EQUIVALENT COMPRESSIVE STRENGTH FROM FLEXURAL TESTING - A CONVERSION FACTOR INVESTIGATION

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INTRODUCTION

During the past fifty years the State of Vermont has been using a factor for converting "Modulus of Rupture" to an "Equivalent Compressive Strength". This conversion factor was derived by Professor Clemmer at the University of Illinois and adopted by the State of Vermont. A cantilever type beam breaker was acquired and both the factor and machine are being used to report test beam results. The formula for converting the beam strength (lbs.) to the Modulus of Rupture (psi) for the State's cantilever breaker has been recently questioned and recomputed. The formula used to derive the "conversion factor" is not available, but was originally substantiated through laboratory testing. However, changes in concrete technology and design have appeared to invalidate the accuracy of the formula.

An investigation was initiated to determine the validity of our present factor or to establish, if possible, a new factor relevant to concrete designs used by the Vermont Department of Highways.

The tests for this investigation were performed in the laboratory and in the field to substantiate or refute the accuracy of the factor. This report will describe the test methods and results.

CONCRETE MATERIALS AND DESIGN

The original testing data used to determine the conversion factor is unavailable. Therefore, the concrete designs currently being used by the State are basic to the investigation.

AGGREGATES

The aggregates chosen for this investigation were crushed rock from Lebanon Crushed Stone, Inc., West Lebanon, New Hampshire; L. A. Demers, Winooski, Vermont; Kelley Construction, Websterville, Vermont; and crushed gravel from Calkins Construction, Coventry, Vermont. Fine aggregate sources for the testing were S. T. Griswold, Williston, Vermont; Lebanon Crushed Stone, Inc., West Lebanon, New Hampshire; Nadeau's Pit, Johnson, Vermont; and Calkins Construction, Coventry, Vermont. Both the fine and coarse aggregate met State requirements before concrete batching operations were initiated.

CEMENT

For this investigation three brands of Type I cement (Iron Clad, Glens Falls, New York; Northeast, St. Constant, Quebec, Canada; Universal Atlas, Hudson, New York) were used.

MIX DESIGN

Concrete mix designs were based on the specific gravities of the aggregates as used in the individual ready-mix plants. Both Class A (6½ sk/cy) and Class B (6 sk/cy) concrete were used in the field investigation. Laboratory testing utilized only Class A concrete.

ADMIXTURES

The air-entraining admixture used for the field projects and laboratory testing was Grace Chemical's "Darex". This admixture is used by most of the ready-mix concrete plants that produce concrete for State Highway projects. A retarding admixture (Grace Chemical's "Daratard") was used only on the Montpelier project.

CONCRETE

Concrete used for the field projects was produced at three ready-mix concrete plants: Miller Ready-Mix, West Lebanon, New Hampshire for the Royalton-Tunbridge Project; Kelley Transit Mix, Montpelier, Vermont for the Montpelier Project; and S. T. Griswold, Williston, Vermont for the Burlington project.

PROCEDURE

BATCHING

Laboratory personnel inspected the batching operations at the individual ready-mix plants and their daily reports indicate proper plant procedure. Slips accompanying each batch recorded all pertinent data.

TEST SPECIMENS

Test specimens were fabricated at the project site in beam and cylinder molds to provide a comparison between the direct compressive strength and that compressive strength as computed from Modulus of Rupture.

The Vermont Department of Highways specifies test beams and their Modulus of Rupture as the criteria for determining strength even though compressive strength is more commonly used throughout the concrete industry.

TEST BEAMS

The test beams used in the investigation were fabricated in 6 x 6 x 36 in. wooden molds which allow for two breaks per beam. The molds are filled on the project and cured with the structure for the required time period. After initial curing they are transported in their molds to the laboratory for testing. The first test is performed upon arrival and provides information as to the field curing. The remaining beam segment is then laboratory cured. The second break at 28 days is an indication of the concrete quality.

The laboratory test beams were cast in the same manner as above and cured with constant temperature and humidity. These test beams were broken in flexure at ages of 10 and 28 days.

TEST CYLINDERS

The test cylinders were cast in 6 x 12 in. cardboard molds. Two cylinders were cast with each test beam from the same concrete mix. Curing was identical to that of the corresponding test beam.

DISCUSSION OF TEST RESULTS

The primary objective of this investigation was to ascertain the validity of the conversion factor. The results of this investigation did not satisfy that objective due to the presence of too many variables, i.e. too few constants. This condition is prevalent in typical concrete operations throughout the State, and no attempt was made to insure uniformity.

LABORATORY RESULTS

The laboratory tests showed that when large variations in slump and air content are introduced, there is little effect on the resulting factor. All test results of the laboratory investigation are shown in Table I. These results revealed an average conversion factor lower than the present factor 5.25. The average factor for laboratory testing was 4.37.

Of further interest is the comparison shown between the 10 day and 28 day breaks. Although the strengths, in all cases, increased, those tested in flexure gained more rapidly than those broken in compression.

FIELD RESULTS

Data relative to the field projects was more extensive than that of the laboratory. The three projects provided sixty-five beams and their corresponding cylinders. Tables IIA, IIB, & IIC illustrate the normal variations to be expected under field conditions even though the concrete meets the limited tolerances permitted in the State of Vermont specifications. Figures I and II show the frequency distribution curves for both conversion factors and compressive strengths respectively. Figure I shows an arithmetic average of the test results computed along with their standard deviation. Note that 4.31 is the overall average factor. Ninety percent of all results are within one standard deviation of this factor. One standard deviation is .98 (23% of 4.31).

Figure II is a distribution curve based on the direct compressive strengths of test cylinders. The average compressive strength of 3042 psi is computed. Seventy-five percent of the cylinders are within one standard deviation of 479 (15.7% of the average compressive strength).

Of interest is the result that 95% of all cylinders lie within ± 956 psi while 50% of them lie within ± 350 psi from the average compressive strength (3042 psi).

These figures show large variations when all tests are presented together. Thus, the field projects are examined individually to ascertain if a single conversion factor can be established when the number of variables common to concrete are reduced.

Figures IIIA, IIIB, & IIIC present a graphic comparison between the individual factors plotted according to their direct compressive strengths and their moduli of rupture. Symbols are used to depict the class and age of test of the specimens. The present factor has been plotted on the graphs along with all test results of the individual field projects. The average of all factors for each project is also illustrated.

One of the major problems in trying to correlate results of field testing comes from the lack of relatable material. Constants which would enable accurate comparison seldom appear. Table III lists those specimens by project which have common properties. It can be seen that even when limiting the variables, the factor continues to be unstable. Table IV summarizes the averages of all laboratory and field project test results. Note that the Modulus of Rupture varies from 18% to 27% of the compressive strength. This variance indicates that there is no constant relationship between them as had been previously assumed.

SUMMARY

This investigation has established that the equivalent compressive strength, as computed from the concrete test beams broken in flexure, is in error. The accuracy of the present conversion factor of 5.25 or any other factor which could be established is invalid except for the purpose of comparing specimens with each other.

When considering the entire spectrum of test results from both moduli of rupture and compressive strengths, the deviation is such that the average would be meaningless. The factors resulting from these tests ranged from a low of 2.55 to a high of 6.15 showing that the modulus of rupture compared to actual compressive strength varies from batch to batch.

The properties affecting the constancy of concrete strength include air content, aggregate and cement characteristics, consistency, method and effectiveness of curing, age of test, and numerous others. However, the magnitude of their effect may vary depending on whether the concrete is tested in compression or flexure.

Although relationships between the two methods of testing concrete strengths do exist, it is shown that our past and present practice of correlation and the reporting of these figures is incorrect.

CONCLUSIONS AND RECOMMENDATIONS

1. The modulus of rupture only should be reported when testing concrete strength in flexure.

2. Tests should be performed comparing the methods and the effect of various machines available for obtaining flexural strength.

3. Test beams should be required only when unreinforced concrete is to be subjected to flexural loading. Since all structural concrete used by the Department of Highways is reinforced, the use of test cylinders should be reconsidered.

4. It should be established that the concrete strength be tested to show either field curing effectiveness or concrete quality at a specified age. Deriving both factors from a single specimen is erroneous.

5. Concrete specimens, whether test beams or cylinders, should be molded, cured, and tested in strict compliance with applicable AASHO procedures.

MIX NO.	QUANTITY WATER LBS.	OZ.	PERCENT AIR	SLUMP	CURE TIME (DAYS)	MODULUS OF RUPTURE	COMPRESSIVE STRENGTH	F = COMP. STRENGTH / MODULUS OF RUPTURE	% = MODULUS OF RUPTURE / COMPRESSIVE STRENGTH	FACTOR DIFFERENCE 10 TO 28 DAY
1	17	2	5¼	4"	10	751	3395	4.52	22.1	(-) .22
					28	960	4129	4.30	23.3	
2	15	10	5¼	2"	10	838	3829	4.57	21.9	(-) .26
					28	1065	4589	4.31	23.0	
3	16	15	4½	4"	10	943	4536	4.81	20.8	(-) .71
					28	1170	4802	4.10	24.4	
4	17	7	8	3 3/4"	10	681	2980	4.38	22.9	(-) .40
					28	856	3404	3.98	25.2	
5	15	12	5½	4"	10	821	3369	4.10	24.4	(-) .09
					28	978	3917	4.01	25.0	
6	15	7	7½	2½"	10	681	3687	5.41	18.5	(-) .48
					28	1030	4050	3.93	25.4	
			AVERAGE		10	786	3632	4.63	21.7	(-) .36
					28	1009	4148	4.10	24.4	
			OVERALL			897	3890	4.37	23.05	

MIX NO.	AGGREGATE SOURCE	CEMENT BRAND & TYPE	
#1 & #2	CALKINS CONSTRUCTION, COVENTRY, VERMONT	UNIVERSAL ATLAS	TYPE #1
#3 & #4	L.A. DEMERS & S.T. GRISWOLD, WINOOSKI, VT	GLENNS FALLS	TYPE #1
#5 & #6	LEBANON CRUSHED STONE, INC. WEST LEBANON, NEW HAMPSHIRE	NORTHEAST	TYPE #1

LABORATORY INVESTIGATION FOR FACTOR DETERMINATION

TABLE I

DATE	AIR-ENTRAINING AGENT (DAREX)	SLUMP (INCHES)	AIR CONTENT (PERCENT)	CLASS OF CONCRETE	RETARDER	AMBIENT TEMPERATURE
8/24/70	6 oz	3	5½	B	None	70°
5/22/70	6½ oz	3¼	6	B	None	..
5/28/70	6 oz	2 3/4	6¼	B	None	38° -
6/5/70	6 oz	3¼	6¼	B	None	
6/8/70	6 oz	3	6 3/4	B	None	75°
6/12/70	6 oz	2½	5½	B	None	
8/21/70	6-6½ oz	3	6	A	None	50°
8/25/70	6 oz	3¼	6	B	None	
8/12/70	2½-5 oz			A	Daratard 8-12 oz/sack	62° +
8/12/70	5 oz	3	7	A	8 oz	
8/12/70	2½ or 3½ oz	2 3/4	6	A	12 oz	
8/12/70	2½ or 3½ oz	2½	6	A	12 oz	

PROJECT CONCRETE DATA

MONTPELIER

TABLE IIA

DATE	AIR-ENTRAINING AGENT (DAREX)	SLUMP (INCHES)	AIR CONTENT (PERCENT)	CLASS OF CONCRETE	RETARDER	AMBIENT TEMPERATURE
8/25/70	6½ oz	3 3/4	6¼	A	None	57°
8/25/70	6½ oz	4	6	A	None	57°
8/25/70	6½ oz	3	6¼	A	None	57°
6/19/70	6 oz	3	6½	B	None	65°
6/11/70	6 oz	2 3/4	6½	B	None	70°
6/10/70	6 oz	4	7	B	None	85°
6/5/70	6 oz	3	6½	B	None	55°
6/1/70	6 oz	3½	5½	B	None	70°
6/1/70	6 oz	3½	6½	B	None	70°

PROJECT CONCRETE DATA

BURLINGTON

TABLE IIB

DATE	AIR-ENTRAINING AGENT (DAREX)	SLUMP (INCHES)	AIR CONTENT (PERCENT)	CLASS OF CONCRETE	RETARDER	AMBIENT TEMPERATURE
6/3/70	6 oz	4	6	B	None	70°
6/10/70	4½ oz	3	6	B	None	85°
6/24/70	4½ oz	3½	5½	B	None	80°
7/2/70	5 oz	3	6	B	None	60°
7/17/70	5½ oz	3	6¼	B	None	80°
7/23/70	5 oz	4	6	B	None	85°
7/24/70	5 oz	3	6½	B	None	85°
8/11/70	5 oz	--	--	B	None	80°
10/13/70	6-6½-7 oz	3	6½	A	None	55-70°
10/13/70	6 oz	3	6	A	None	65°
10/29/70	5½ oz	2½	4½	B	None	50°
11/12/70	5½ oz	3½	7	B	None	60°

PROJECT CONCRETE DATA

ROYALTON – TUNBRIDGE

TABLE IIC

Project	Class Concrete	Darex	Concrete Testing Air	Concrete Testing Slump	Factors 10 days	Factors 28 days	Difference
Montpelier	A	*2.5 oz/cy	6%	2 3/4"	5.73	5.83	+ .10
"	A	*3.5 oz/cy	6%	2 1/2"	5.30	4.86	- .44
"	A	6.5 oz/cy	6%	3"	6.15	5.30	- .85
"	B	--	6%	3 1/4"	4.22	4.59	+ .37
"	B	--	6%	3 1/4"	4.12	4.75	+ .63
Burlington	A	6.5 oz/cy	6¼%	3 3/4"	3.50	3.98	+ .48
"	A	6.5 oz/cy	6¼%	3"	4.04	4.30	+ .26
"	B	6 oz/cy	6½%	3"	4.15	3.94	- .21
"	B	6 oz/cy	6½%	2 3/4"	4.55	4.03	- .52
"	B	6 oz/cy	6½%	3"	4.75	3.60	-1.15
Royalton-Tunbridge	A	6-7 oz/cy	6½%	3"	3.95	4.50	+ .55
"	A	6 oz/cy	6%	3"	3.75	4.20	+ .45
"	B	6 oz/cy	6%	4"	4.05	4.40	+ .35
"	B	4.5 oz/cy	6%	3"	4.30	3.40	- .90
"	B	5 oz/cy	6%	3"	4.40	3.72	- .68
"	B	5 oz/cy	6%	4"	4.52	3.84	- .68
"	B	5 oz/cy	6%	3"	4.40	3.72	- .68
"	B	4.5 oz/cy	6%	3"	4.30	3.40	- .90
"	B	5 oz/cy	6½%	3"	4.40	4.45	+ .05
"	B	5.5 oz/cy	6%	3"	2.55	3.37	+ .82

*Contains Daratard retarding admixture (12 oz/sack)

FACTOR COMPARISON

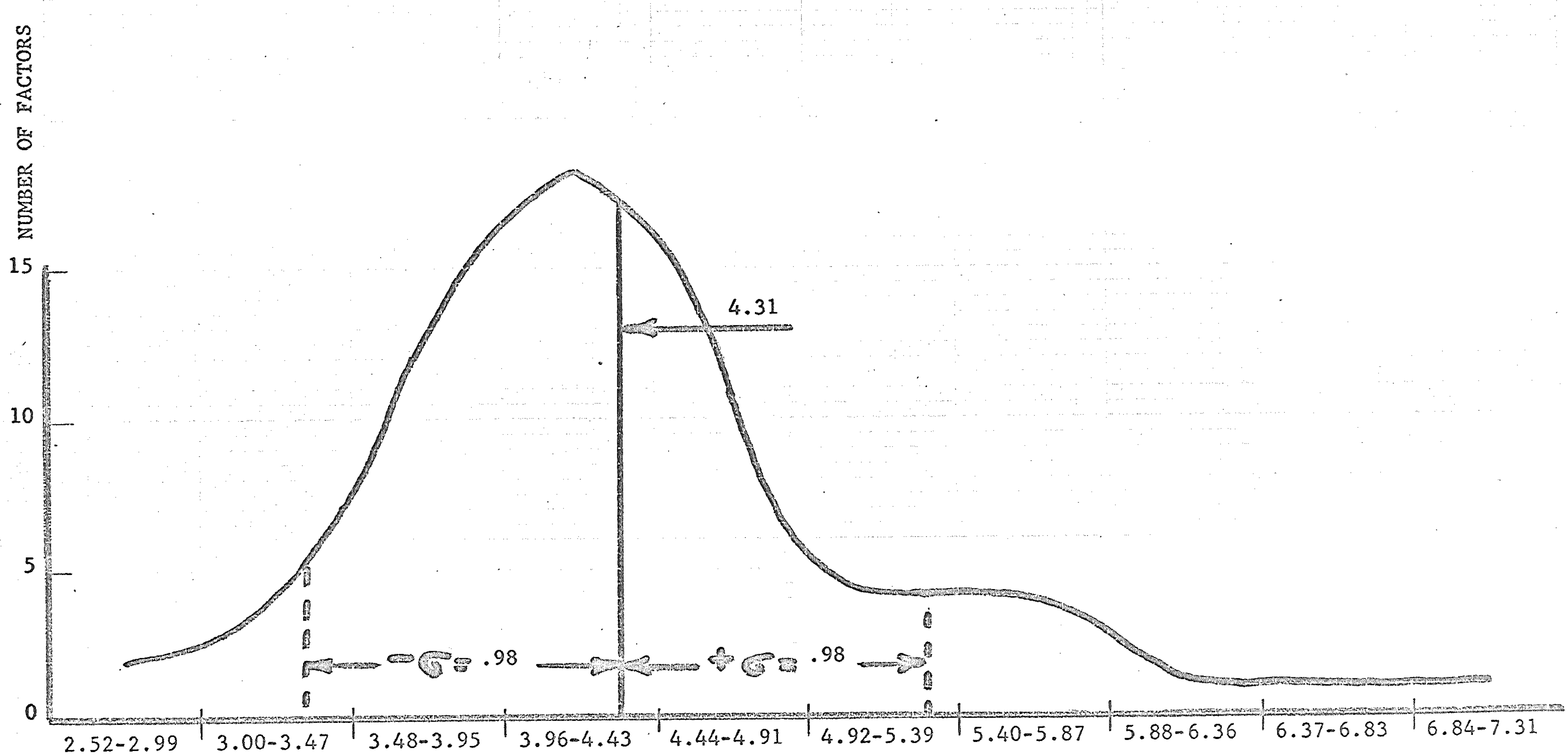
FIELD SPECIMENS WITH COMMON PROPERTIES

TABLE III

Project		Class Concrete	Age Of Test (Days)	Mod. Of Rupt. (Avg.)	Compressive Strength (Avg.)	Factor (Avg.)	Percent (Avg.)
Laboratory		A	10	786	3632	4.62	22
			28	1009	4148	4.11	24
	Avg.			898	3890	4.37	23
Montpelier		A	10	586	3265	5.57	18
		A	28	707	3711	5.25	19
		B	10	671	2698	4.02	25
		B	28	771	3277	4.25	24
	Avg.			684	3238	4.77	22
Burlington		A	10	710	2679	3.77	27
		A	28	809	3269	4 04	25
		B	10	663	2880	4.34	23
		B	28	762	3098	4 07	25
	Avg.			726	2982	4.06	25
Royalton-Tunbridge		A	10	760	2926	3.85	26
		A	28	900	3913	4.35	23
		B	10	631	2578	4.09	24
		B	28	811	3239	3.99	25
	Avg.			776	3164	4.07	24
Field Project Average				729	3138	4.31	24
Average (All Tests)				771	3319	4.32	24

SUMMATION OF TEST AVERAGES

TABLE IV

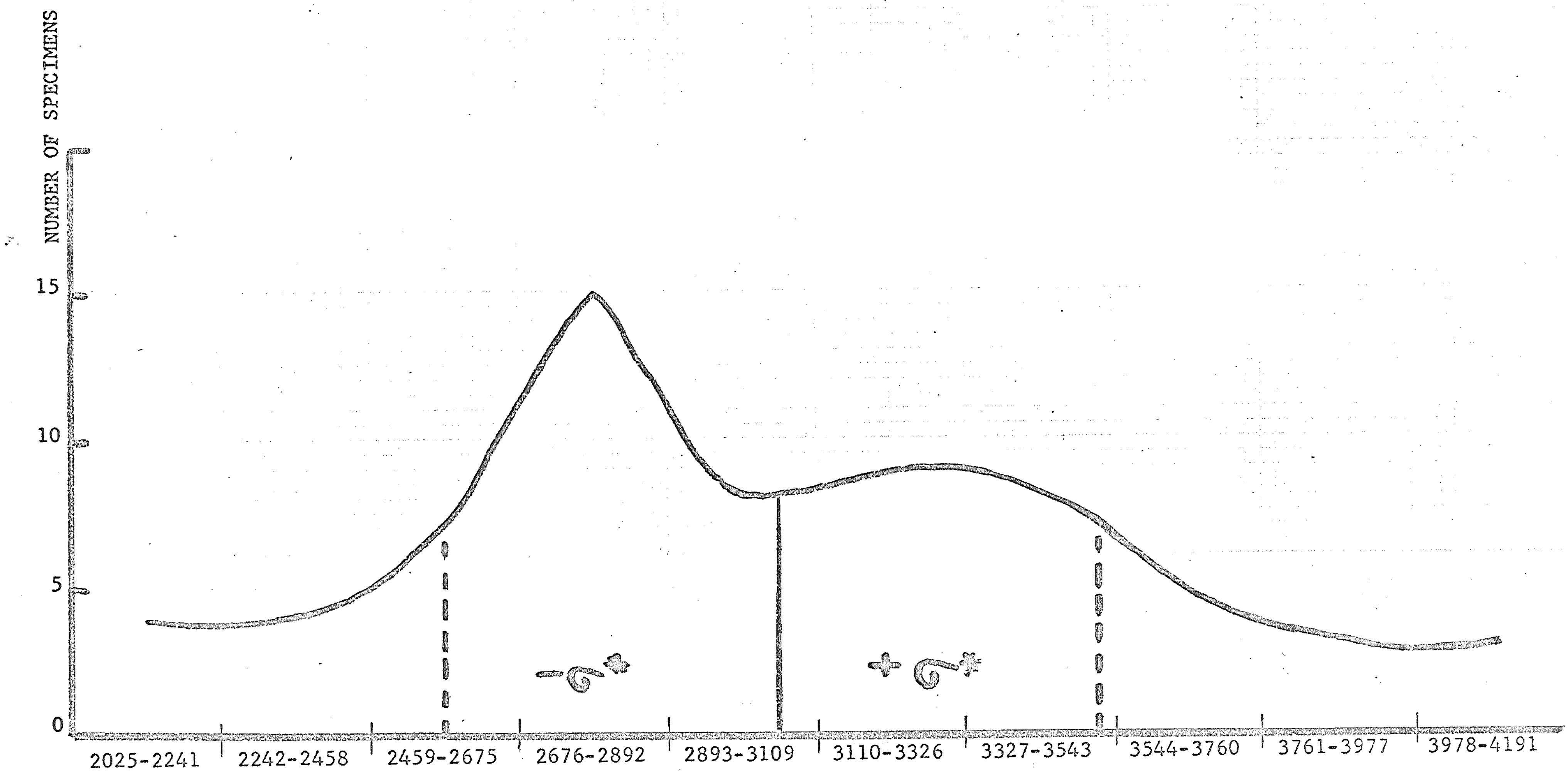


CONVERSION FACTOR $\left(\frac{\text{COMP. STR.}}{\text{MOD. RUPT.}}\right)$

ONE STANDARD DEVIATION ($\pm\sigma$ = .98) CONTAINS 90% OF ALL FACTORS CALCULATED

CONVERSION FACTOR DISTRIBUTION CURVE

FIGURE I

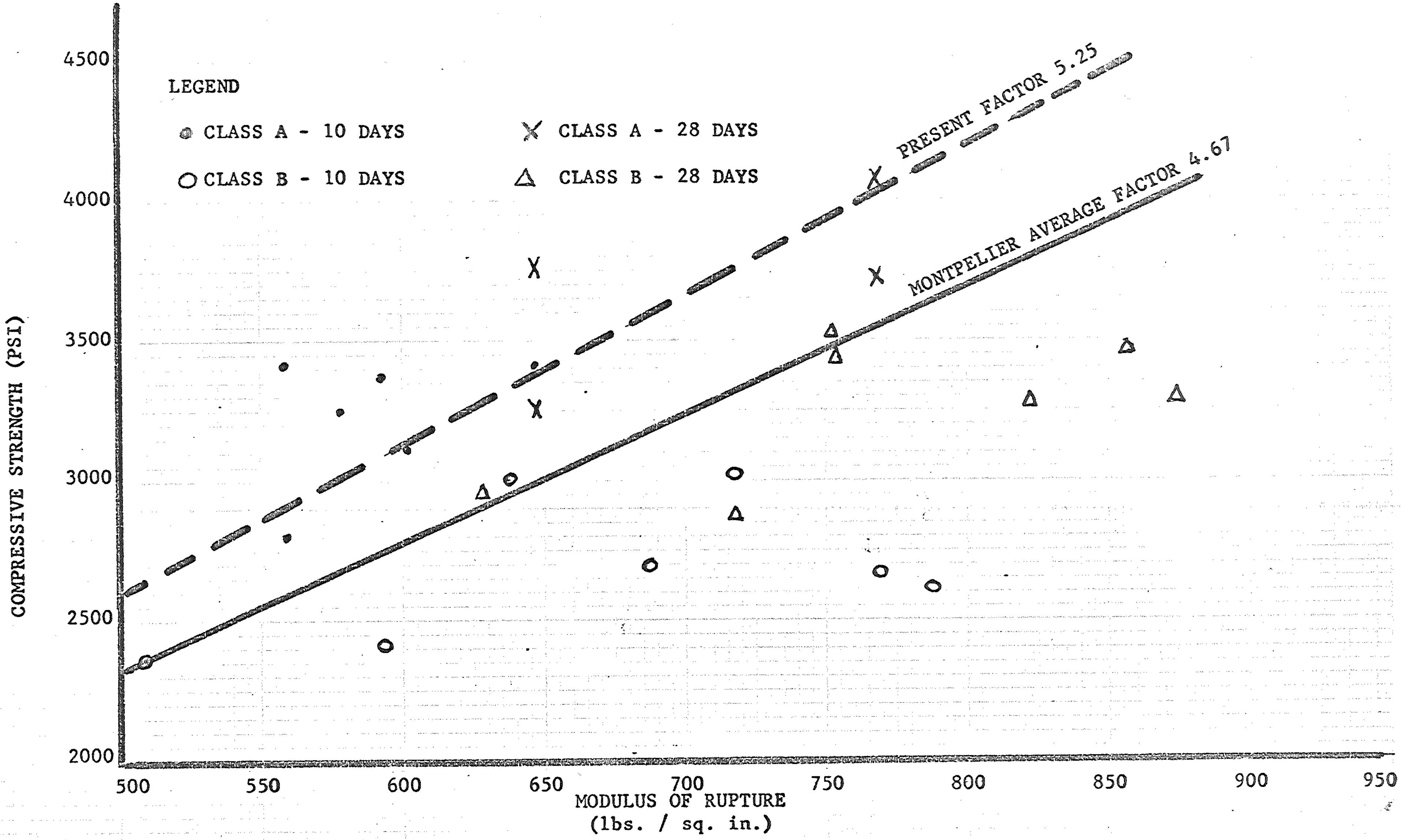


COMPRESSIVE STRENGTH (P.S.I.)

*ONE STANDARD DEVIATION ($\pm\sigma$ = 479) CONTAINS 75% OF ALL SPECIMENS TESTED

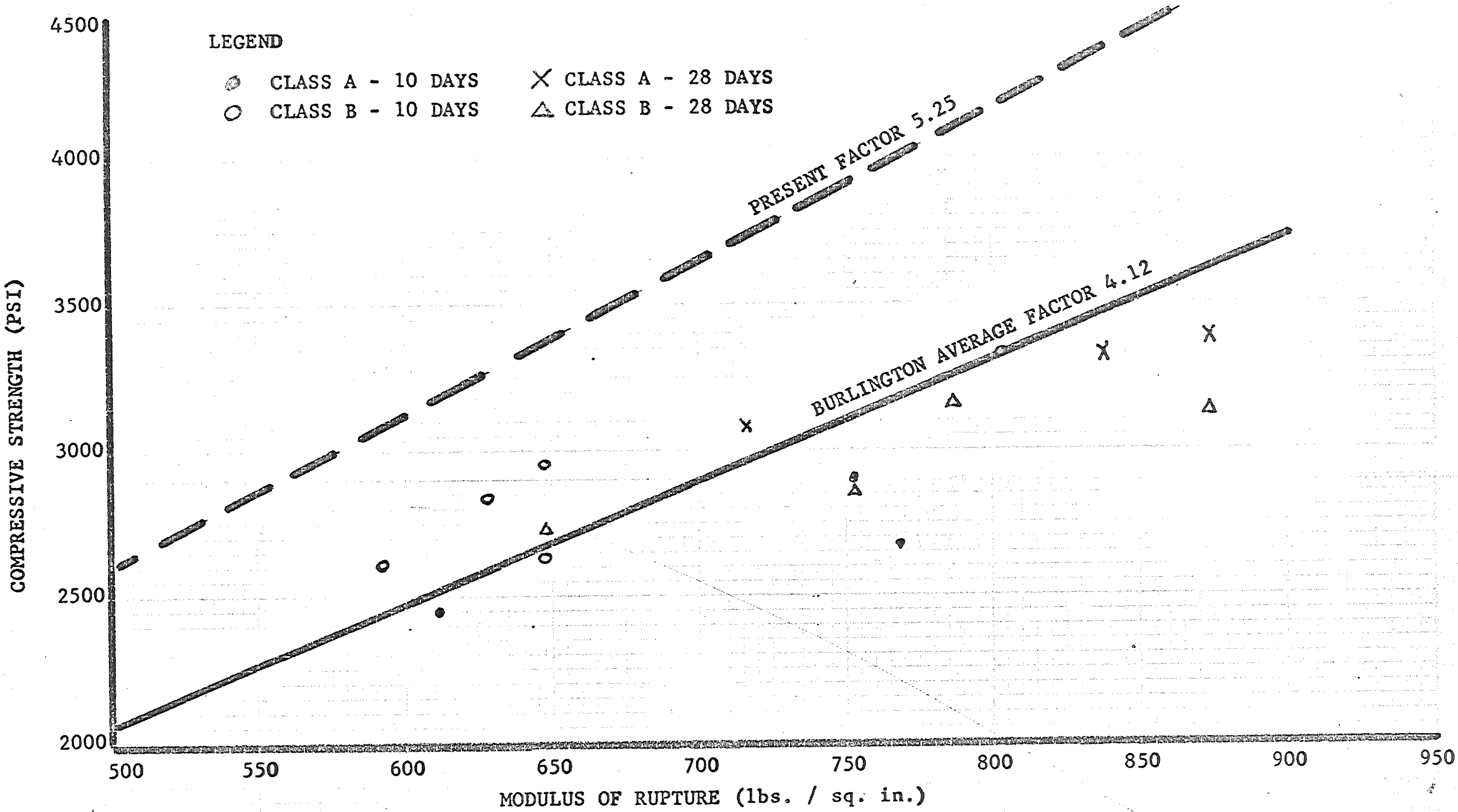
COMPRESSIVE STRENGTH DISTRIBUTION CURVE

FIGURE II



COMPRESSIVE STRENGTH/MODULUS OF RUPTURE COMPARISON
(MONTPELIER PROJECT)

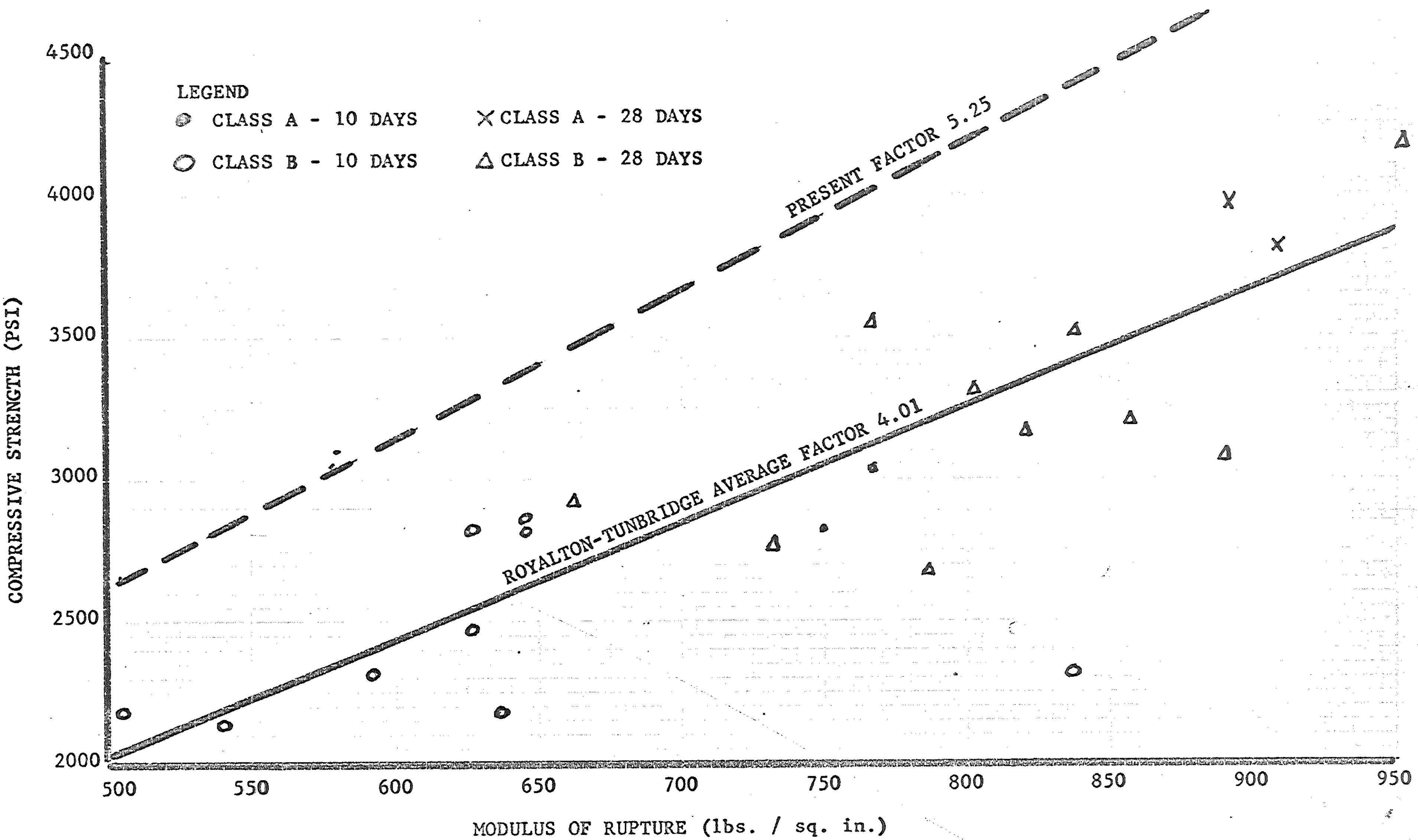
FIGURE IIIA



COMPRESSIVE STRENGTH / MODULUS OF RUPTURE COMPARISON

(BURLINGTON PROJECT)

FIGURE IIIB



COMPRESSIVE STRENGTH/MODULUS OF RUPTURE COMPARISON

(ROYALTON TUNBRIDGE PROJECT)

FIGURE IIIC