TECHNICAL REPORT STANDARD PAGE

1. Report No. FHWA/LA-95/293	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Early Strength Prediction of Concrete Based on Accelerated Curing Methods	5. Report Date December 1995	
	6. Performing Organization Code	
7. Author(s) Nick A. Rabalais, P.E.	8. Performing Organization Report No.	
9. Performing Organization Name and Address Louisiana Transportation Research Center 4101 Gourrier Ave. Baton Rouge, LA 70808	10. Work Unit No. 91-1C	
	11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Louisiana Transportation Research Center 4101 Gourrier Avenue Baton Rouge, LA 70808	13. Type of Report and Period Covered Final Report December 1991 - March 1996	
	14. Sponsoring Agency Code	

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation. Federal Highway Administration.

16. Abstract

Concrete mix designs and components may currently be changed during the course of a project. The possible negative effects of such changes on concrete strength, especially early strength, are not determined under the current plant control/project control process. Also, the current La. DOTD specification for acceptance of concrete is based on 28 day compressive strength, but design is based on 28 day flexural strength. This study was proposed to develop an early strength test would allow concrete to be tested within 24 hours to identify potentially inferior concrete prior to placement of large quantities and to evaluate 28 day flexural strength of Louisiana concrete.

Towards this end, LTRC sampled and tested concrete from 9 paving projects and 1 structural project over a 15 month period. Thirty specimens were collected from each project for each of these three tests: 24 hour accelerated cure flexural strength; 28 day flexural strength; and, 28 day compressive strength. The 24 hour specimens were cured in an accelerated manner in a tank of 35 C water, usually at the construction site. Linear regressions were examined to determine the relationships between these mix characteristics. In addition, the sensitivity of the 24 accelerated flexural strength was evaluated by varying a standard mix design to simulate field control problems.

The field data were found to be normally distributed and had acceptable variation in strength. This was true for all projects as well as within individual projects. R^2 (coefficients of determination) values for relationships between 24 hour accelerate/28 day flexural and 28 day flexural/28 day compressive were good within individual projects, but not for the sample that includes all data from all projects. The early strength test can be used to identify the placement of potentially inferior concrete. The LA DOTD design 28 day flexural strength value of 3790 KPa was examined with respect to data obtained for 28 flexural and 28 day compressive strengths for individual projects. Based on the correlation developed herein, the 28 day design flexural strength was exceeded in almost every mix evaluated. Lastly, a paired sample t-test indicated significant difference between decreases in 24 hour flexural strength due to small variations in mix design indicating that this test has potential for quality control testing.

17. Key Words accelerated cure, flexural strength, compressive strength, linear regression		18. Distribution Statement Unrestricted. This document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 64	22. Price

Form DOT F1700.7 (1-92)

EARLY STRENGTH PREDICTION OF CONCRETE BASED ON ACCELERATED CURING METHODS

FINAL REPORT

BY

NICK A. RABALAIS, P.E.
CONCRETE RESEARCH SUPERVISOR

LTRC RESEARCH PROJECT NO. 91-1C
LTRC REPORT NO. 293

Conducted By

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
LOUISIANA TRANSPORTATION RESEARCH CENTER

In Cooperation With

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Louisiana Department of Transportation and Development, the Louisiana Transportation Research Center, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

DECEMBER 1995

ACKNOWLEDGEMENTS

The author is grateful to the following individuals for their invaluable assistance: Dr. Anand Puppala. Messrs. Harold Paul. Mark Martinez. Mark Polson. Randy Young and Ms. Angela Nicholas.

ABSTRACT

Concrete mix designs and components may currently be changed during the course of a project. The effects of such changes on concrete strength, especially early strength, are not determined under the current plant control/project control process. Also, the current LA DOTD specification for acceptance of concrete is based on 28 day compressive strength, however; design is based on 28 day flexural strength. This study was proposed to develop an early strength test which would allow concrete to be tested within 24 hours to identify potentially inferior concrete prior to placement of large quantities and to evaluate 28 day flexural strength of Louisiana concrete.

Towards this end, LTRC sampled and tested concrete from 9 paving projects and 1 structural project over a 15 month period. Thirty specimens were collected from each project and the following tests were run: 24 hour accelerated cure flexural strength, 28 day flexural strength and 28 day compressive strength. The 24 hour specimens were cured in an accelerated manner utilizing a tank of 35 C water, usually at the construction site. Linear regressions were examined to determine the relationships between mix characteristics. In addition, the sensitivity of the 24 accelerated flexural strength was evaluated by varying a standard mix design to simulate field control problems.

The field data were found to be normally distributed and had acceptable variation in strength. This was true for all projects as well as within individual projects. R^2 (coefficients of determination) values for relationships between 24 hour accelerate/28 day flexural and 28 day flexural/28 day compressive were good within individual projects, but when all projects were compared the R^2 values for the same relationships were not as good. Data showed that the early strength test can be used to identify potentially inferior concrete. The LA DOTD 28 day flexural strength design value of 3790 KPa was examined with respect to data obtained from the 28 flexural and 28 day compressive strengths for individual projects. Based on the correlation developed, the 28 day design flexural strength was exceeded in almost every mix evaluated. Finally, a paired sample t-test indicated significant difference between 24 hour flexural strength due to small variations in mix design indicating that this test has potential for quality control testing.

IMPLEMENTATION

The 24 hour accelerated flexural strength test developed in this study can be used for quality control at the concrete plant. With this test, mix design changes made at the plant can be evaluated within 24 hours for concurrence to specifications which can reduce the possibility of placing inferior concrete.

The findings of this study indicated that based on the relationships found in a variety of concrete mix design between 28 day flexural and compressive strengths, the current design flexural strength, 3790KPa is conservative.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

There is a need for early strength determination of concrete for quality control. Mix designs, aggregate and cement sources and admixtures may currently be changed during the course of a project. The negative effects of such changes on concrete strength, especially early strength, are not determined under current plant process control. With an early strength test, concrete can be tested within 24 hours to identity potentially inferior concrete prior to placement of large quantities. An accelerated curing method is proposed whereby specimens can be cured and tested in the field. The 24 hour accelerated cure flexural strengths can then be correlated to 28 day strengths to determine if the concrete will meet acceptance requirements. As additional quality control, a test which can identify changes in mix design would be useful tool.

Current DOTD acceptance specifications for concrete pavement are based on 28 day compressive strength only. Since concrete pavement design is based on flexural strength criteria, an acceptance standard that takes this into account in addition to compressive strength may be more appropriate. Therefore, in addition to the early flexural strength test, 28 day flexural strengths of typical large concrete mixes will be correlated with 28 day compressive strengths to determine if current acceptance strength specification should be modified.

OBJECTIVES AND SCOPE

The objectives of this study are to:

1) Develop an early strength test based on an accelerated cure, flexural strength;

2) Determine field variation of concrete for 24 hour flexural strength, 28 day flexural strength and 28 day compressive strength;

3) Evaluate the relationships between 24 hour flexural strength, 28 day flexural strength and 28 day compressive strength; and,

4) Determine the sensitivity of the 24 hour accelerated flexural test for potential implementation as a quality control procedure.

Concrete from 10 different construction projects representing a wide variety of mixes were sampled and used in this evaluation. From each project, 30 samples were obtained for each of three tests for a total of ninety (90) specimens per project.

The sensitivity of the 24 hour flexural strength test was concluded to detect minor changes in mix design. Design parameters including cement content and flyash content were examined in both chert gravel and limestone concrete mixes.

METHOD OF PROCEDURE

Accelerated Test Method and Test Program

The method chosen for curing 24 hour flexural strength specimens was a variation of ASTM C 684-89 - Standard Test Method for Making, Accelerated Curing, and Testing Concrete Compression Test Specimens. Procedure A, the warm water method was used. In this method specimens are molded and then submerged in water at 35 C for 23½ hours ± 30 minutes and tested at 24 hours ± 15 minutes. The variation used in this study involved using standard 0.15m x 0.15m x 0.56m beams instead of cylinders. Because no molds are specifically made for submersing concrete beam specimens conventional molds had to be modified. Plexiglas plating 6.4mm thick was cut to a size slightly larger than the exposed surface of the beam specimens and taped over the top. This made the specimens almost water tight. The tank was made of welded sheet aluminum of dimensions of 0.61m x 1.2m x 2.4m. A commercial combination circulation pump/water heater was used to keep the water temperature at 35 C± 5 C.

From each project, a total of 90 specimens were obtained; 30 of these were beams to be cured in an accelerated manner and tested 24 hours after molding and submersion. Figure 1 illustrates the test factorial. It was soon discovered that to obtain enough concrete for our entire test factorial (approx. 0.31m^3), sampling would need to take place on 3 different construction days, taking ⅓ of the samples each day. Sampling was limited because of the number of specimen molds available and the amount of concrete available manpower could work with.

Those specimens subject to accelerated curing, needed to be tested in 24 hours. Because of this, concrete was never obtained 2 days in a row. The day after sampling was devoted to 24 hour testing. On each sampling day ⅓ of the 28 day specimens (cylinders and beams) were fabricated as well.

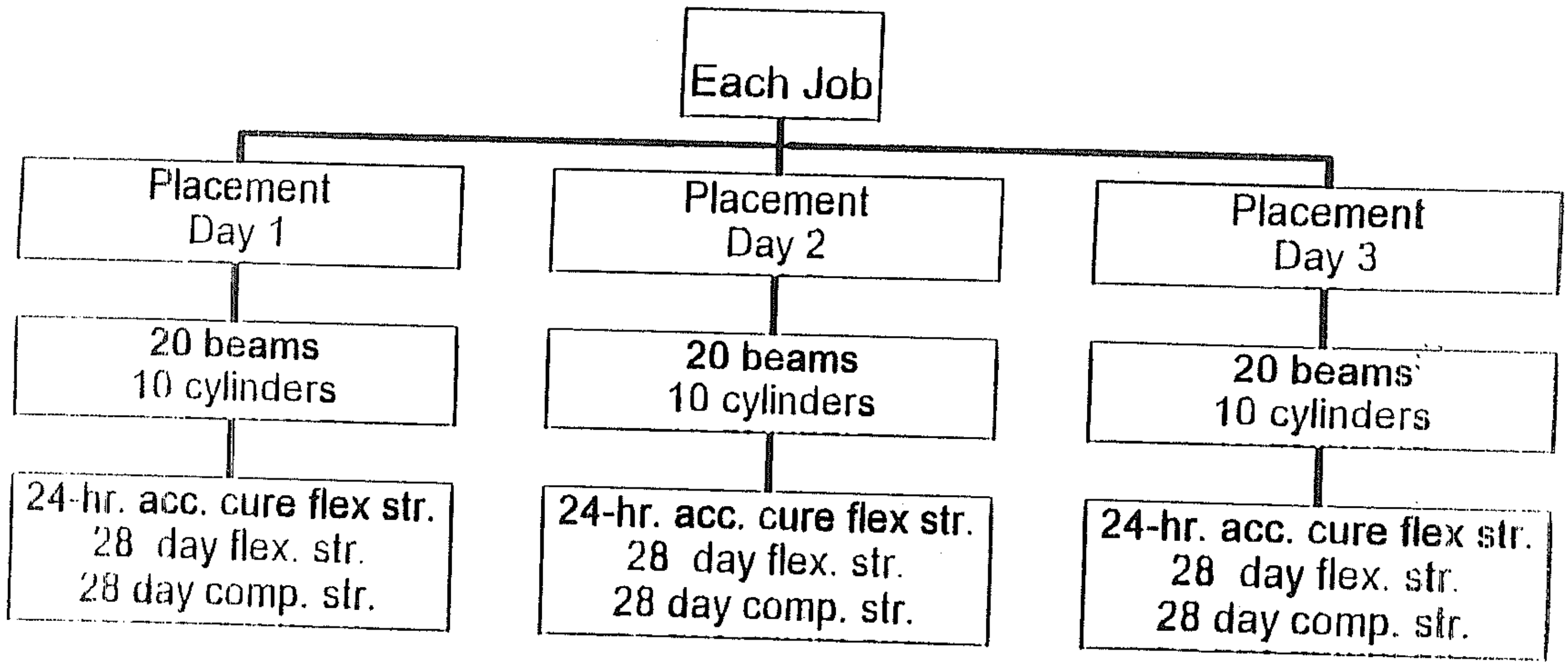

Figure 1. Sampling Program

A portable curing tank and a flexural testing apparatus were used in this study. The curing tank was light enough when empty to be portable as was the Rainhart Series 416 hydralically operated flexural strength tester. Electricity and potable water were obtained at the plant site for the heater and circulating pump.

Specimens cured in the field that were to be tested in 28 days were cured according to ASTM C 31 and then transported back to the LTRC Concrete Lab for testing. Of the ten projects, six were in close enough proximity that the fresh concrete was able to be transported back to the LTRC Concrete Lab. A maximum of 45 minutes is allowed from time of sampling to time of forming specimens according to Louisiana DOTD specs. Specimens could be then be made (and tested) in the lab.

For each of the projects sampled, slump, air content and unit weight of the fresh concrete was measured. The projects were sampled from June 25, 1992 to August of 1993.

Table 1 provides a listing of the mix design and plastic concrete characteristics for each project. Job mix information was obtained from the contractor or state inspector on site. The projects are listed in the order they were sampled. All of the mixes were designed to meet Louisiana DOTD standard specifications for air content, slump, and 28 day compressive strength. All of the mixes were paving mixes except the last one. I-10 near Baton Rouge was a structural mix (bridge deck). All mixes used Type I cement. All but three were Class B concrete using LA DOTD grade B coarse aggregate. Two mixes, Kaliste Saloom in Lafayette and I-49 in Alexandria were Class D concrete using Grade D limestone coarse aggregate. The bridge deck on I-10 near Baton Rouge used a Class AA mix. Seven of the ten jobs used fly ash, including the 3 non - Grade B mixes. All but two mixes used water reducers. Four of the ten mixes used air entrainnment. Water to cement ratios ranged from 0.21 to 0.48. This relatively large difference may be due to the fact that mixes were placed at different times of the year. Also, differing amounts and brands of air entraining and water reducing admixtures were used depending on specific needs or limitations of each contractor. For example, some pavements were slip-formed, others were conventionally formed. Unit weights of all mixes were in the normal range. Slumps and air contents were for the most part within LA DOTD Standard Specifications for Roads and Bridges, although a few were not. For all projects, the range of 24 hour flexural strengths was from 1950 KPa to 3390 KPa. 28 day flexural strengths were from 3330 KPa to 5800 KPa. 28 day compressive strengths were from 26360 KPa to 50060 KPa. Strength values of specimens from each age group for each project is presented in Appendix I.

TABLE 1 - PROJECT LISTING AND JOB MIX DESCRIPTION

Description:

Batch Weights and Plastic Concrete Data (1 Cubic Yard)

Job	Pour	Location	Type	Coarse	Fine	Cement kg	Ash kg	Water Design liters	Water Actual	Water Wt. (kg)	Admixture W.R.	Dosage (oz) gms.	Admixture Air	Dosage (oz) gms.	W/C Ratio		Weight kg/m³	Slump cm	Air Content
1	1	Kaliste Saloom, Lafayette	D	1939	1358	184.6	45.8	106.0	106.0		N/A	N/A	N/A	N/A	.57	.46	2230.32	9.53	N/A
2	1	Perkins, Baton Rouge	B	1907	1338	247.2	N/A	110.0	71.9		Hunts (NS)	793.8	N/A	N/A	.29		2350.4	5.72	1.5
2	2	Perkins, Baton Rouge	B	1911	1358	247.2	N/A	86.7	87.1		Hunts (NS)	793.8	N/A	N/A	.35		2353.6	6.35	1.5
2	3	Perkins, Baton Rouge	B	1909	1342	247.2	N/A	94.6	94.6		Hunts (NS)	793.8	N/A	N/A	.38		2340.8	6.35	1.5
3	1	I-55 Kentwood	B	1778	1223	247.2	N/A	118.5	118.5		Grace (SR)	463.51	Grace	115.9	.48		2257.4	8.89	3.4
3	2	I-55 Kentwood	B	1778	1223	247.2	N/A	118.5	118.5		Grace (SR)	463.51	Grace	115.9	.48		2307.14	8.89	3.8
3	3	I-55 Kentwood	B	1778	1223	247.2	N/A	118.5	118.5		Grace (SR)	463.51	Grace	115.9	.48		2307.14	[illegible]	4.2
4	1	Siegen Lane	B	1913	1353	210.5	36.7	83.5	83.5		N/A	N/A	N/A	N/A	.40	.34	2334.40	7.62	1.7
4	2	Siegen Lane	B	1898	1364	210.5	36.7	85.33	78.1		N/A	N/A	N/A	N/A	.37	.32	2347.23	7.62	1.3
4	3	Siegen Lane	B	1892	1352	210.5	36.7	93.4	93.4		N/A	N/A	N/A	N/A	.44	.38	2353.65	[illegible]	[illegible]
5	1	Joor Road, Baton Rouge	B	1924	672	197.8	49.4	80.4	54.9		Master (SR)	318.9	Pave-Air	124.0	.28	.22	2321.5	3.81	3.5
5	2	Joor Road, Baton Rouge	B	1913	1171	197.8	49.4	80.4	55.4		Master (SR)	318.9	Pave-Air	124.0	.28	.22	2295.9	7.62	3.1
5	3	Joor Road, Baton Rouge	B	1929	1167	197.8	49.4	74.8	56.8		Master (SR)	318.9	Pave-Air	124.0	.29	.23	2327.9	5.72	3.5

TABLE 1 - PROJECT LISTING AND JOB MIX DESCRIPTION

6	1	La 415, Port Allen	B	1898	1176	197.8	49.4	78.5	49.7	Master (SR)	106.3	Pave-Air	124.0	.25	.21	2308.7	9.52	3.9
6	2	La 415, Port Allen	B	1897	1178	197.8	49.4	78.1	52.0	Master (SR)	106.3	Pave-Air	124.0	.26	.23	2321.6	8.80	3.4
6	3	La 415, Port Allen	B	1878	1178	197.8	49.4	86.1	56.8	Master (SR)	106.3	Pave-Air	124.0	.29		2308.8	9.52	3.6
7	1	N. Sherwood, Baton Rouge	B	1913	1369	247.2	N/A	80.9	80.9	Hunts (NS)	793.8	N/A	N/A	.33		2327.9	9.52	1.3
7	2	N. Sherwood, Baton Rouge	B	1913	1369	247.2	N/A	80.9	71.0	Hunts (NS)	793.8	N/A	N/A	.29		2334.4	3.81	2.4
7	3	N. Sherwood, Baton Rouge	B	1913	1361	247.2	N/A	84.7	78.1	Hunts (NS)	793.8	N/A	N/A	.32		2360.10	8.[illegible]	1.3
8	1	Hwy 167, Ville Platte	B	1952	1276	247.2	N/A	101.6	67.6	Cormix(SR)	462	N/A	N/A	.27		2344.1	8.25	1.6
8	2	Hwy 167, Ville Platte	B	1942	1276	247.2	N/A	106.5	90.3	Cormix(SR)	462	N/A	N/A	.37		2443.4	9.75	1.3
8	3	Hwy 167, Ville Platte	B	1944	1272	247.2	N/A	107.1	89.2	Cormix(SR)	462	N/A	N/A	.36		2334.4	5.08	1.5
9	1	I-49, Alexandria	D	2036	1165	184.2	46.3	73.2	68.1	Hunts (SR)	1006	Hunts	70.9	.37	.30	2379.30	1.90	2.8
9	2	I-49, Alexandria	D	2026	1161	184.2	46.3	79.5	74.3	Hunts (SR)	1006	Hunts	70.9	.40	.32	2321.62	3.81	4.5
9	3	I-49, Alexandria	D	2029	1163	184.2	46.3	77.2	77.2	Hunts (SR)	1006	Hunts	70.9	.41	.33	2340.8	3.81	4.0
10	1	I-10, Baton Rouge	AA	1740	1237	235.4	41.7	68.2	68.1	Grace	519	Grace	130.4	.29	.25	2278	8.87	3.6
10	2	I-10, Baton Rouge	AA	1737	1228	235.4	41.7	96.5	80.6	Grace	521.6	Grace	141.7	.34	.29	2308.7	6.98	3.1
10	3	I-10, Baton Rouge	AA	1740	1241	235.4	41.7	89	56.8	Grace	517.3	Grace	141.7	.24	.20	2334.4	3.18	2.7

The following tests were conducted:

1) ASTM C 31-91 Standard Practice for Making and Curing Concrete Test Specimens in the Field
2) ASTM C 39-94 Test Method for Compressive Strength of Cylinder Concrete Specimens
3) ASTM C 78-94 Test Method for Flexural Strength of Concrete (using simple beam with third-paint loading)
4) ASTM C 143-90a Test Method for Slump Hydraulic Cement Concrete
5) ASTM C 138-92 Test for Unit Weight, Yield and Air Content (gravimetric) of Concrete
6) ASTM C 231-91b Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
7) ASTM C 684-95 Test Method for Making, Accelerated Curing and Testing Concrete Compression Test Specimens Warm Water Method (a).
   A variation of this test was used beam specimens were made and tested according to ASTM C-78 instead of cylindrical specimens tested according to ASTM C-39.

Because of logistical difficulties encountered in sampling concrete and co-ordinating contractor schedules, only 10 specimens for each test were obtained for the first project Kaliste Saloom Road in Lafayette. As previously noted, 30 specimens were sampled from all other projects.

Data Analysis

General descriptive statistics for each project was conducted using the Statistical Analysis System, **SAS** (ref). This analysis was used to establish normality of data.

Because of daily changes in weather, aggregate stockpile or placement conditions, a differing amount of water or admixtures may have been used for each pour. For this reason, each days production was identified in the data set as a batch. The variation within the batch and between batch was evaluated. Within test variation applies to variation within the same batch and is a measure of the quality of procedures of Lab personnel. Overall or between-test variation applies to variation between different batches of the same concrete and is an indicator of the quality of production and control procedures by the contractor and supplier.

Regression analysis was performed on the data using "Grapher" software. Correlations were obtained between 24 hour accelerated cure and 28 day flexural strengths and between 28 day flexural strength and 28 day compressive strength data for the all specimens and from within each project. Linear equations were used to represent the correlations. Polynomial and other higher order equations were tried but yielded only minimally higher R^2 (co-efficient of determination) values.

DISCUSSION OF RESULTS

Statistical data including normality:(W:N), mean ($\bar{x}$), standard deviation (σ) and coefficient of variation (C.V.) for each strength test are presented in Tables 2 through 4. The values of W:N produced by SAS ranged from 0.80 to 0.98. The values less than 0.90 all occurred for the Kaliste Saloom project where only 10 specimens were obtained for each strength test. The W:N values for the remainder of projects for each strength test were generally greater than 0.90 with many values approaching 1.00. The normality of the date was supported by other factors (skewness, kurtosis, etc.) and by the appearance of the stem leaf, probability and box plots.

According to ACI 214, for overall (between batch) variation in general construction testing, a standard deviation less than 2760 KPa for compressive strength is considered excellent. Between 2760 KPa and 3450 KPa is considered very good and between 4140 KPa and 4830 KPa is considered fair. Only 3 projects had standard deviations exceeding 2760 KPa and only one exceeding 4140 KPa (Kaliste Saloom). Using within batch criteria, ACI 214 requires a C.V. value of 3 to 4. The Kaliste Saloom project had a compressive strength C.V. of 4.01. This was an indication of quality lab procedures by personnel.

TABLE 2 - STATISTICAL DATA
24 HOUR FLEXURAL STRENGTH

Roadway	W:N	Mean	Standard Deviation	C.V.
All Projects	0.971	405.50	41.56	10.25
Kaliste Saloom	0.870	437.30	31.81	7.27
Perkins Road	0.940	424.57	26.61	6.27
I-55. Kentwood	0.918	427.10	28.64	6.71
Siegen Lane	0.953	361.37	36.07	9.98
Joor Road	0.971	395.93	34.10	8.61
La. 415. Port Allen	0.959	364.93	34.08	9.34
N. Sherwood	0.967	377.67	35.30	9.35
Hwy. 167(Ville Platte)	0.917	434.73	25.81	5.93
I-49, Alexandria	0.950	426.70	24.75	5.80
I-10 Baton Rouge	0.942	425.90	32.06	7.53

TABLE 3 - STATISTICAL DATA
28 DAY FLEXURAL COMPRESSIVE STRENGTH

Roadway	W:N	Mean	Standard Deviation	C.V.
All Projects	0.987	674.69	60.20	8.925
Kaliste Saloom	0.805	640.40	53.54	8.36
Perkins Road	0.969	648.0	35.42	5.47
I-55, Kentwood	0.979	593.57	47.97	8.08
Siegen Lane	0.946	638.50	33.07	5.18
Joor Road	0.938	667.97	43.85	6.56
La. 415, Port Allen	0.986	691.57	47.55	6.88
N. Sherwood	0.933	693.37	34.46	4.98
Hwy. 167(Ville Platte)	0.960	701.07	49.37	7.04
I-49. Alexandria	0.893	758.87	47.30	6.23
I-10 Baton Rouge	0.973	690.73	30.92	4.48

TABLE 4 - STATISTICAL DATA
28 DAY COMPRESSIVE STRENGTH

Roadway	W:N	Mean	Standard Deviation	C.V.
All Projects	0.965	5479.4	671.78	12.26
Kaliste Saloom	0.950	4078.10	163.33	4.01
Perkins Road	0.989	5554.13	208.53	3.75
I-55, Kentwood	0.988	4364.07	170.55	3.91
Siegen Lane	0.939	5367.07	306.35	5.71
Joor Road	0.988	5699.67	222.82	3.91
La. 415. Port Allen	0.928	5472.33	444.47	8.12
N. Sherwood	0.954	5617.10	235.09	4.19
Hwy. 167(Ville Platte)	0.958	5246.37	188.12	3.59
I-49, Alexandria	0.887	6488.53	479.48	7.393
I-10 Baton Rouge	0.896	5973.13	429.85	7.20

Values for R^2 are presented in Table 5. Figures 1 through 22 in Appendix II present the regression curves and data and the spread of data points. Values for R^2 range from 0.87 to 0.96 for the 24 hour accelerated flexural strength to 28 day flexural strength correlations for individual projects. For the sample of all projects, 280 data points, R^2 was 0.24 which indicates a weak relationship between the 24 hour and 28 day flexural test. This understandable provided the many variables in this sample. However, the R^2 values for the individual projects (with the exception of N. Sherwood) are excellent indicating that good relationships can be established for a particular mix design. The 24 hour flexural test then, demonstrates potential as a quality control test. This relationship could be established with trial mixes prior to field production.

R^2 values for the 28 day flexural strength to 28 day compressive strength correlations for individual projects ranged from 0.71 to 0.97. For the all specimens from all projects, the value was 0.64, substantially higher than was the case for the accelerated vs. 28 day flexural. relationship. Given the variety of mixes represented, the relationship for all projects is good. An attempt was made to isolate particular mix variables (such as flyash vs. no flyash) in order to improve the correlations. In general, the R^2 could not be significantly improved.

TABLE 5 - COEFFICIENTS OF DETERMINATION (R^2)

Roadway	R^2_1	R^2_2
All Projects	0.24	0.64
Kaliste Saloom	0.96	0.71
Perkins Road	0.95	0.95
I-55, Kentwood	0.95	0.96
Siegen Lane	0.88	0.82
Joor Road	0.92	0.95
La 415, Port Allen	0.96	0.90
N. Sherwood	0.48	0.94
Hwy. 167 (Ville Platte)	0.96	0.96
I-49, Alexandria	0.87	0.97
I-10 Baton Rouge	0.92	0.88

1 Model Relating 24 hr. Flexural Strength to 28 day Flexural Strength

2 Model Relating 28 Day Flexural Strenth to 28 Day Compressive Strength

In examining the 28 day flexural to 28 day compressive strength relationships, it is observed that only 3 points out of 280 fail to meet the specification compressive strength requirement of 27570 KPa at 28 days. These specimens came from the Kaliste Saloom project. The median 28 day compressive strength for all points is 37780 KPa. The median 28 day flexural strength is 4650 KPa. According to the Department's pavement design section, the current design criteria calls for a 28 day flexural strength of 3790 KPa. Only 5 points out of 280 fall below the 3790 KPa flexural strength design value. If the 3790 KPa flexural strength value is substituted in the 28 day flexural vs. 28 day compressive strength regression equation developed for all samples from all projects, the resulting 28 day compressive strength is 25770 KPa. This indicates that the department's current design strength is conservative with respect to field produced concrete mix.

The last statistical procedure conducted was to determine the sensitivity of the 24 hour flexural strength test to changes in mix design. The sensitivity would show up as an identifiable reduction in strength. A paired sample t-test was used to determine if changes in mix design, such as a reduction in the cement content or increase in flyash substitution could be detected. Specimens were tested for 24 hour accelerated flexural strength, 28 day flexural strength and 28 day flexural strength. For the cement mixes, each mix was comprised of: two aggregate types: either chert gravel or limestone, both at Gradation Class "A"; two cement contents: either the reference amount or -0.5 bags. In the -0.5 bag mixes, no other adjustments in mix design were made. That is, the amounts of all other constituents remained the same. All contained the same type and amount of admixtures and had the same water/cement ratio (0.40).

For the flyash mixes, the control mix was 20% substitution by weight of cement. This is currently the maximum allowable by La. DOTD Standard Specifications for Roads and Bridges. The test mix contained 25% fly ash substitution. All other parameters are identical to the all cement mixes.

A paired sample t-test compared the means between reference cement content and -0.5 bag cement content or the 20% fly asn and 25% fly ash mixes within each group to determine if they were statistically different. A significance level of 0.05 was used; the limiting t-value was 2.92.

Table 6 presents the t-values for all mixes tested with a range of 2.29 to 22.19. All mixes provided values exceeding the limiting value of 2.92 in the 24 hour flexural test, indicating an easily identifiable difference in the means. In fact the 28 day flexural and 28 day compressive tests also demonstrated significant differences in means with the exception of the reduced cement content, limestone mix in the 28 day flexural test. This finding leads further credence to the use of the 24 hour flexural strength test as a quality control tool.

TABLE 6 - EFFECTS OF VARIATION IN CEMENT CONTENT ON STRENGTH

Cement Content (bags)	Bag Mix	Aggregate Type	w/c Ratio	Water (kg)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Slump (cm)	Air Content %	Unit Weight (kg/m³)
5.8	Control	Chert Gravel	0.40	98.9	247.3	514.8	514.8	2.54	4.9	65.86
5.3	-0.5 bag	Chert Gravel	0.44	98.9	226.0	514.8	514.8	7.62	7.6	63.14
5.8	Control	Limestone	0.40	98.9	247.3	514.8	514.8	3.175	4.6	66.95
5.3	-0.5 bag	Limestone	0.44	98.9	226.0	514.8	514.8	5.08	7.2	61.8
6.5	Control	Chert Gravel	0.40	110.9	277.1	492.4	865.0	8.89	6.5	62.96
6.0	-0.5 bag	Chert Gravel	0.43	110.9	255.8	492.4	865.0	15.875	10.0	61.3
6.5	Control	Limestone	0.40	110.9	277.1	492.4	905.7	6.35	5.3	65.9
6.0	-0.5 bag	Limestone	0.43	110.9	255.8	492.4	905.7	9.525	9.5	62.6

Cement Content (bags)	Bag Mix	Aggregate Type	24 hr. Accelerated Cure Flexural Strength (psi) (kPa)				28 day Flexural Strength (psi) (kPa)				28 day Compressive Strength (psi) (kPa)				t-value (24 hr.)	t value (28 day flex)	t value (28 day comp.)
			#1	#2	#3	avg	#1	#2	#3	avg	#1	#2	#3	avg			
5.8	Control	Chert Gravel	2703	3041	2703	2813	5199	4944	5075	5075	34005	32357	34970	33777	5.25	9.93	6.54
5.3	0.5 bag	Chert Gravel	2013	2124	2241	2124	4054	4102	3902	4020	28772	28310	28082	28386			
5.8	Control	Limestone	2930	3330	2868	3041	5309	4937	5206	5150	40851	41086	39031	40321	4.35	2.29	22.19
5.3	0.5 bag	Limestone	2413	2413	2413	2413	4509	4868	4420	4599	32288	31116	30006	31137			
6.5	Control	Chert Gravel	2124	2124	2124	2124	4040	4185	4075	4102	27110	28462	27462	27676	11.37	3.8	4.0
6.0	0.5 bag	Chert Gravel	1951	1896	1896	1917	3413	3765	3833	3668	24428	23180	24807	24139			
6.5	Control	Limestone	2868	2703	2868	2813	704	5288	5157	5102	35391	33467	34239	34363	8.19	9.47	24.65
6.0	-0.5 bag	Limestone	2187	2013	1896	2013	551	3758	3820	3792	24070	22511	24366	23649			

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
LOUISIANA TRANSPORTATION RESEARCH CENTER
Concrete Research Laboratory

EFFECTS OF VARIATIONS IN FLY ASH CONTENT ON STRENGTH

96-1GEN (PROJECT ADDITION TO 91-1C)

CONCRETE BATCH WEIGHTS & FRESH CONCRETE CHARACTERISTICS

Lab No.	Cement Content (bag/yd)	Fly Ash Content (%)	Grade "B" Aggregate Type	W/C Ratio	WATER (lbs/yd)	CEMENT (lbs/yd)	FLY ASH (lbs/yd)	FINE AGGREGATE (lbs/yd)	COARSE AGGREGATE (lbs/yd)	SLUMP (inches)	AIR CONTENT (%)	UNIT WEIGHT (lbs/ft)
C-2077	5.8	20	GRAVEL	0.40	218.1	436.2	109.0	1135.0	1979.3	1.25	5.5	140.4
C-2078	5.8	25	GRAVEL	0.40	218.1	408.9	136.3	1135.0	1979.3	3.25	8.6	136.8
*C-2087	5.8	25	GRAVEL	0.40	218.1	408.9	136.3	1135.0	1979.3	3.00	4.8	144.4
**C-2088	5.8	25	GRAVEL	0.40	218.1	408.9	136.3	1135.0	1979.3	2.00	4.5	144.0
C-2079	5.8	20	LIMESTONE	0.40	218.1	436.2	109.0	1135.0	2072.4	1.25	4.9	146.4
C-2080	5.8	25	LIMESTONE	0.40	218.1	408.9	136.3	1135.0	2072.4	2.00	5.5	146.0

PHYSICAL STRENGTHS

Lab No.	Bag Mix	Percent Fly Ash	Grade "B" Aggregate Type	ASTM C 684 Procedure A 24 hr Accelerated Cure Flexure Strength (psi)				ASTM C 78 28 day Flexure Strength (psi)				ASTM C 39 28 day Compressive Strength (psi)			
				#1	#2	#3	avg	#1	#2	#3	avg	#1	#2	#3	avg
C-2077	5.8	20	GRAVEL	342	337	333	338	636	611	611	619	4034	4381	4320	4245
C-2078	5.8	25	GRAVEL	263	257	277	266	537	520	567	541	3514	3275	3779	3523
*C-2087	5.8	25	GRAVEL	369	370	396	378	615	643	633	630	5190	5125	5169	5161
**C-2088	5.8	25	GRAVEL	437	376	421	412	626	686	666	659	5178	5197	5079	5151
C-2079	5.8	20	LIMESTONE	444	500	421	455	770	727	731	742	5755	5938	5821	5838
C-2080	5.8	25	LIMESTONE	400	411	440	417	765	761	799	775	5927	5720	5851	5833

NOTE #1:
The above pavement mixes contain 3 oz/100ct of DARAVAIR 10,000® and 3 oz/100ct of WRDA with HYCOL®.
Bayou Ash® a class "C" fly ash substituted Holnam® type I portland cement by percent weight.

NOTE #2:
*Lab No. C-2087 is a re-make of Lab No. C-2078 with the following admixture dosage changes.
1 oz/100ct of DARAVAIR 10,000® and 2 oz/100ct of WRDA with HYCOL®.

NOTE #3:
**Lab No. C-2088 is a re-make of Lab No. C-2078 with the following admixture dosage changes.
1 oz/100ct of DARAVAIR 10,000® ONLY.

CONCLUSIONS

1) Specimens were fabricated and data was obtained representing strengths of concrete at 24 hours accelerated cure, 28 day flexural and 28 day compressive from construction projects. The data was found to be normally distributed.

2) The variation in strength for the tests conducted was considered acceptable for the sample tested.

3) Regression equations were developed that can be used as a way of predicting 28 day flexural strength from 24 hour flexural strength. The correlation coefficients for individual projects indicate that the 24 hour flexural strength test can be used for plant quality control.

4) The sensitivity of the 24 hour flexural strength test to identify plant control problems, was tested using typical variations of standard mix designs. The test correctly identified the altered mixes.

RECOMMENDATIONS

1) If feasible, laboratory trial mixes based on field mix designs should be made and tested at least 28 days before concrete placement begins on the project that strength prediction is to be used on.

2) Regression models can be developed based on procedures documented in this report. They can then be employed to determine if the concrete will meet its required 28 day flexural strength. In this way, the strength prediction model functions as a quality control tool. If desired, this strength can be cross referenced to 28 day compressive strength.

REFERENCES

1. "Business Statistics for Management and Economics", Wayne W. Daniel, Georgia State University and James C. Terrell: fifth edition; Copyright 1989 by Houghton Mifflin Company.

2. ACI Manual of Concrete Practice Part 2 - 1995; American Concrete Institute; " Recommended Practice for Evaluation of Strength Test Results of Concrete (ACI 214-77).

3. ACCELERATED STRENGTH TESTS FOR QUALITY CONTROL OF CONCRETE PAVEMENTS; Jeffrey P. Armstrong; USAE Waterways Experiment Station, Vicksburg, MS

APPENDIX 1

Project Strength Data

Appendix I - Project Strength Data

Sample No.	Flexural Strength (24 hours)	Flexural Strength (28 day)	Compressive Strength (28 day)
Kaliste Saloom Road, Lafayette, LA			
1	400	583	3823
2	408	591	3876
3	408	591	3921
4	417	591	4083
5	417	600	4098
6	433	658	4105
7	466	691	4126
8	466	691	4187
9	475	700	4204
10	483	708	4358
Perkins Road, Baton Rouge, LA			
1	375	583	4997
2	383	591	5238
3	400	600	5281
4	400	600	5330
5	400	608	5365
6	408	616	5396
7	408	620	5400
8	408	633	5441
9	408	633	5448
10	408	633	5462
Pour # 2			
11	416	636	5474
12	416	641	5488

13	416	641	5529
14	416	641	5542
15	417	641	5565
16	417	650	5578
17	417	650	5586
18	424	650	5608
19	424	650	5614
20	433	650	5634
Pour #3			
21	433	666	5640
22	433	666	5658
23	441	666	5664
24	441	666	5685
25	441	683	5730
26	450	685	5740
27	466	700	5758
28	466	700	5853
29	481	716	5891
30	491	725	6029
I-55 Southbound, Kentwood, LA			
1	375	325	4011
2	383	483	4061
3	383	516	4152
4	408	533	4154
5	408	550	4214
6	408	550	4230
7	408	558	4234
8	408	566	4246
9	416	566	4248

10	416	566	4281
Pour #2			
11	416	566	4304
12	416	566	4315
13	416	566	4316
14	416	575	4334
15	424	583	4343
16	425	583	4343
17	425	583	4356
18	433	591	4416
19	433	596	4423
20	433	600	4428
Pour #3			
21	433	616	4439
22	433	616	4448
23	433	625	4463
24	441	625	4500
25	441	625	4544
26	450	633	4564
27	458	641	4581
28	483	650	4583
29	491	679	4657
30	500	716	4727
Siegen Lane, Baton Rouge			
1	283	541	4922
2	292	591	4940
3	325	599	4952
4	333	600	5012
5	333	600	5084

6	333	600	5105
7	342	616	5114
8	342	616	5115
9	342	624	5131
10	350	625	5137
Pour #2			
11	350	633	5187
12	350	633	5189
13	350	641	5237
14	358	649	5245
15	358	649	5265
16	358	649	5346
17	358	650	5405
18	358	650	5424
19	367	650	5459
20	367	650	5461
Pour #3			
21	367	650	5479
22	375	650	5548
23	375	658	5583
24	383	658	5654
25	392	666	5760
26	392	666	5795
27	400	675	5795
28	425	683	5795
29	433	683	5901
30	450	700	5972
Joor Road, Baton Rouge, LA			
1	333	591	5230

2	350	591	5336
3	350	600	5371
4	350	600	5406
5	358	600	5442
6	367	616	5548
7	375	632	5548
8	375	641	5548
9	375	650	5548
10	375	650	5583
Pour #2			
11	383	650	5583
12	383	600	5618
13	383	666	5654
14	383	666	5689
15	392	666	5689
16	392	675	5724
17	392	675	5760
18	400	675	5760
19	400	683	5760
20	408	683	5795
Pour #3			
21	416	700	5795
22	416	700	5830
23	416	708	5866
24	425	708	5901
25	433	716	5901
62	433	716	5936
27	441	716	5972
28	450	716	6007

29	458	716	6042
30	466	750	6148
LA 415, Port Allen			
1	317	591	4148
2	325	616	4770
3	325	633	4876
4	333	641	4982
5	342	641	5018
6	350	641	5018
7	350	650	5088
8	350	666	5088
9	350	666	5088
10	350	675	5124
Pour #2			
11	350	675	5124
12	350	675	5141
13	358	683	5230
14	358	683	5230
15	358	691	5230
16	367	700	5265
17	367	700	5442
18	367	700	5513
19	367	700	5548
20	375	708	5654
Pour #3			
21	383	708	5689
22	383	716	5760
23	383	716	5760
24	383	716	5854

25	383	733	5883
26	400	741	5989
27	400	750	6007
28	400	750	6060
29	441	766	6184
30	450	816	6307
N. Sherwood Forest			
1	317	633	5230
2	333	633	5247
3	333	641	5336
4	333	650	5336
5	333	650	5371
6	342	650	5389
7	350	650	5415
8	350	658	5424
9	350	675	5424
10	358	683	5424
Pour #2			
11	358	683	5459
12	367	691	5548
13	367	691	5574
14	367	700	5583
15	375	700	5601
16	375	700	5610
17	383	700	5618
18	383	700	5618
19	383	700	5698
20	400	708	5742

Pour #3			
21	400	716	5759
22	400	716	5777
23	408	725	5777
24	408	725	5786
25	408	733	5857
26	416	733	5901
27	417	733	5945
28	417	733	5989
29	433	741	6033
30	466	750	6042
Hwy. 167, Ville Platte			
1	400	616	4327
2	400	625	4894
3	400	641	4965
4	408	641	4982
5	408	650	4991
6	408	658	5000
7	416	666	5053
8	416	666	5053
9	416	666	5088
10	416	675	5106
Pour #2			
11	417	675	5124
12	425	675	5194
13	425	675	5194
14	425	683	5212
15	433	691	5221
16	433	691	5230

17	433	700	5265
18	433	700	5300
19	441	725	5300
20	450	733	5389
Pour #3			
21	450	733	5406
22	450	733	5452
23	450	733	5522
24	450	741	5361
25	466	750	5393
26	466	766	5412
27	475	766	5433
28	483	775	5455
29	483	783	5504
30	483	800	5565
I-49, Alexandria			
1	367	600	4740
2	383	658	5771
3	400	700	5991
4	400	716	6102
5	400	733	6102
6	400	741	6118
7	408	741	6261
8	408	750	6290
9	408	750	6338
10	416	750	6359

Pour #2			
11	416	750	6376
12	416	750	6393
13	416	758	6395
14	425	758	6471
15	425	758	6472
16	433	758	6485
17	433	758	6530
18	433	766	6531
19	433	775	6579
20	433	775	6647
Pour #3			
21	433	783	6744
22	433	783	6784
23	433	791	6787
24	450	791	6797
25	450	791	6801
26	450	800	6802
27	450	808	6828
28	458	808	6926
29	466	825	6984
30	466	841	7252
I-10 Baton Rouge			
1	375	616	4546
2	383	641	5102
3	383	650	5577
4	383	650	5590
5	392	666	5602
6	392	666	5631

7	400	666	5716
8	400	675	5729
9	400	683	5733
10	408	683	5870
Pour #2			
11	416	683	5871
12	416	683	5876
13	416	683	5923
14	416	683	6024
15	416	691	6029
16	425	691	6117
17	425	691	6158
18	425	691	6175
19	433	691	6185
20	433	700	6195
Pour #3			
21	441	700	6207
22	442	708	6210
23	458	708	6246
24	458	708	6291
25	466	725	6315
26	467	733	6364
27	467	733	6385
28	475	733	6462
29	483	733	6501
30	483	758	6564

APPENDIX 2

Regression Graphs

APPENDIX II-Regression Figures

Figure 1. 28 Day Flexural Strength vs. 24 Hour Flexural Strength

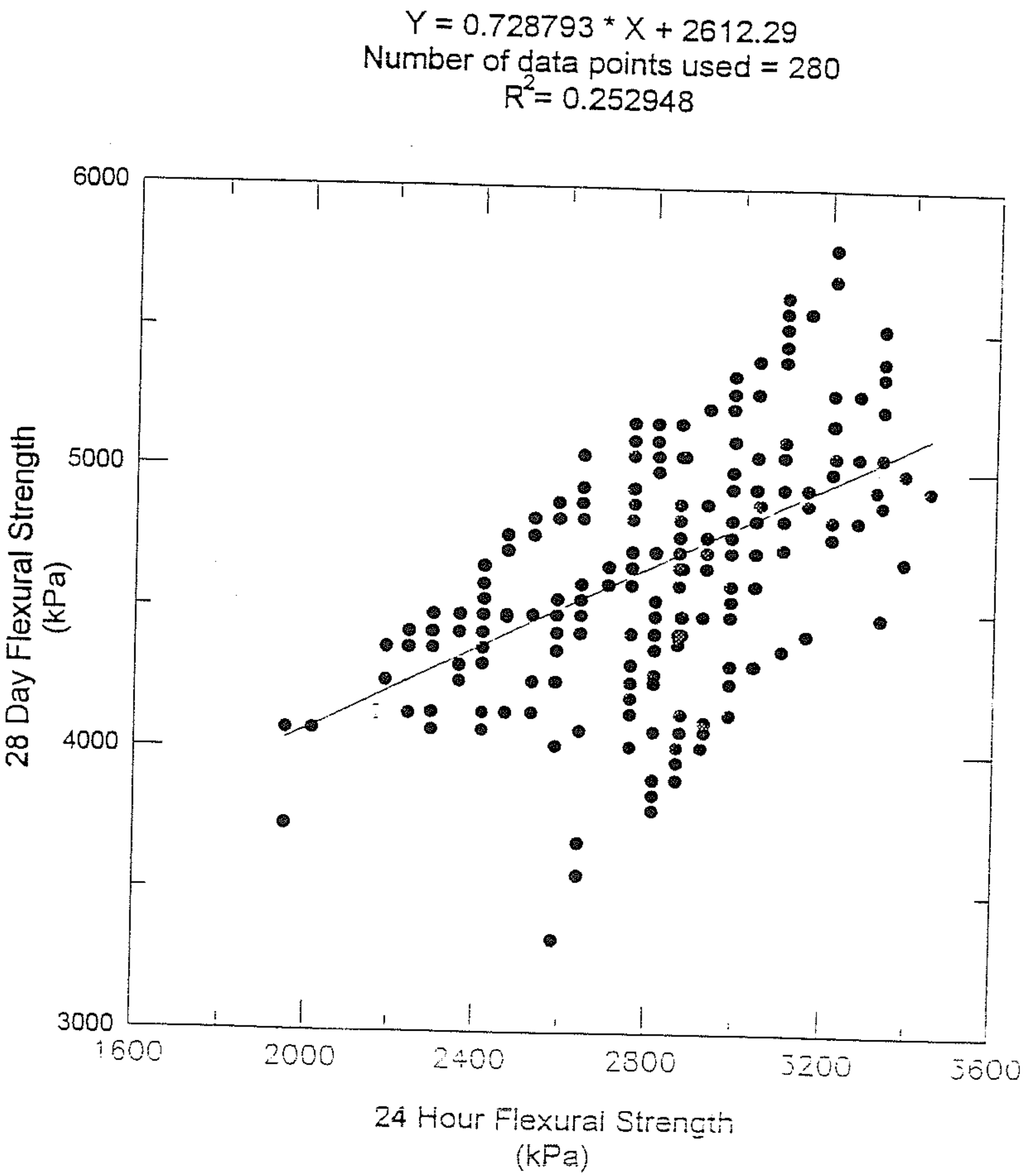

Figure 2. 28 Day Flexural Strength vs. 24 Hour Flexural Strength Kaliste Saloom

Y = 1.6495 * X + -557.58
Number of data points used = 10
R^2= 0.960518

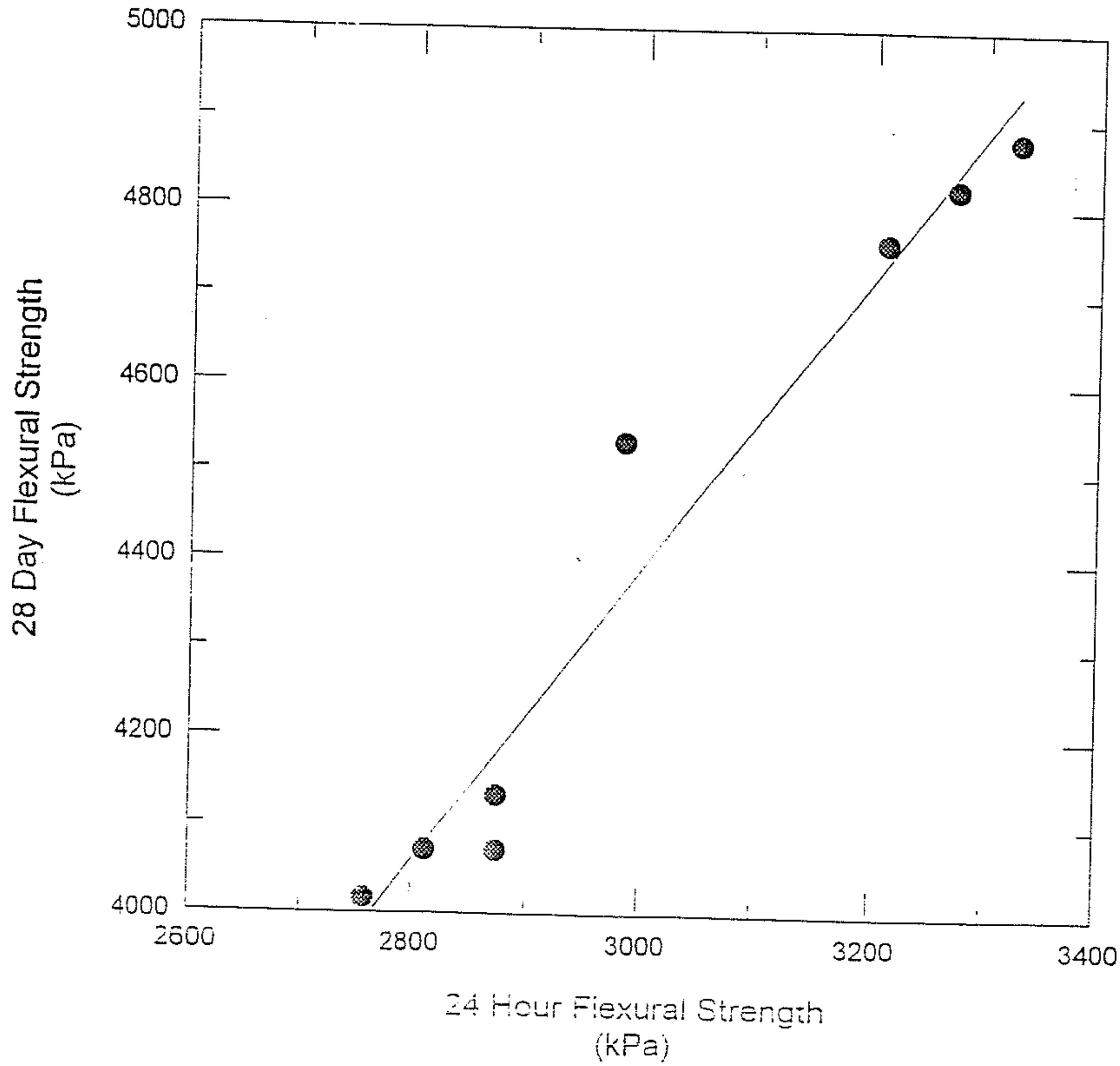

Figure 3. 28 Day Flexural Strength vs. 24 Hour Flexural Strength Perkins Road

Y = 1.29849 * X + 666.289
Number of data points used = 30
R^2= 0.951844

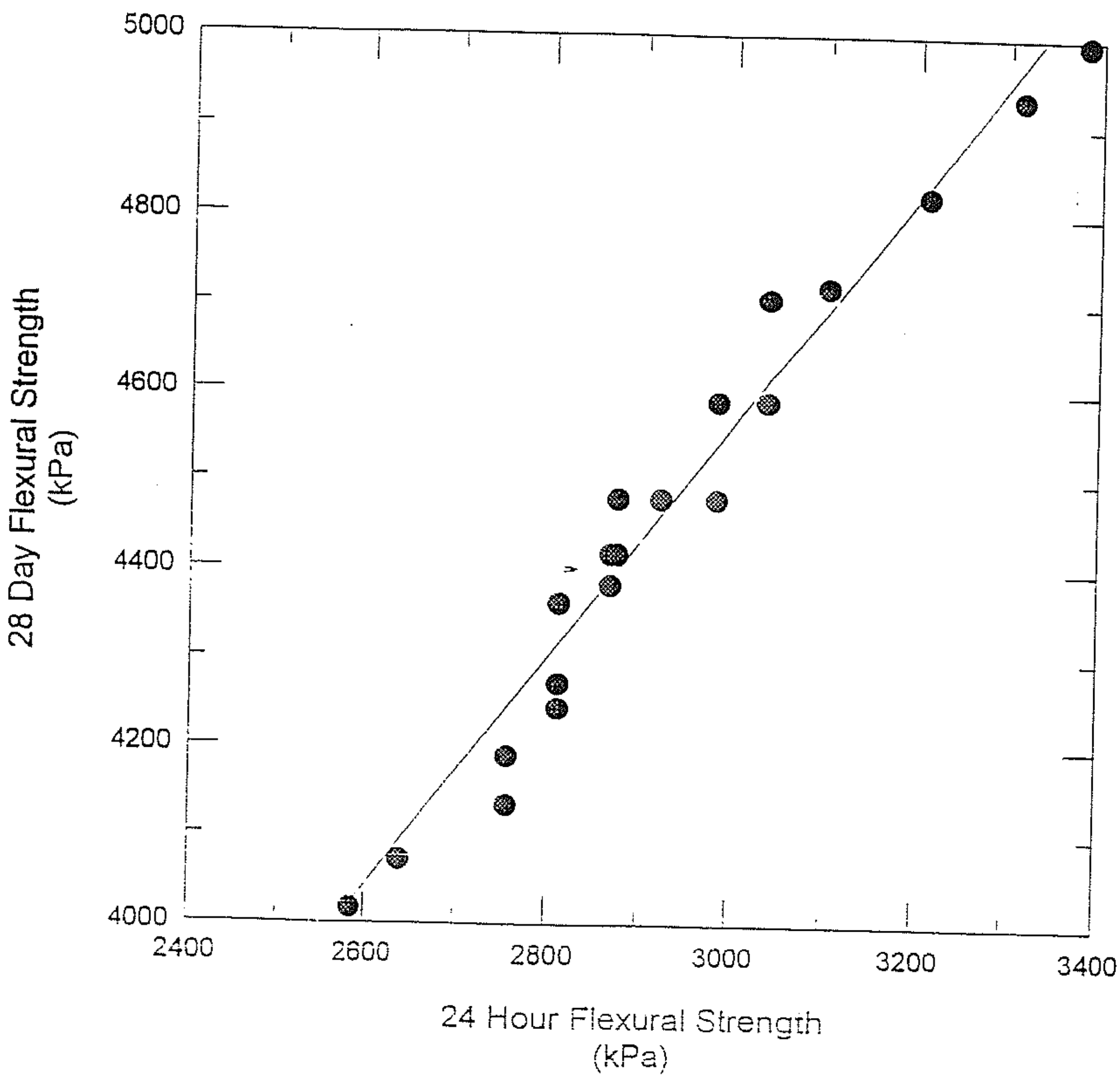

Figure 4. 28 Day Flexural Strength vs. 24 Hour Flexural Strength I-55

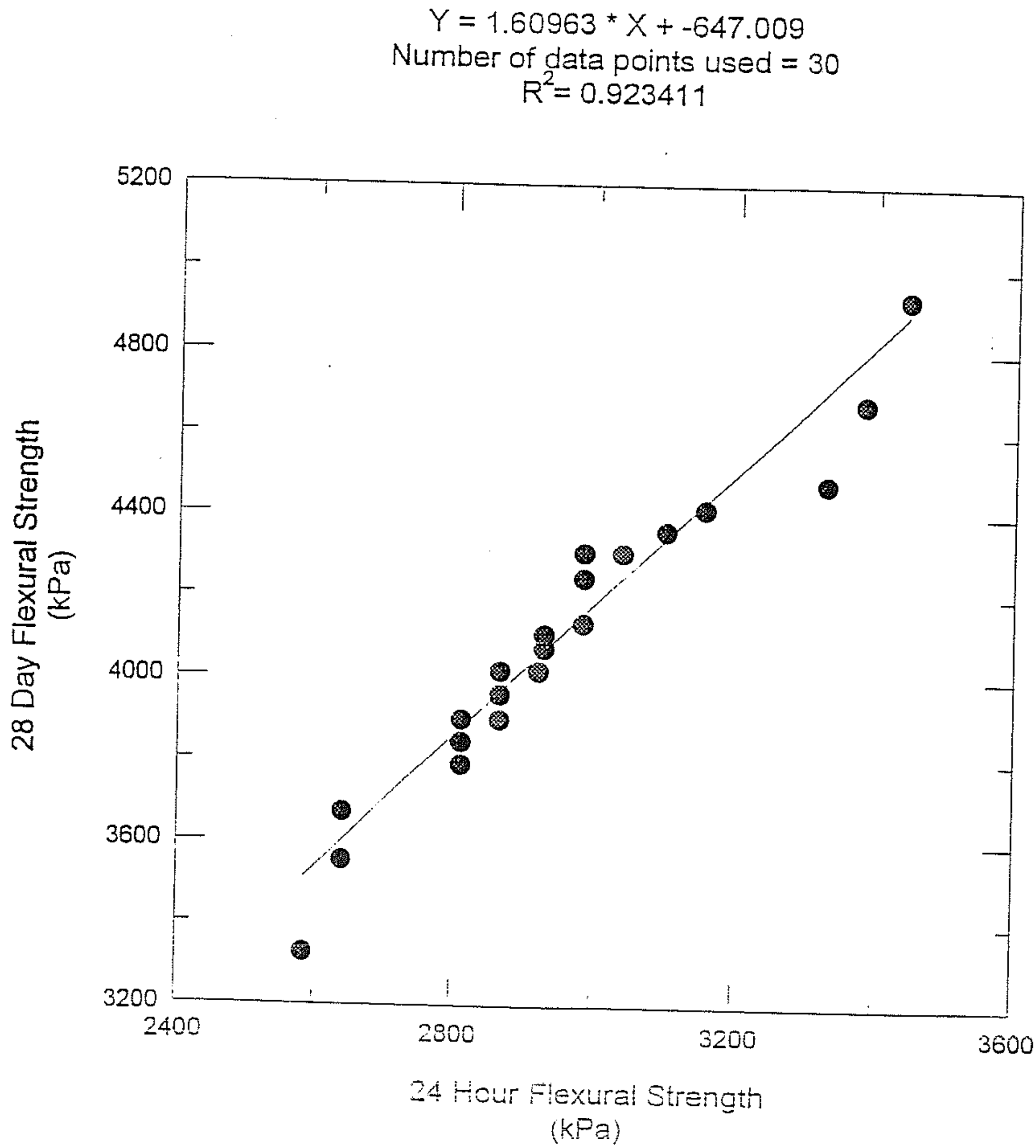

Figure 5. 28 Day Flexural Strength vs. 24 Hour Flexural Strength Siegen Lane

Y = 0.860652 * X + 2256.4
Number of data points used = 30
R^2= 0.881223

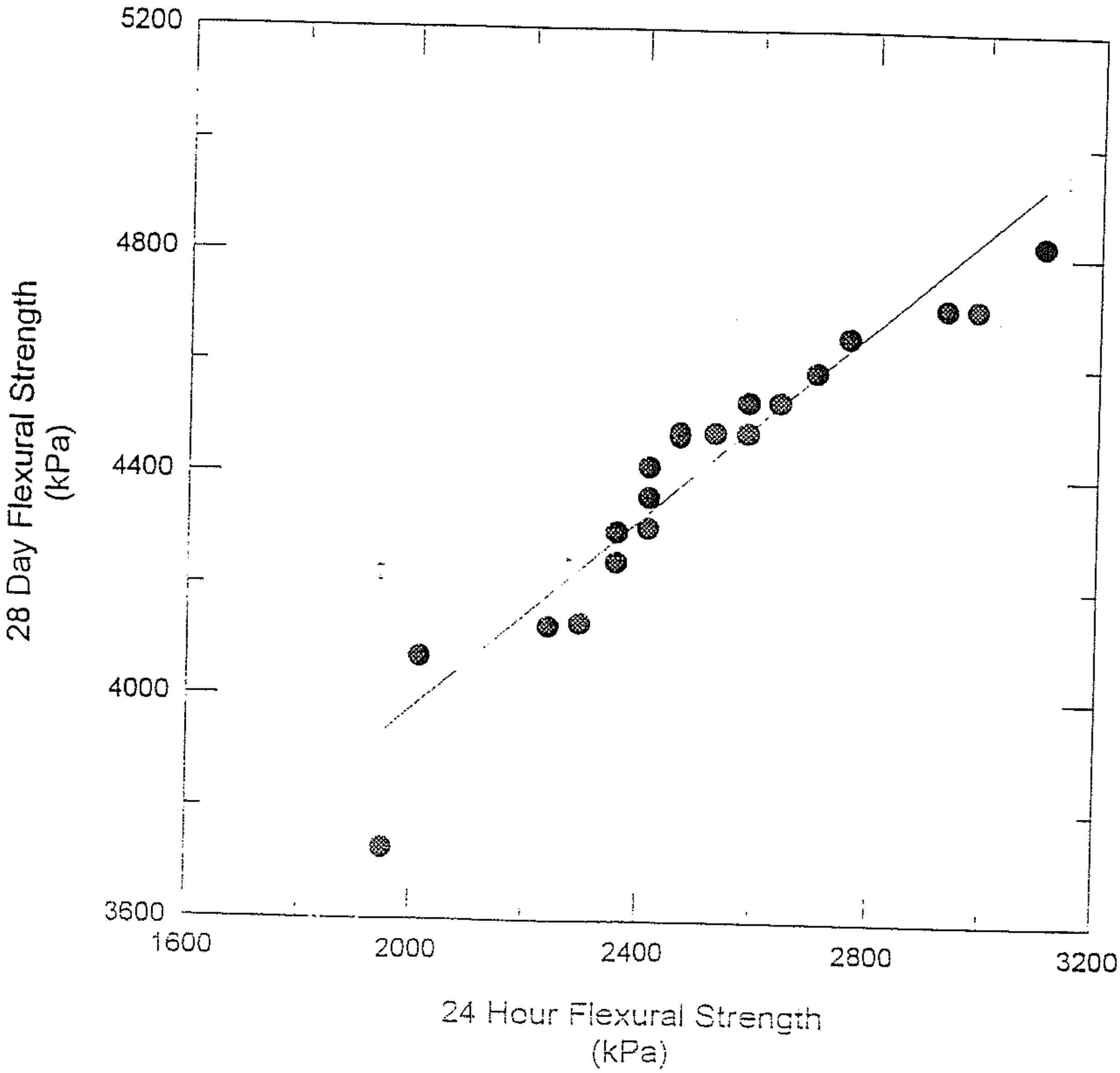

Figure 6. 28 Day Flexural Strength vs. 24 Hour Flexural Strength Joor Road

Y = 1.23356 * X + 1237.15
Number of data points used = 30
R^2= 0.920531

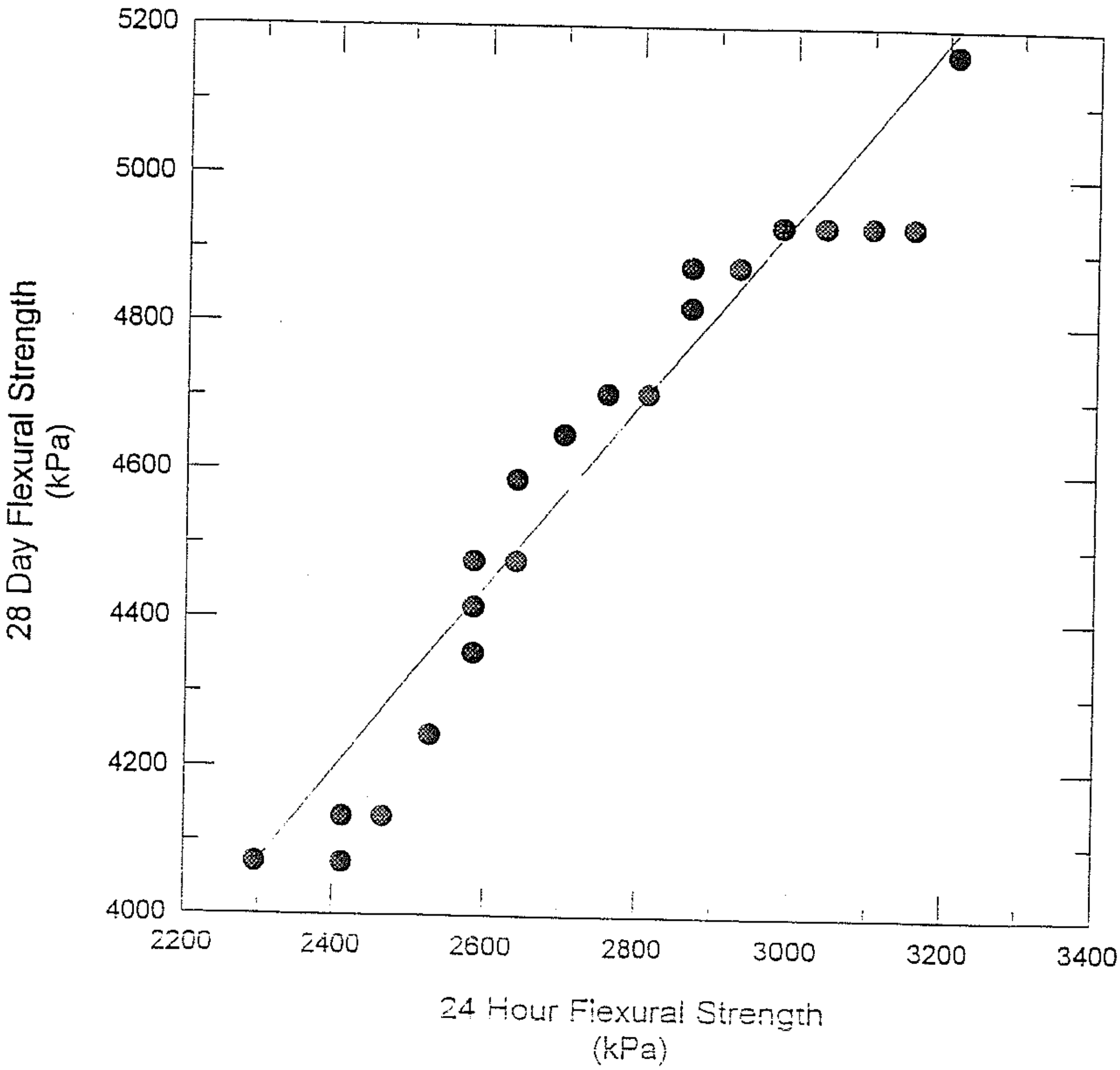

Figure 7. 28 Day Flexural Strength vs. 24 Hour Flexural Strength LA 415

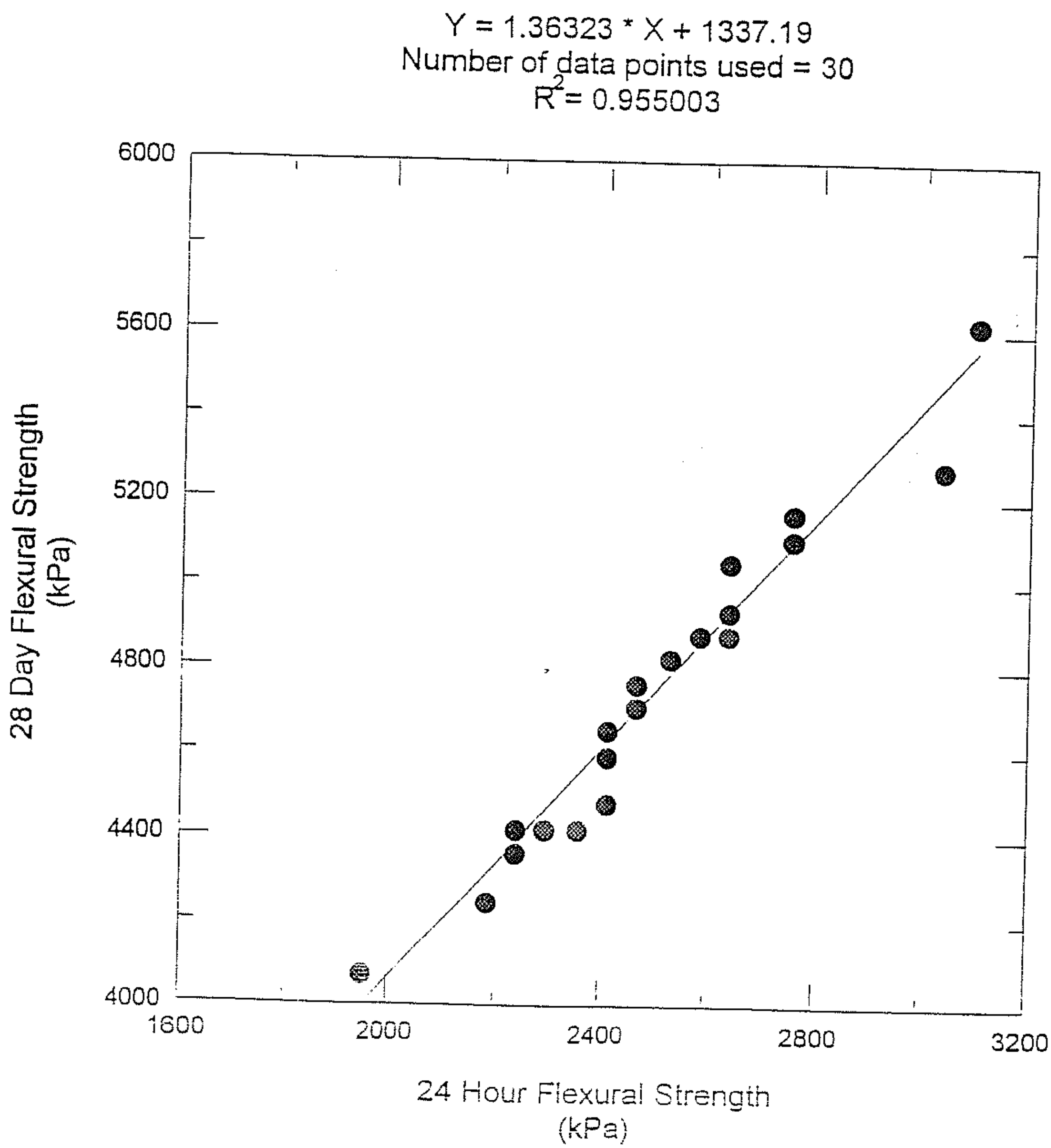

Figure 8. 28 Day Flexural Strength vs. 24 Hour Flexural Strength North Sherwood

$Y = 0.940334 * X + 2328.66$
Number of data points used = 30
$R^2 = 0.923808$

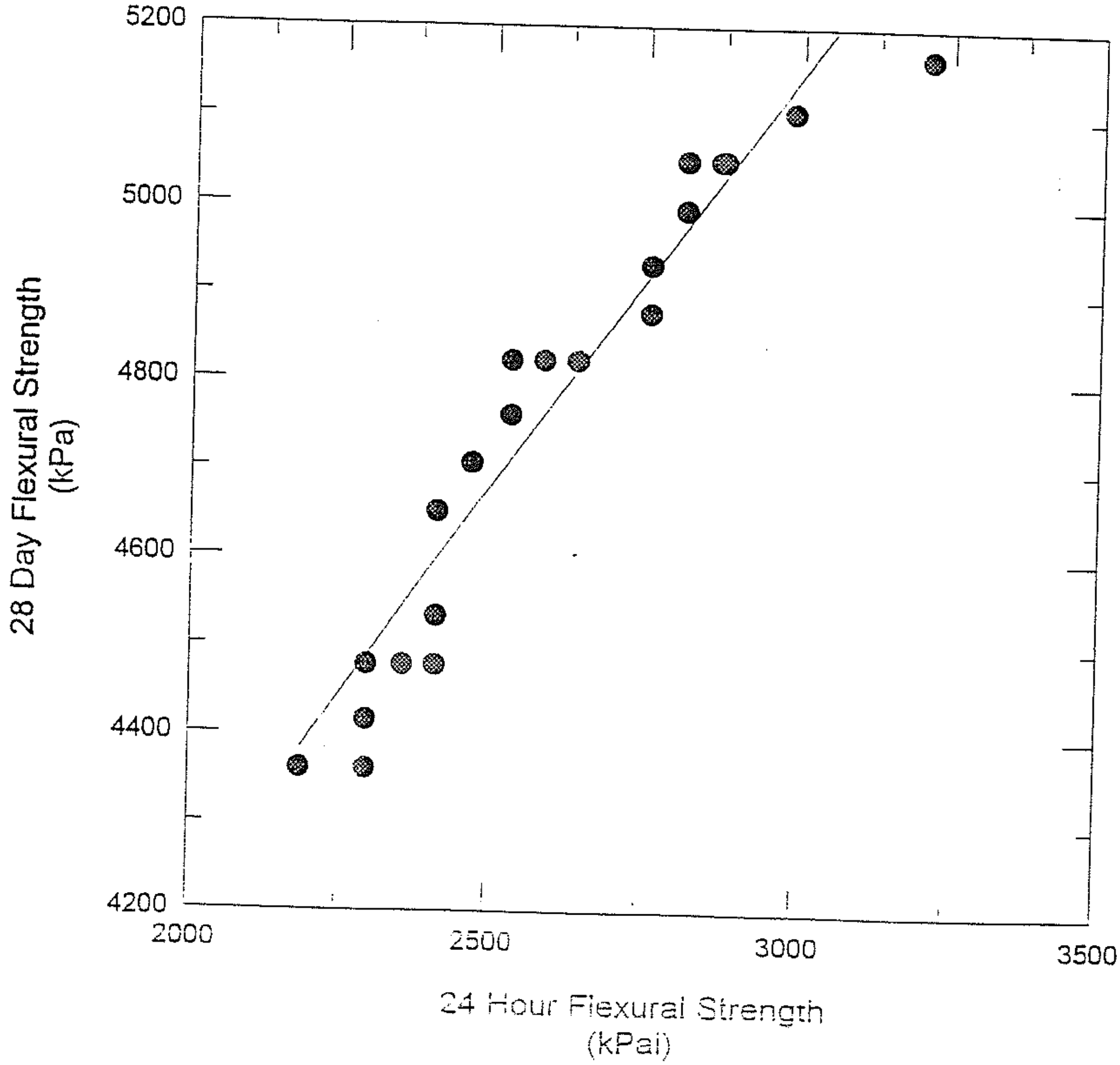

Figure 9. 28 Day Flexural Strength vs. 24 Hour Flexural Strength US 167 Ville Platte

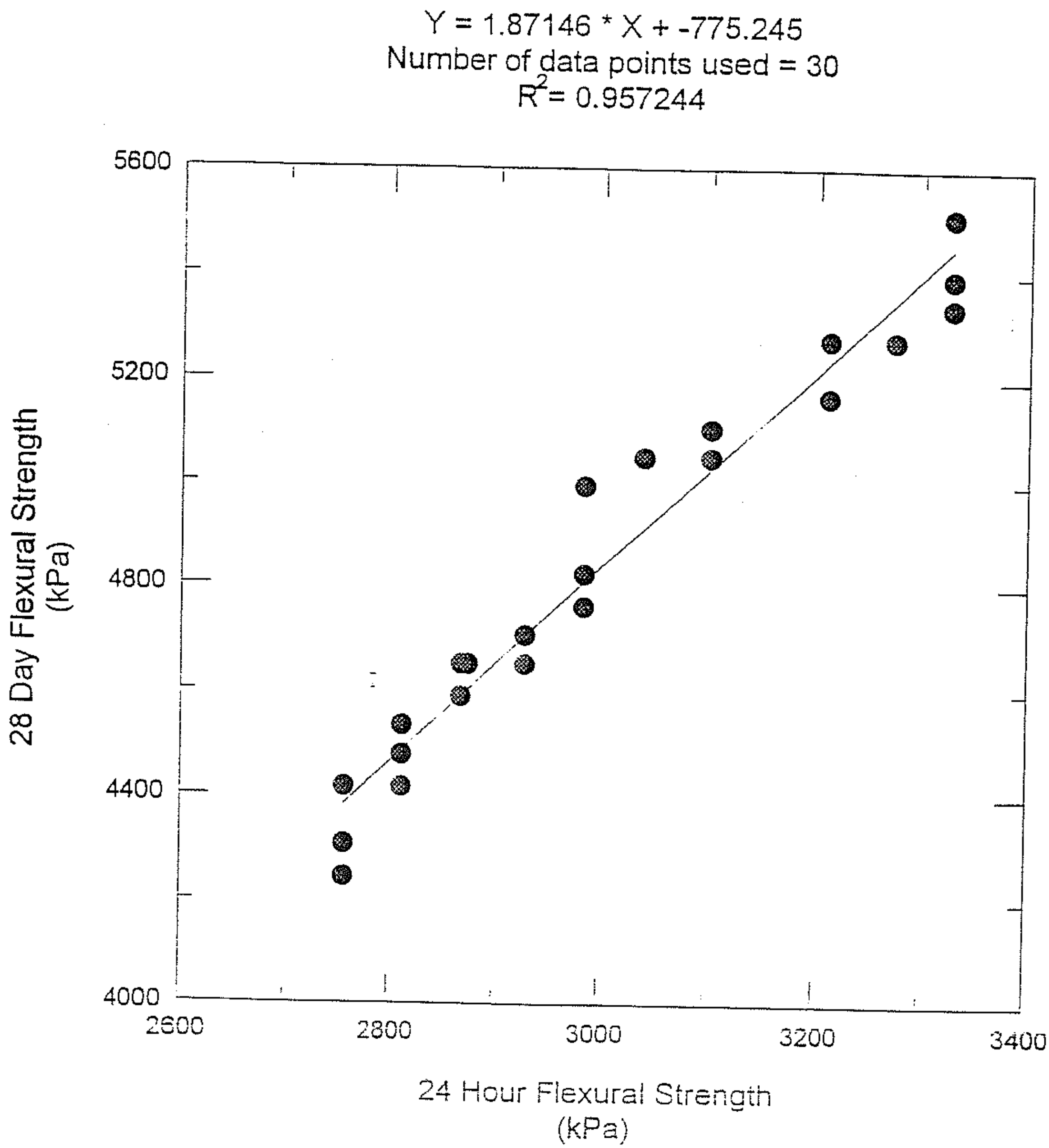

Figure 10. 28 Day Flexural Strength vs. 24 Hour Flexural Strength I 49 Alexandria

Y = 1.78148 * X + -8.90351
Number of data points used = 30
R^2= 0.868782

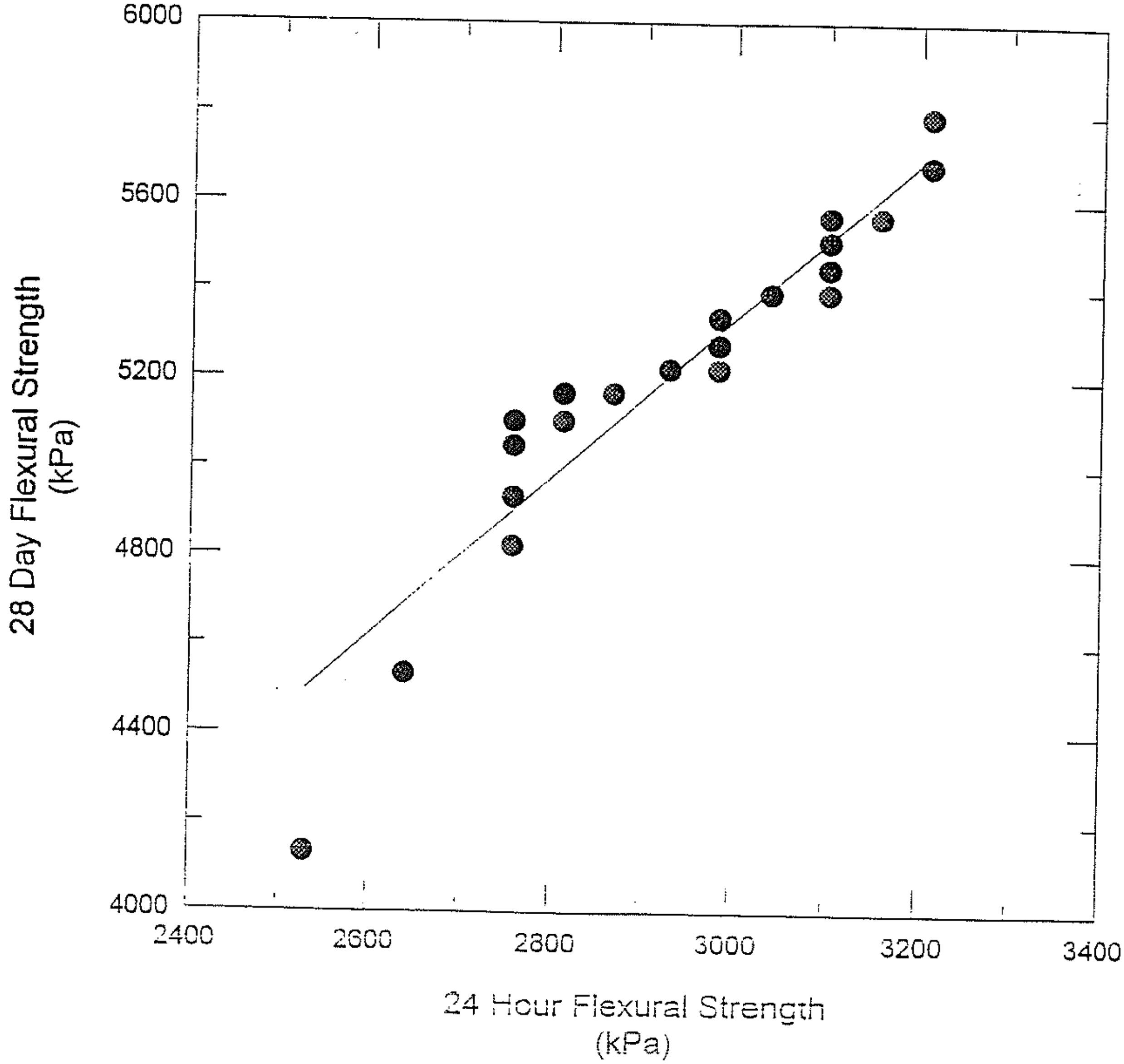

Figure 11. 28 Day Flexural Strength vs. 24 Hour Flexural Strength I 10 Baton Rouge

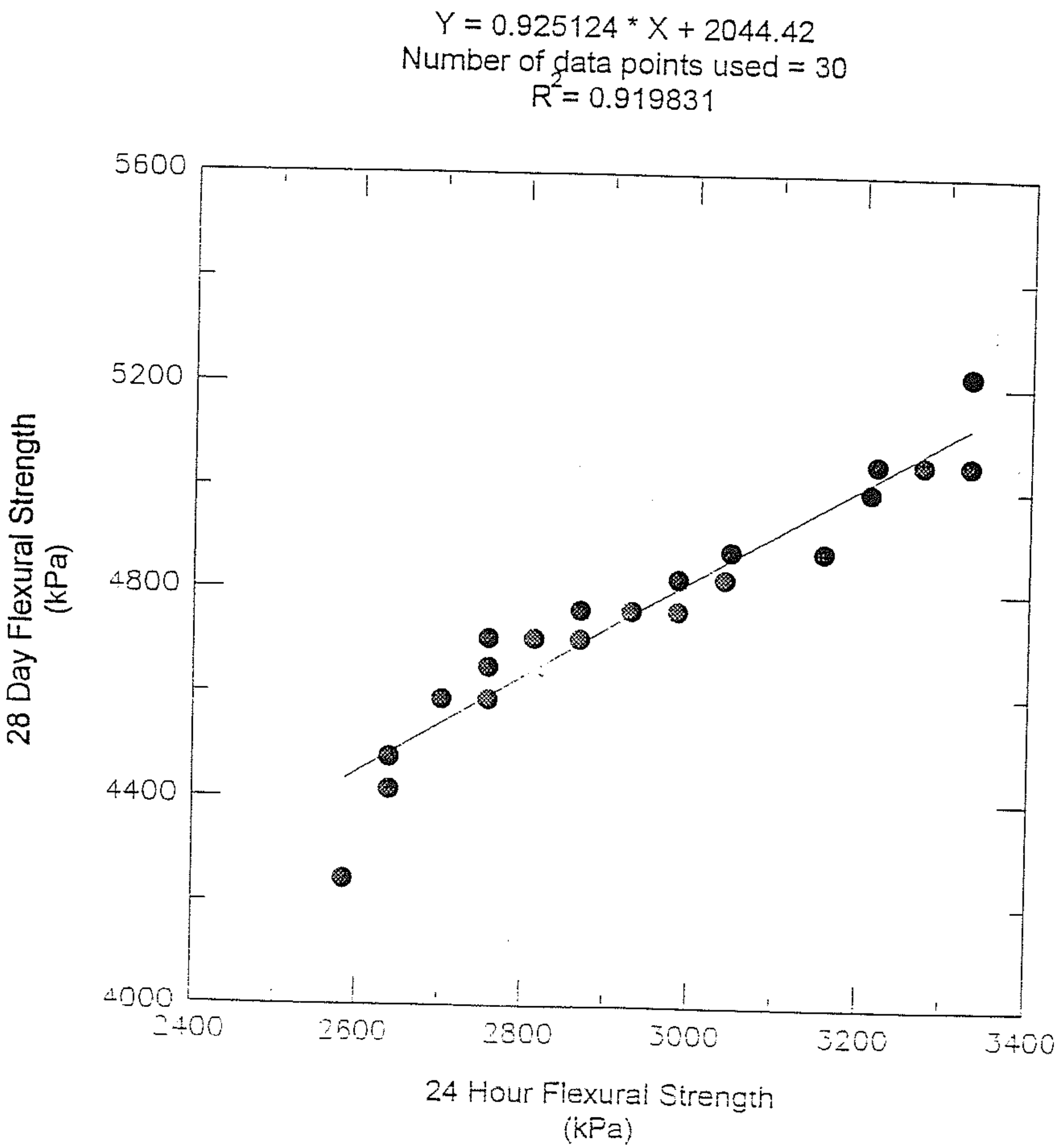

Figure 12. 28 Day Compressive Strength vs. 28 Day Flexural Strength

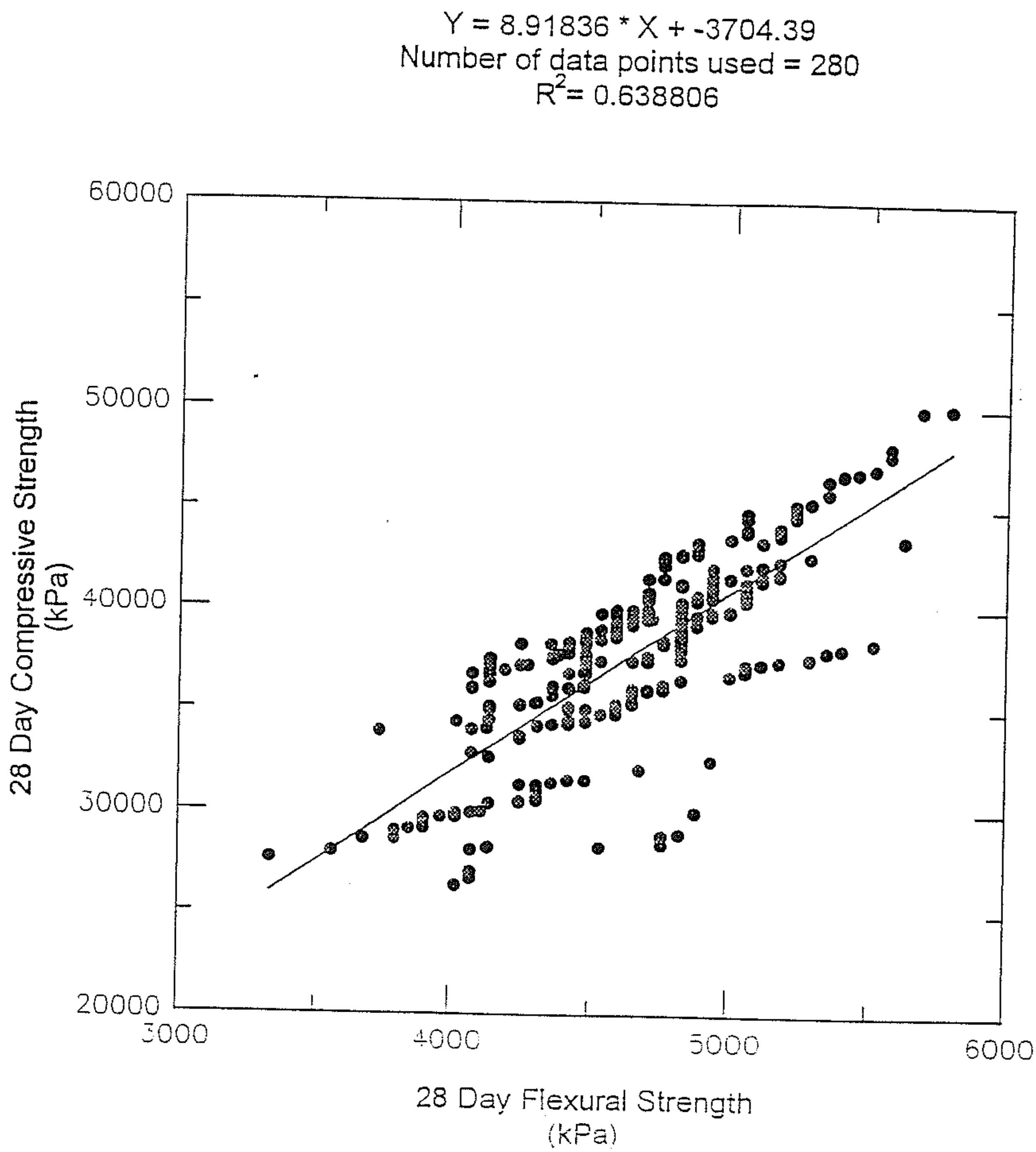

Figure 13. 28 Day Compressive Strength vs. 28 Day Flexural Strength Kaliste Saloom

Y = 2.56483 * X + 16781.2
Number of data points used = 10
R^2= 0.70691

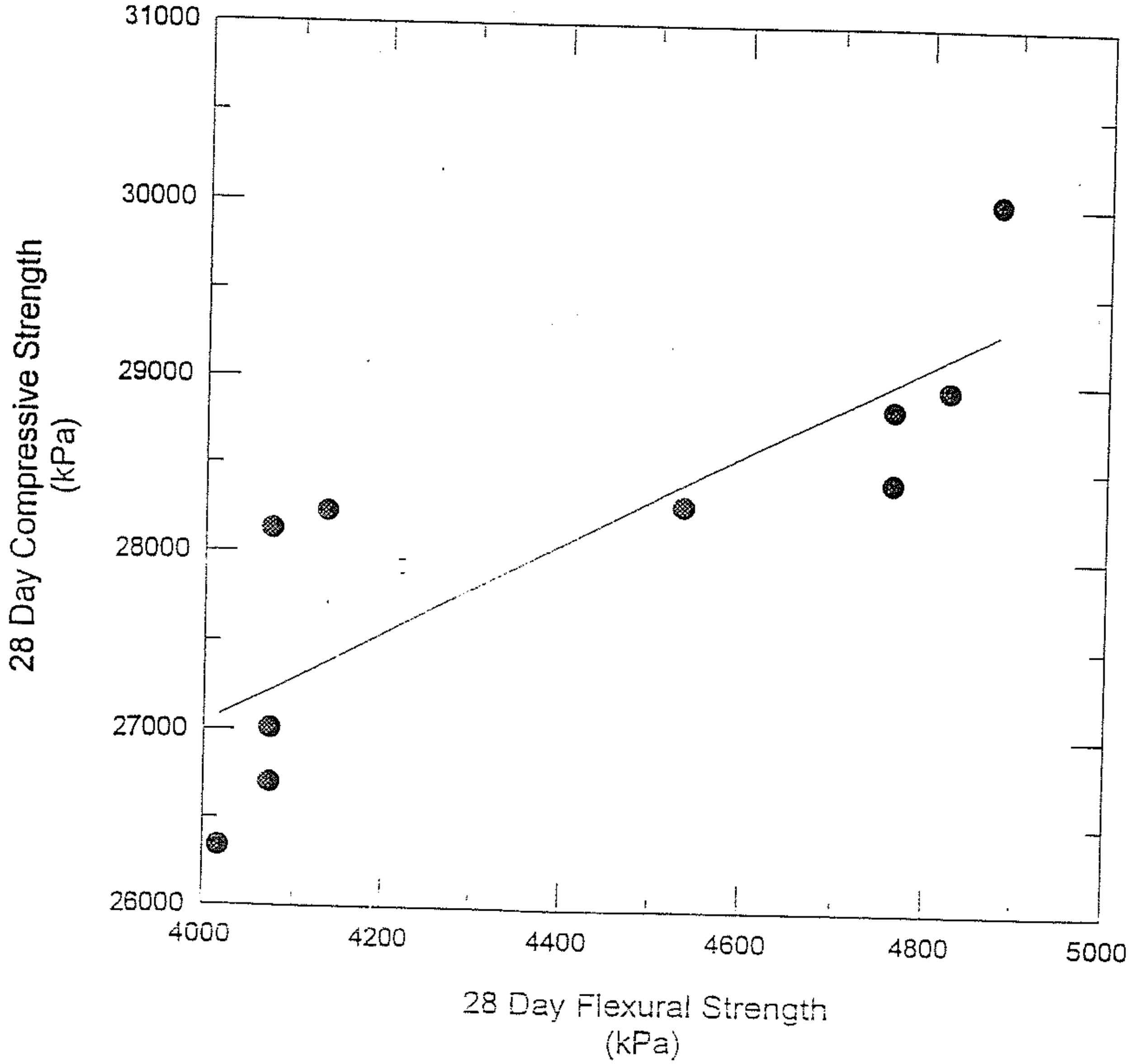

Figure 14. 28 Day Compressive Strength vs. 28 Day Flexural Strength Perkins Road

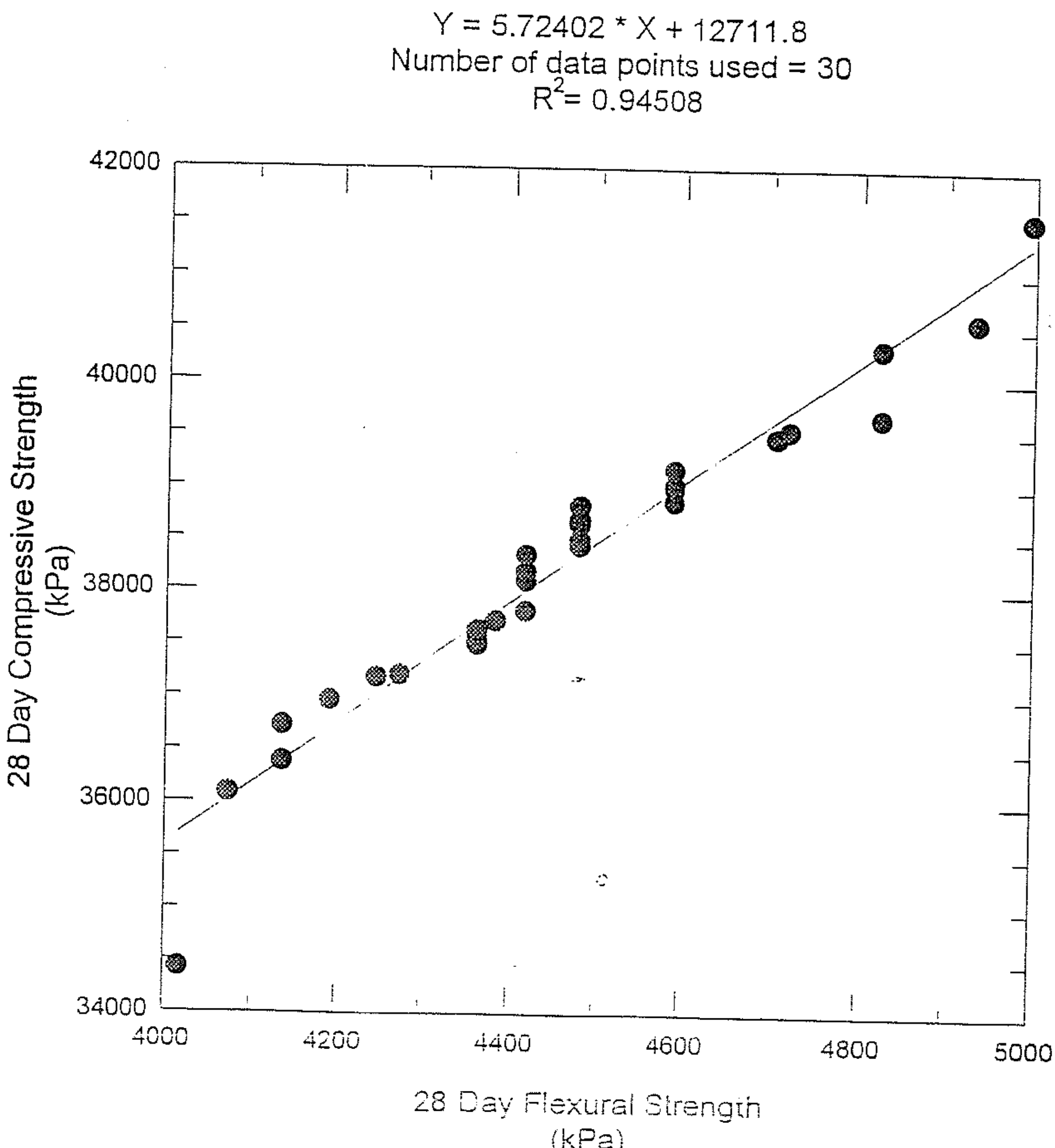

Figure 15. 28 Day Compressive Strength vs. 28 Day Flexural Strength I-55

Y = 3.49092 * X + 15791.7
Number of data points used = 30
R^2= 0.964043

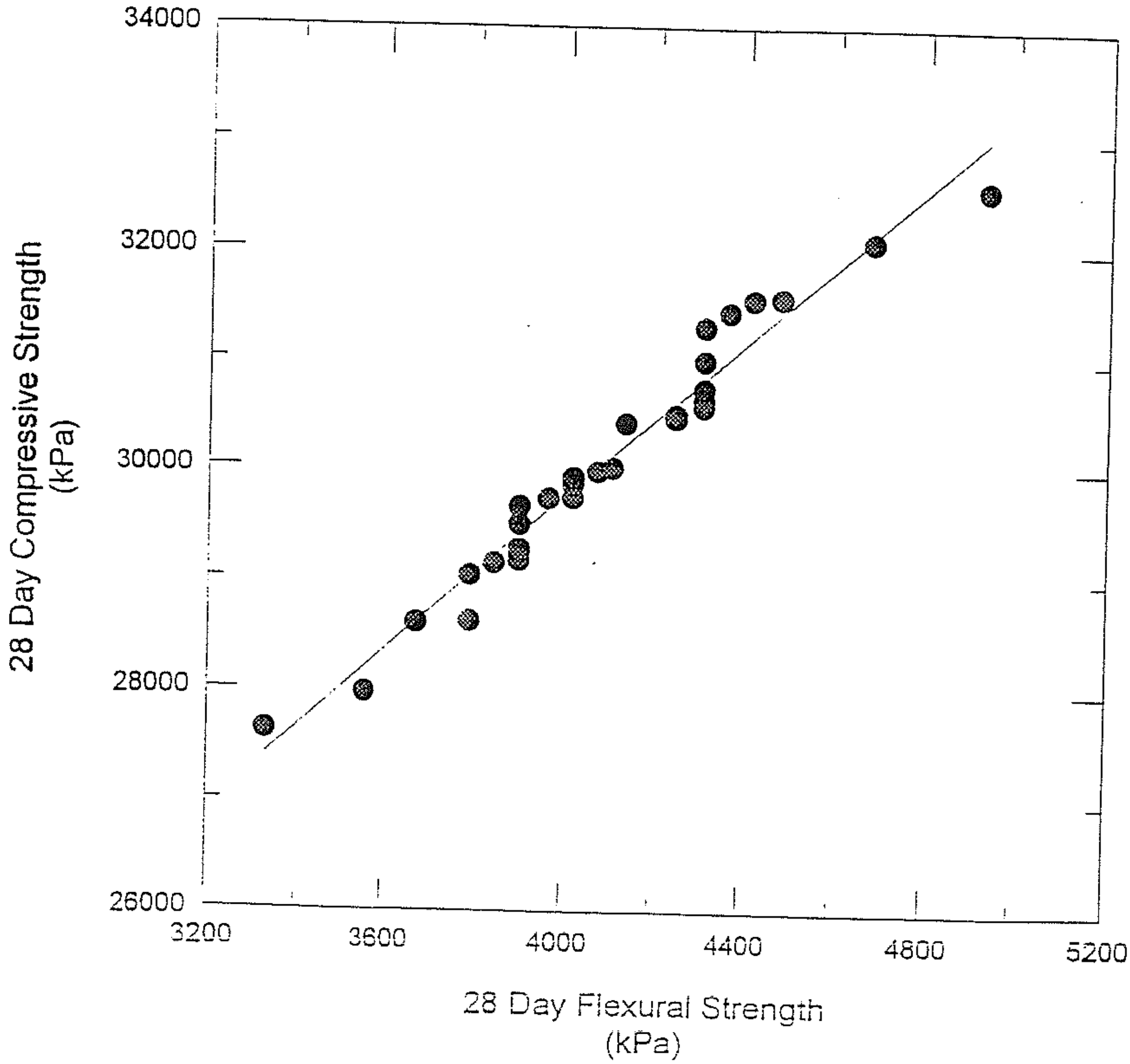

Figure 16. 28 Day Compressive Strength vs. 28 Day Flexural Strength Siegen Lane

$Y = 8.39702 * X + 38.3606$
Number of data points used = 30
$R^2 = 0.8216$

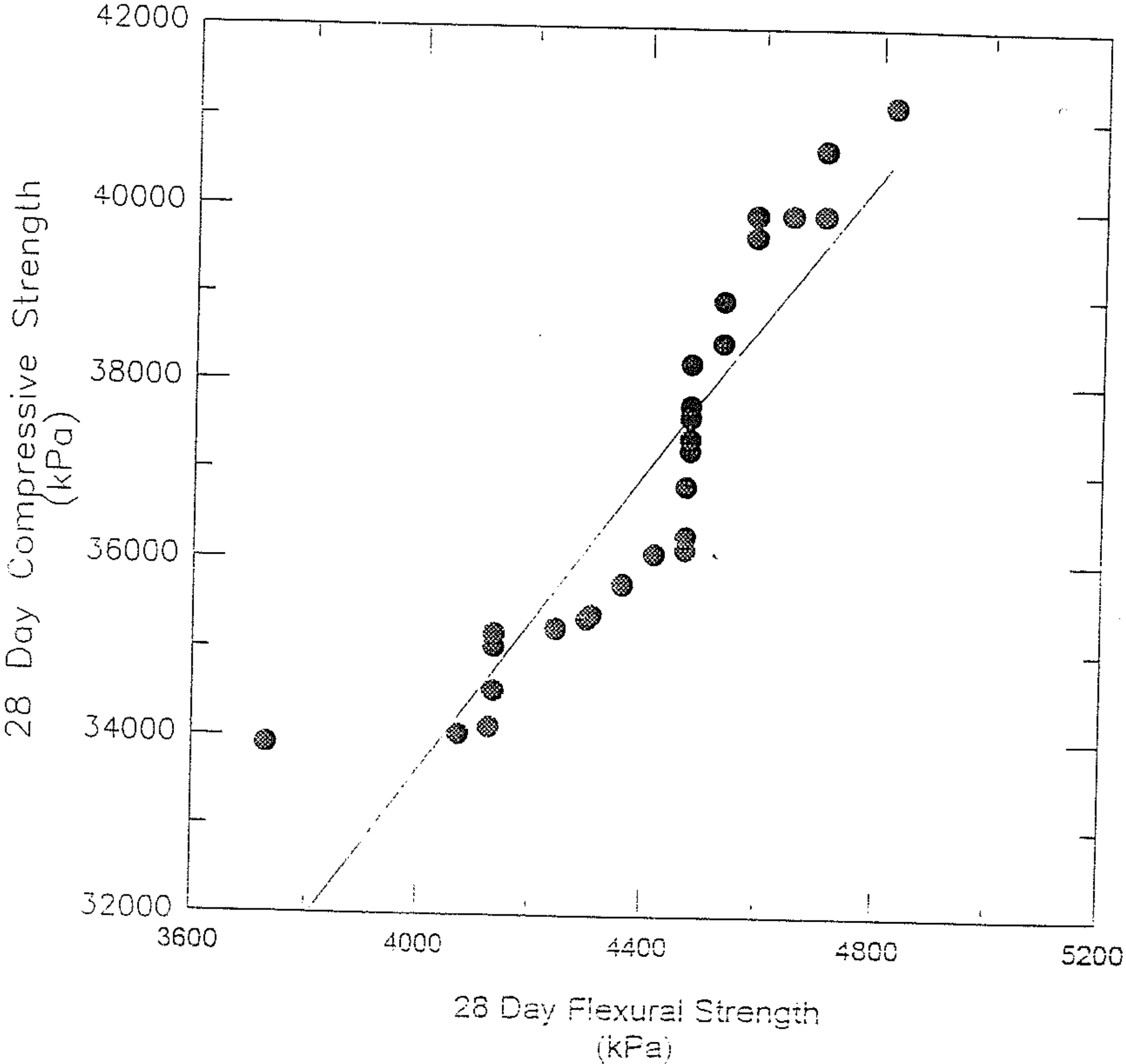

Figure 17. 28 Day Compressive Strength vs. 28 Day Flexural Strength Joor Road

$Y = 4.95665 * X + 16458.8$
Number of data points used = 30
$R^2 = 0.951428$

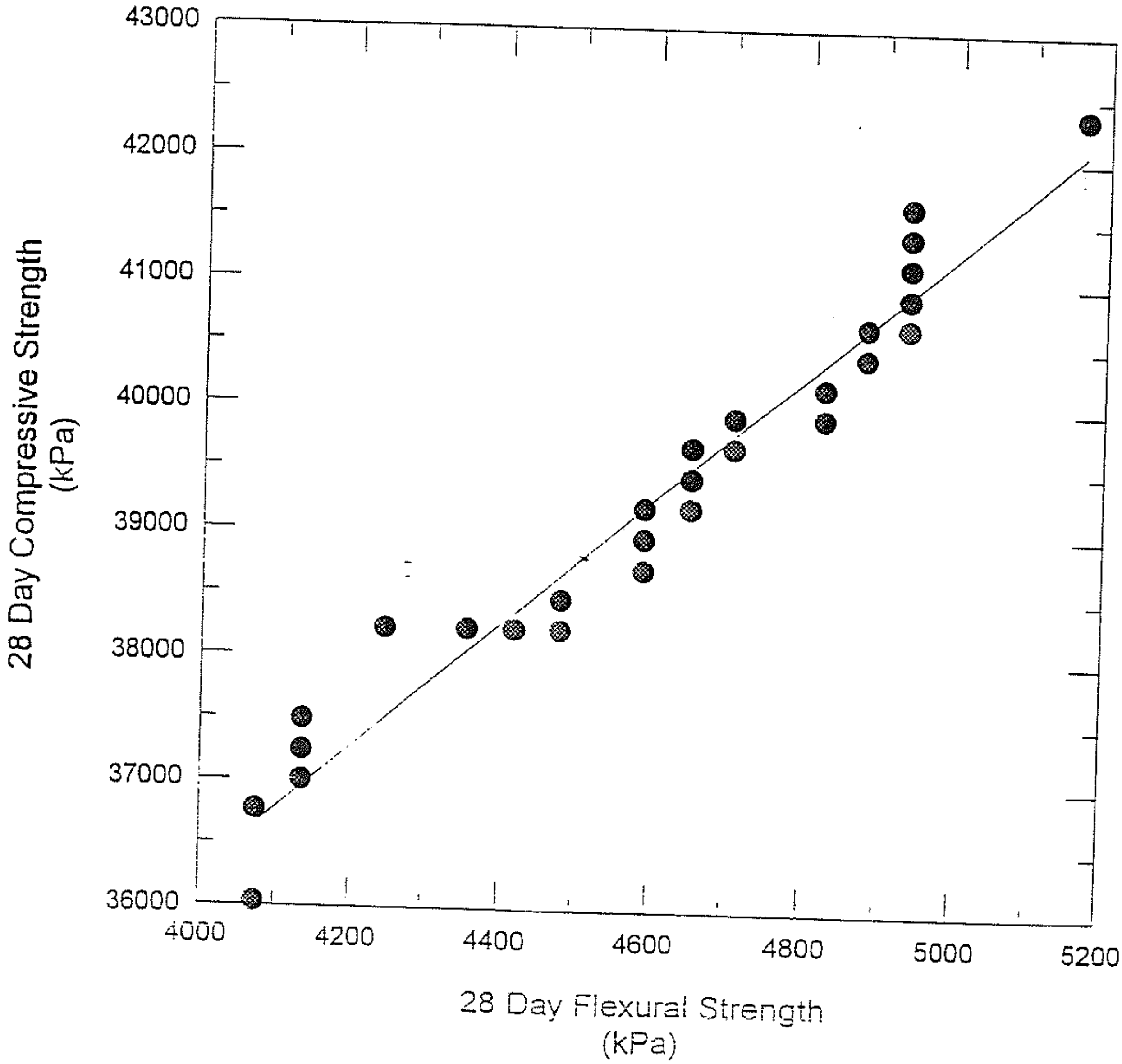

Figure 18. 28 Day Compressive Strength vs. 28 Day Flexural Strength LA 415

Y = 8.87611 * X + -4589.36
Number of data points used = 30
R^2= 0.901553

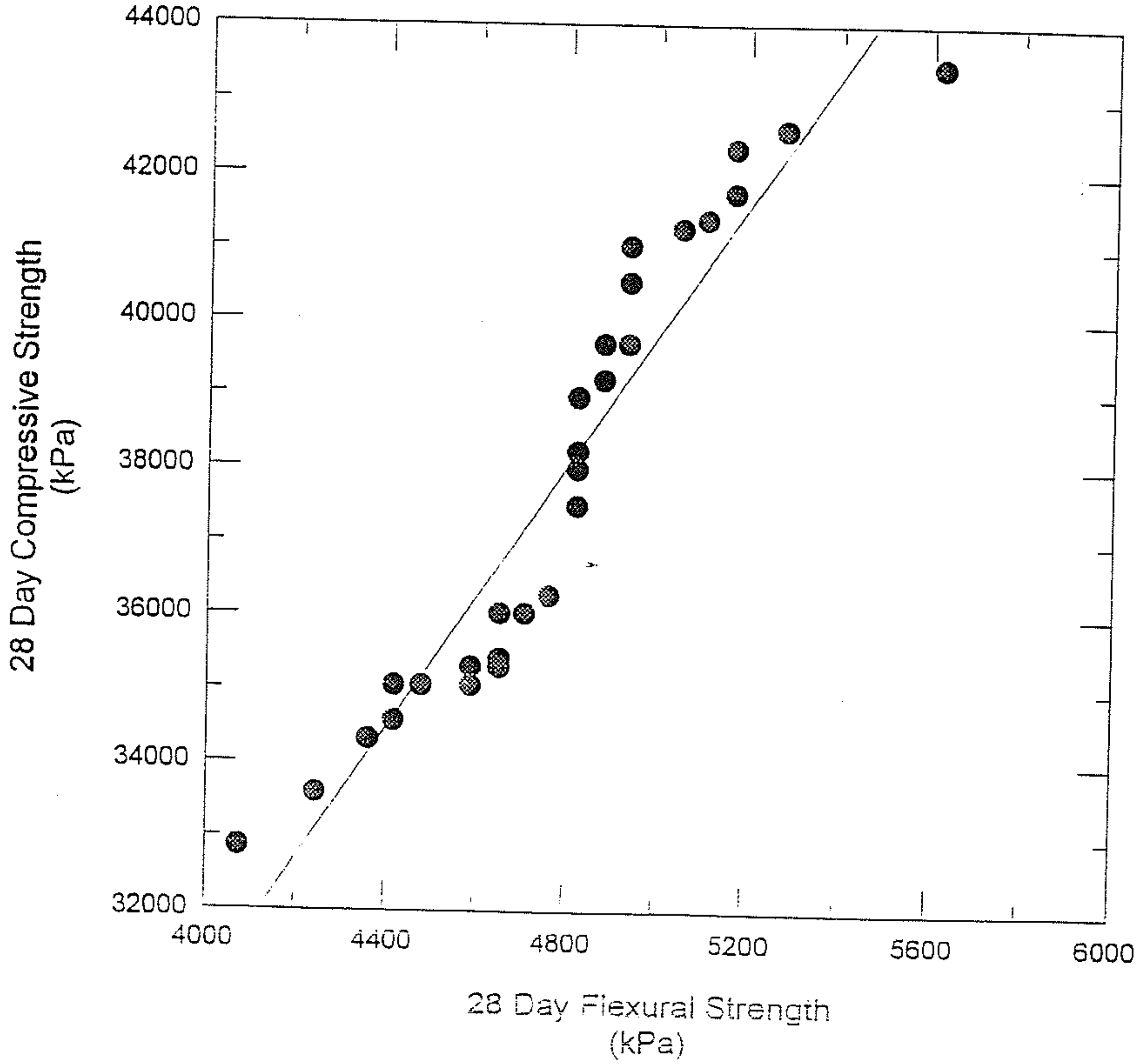

Figure 19. 28 Day Compressive Strength vs. 28 Day Flexural Strength North Sherwood

Y = 6.57876 * X + 7273.12
Number of data points used = 30
R^2 = 0.935195

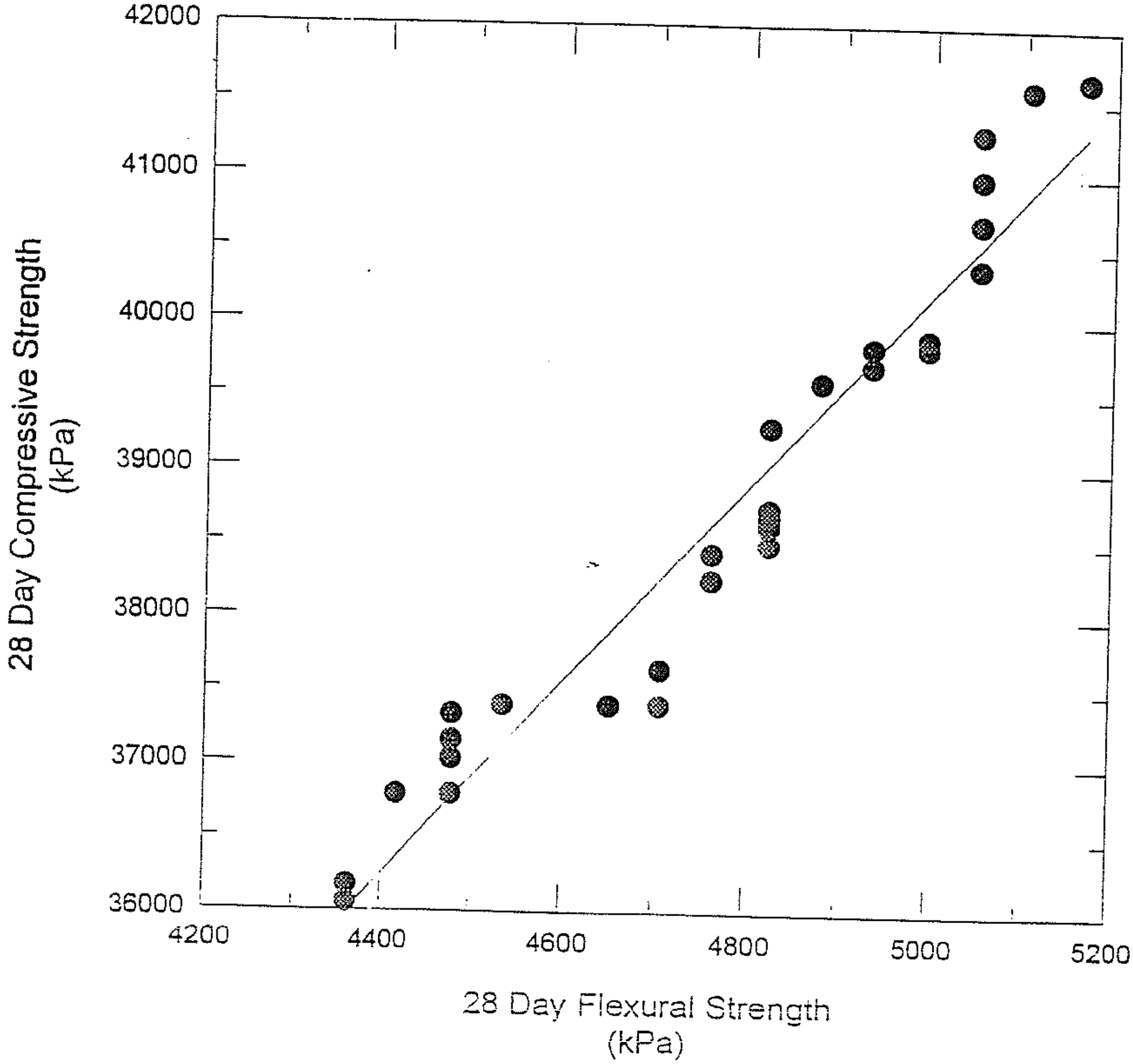

Figure 20. 28 Day Compressive Strength vs. 28 Day Flexural Strength US 167 Ville Platte

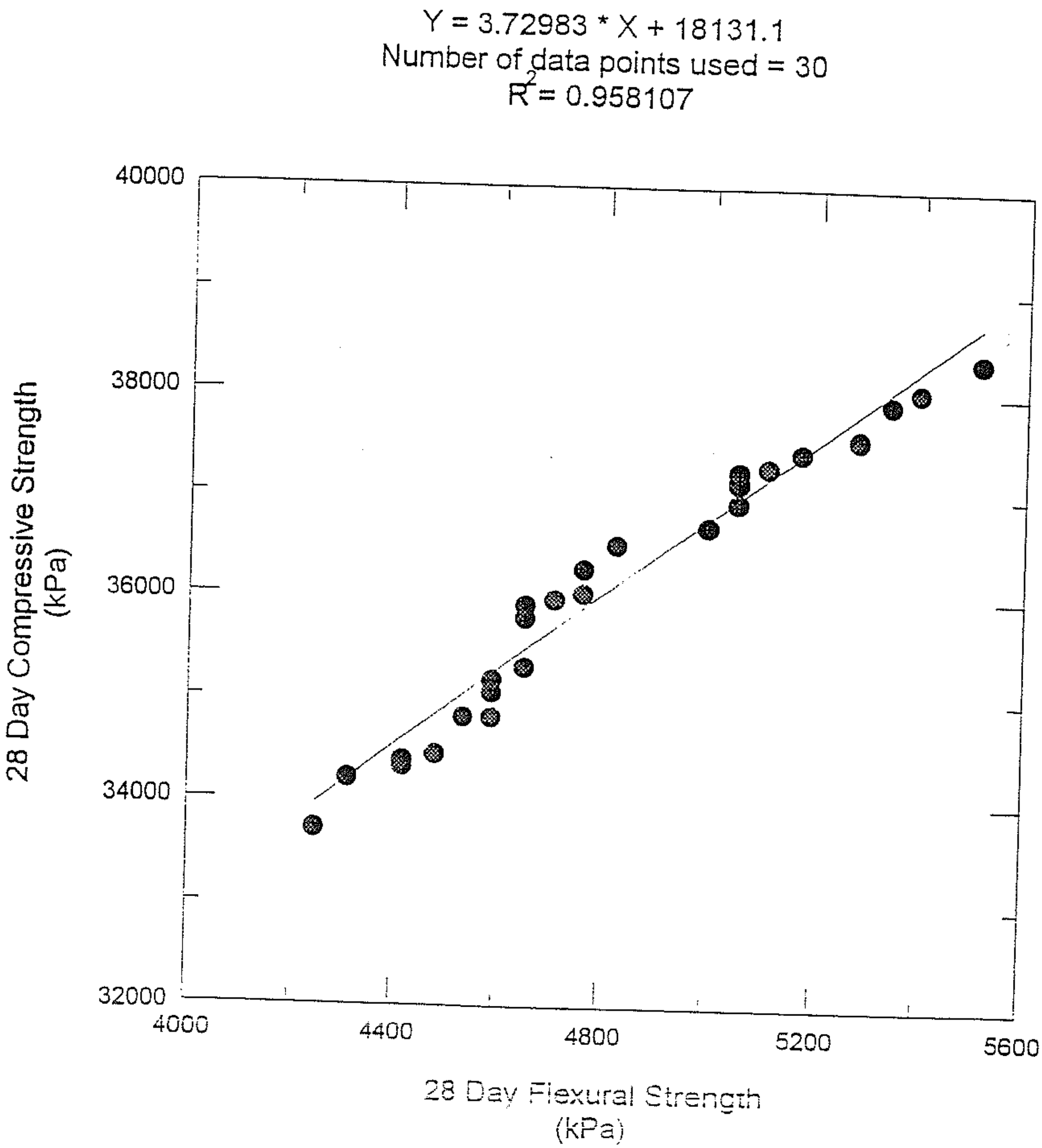

Figure 21. 28 Day Compressive Strength vs. 28 Day Flexural Strength
I 49 Alexandria

Y = 9.96586 * X + -7401.41
Number of data points used = 30
R^2 = 0.966709

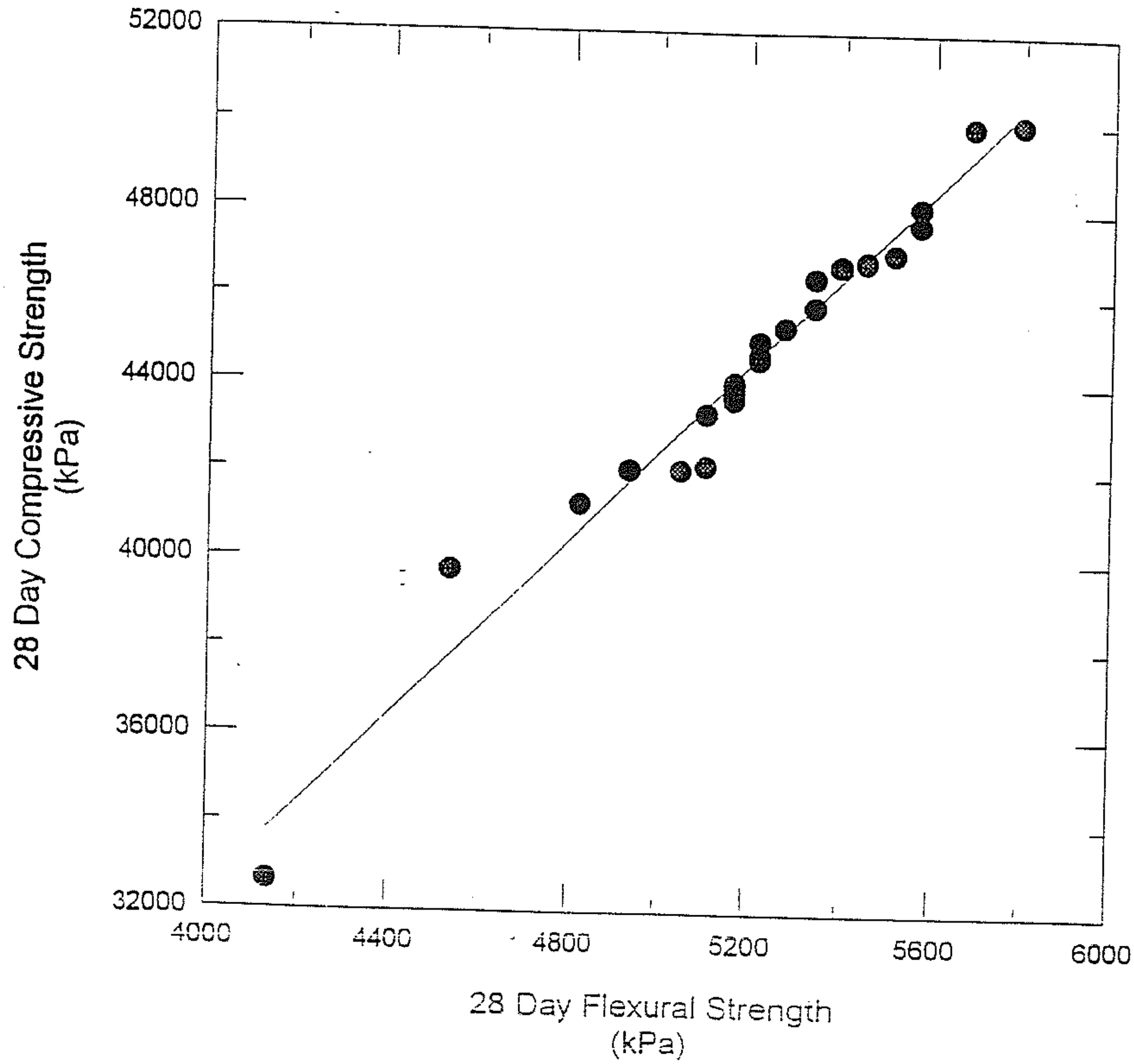

Figure 22. 28 Day Compressive Strength vs. 28 Day Flexural Strength I 10 Baton Rouge

Y = 13.0128 * X + -20774.8
Number of data points used = 30
R^2= 0.876319