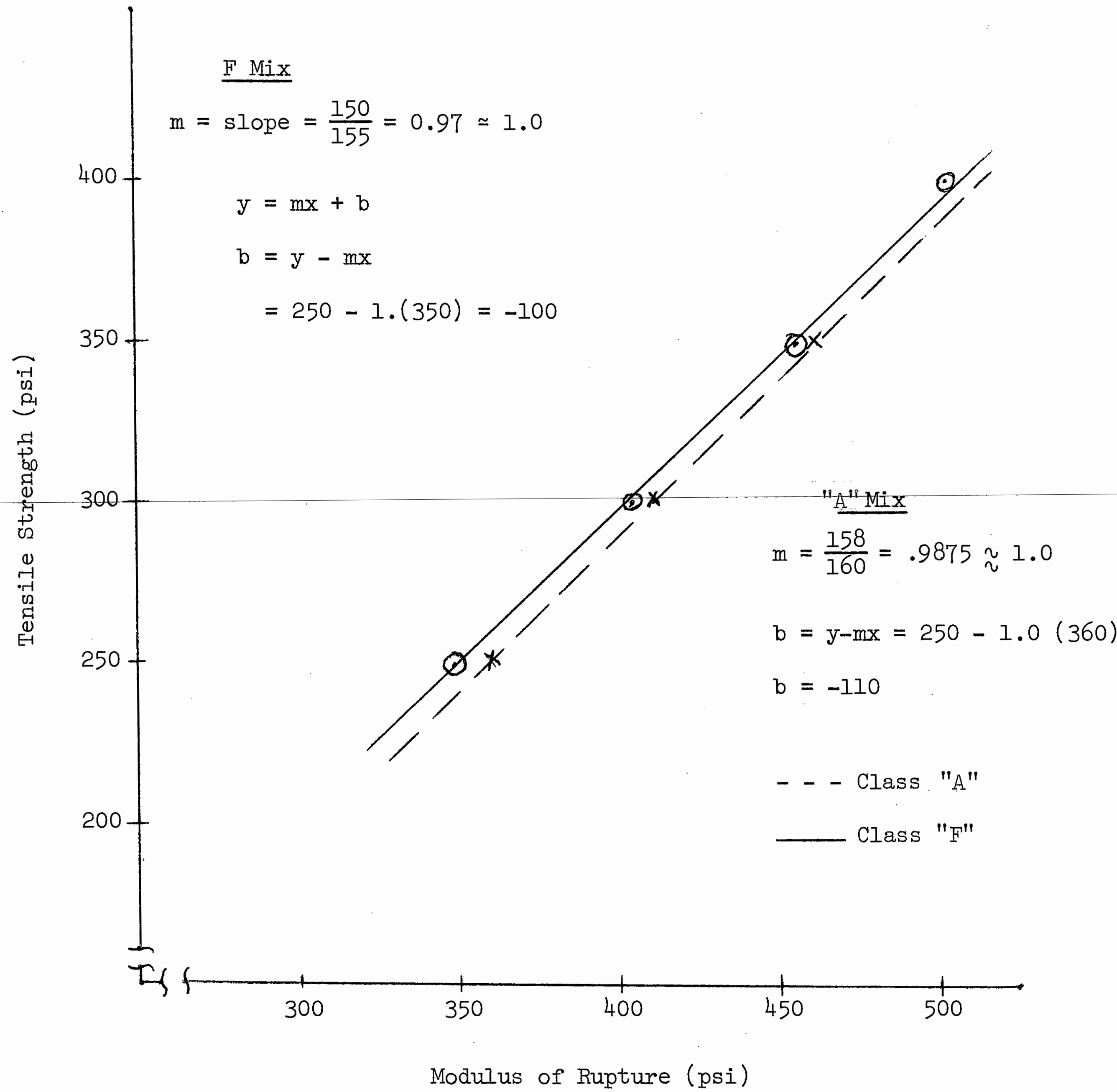


(Fig. 2b) <u>STRENGTH OF CLASS "A" CONCRETE</u>
<u>AT VARIOUS AGES</u>

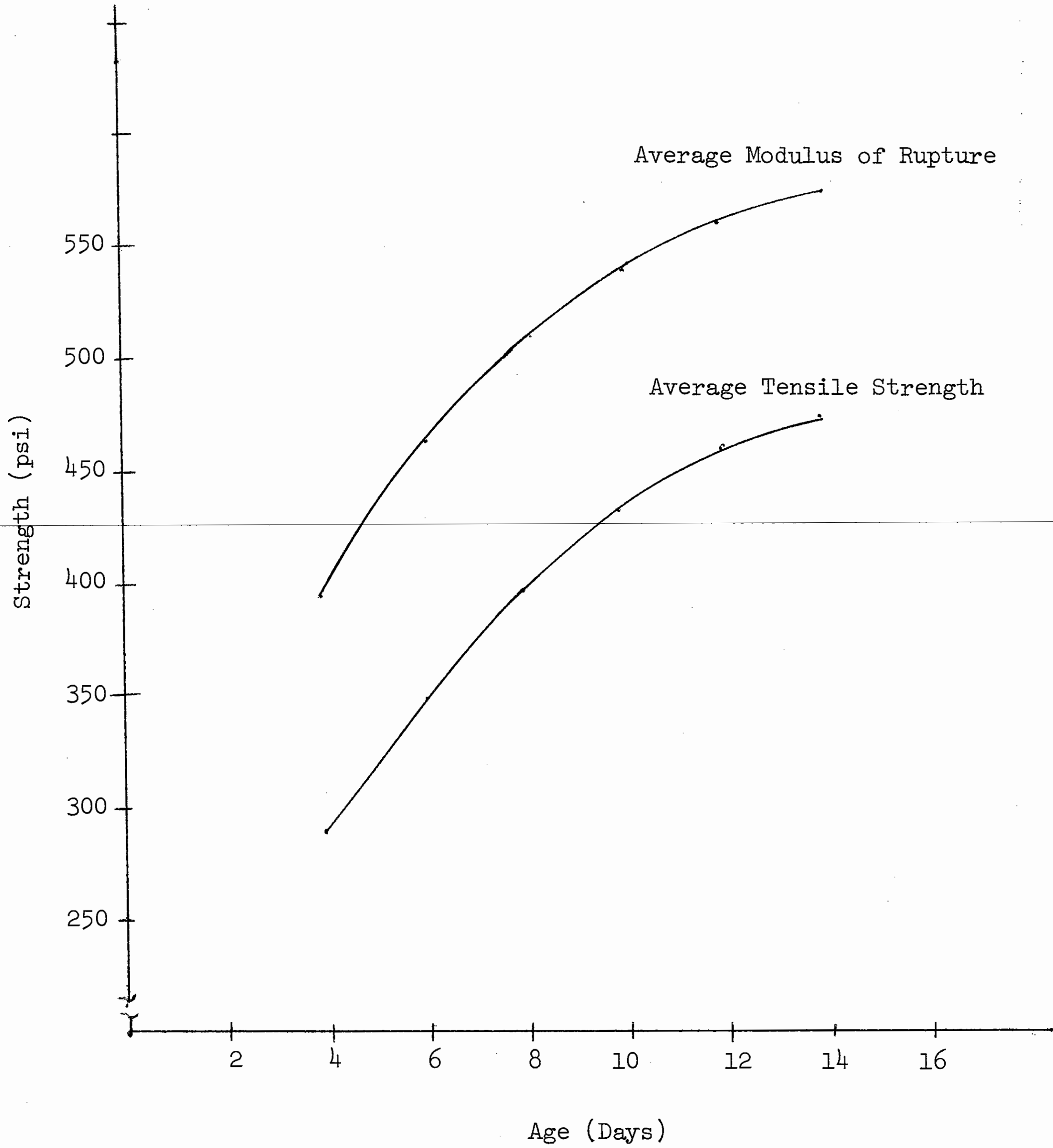
(GROUP 2)



(Fig. 3a) RATIO OF TENSION STRESS TO MODULUS OF RUPTURE AT VARIOUS STRESS LEVELS

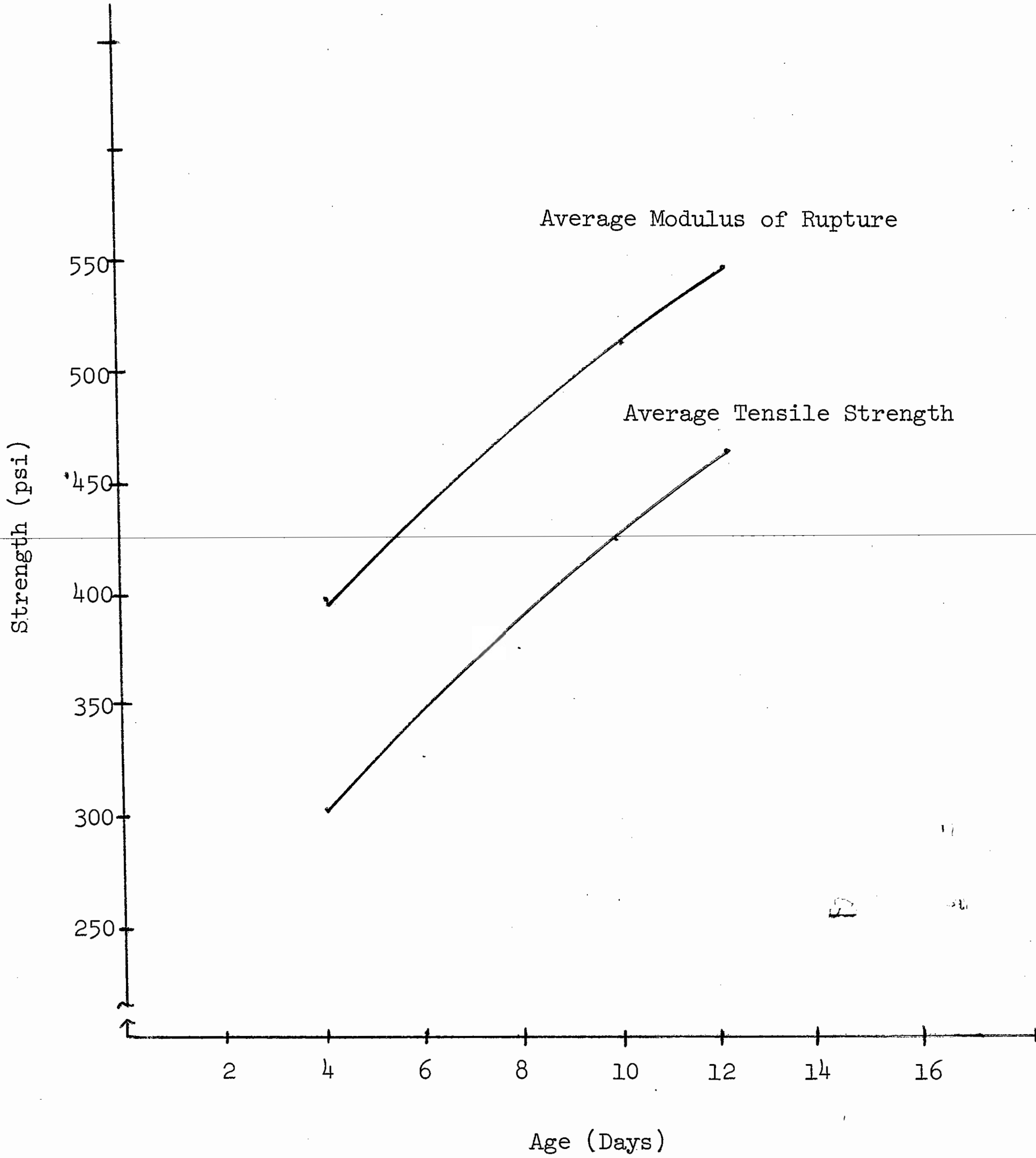


(Fig. 3b) <u>RELATION OF TENSION STRESS TO MODULUS OF RUPTURE</u>



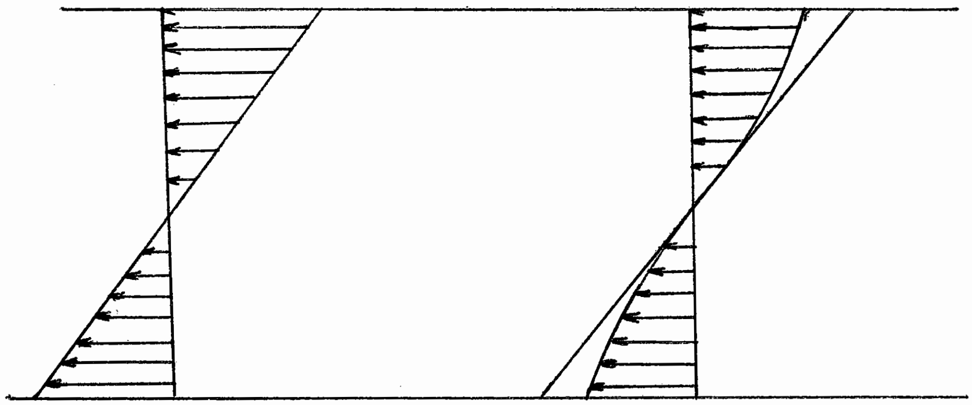
(Fig. 4a) <u>MODULUS OF RUPTURE VS. TENSILE STRENGTH</u>

<u>CLASS "F" CONCRETE</u>



(Fig. 4b) MODULUS OF RUPTURE VS. TENSILE STRENGTH

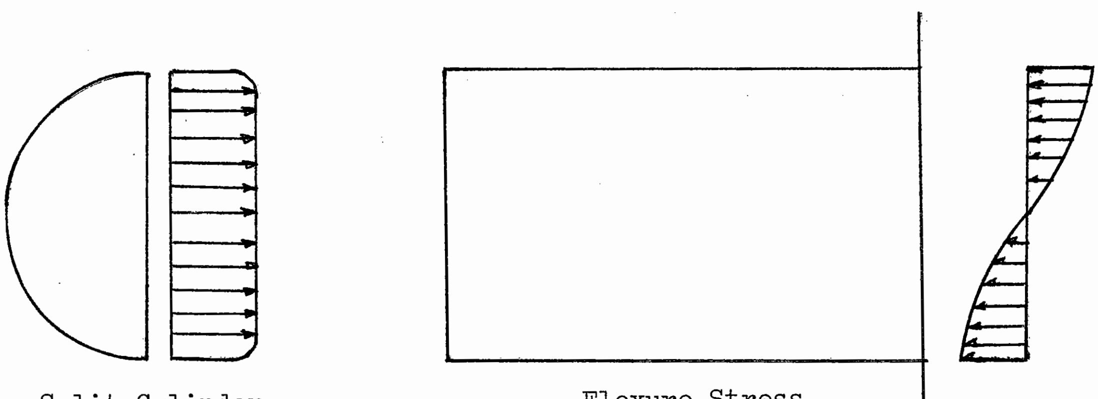
CLASS "A" CONCRETE



Predicted Stress Distribution
(a)

Actual Stress Distribution
(b)

Fig. 5



Split Cylinder Stress Distribution
(a)

Flexure Stress Distribution
(b)

Fig. 6

		BEAMS				CYLINDERS		
AGE (DAYS)	SAMPLE NO.	DIAL READING	LOAD (lbs.)	R = LOAD/12 (PSI)	AVG. MODULUS OF RUPTURE (PSI)	LOAD (lbs.)	T = LOAD/113.1 (PSI)	AVG. TENSION (PSI)
4	1	310	6430	536 (N.G)	614	56500	500 (N.G)	389
	2	355	7362	614		41500	367 (N.G)	
	3	398	8255	688 (N.G)		44000	389	
7	1	400	8296	691	637	55500	491	485
	2	335	6948	579		57500	508	
	3	370	7674	640		51500	455	
11	1	315	6533	544	541	55000	486	478
	2	330	6844	570		51500	455	
	3	295	6119	510		53000	469	
14	1	370	7674	640	592	57500	508	495
	2	---	---	---		----	---	
	3	315	6533	544		54500	482	

TABLE 1A

TEST DATA FOR CLASS "F" CONCRETE (GROUP 1)

TABLE 1B TEST DATA FOR CLASS "F" CONCRETE (GROUP 2)

	BEAMS					CYLINDERS			
Age (Days)	Sample No.	Dial Reading	Load (lbs.)	R = Load/12 (psi)	Avg. Modulus of Rupture (psi)	Sample No.	Load (lbs.)	T = Load/113.1 (psi)	Avg. Tension (psi)
	1	230	4770	398		1S	30000	265	
	2	215	4459	372		2S	32500	287	280
						3S	32500	287	
4					395		---	---	--- 289
						1P	34500	305	
	3	230	4770	398		2P	32000	283	298
	4	237	4915	410		3P	34500	305	
	1	285	5911	493		1S	44500	393	
	2	275	5704	475		2S	42500	376	383
						3S	43000	380	
7					510		---	---	--- 378
						1P	41000	363	
	3	325	6741	562		2P	40000	354	372
	4	--				3P	45000	398	
	1	272	5641	470		1S	46000	407	
	2	259	5372	448		2S	49000	433	441
						3S	54500	482	
11					462		---	---	--- 456
						1P	53500	473	
	3	325	6741	562		2P	52500	464	471
	4	270	5600	467		3P	53750	475	
	1	335	6948	579		1S	49500	438	
	2	310	6924	577		2S	52500	464	454
						3S	52000	460	
14					561		---	---	--- 476
						1P	52500	464	
	3	377	7819	652		2P	60000	531	498
	4	305	6326	527		3P	56500	500	

S - STEEL
P - CARDBOARD

TABLE 2 TEST DATA FOR CLASS "A" CONCRETE (GROUP 2)

	BEAMS					CYLINDERS			
Age (Days)	Sample No.	Dial Reading	Load (lbs.)	R = Load/12 (psi)	Avg. Modulus of Rupture (psi)	Sample No.	Load (lbs.)	T = Load/113.1 (psi)	Avg. Tension (psi)
	1	235	4874	406		1S	30000	265	
	2	227	4708	392		2S	35500	314	319
						3S	36500	323	
4				400	400		---	---	--- 296
	3	240	4978	415		1P	31000	274	
	4	225	4667	389		2P	32000	283	273
						3P	29500	261	
	1	237	4915	410		1S	39000	345	
	2	235	4874	406		2S	37600	332	350
						3S	42200	373	
7					423		---	---	--- 362
	3	262	5434	453		1P	41000	363	
	4	--	--	--		2P	39500	349	373
						3P	46000	407	
	1	305	6326	527		1S	47000	416	
	2	300	6222	519		2S	52000	460	454
						3S	55000	486	
11					532		---	---	--- 440
	3	316	6544	545		1P	48500	429	
	4	310	6429	536		2P	50000	442	426
						3P	46000	407	
	1	228	4680	390		1S	50500	447	
	2	285	5640			2S	49100	434	427
						3S	45400	401	
14							---	---	--- 421
	3	226	4500	375		1P	49400	437	
	4	218	4260			2P	46500	411	414
						3P	44600	394	

S - STEEL
P - CARDBOARD

Age (Days)	Minimum Tensile Strength (psi)	Maximum Tensile Strength (psi)	Average Tensile Strength (psi)	Minimum Modulus of Rupture (psi)	Maximum Modulus of Rupture (psi)	Average Modulus of Rupture (psi)	D Average Difference (psi)	Avg. Tension / Avg. Modulus
CLASS "F" MIX								
4	265	305	285	370	410	390	105	0.73
7	340	398	369	450	507	479	110	0.77
10	395	470	433	498	592	545	112	0.79
13	427	520	474	523	640	582	108	0.81
CLASS "A" MIX								
4	261	314	288	389	415	402	114	0.72
7	332	407	370	406	453	430	60	0.86
10	407	486	447	519	545	532	85	0.84
13	401	447	424	--	--	--	--	--

TABLE 3

MINIMUM AND MAXIMUM VALUES OF TENSILE STRENGTH AND MODULUS OF RUPTURE WITH AGE

CLASS "F" MIX

TIME (DAYS)	AVG. TENSILE STRENGTH (PSI)	AVG. MODULUS OF RUPTURE (PSI)	DIFFERENCE	AVG. TENSION / AVG. MOD. OF RUPTURE
4	285	395	110	0.72
6	350	465	115	0.75
8	400	510	105	0.78
10	435	540	105	0.81
12	460	560	100	0.82
14	470	575	105	0.82
		CLASS "A" MIX		
4	300	400	100	.75
6	340	430	90	.79
8	370	470	100	.787
10	420	510	90	.82
12	465	550	85	.845
14	---	---	--	---

(ALL VALUES FROM DATA PLOT)

TABLE 4

AVERAGE VALUES OF TENSILE STRENGTH
AND MODULUS OF RUPTURE WITH AGE