DRAINAGE PIPE STUDY

by

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SYNOPSIS

This report is the result of a research program in which various types of submerged drainage structures were evaluated in an effort to determine the life expectancy of such a structure. California's method of predicting the behavior pattern of submerged metal pipe, California No. 643-B, was found to be applicable to Louisiana Soils, and a good correlation coefficient was obtained. By using the laboratory values obtained for resistivity and pH, the years to perforation for a metal structure can be estimated disregarding the abrasive forces which occur during peak discharge conditions.

It was also found that an additional 8 years prolonged life of a structure was obtained by over coating the galvanized steel with a moderate thickness of asphalt. This asphalt coating, protected from UV light, actually served as a protected barrier for the galvanized surface and thereby reduced the sacrificial properties of the zinc.

Summary of Service Life Expectancy for Highway Districts are included which predict an estimated service life of the pipe in question according to the various soil types present within the district together with the average pH and resistivity values possibly encountered in the soil types.

SCOPE

There is a two fold purpose for this study. The first is to determine the life expectancy of different types of pipe in various Louisiana soils and second, to correlate the data obtained with California's "Method of Estimating the Service Life of Metal Culverts, "Test Method No. California 643-B, 1963.

INTRODUCTION

Underground corrosion, as we know it today, is the loss of metal due to chemical attack. Chemical attack is governed by moisture, oxygen and electrolytes or dissolved salts. The degree of chemical attack can be altered significantly by altering any of the three variables. The duration of chemical attack is dependent upon the acidity of the soil. The lower the pH of the soil, the longer the duration of chemical attack, therefore, the greater the metal loss.

Generally speaking, if a metal alloy was placed in a low pH soil environment where there was adequate moisture and oxygen, this metal would begin to corrode severely until all the iron in the metal alloy was completely oxidized. Since it would be impractical to alter the soil conditions, it becomes necessary to protect the metal. This can be done in many ways, but the most economical is to coat the steel with either some type of sacrificial metal or a cheap organic coating such as asphalt. In most cases both types of protection are employed.

This study has shown that using a sacrificial metal such as zinc does improve the life of a steel structure and that the addition of a bituminous coating over the zinc adds additional life also.

METHODOLOGY

I. Sample Selection

Approximately 1400 in-place drainage structures were surveyed. The criteria used in selection for this surveillance were:

1. Type of Pipe

    a. Reinforced concrete pipe
    b. Bituminous coated corrugated metal pipe
    c. Asbestos bonded bituminous coated corrugated metal pipe
    d. Structural pipe

For simplicity, bituminous coated corrugated metal pipe and asbestos bonded bituminous coated corrugated metal pipe will be referred to hereafter as BCCMP and ABCMP respectively.

2. Length of Exposure

    The plans for projects using drainage structures were surveyed, and it was decided that in order to obtain a complete economic evaluation the years selected, whenever possible, for observation should be: 1963 (three years exposure), 1961 (five years exposure), 1956 (ten years exposure), 1951 (fifteen years exposure) and all pipe placed in the field prior to the year of 1947. Certain highways constructed during these years were selected for study and each soil type was represented.

3. Soil Type

    There are seven general soil areas classified by Department of Agronomy, Louisiana State University that were selected for this study.

    a. Recent alluvium
    b. Coastal marsh
    c. Coastal prairies
    d. Flatwoods
    e. Mississippi terrace
    f. Coastal plains
    g. Coastal alluvium

II. Laboratory Tests

The laboratory tests were performed on the samples collected from each area under observation. The measurements and tests performed in the laboratory were:

a. Resistance of soil and water (ohm/cc)
b. pH of soil

III. Field Data Evaluation

Correlation of field evaluation with laboratory data was made in an effort to establish certain criteria to aide the design and construction engineers. These facts will aide in eliminating such costly mistakes as improper selection of material for a particular medium.

In order to properly evaluate the drainage structures, certain types of information were considered during field evaluation.

This information included the following:

a. Type of pipe
b. Length of time pipe has been submerged
c. Size and gauge (if metal) of pipe and its respective coatings
d. General type of fluid flowing through pipe
e. Condition of pipe. This included:

1 Pipe in excellent condition with less than 10 percent deterioration to the coating only.

1.5 Pipe in excellent to good condition with 10-15 percent deterioration to the coating only.

2 Pipe in good condition with approximately 20 percent deterioration to the coating and appearance of **very slight rusting.**

2.5 Pipe in good to fair condition with less than 40 percent deterioration to the coating and less than 5 percent deterioration to the pipe itself. In other words, slight to moderate rusting was allowed.

3 Pipe in fair condition with less than 40 percent deterioration to the coating and less than 10 percent deterioration to the pipe. Moderate rusting was present.

3.5 Pipe in fair to poor condition with more than 40 percent deterioration of the coating and moderate to excessive rusting present. Perforation of the metal was almost complete.

4 Pipe in poor condition with more than 40 percent deterioration of the coating, excessive rusting of the pipe and perforation of the metal was complete.

f. Condition of coating. This includes:

a. Blistering
b. Puncture or pitting
c. Loss of adhesion
d. Brittleness
e. Unaffected

Judging the condition of the pipe was subjective. The coatings on the wall of the pipe were observed, and the overall appearance of the pipe was evaluated. These measurements and evaluations are given in Table I of the Appendix.

The list of Revised Drainage Structures under surveillance is included in the Appendix. This list includes types of pipe, year submerged, highway number, soil classification and finally the actual location of the job with respect to a know reference point.

Also included in the Appendix is the General Soil Classifications as prepared by the Louisiana State University's Department of Agronomy.

DISCUSSION OF RESULTS

This research project, although not subdivided into various phases, was conducted similarly to a project consisting of three phases. The first step was to study construction plans to set-up a cross section representation of all types and ages of pipe located within a given soil types. The second step was to gather soil samples near each pipe location to determine resistivity and pH values. While gathering soil samples, a field inspection was made on each in-place pipe. The third phase was to make additional field inspections every other year for four years.

The above procedure was carried out in an effort to utilize California's method of evaluating metal drainage structures.

Thus, one of the most significant objectives of this report was the actual correlation of data obtained from the behavior characteristics of metal pipe in Louisiana soils with the test results from California as published in California Test Method, 643-B, 1963.

Figure 1A is the chart for estimating metal culvert life as produced in California Test Method, California No. 643-B, 1963 and Figure 1B is an adaptation of the graph provided in California Test Method, 643-B, 1963. By substituting the varying pH values for the years to perforation along the dependent axis and the minimum resistance (ohm/cc) along the independent axis, Figure 1B was obtained.

The next step was to superimpose the points obtained from this survey over the chart, and it was readily seen that complete coverage of the entire chart was obtained. The only fallacy with this method was that all the pipe connected with the superimposed points were not in poor condition. By observing Figure 1B, it was seen that the deviation of pH appeared to be more critical than the resistivity in determining the years to perforation of metal drainage structures.

Since a good coverage of the entire chart was evident, and since the pipe selected were not in poor condition, it was decided to estimate the life of the pipe from Test Method California No. 643-B, 1963, and form a ratio of the actual age of the pipe divided by the estimated years to perforation of the pipe as predicted from Test Method California No. 643-B, 1963. Thus, this relationship was warranted.

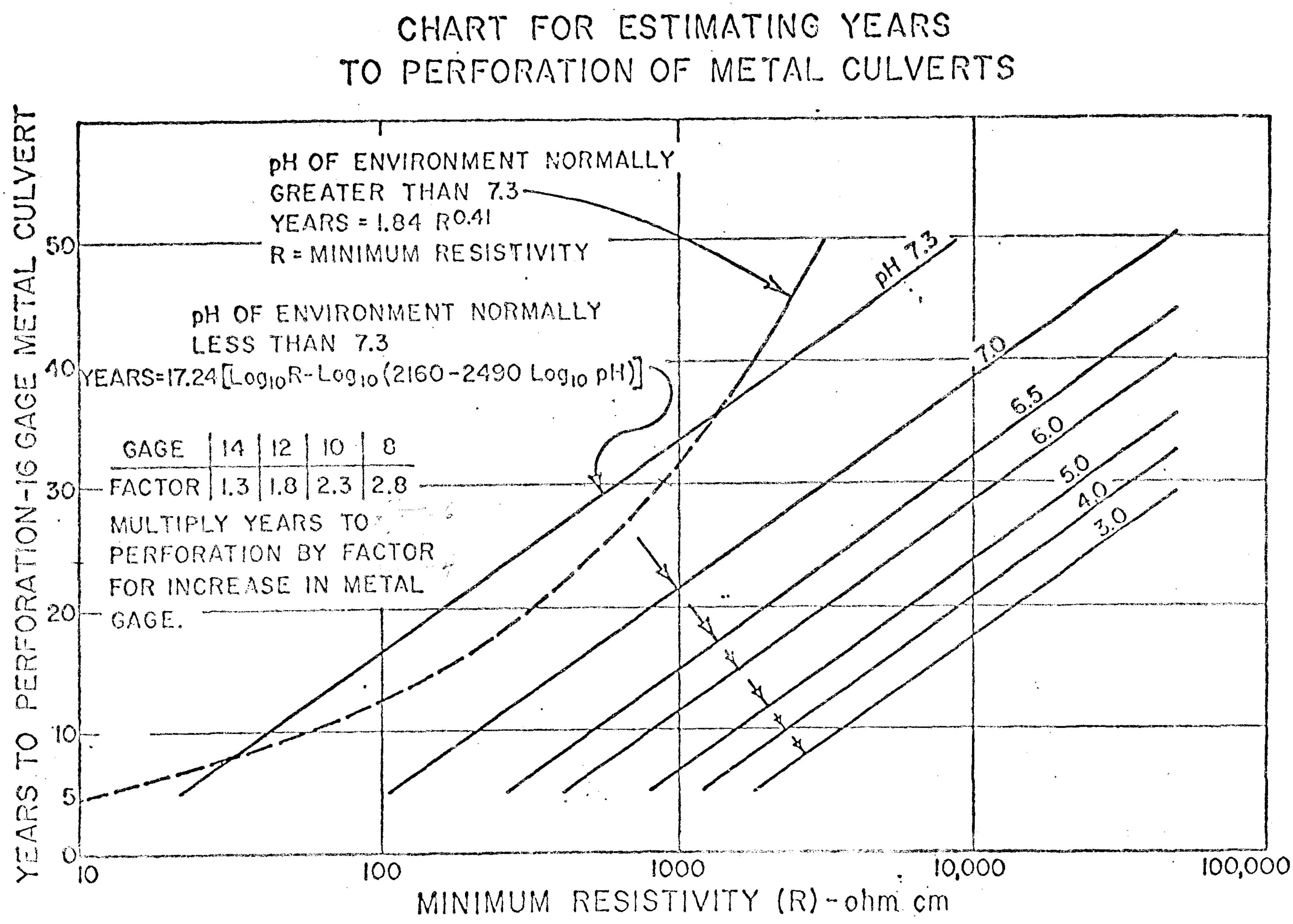

FIGURE 1A

CHART FOR ESTIMATING METAL CULVERT SERVICE LIFE
as produced in California Test Method 643-B, 1963

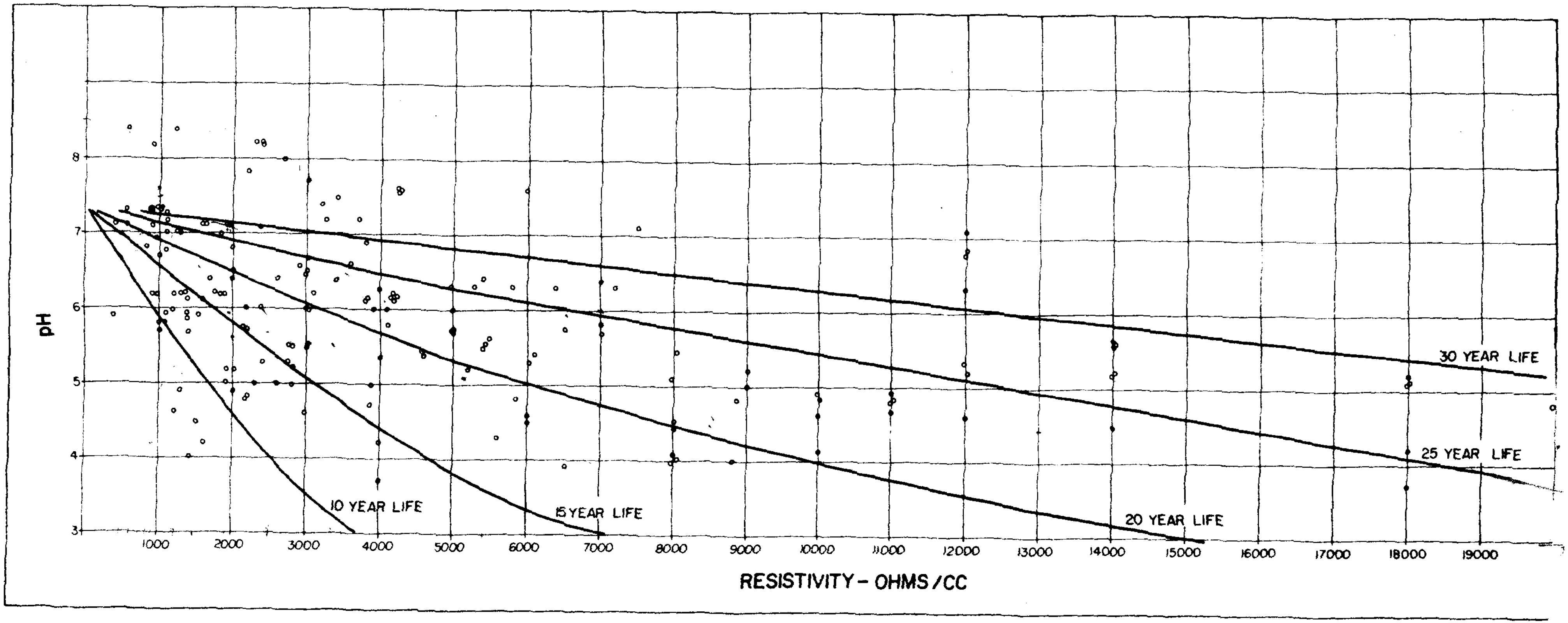

Figure 1B - An adaptation of California graph as produced in California Test Method 643B.

$$\frac{\text{Actual Age of Pipe}}{\text{Years to Perforation}} \times 100 = \text{Percent of Pipe Life Completed}$$

The next step involved a subjective rating by two people thoroughly familiar with determining the pipe life expectancy and grading these pipe according to designated criteria in the "Methodology Section."

Results From Initial Report

Figure 2 is a graph of percent pipe life completed versus condition of pipe for structural pipe. By using the method of least squares, the slope of the line governed by the points plotted was computed. The line which gave the best correlation coefficient did not pass through the origin, but rather gave an intercept along the dependent axis. The correlation coefficient of the graph, 0.95 was very good. Therefore, for estimating the service life of structural pipe in Louisiana soils, it is apparent that California's Test Method, California No. 643-B, 1963, may be used.

An insufficient number of the ABCMP available for study were not submerged long enough to obtain correlation of ABCMP with California's Test Method, California No. 643-B, 1963. From the data obtained, the pipe appeared to have a much stronger coating due to impregnation of the asphalt layer with asbestos bonding and a longer service life than BCCMP or structural pipe.

Figure 3 through 8 in the Appendix are graphs of percent pipe life completed versus condition of pipe for BCCMP. According to California's Test Method, California No. 643-B, 1963, an additional 6 years service life of metal culverts was obtained by using a bituminous coating over the galvanized coating of the metal pipe.

The results of the initial field inspection indicated that in Louisiana Soils an additional 6 years of service life of metal culverts (see Figure 9) was obtained by using a bituminous coating over the galvanized coating of the metal pipe. Graphs 3 through 8 are the results of assuming various values of increased life from bituminous coatings. Figure 9 is a graph of added service life from bituminous coatings versus correlation coefficient. From this graph it can be readily seen that the maximum service life from bituminous coatings is 6 years which is in agreement with California No. 643-B, 1963.

Final Field Results

The final field evaluation was completed 6 years after the initial field evaluation. Therefore, a new set of curves governing the correlation coefficients had to be

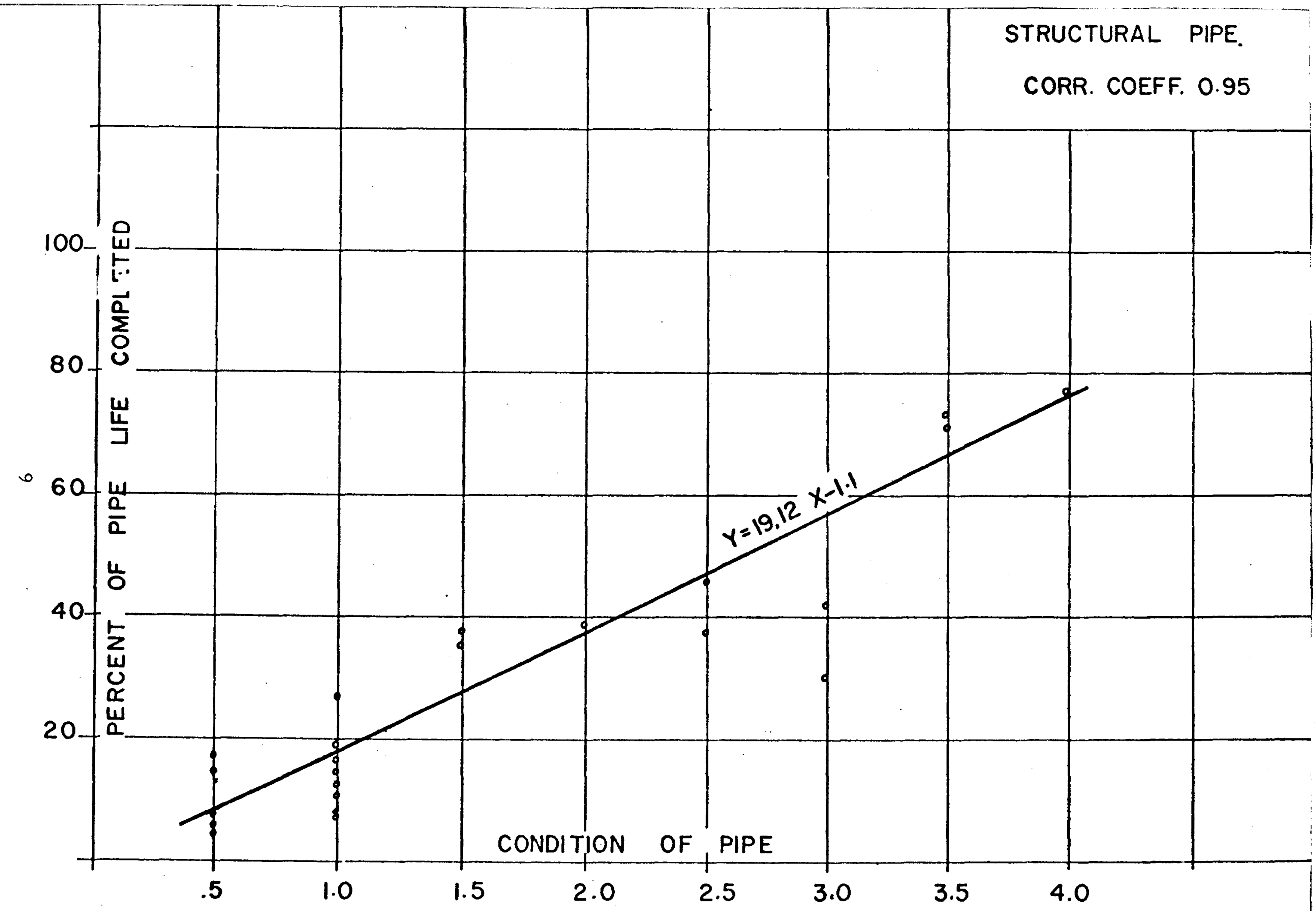

Figure 2 - Fitted Curve Shows Relationship Between Percent Pipe Life Completed Versus Condition of Pipe for Structural Pipe.

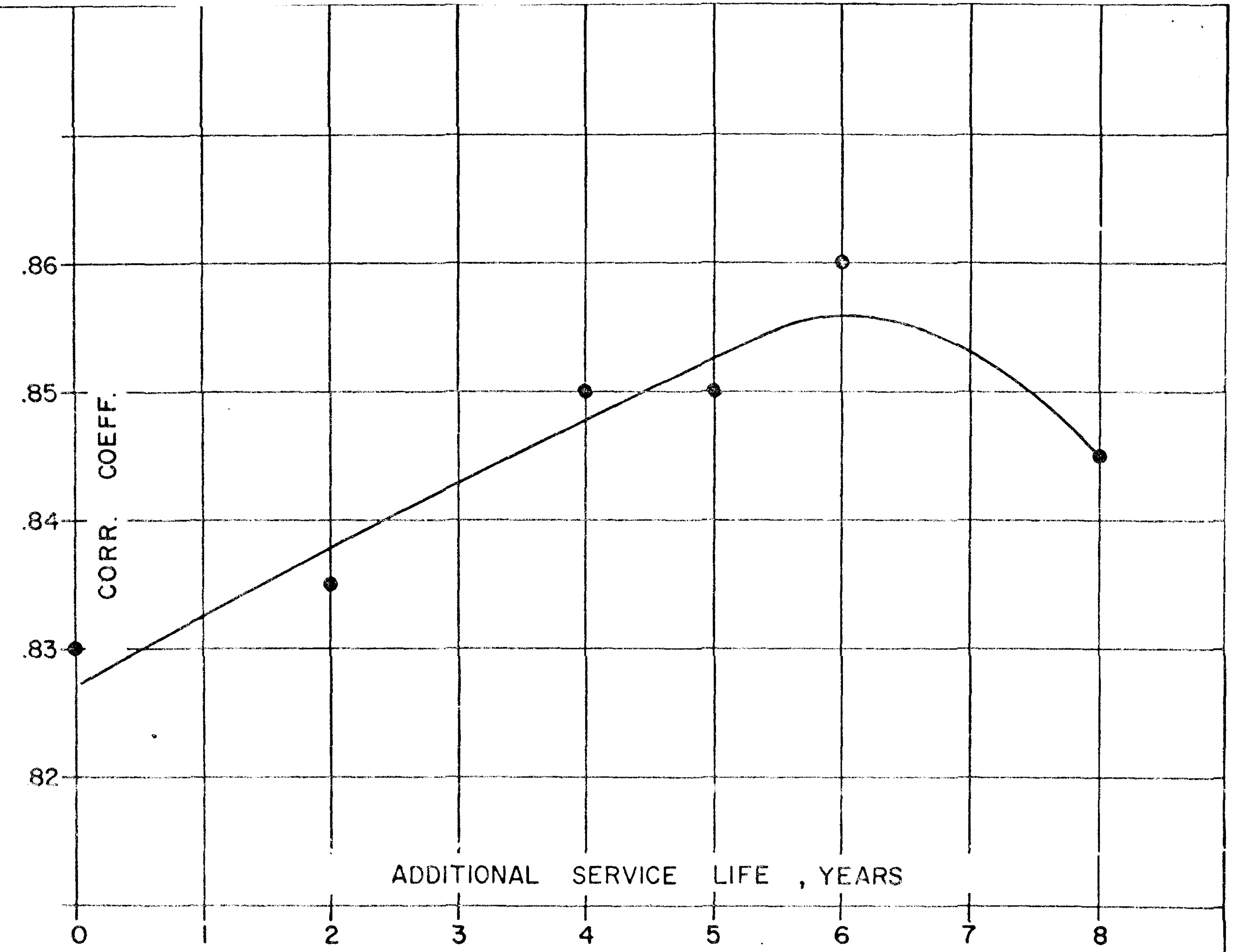

Figure 9 - Fitted Curve Shows Relationship Between Correlation Coefficient and Additional Service Life Obtained From Bituminous Coating.

computed to determine if there was any change in the expected additional life from asphalt coatings. These results are shown in Figures 10 through 14.

Figure 10 which is a graph of percent pipe life completed versus condition of pipe, assumed that an added service life of 4 years is obtained from the bituminous coating. By using the method of least squares, the slope of the line, the intercept and the correlation coefficient was computed. The correlation coefficient of 0.74 was obtained.

Figure 11 which is a similar graph to Figure 10 assumed an added service life of 6 years was obtained for metal pipe from the bituminous coatings. Again the slope of the line, the intercept and the correlation coefficient were completed by the method of least squares. The correlation coefficient of 0.78 was higher than the aforementioned figure.

Figure 12 which is a similar graph to Figures 10 and 11 assumed an added service life of 8 years was obtained for metal pipe from the bituminous coatings. After computing the slope of the line, the intercept and the correlation coefficient, it was observed that the correlation coefficient of 0.79 was higher than the previous correlation coefficient of Figure 11.

Figure 13 which is a similar graph to Figures 10, 11, 12 assumed an added service life of 10 years was obtained for metal pipe from the bituminous coating. After computing the slope of the line, the intercept and the correlation coefficient, it was observed that there was a decrease in the correlation coefficient to 0.78.

Figure 14 which is a graph of correlation coefficient versus added service life of metal pipe with bituminous coating, indicated that metal culvert life in Louisiana soils was increased 8 years by coating the surface of the metal structure with asphalt. The 8 years of added service of metal structure in Louisiana soils were slightly greater than the normal 6 years chosen by California in Test Method, California No. 643-B, 1963.

Figure 15 is a graph of percent pipe life completed versus condition of pipe for structural pipe. By using the method of least squares, the slope of the line governed by the points plotted was computed. The correlation coefficient of the graph, 0.830, was good. This correlation coefficient indicated that correlation of the data obtained during the initial field evaluation with the data from California's Test Method, California No. 643-B, 1963, was adequate. For estimating the service life of structural pipe in Louisiana soils, it is apparent that California's Test Method, California No. 643-B, 1963, may be used.

There was no re-evaluation of concrete pipe. All concrete pipe evaluated in the initial report showed no deterioration due to soil or water conditions. All concrete pipe surveyed were in excellent condition regardless of age.

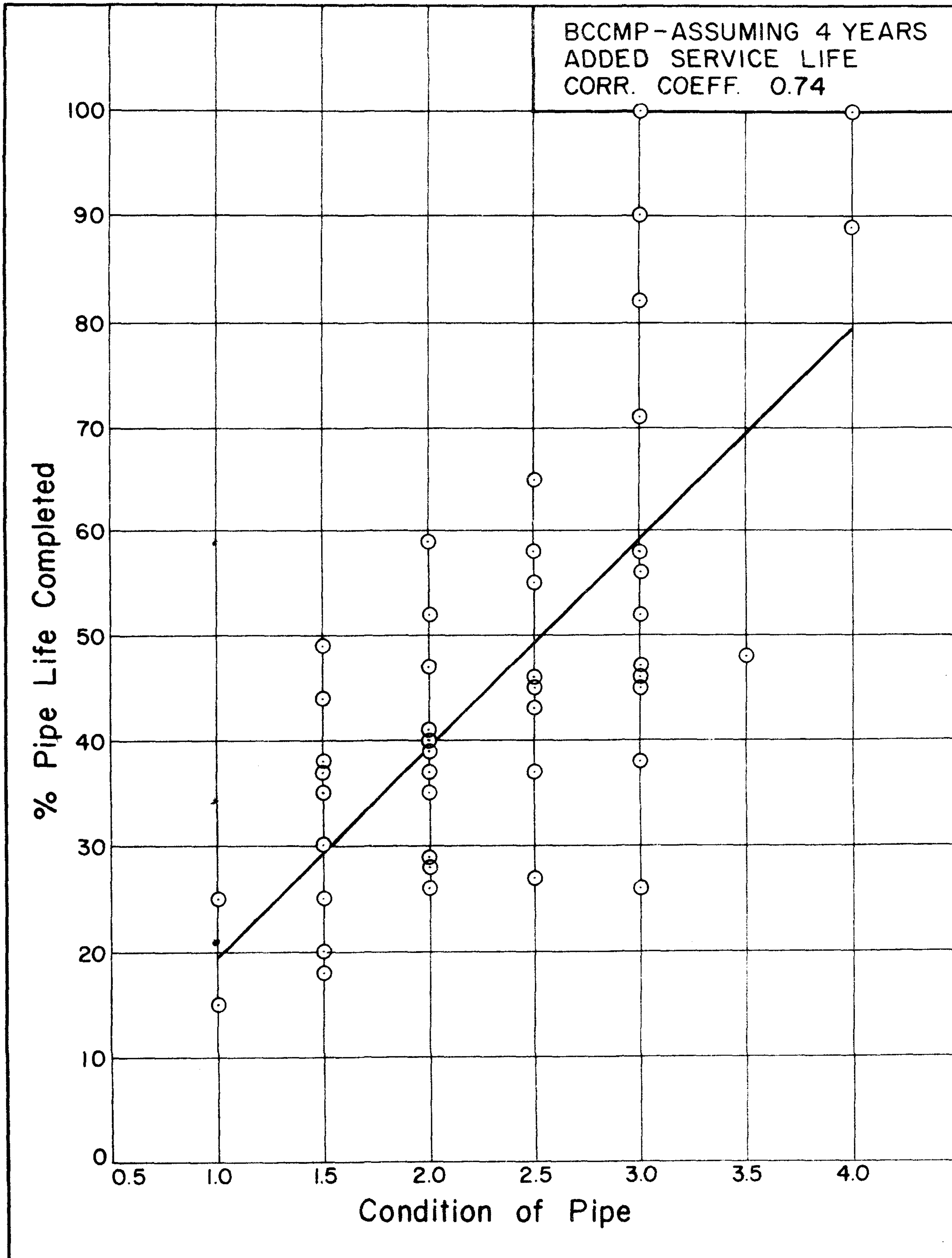

FIGURE 10- Graph of Condition of Pipe versus Percent Pipe Life. BCCMP- Assuming 4 Years Added Service Life

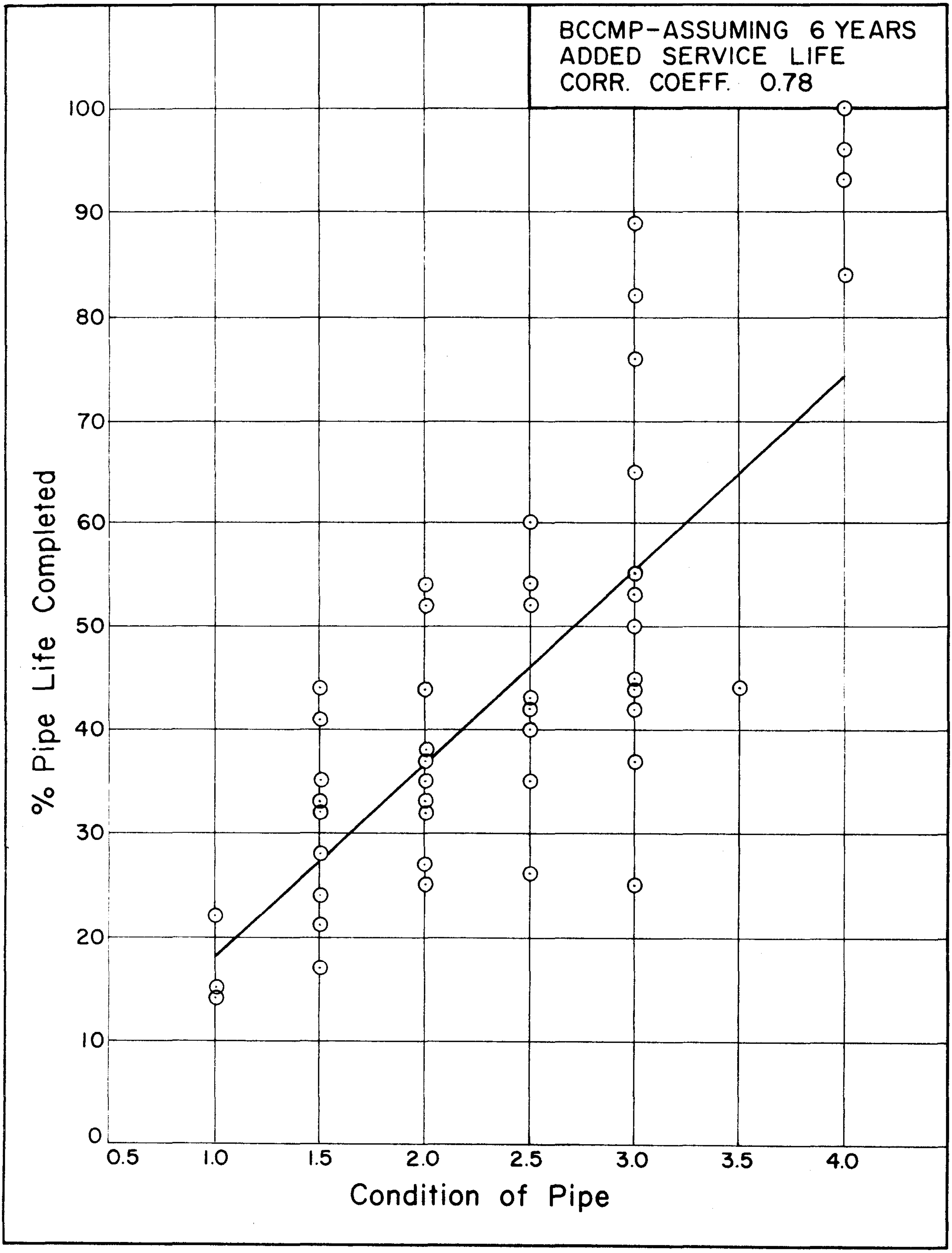

FIGURE 11 - Graph of Condition of Pipe versus Percent Pipe Life.
BCCMP- Assuming 6 Years Added Service Life

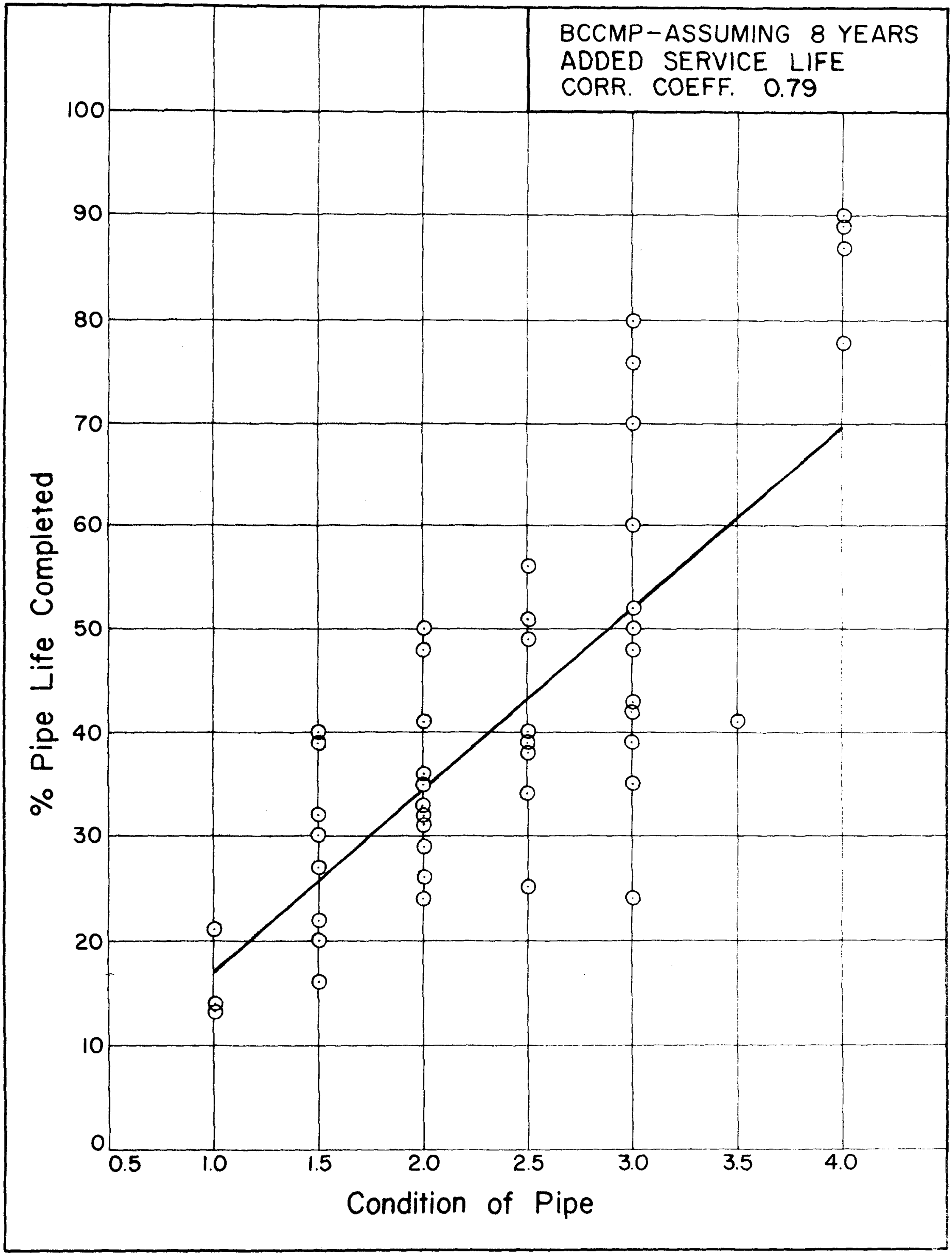

FIGURE 12 - Graph of Condition of Pipe versus Percent Pipe Life.
BCCMP - Assuming 8 Years Added Service Life

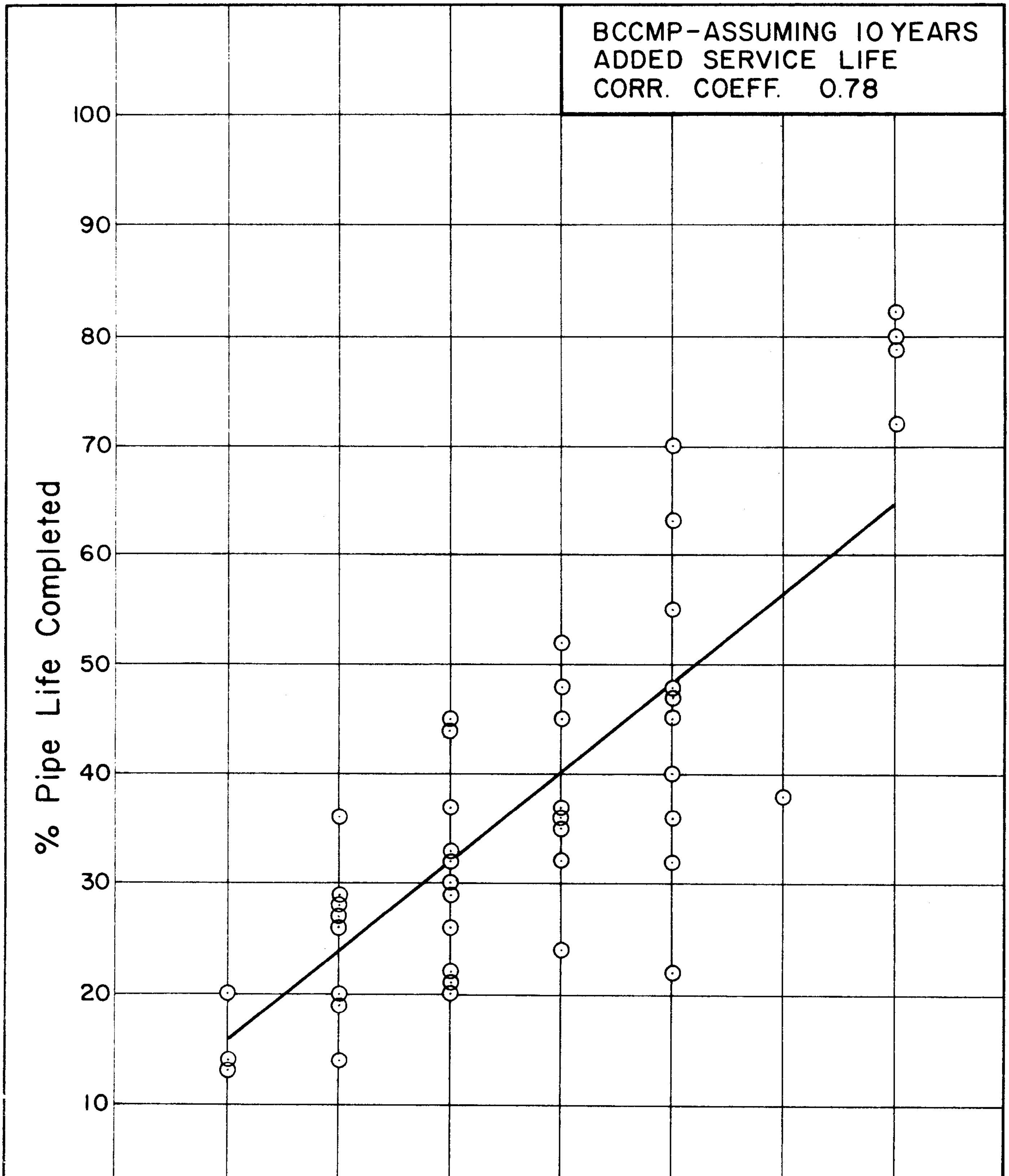

FIGURE 13- Graph of Condition of Pipe versus Percent Pipe Life.
BCCMP - Assuming 10 Years Added Service Life

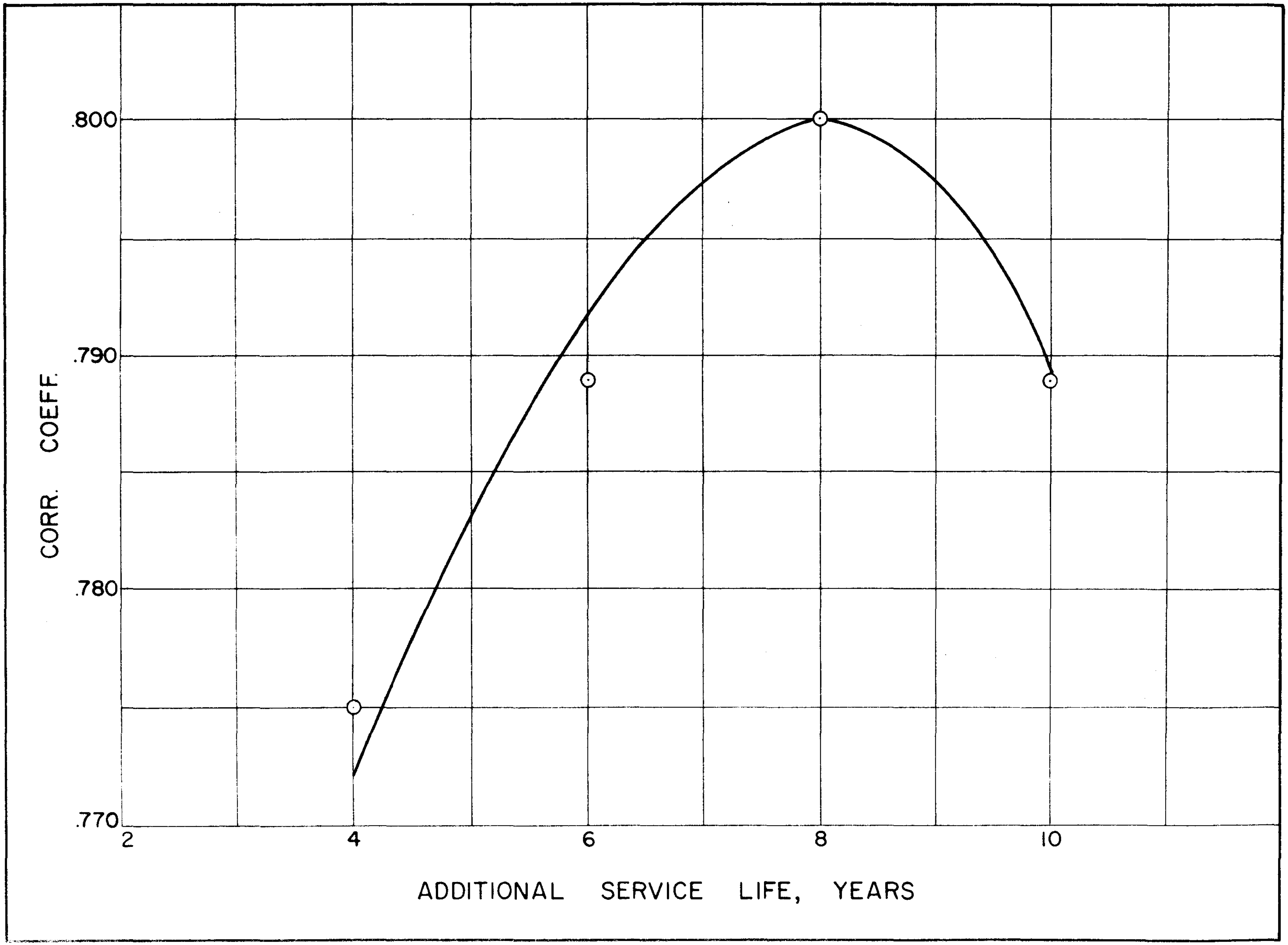

FIGURE 14 - Graph of Correlation Coefficient versus Additional Service Life

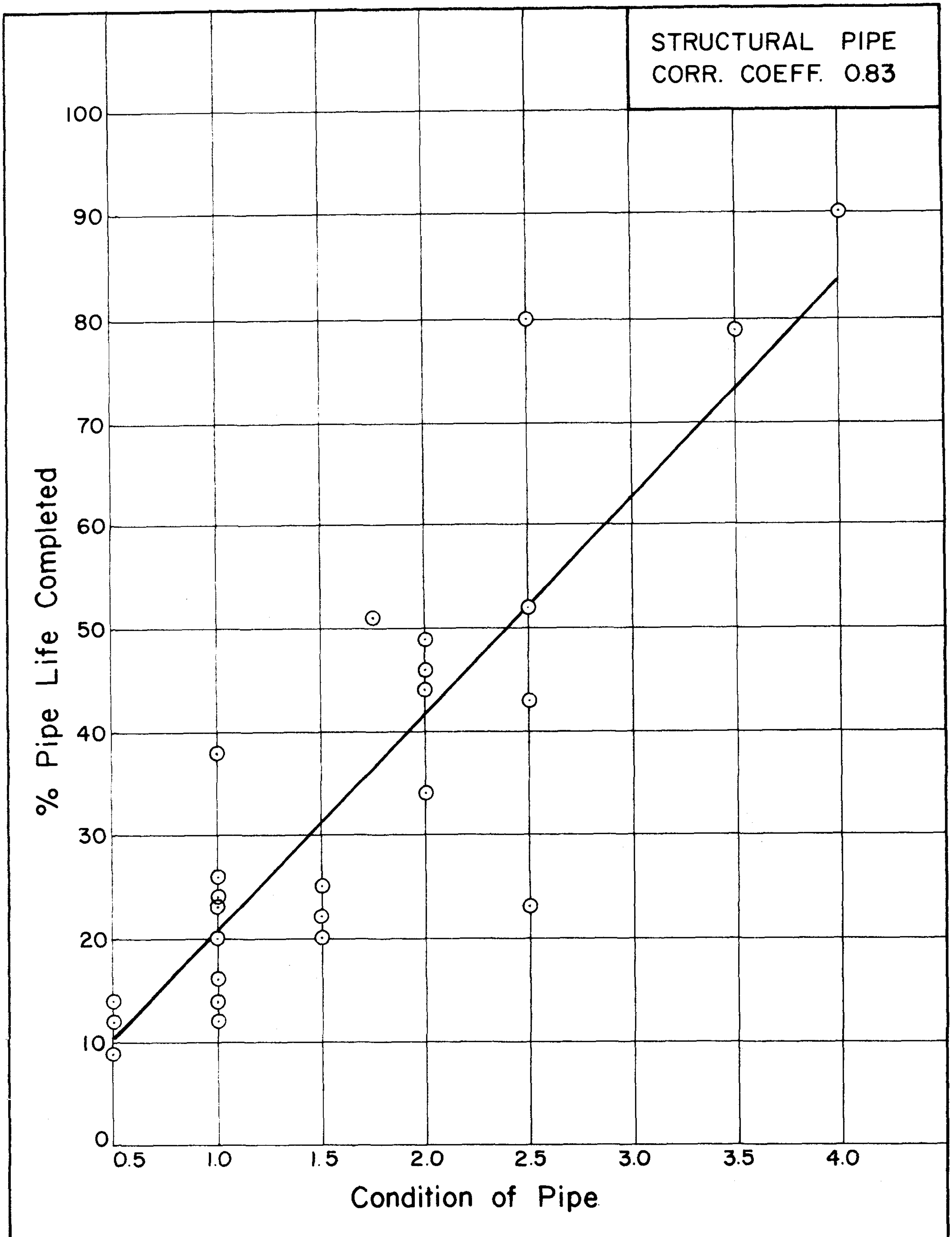

FIGURE 15 - Graph of Condition of Pipe versus Percent Pipe Life Completed of Structural Pipe

CONCLUSIONS

The following conclusions regarding the evaluation of submerged drainage structures are as follows:

1. The California's method of predicting the behavior pattern of submerged metal structures, California No. 643-B, 1963, is applicable to Louisiana soils.

2. The addition of an asphalt coating gives an added 8 years service life of galvanized drainage structures.

3. Concrete drainage pipe regardless of age showed no indication of deterioration.

4. The addition of asbestos bonded asphalt coating appears to be superior to a pure asphalt coating but additional service life will be necessary to predict the performance.

RECOMMENDATIONS

The following recommendations are warranted based on the value of this report.

1. Adoption of California's method of predicting the behavior pattern of submerged metal structures, California No. 643-B, 1963, except that 8 years added service life is obtained from an asphalt coating in lieu of 6 years.

2. Whenever it is impractical to conduct pH and resistivity tests then the Summary of Service Life Expectancy may be used.

APPENDIX

REVISED DRAINAGE STRUCTURES UNDER SURVEILLANCE

Type of Pipe	Year	Hwy. No.	Soil Class.	Location
Concrete	1963	Lake	Coastal	Bienville Parish-La. 154
Structural	"	Bisteneau	Plain	north to La. 7(South and
Asphalt & Asb. Bond	"	Road	Plain	east of Lake Bisteneau)
Concrete	1963	La. 449	Mississippi Terrace	St. Helena Parish-0.3 miles north to Livingston
Asphalt & Asb. Bond	"	"	"	Parish line.
Concrete	1963	La. 1077	Flatwoods	St. Tammany Parish-
Structural	"	"	"	from La. 25 west 4.3
Asphalt & Asb. Bond	"	"	"	miles to Parish line.
Concrete	1963	La. 696	Coastal	Vermillion Parish-from
Structural	"	"	Prairies	US 167 west to La. 35
Asphalt & Asb. Bond	"	"	"	"
Asphalt & Asb. Bond	1963	La. 3011	Coastal Marsh	Terrebonne Parish - 0 to 1.5 miles southwest of La. 57 (Dulac)
Concrete	1961	La. 31	Recent	St. Martin Parish-Breaux
Asphalt Coated	"	"	Alluvium	Bridge south to Ruth
Concrete	"	La. 314	"	St. Martin Parish-Jct. La.
Structural	"	"	"	31 South to La. 31
Asphalt & Asb. Coated	"	La. 353	"	"
Structural	1955	La. 577	Mississippi	West Carroll Parish-
Asphalt Coated	"	"	Terrace	3.0 miles east of Jct. La. 17 at Darnell

Type of Pipe	Year	Hwy. No.	Soil Class.	Location
Concrete	1956	La. 528	Flatwoods	Bossier Parish from La.
Structural	''	''	''	157(south of Bellevue)
Asphalt Coated	''	''	''	east for 2.2 miles to
				parish line
Structural	1956	La. 713	Coastal	Vermillion Parish from
Asphalt & Asb. Coated	''	''	Prairies	La. 91 east to termination
Concrete	''	''	''	of road
Asphalt Coated	1957	La. 374	''	Evangeline Parish
Structural	1955	La. 16	Coastal Alluvial	Livingston Parish - 13.6 miles northwest of Jct. La. 42 & 16 at Port Vincent
Concrete	1955	La. 3033	Coastal	Ouachita Parish - South
Asphalt Coated	''	''	Alluvial	of West Monroe from La. 838 to La. 34
Concrete	1959	La. 1037	Coastal	Livingston Parish -Spring-
Structural	''	''	Alluvial	field southwest 5 miles
Asphalt Coated	''	''	''	(Lizard Creek)
Concrete	1958	La. 57	Coastal	Terrebonne Parish 4.8
Asphalt Coated	''	''	Marsh	miles North Bayou Duloc Bridge
Concrete	1955	La. 82	Coastal	Vermillion Parish from
Asphalt Coated	''	''	Marsh	Esther west to Forked Island
Asphalt & Asb. Coated	1953	La. 82	Coastal Marsh	Vermillion Parish - 8.5 miles south of old Intra-
			''	coastal Canal
Concrete	1952	''	''	Vermillion Parish - 7.8
Asphalt Coating	''	''	''	miles south of Forked Island Ferry to Intra-coastal Canal
Concrete	1952	La. 107	Mississippi Terrace	Avoyelles Parish - Marksville north to Effie
Asphalt Coated	1951	La. 308	Coastal Marsh	Lafourche Parish - Cut Off south to Golden Meadow
Concrete	1951	La. 329	Recent	Iberia Parish from
Asphalt Coating	''	''	Alluvial	Brannon south to Avery Island
Structural	''	La. 982	''	Pointe Coupee Parish - [illegible] miles east of Jct. 416 at Glynn

Type of Pipe	Year	Hwy. No.	Soil Class.	Location
Asphalt & Asb. Coating	1951	La. 726	Recent	Lafayette Parish - 5.4
			Alluvial	miles east of Carencro
Asphalt Coated	1961	La. 483	Coastal	Sabine Parish-Noble
Asphalt & Asb. Coated	"	"	Plain	north to Oak Grove
Concrete	"	La.25	"	Washington Parish - 0 to
Structural	"	"	"	2 miles north of St.
Asphalt & Asb. Bonded	"	"	"	Tammany Parish line
Concrete	1961	La. 1026	Mississippi	Livingston Parish - US
Structural	"	"	Terrace	190 south to La. 16
Asphalt & Asb. Coated	"	"	"	
Concrete	"	Lovett	"	East Baton Rouge Parish
Asphalt Coated	"	Road	"	from Hooper Road to
				Sullivan
Concrete	1961	La. 109	Flatwoods	Calcasieu Parish - 0 to
Structural	"	"	"	6 miles north of Starks
Asphalt & Asb. Coated	"	"	"	to parish line
Concrete	"	La. 63	"	Livingston Parish - 0 to
Asphalt Coated	"	"	"	5.7 miles north of
Structural	"	"	"	Livingston
Concrete	1962	La. 757	Coastal	St. Landry Parish from
Asphalt Coated	"	"	Prairies	US 190 north to parish
Asphalt & Asb. Coated	"	"	"	line
Concrete	1961	La. 374	"	Evangeline Parish from
Structural	"	"	"	La. 371 east 2 miles past
Asphalt & Asb. Coated	"	"	"	Fenier
Concrete	1962	La. 21	Coastal	Washington Parish -
Asphalt & Asb. Coated	"	"	Alluvial	Bogalusa north to Varnado
Concrete	1961	La. 711	Coastal	Vermillion Parish from
Structural	"	"	Marsh	La. 14 south to termination
Asphalt & Asb. Coated	"	"	"	of road
Concrete	1956	La. 1200	Recent	Rapides Parish - Boyce
Asphalt Coated	"	"	Alluvial	south to Crane
Structural	"	"	"	"
Concrete	1956	La. 1129	Coastal	St. Tammany Parish -
Asphalt Coated	"	"	Plain	0 to 2.6 miles north of
				La. 40
Structural	1956	La. 577	Mississippi	West Carroll Parish -
Concrete	1955	La. 93	Terrace	1/4 mile east of Jct. La.
Asphalt Coated	"	"	"	585 Lafayette Parish -
				Scott north to parish line

Type of Pipe	Year	Hwy. No.	Soil Class.	Location
Concrete Structural Asphalt Coating	1950 " "	La. 145 " "	Coastal Plain "	Lincoln Parish from Choudrant northwest to Dawnville
Structural	1950	La. 577	Mississippi Terrace	West Carroll Parish - 1. 3 miles east of Jct. 17 at Darnell
Structural	1951	La. 577	Mississippi Terrace	West Carroll Parish - 0. 6 miles west of Jct. 17 at Darnell
Concrete Asphalt Coating	1950 "	La. 162 "	Flatwoods "	Bossier Parish - 0 to 3. 7 miles east of Benton
Concrete Asphalt Coating	1951 "	La. 13 "	Coastal Prairies	Vermillion Parish La. north to Leleux
Asphalt Coating	1951	La. 1032	Coastal Alluvial	Livingston Parish -2. 9 miles northwest of Jct. 16
Concrete Asphalt Coating	1949 "	La. 4 "	Mississippi Terrace	Franklin Parish from La. 128 to Winnsboro
Asphalt Coating	1948	La. 2	Coastal Alluvial	Ouachita Parish - 1 mile east of Ouachita Bridge at Sterlington
Concrete Asphalt & Asb. Coating	1948 "	La. 27 "	Coastal Marsh	Cameron Parish - Ship Canal west to Holly Beach then north to La. 390
Structural	1947	La. 573	Recent Alluvial	Tensas Parish - 1. 4 miles west of Mayflower
Concrete Asphalt Coating	1947 "	La. 154 "	Coastal Plain	Bienville Parish from La. 4 east to Jamestown
Structural	1947	La. 577	Mississippi Terrace	West Carroll - 3. 4 miles east of Jct. 17 at Darnell
Concrete	1947	La. 2	Flatwoods	Caddo Parish from Vivian to Hosston
Concrete Asphalt Coating	1946 "	La. 20 "	Recent Alluvial	St. James Parish from Vacherie south 1. 4 miles
Concrete	1945	La. 82	Coastal Marsh	Cameron Parish from Holly Beach west to Johnson Bryan School

Type of Pipe	Year	Hwy. No.	Soil Class.	Location
Concrete Asphalt Coating	1941 "	La. 818 "	Coastal Plain	Lincoln Parish - 0 to 4.5 miles north of Woodville
Concrete	1941	La. 308	Coastal Marsh	Lafourche Parish - Cut Off south to Golden Meadow
Concrete Structural Asphalt Coating	1940 " "	La. 561 " "	Recent Alluvial "	Richland Parish - last 3.5 miles to Caldwell Parish line south of Buckner
Concrete Structural	1938 "	US 167 "	Mississippi Terrace	Lafayette Parish from Lafayette southwest to Maurice
Concrete Structural	1936 "	La. 556 "	Coastal Plain	Lincoln Parish - Choudrant to Cartwright
Asphalt & Asb. Coating	1935	La. 856	Mississippi Terrace	Richland Parish - east of Archiblad to Big Creek
Aluminum	1963	La. 1064	Flatwoods	From Breckwoldt to Ebenezer Church

GENERAL SOIL CLASSIFICATIONS

a) Coastal Plains - Soils with slowly permeable subsoils developed from Pleistocene and Tertiary materials. The pH of the soils vary from 5.1 to 6.0.

b) Mississippi Terrace and Loessial Hills - Loessial Hills soils developed from silty and sandy materials of the Pleistocene. The average pH values of these soils vary from 5.1 to 6.0.

c) Flatwoods - Poorly drained forested soils developed from Pleistocene and Tertiary materials. The average pH values of these soils vary from 5.1 to 6.0.

d) Coastal Prairies - Prairie soils with very slowly permeable subsoils developed from Pleistocene sediments. The average pH values of these soils vary from 5.6 to 6.5.

e) Recent Alluvium - Alluvial soils derived from sediments of various rivers. The average pH values of these soils range from 5.6 to 7.8.

f) Coastal Alluvium - Alluvial soils derived from recent sediments from coastal plains and Loessial areas. There is no recording of the average pH these soils.

g) Coastal Marsh - Organic soils, clays and sandy beaches derived from recent streams sediments and marine deposits. There is also no recording of the range of pH values expected for these soils.

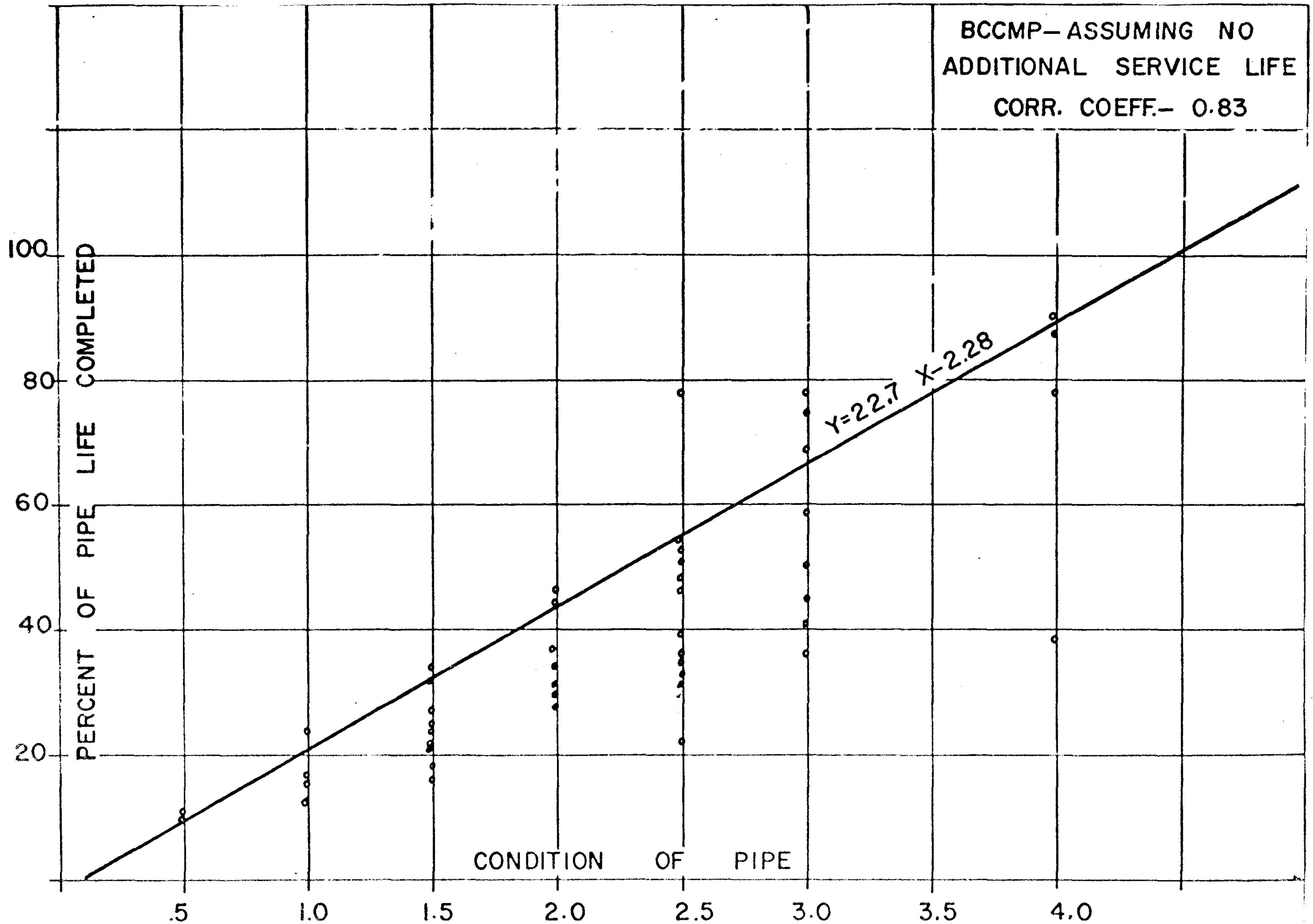

Figure 3 - Fitted Curve Shows Relationship Between Percent Pipe Life Completed Versus Condition of Pipe for BCCMP - Assuming No Additional Service Life is Obtained From Bituminous Coating.

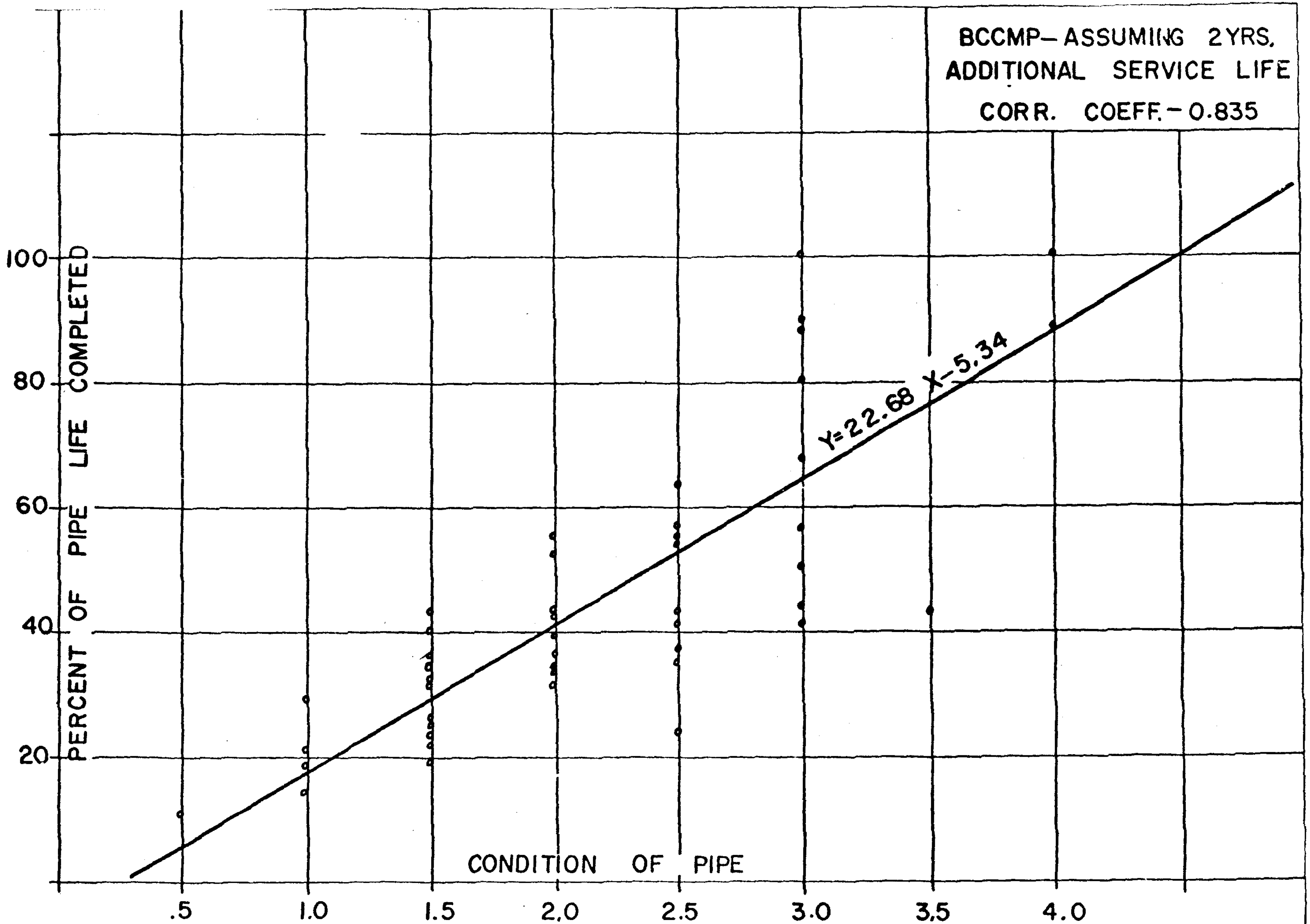

Figure 4 - Fitted Curve Shows Relationship Between Percent Pipe Life Completed Versus Condition of Pipe for BCCMP - Assuming Two Years Additional Service Life is Obtained From Bituminous Coating.

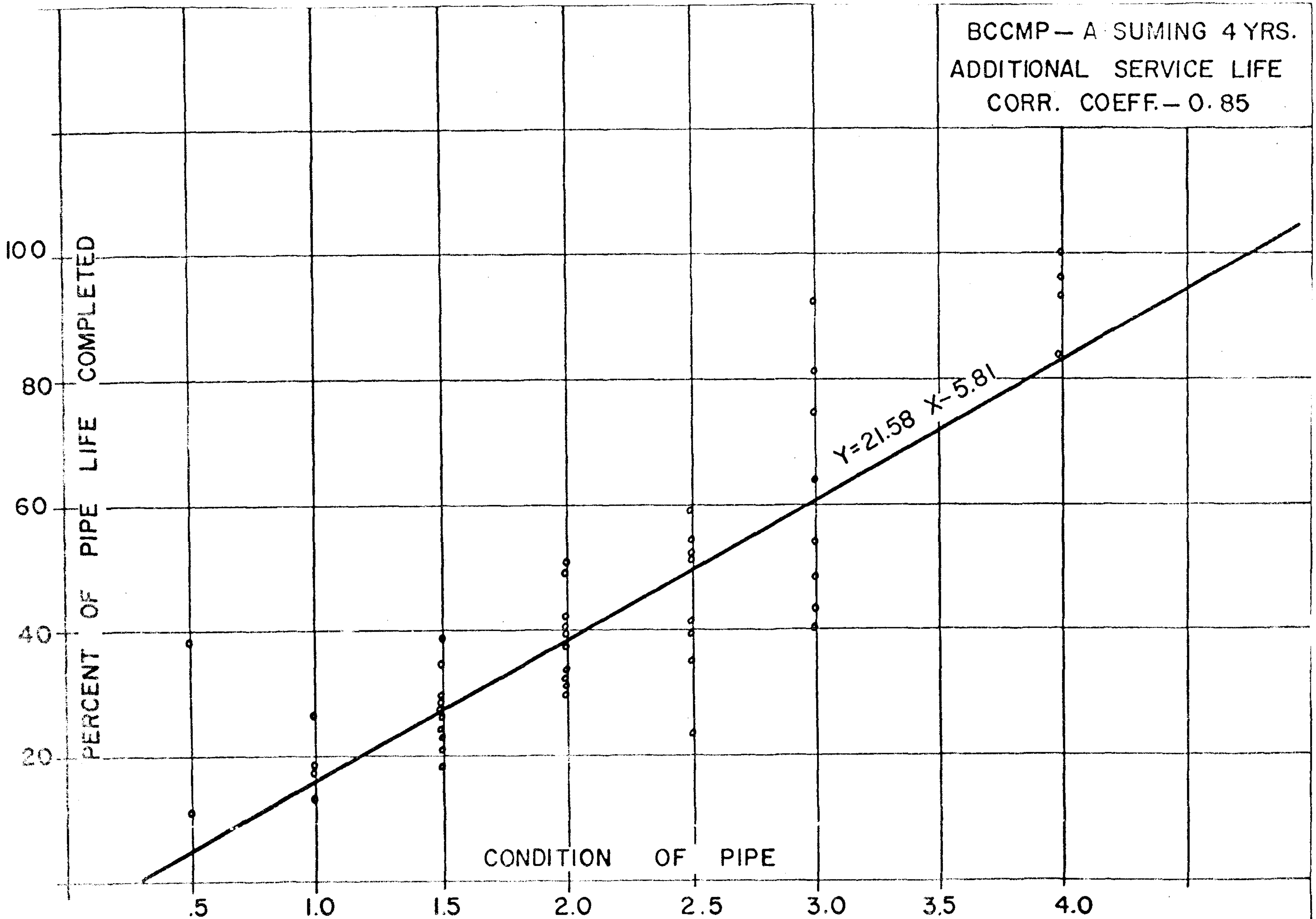

Figure 5 - Fitted Curve Shows Relationship Between Percent Pipe Life Completed Versus Condition of Pipe for BCCMP - Assuming Four Years Additional Service Life is Obtained From Bituminous Coating.

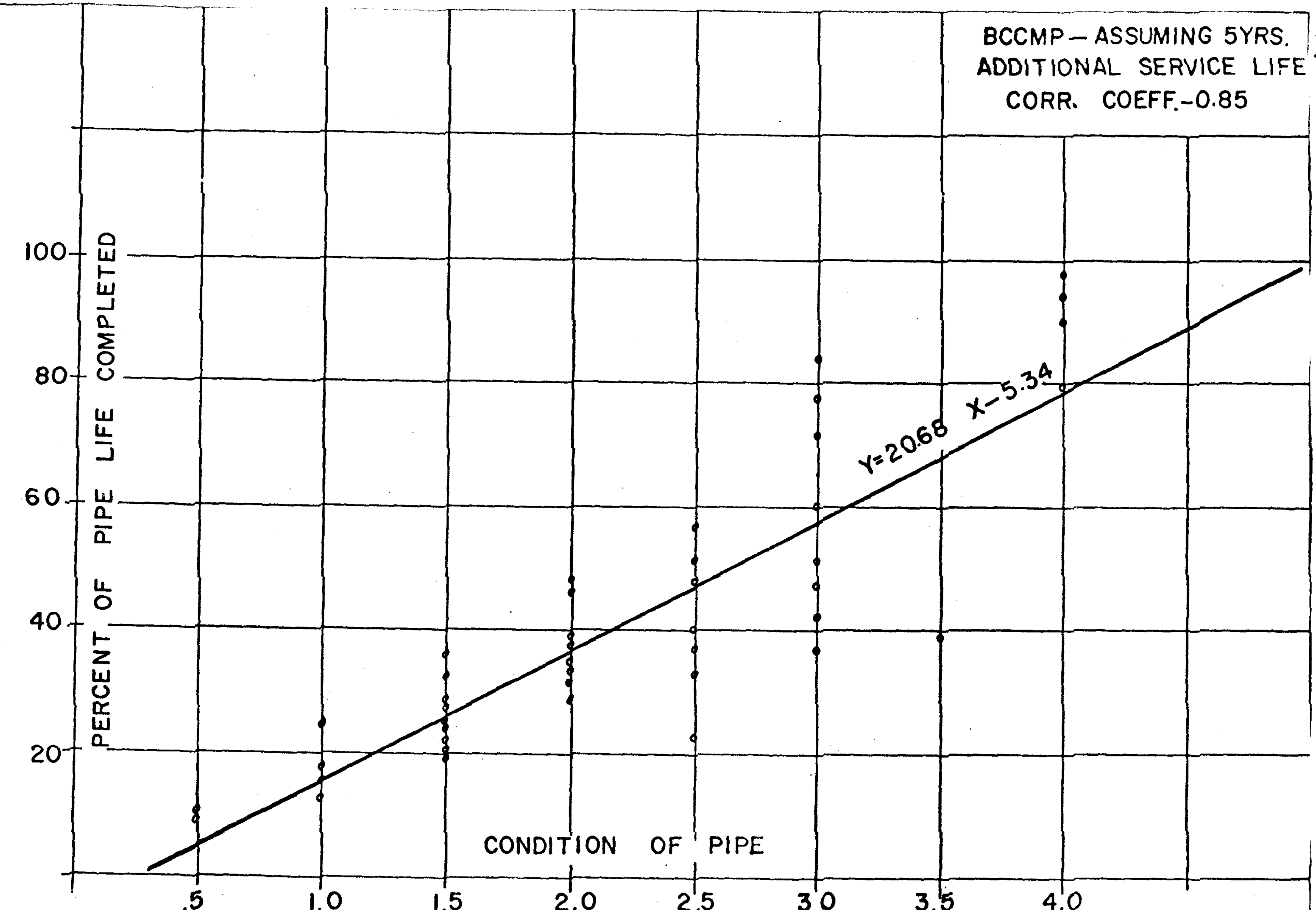

Figure 6 - Fitted Curve Shows Relationship Between Percent Pipe Life Completed Versus Condition of Pipe for BCCMP - Assuming Five Years Additional Service Life is Obtained From Bituminous Coating.

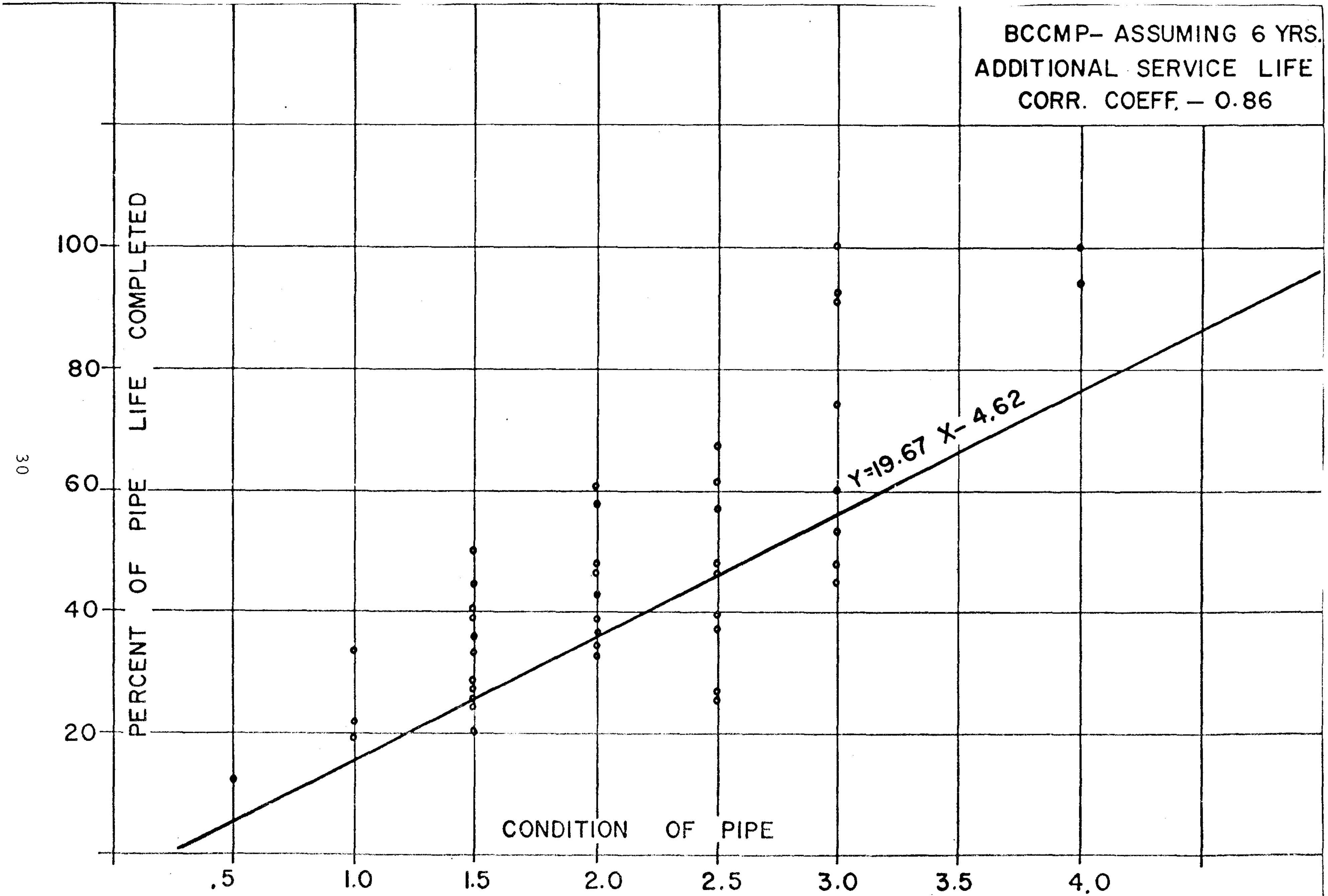

Figure 7 - Fitted Curve Shows Relationship Between Percent Pipe Life Completed Versus Condition of Pipe for BCCMP - Assuming Six Years Additional Service Life is Obtained From Bituminous Coating.

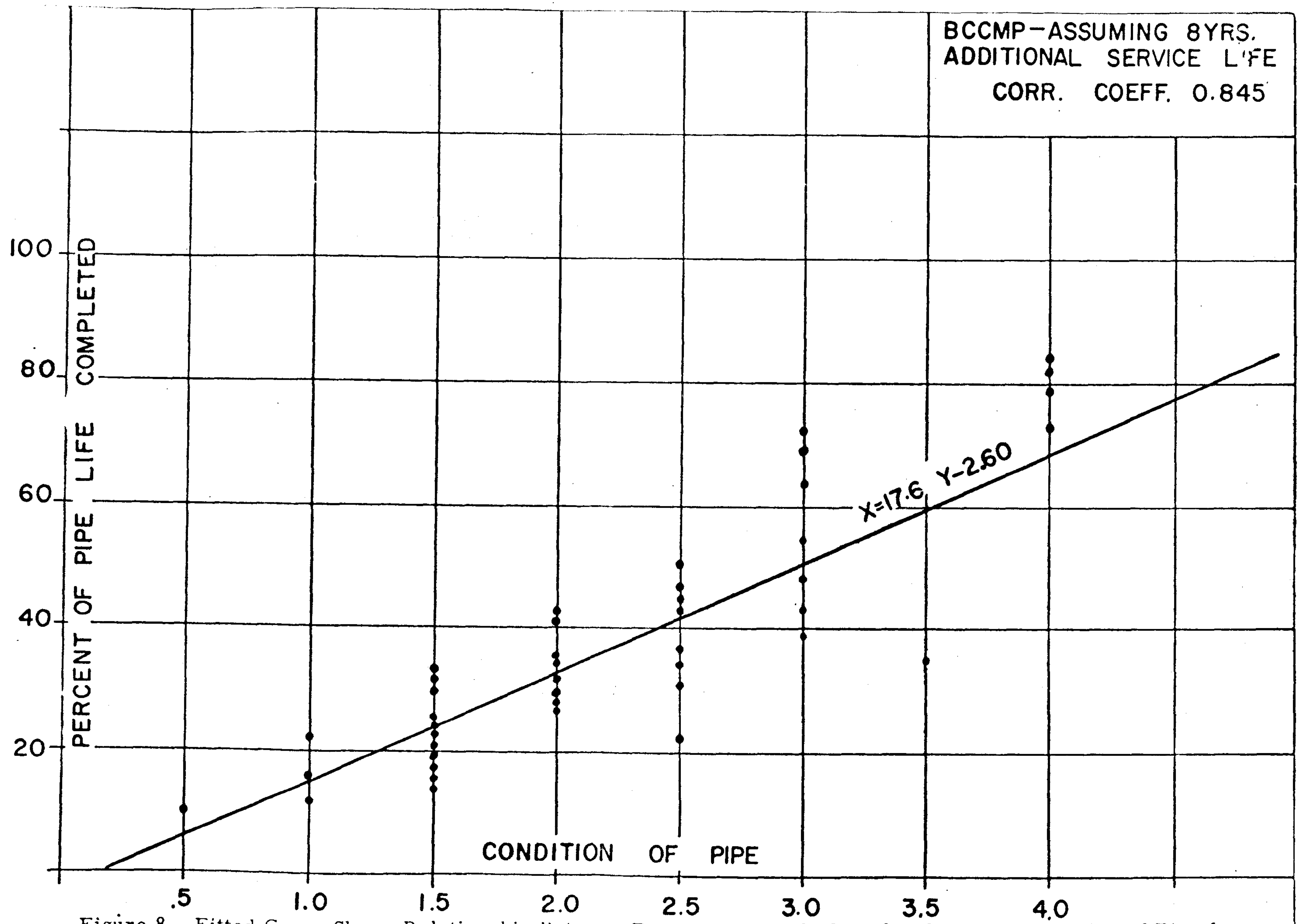

Figure 8 - Fitted Curve Shows Relationship Between Percent Pipe Life Completed Versus Condition of Pipe for BCCMP - Assuming Eight Years Additional Service Life is Obtained From Bituminous Coating.

SUMMARY OF SERVICE LIFE EXPECTANCY

The following list represents the average results of a collection of data according to soil type. These specific recommendations are made according to district, and soil types within each district, indicating the estimated service life of each type of pipe investigated. In some cases, data from other districts had to be used to estimate service life of metal pipe when there was a deficiency of these structures. In any event, a general list follows which does predict an estimated service life of the pipe in question according to the various soil types which are present within the district together with the average pH and average resistivity values which may be encountered in their soil types.

DISTRICT 02

Type of *Pipe*	Soil *Type*	Service Life *Expectancy*	Avg. *pH*	Avg. *Res.*
BCCMP	Recent Alluvium	25 Yrs	7.7	1189
Concrete	Recent Alluvium	25 Yrs	7.7	1189
ABCMP	Recent Alluvium	25 Yrs	7.7	1189
Structural	Recent Alluvium	20-25 Yrs	7.7	1189
BCCMP	Coastal Marsh	18-22 Yrs	8.1	1158
Concrete	Coastal Marsh	25 Yrs	8.1	1158
ABCMP	Coastal Marsh	20-25 Yrs	8.1	1158
Structural	Coastal Marsh	15-20 Yrs	8.1	1158

DISTRICT 03

Type of *Pipe*	Soil *Type*	Service Life *Expectancy*	Avg. *pH*	Avg. *Res.*
BCCMP	Coastal Marsh	20 Yrs	6.4	2000
Concrete	Coastal Marsh	25 Yrs	6.4	2000
ABCMP	Coastal Marsh	25 Yrs	6.4	2000
Structural	Coastal Marsh	20 Yrs	6.4	2000
BCCMP	Coastal Marsh	15-20 Yrs	7.5	1200
Concrete	Coastal Marsh	25 Yrs	7.5	1200
ABCMP	Coastal Marsh	18-22 Yrs	7.5	1200
Structural	Coastal Marsh	15-20 Yrs	7.5	1200

DISTRICT 03 (cont'd)

Type of Pipe	Soil Type	Service Life Expectancy	Avg pH	Avg Res
BCCMP	Miss. Terrace	20-25 Yrs	6.5	2047
Concrete	Miss. Terrace	> 25 Yrs	6.5	2047
ABCMP	Miss. Terrace	25 Yrs	6.5	2047
Structural	Miss. Terrace	20-25 Yrs	6.5	2047
BCCMP	Coastal Prairies	20-25 Yrs	7.3	2316
Concrete	Coastal Prairies	> 25 Yrs	7.3	2316
ABCMP	Coastal Prairies	25 Yrs	7.3	2316
Structural	Coastal Prairies	20-25 Yrs	7.3	2316
BCCMP	Recent Alluvium	20-25 Yrs	6.4	3316
Concrete	Recent Alluvium	> 25 Yrs	6.4	3316
ABCMP	Recent Alluvium	25 Yrs	6.4	3316
Structural	Recent Alluvium	20-25 Yrs	6.4	3316

DISTRICT 04

Type of Pipe	Soil Type	Service Life Expectancy	Avg pH	Avg Res
BCCMP	Flatwoods	20 Yrs	5.9	9749
Concrete	Flatwoods	> 25 Yrs	5.9	9749
ABCMP	Flatwoods	25 Yrs	5.9	9749
Structural	Flatwoods	20 Yrs	5.9	9749
BCCMP	Coastal Plain	20 Yrs	5.6	6410
Concrete	Coastal Plain	> 25 Yrs	5.6	6410
ABCMP	Coastal Plain	25 Yrs	5.6	6410
Structural	Coastal Plain	20 Yrs	5.6	6410
BCCMP	Recent Alluvium	25 Yrs	5.8	7000
Concrete	Recent Alluvium	> 25 Yrs	5.8	7000
ABCMP	Recent Alluvium	> 25 Yrs	5.8	7000
Structural	Recent Alluvium	20-25 Yrs	5.8	7000

DISTRICT 05

Type of Pipe	Soil Type	Service Life Expectancy	Avg pH	Avg Res
BCCMP	Coastal Plain	25 Yrs	5.1	5482
Concrete	Coastal Plain	> 25 Yrs	5.1	5482
ABCMP	Coastal Plain	> 25 Yrs	5.1	5482
Structural	Coastal Plain	20-25 Yrs	5.1	5482
BCCMP	Coastal Alluvium	25 Yrs	5.3	6950
Concrete	Coastal Alluvium	> 25 Yrs	5.3	6950
ABCMP	Coastal Alluvium	>25 Yrs	5.3	6950
Structural	Coastal Alluvium	20-25 Yrs	5.3	6950
BCCMP	Miss. Terrace	20-25 Yrs	6.2	3065
Concrete	Miss. Terrace	> 25 Yrs	6.2	3065
ABCMP	Miss. Terrace	25 Yrs	6.2	3065
Structural	Miss. Terrace	20-25 Yrs	6.2	3065
BCCMP	Recent Alluvium	20-25 Yrs	5.7	5500
Concrete	Recent Alluvium	> 25 Yrs	5.7	5500
ABCMP	Recent Alluvium	25 Yrs	5.7	5500
Structural	Recent Alluvium	20-25 Yrs	5.7	5500

DISTRICT 07

Type of Pipe	Soil Type	Service Life Expectancy	Avg pH	Avg Res
BCCMP	Flatwoods	20 Yrs	7.0	4309
Concrete	Flatwoods	> 25 Yrs	7.0	4309
ABCMP	Flatwoods	25 Yrs	7.0	4309
Structural	Flatwoods	20 Yrs	7.0	4309
BCCMP	Coastal Marsh	15-20 Yrs	8.3	1196
Concrete	Coastal Marsh	>25 Yrs	8.3	1196
ABCMP	Coastal Marsh	18-22 Yrs	8.3	1196
Structural	Coastal Marsh	15-20 Yrs	8.3	1196
BCCMP	Coastal Prairies	20-25 Yrs	8.3	2146
Concrete	Coastal Prairies	> 25 Yrs	8.3	2146
ABCMP	Coastal Prairies	25 Yrs	8.3	2146
Structural	Coastal Prairies	20-25 Yrs	8.3	2146

DISTRICT 08

Type of Pipe	Soil Type	Service Life Expectancy	Avg pH	Avg Res
BCCMP	Miss. Terrace	20-25 Yrs	6.4	3928
Concrete	Miss. Terrace	>25 Yrs	6.4	3928
ABCMP	Miss. Terrace	25 Yrs	6.4	3928
Structural	Miss. Terrace	20-25 Yrs	6.4	3928
BCCMP	Recent Alluvium	20-25 Yrs	7.0	2712
Concrete	Recent Alluvium	>25 Yrs	7.0	2712
ABCMP	Recent Alluvium	25 Yrs	7.0	2712
Structural	Recent Alluvium	20-25 Yrs	7.0	2712
BCCMP	Coastal Plain	20-25 Yrs	6.8	4086
Concrete	Coastal Plain	>25 Yrs	6.8	4086
ABCMP	Coastal Plain	25 Yrs	6.8	4086
Structural	Coastal Plain	20-25 Yrs	6.8	4086

DISTRICT 58

Type of Pipe	Soil Type	Service Life Expectancy	Avg pH	Avg Res
BCCMP	Coastal Plain	20-25 Yrs	5.7	8542
Concrete	Coastal Plain	> 25 Yrs	5.7	8542
ABCMP	Coastal Plain	25 Yrs	5.7	8542
Structural	Coastal Plain	20-25 Yrs	5.7	8542
BCCMP	Recent Alluvium	20-25 Yrs	6.5	1550
Concrete	Recent Alluvium	> 25 Yrs	6.5	1550
ABCMP	Recent Alluvium	25 Yrs	6.5	1550
Structural	Recent Alluvium	20-25 Yrs	6.5	1550
BCCMP	Miss. Terrace	20-25 Yrs	6.3	3392
Concrete	Miss. Terrace	>25 Yrs	6.3	3392
ABCMP	Miss. Terrace	25 Yrs	6.3	3392
Structural	Miss. Terrace	20-25 Yrs	6.3	3392

DISTRICT 61

Type of Pipe	Soil Type	Service Life Expectancy	Avg pH	Avg Res
BCCMP	Miss. Terrace & Recent Alluvium	20-25 Yrs	6.6	2350
Concrete	Miss. Terrace & Recent Alluvium	>25 Yrs	6.6	2350
ABCMP	Miss. Terrace & Recent Alluvium	25 Yrs	6.6	2350
Structural	Miss. Terrace & Recent Alluvium	20-25 Yrs	6.6	2350

DISTRICT 62

Type of Pipe	Soil Type	Service Life Expectancy	Avg pH	Avg Res
BCCMP	Coastal Alluvium	20-25 Yrs	6.1	5072
Concrete	Coastal Alluvium	>25 Yrs	6.1	5072
ABCMP	Coastal Alluvium	25 Yrs	6.1	5072
Structural	Coastal Alluvium	20-25 Yrs	6.1	5072
BCCMP	Miss. Terrace	20-25 Yrs	5.6	6788
Concrete	Miss. Terrace	>25 Yrs	5.6	6788
ABCMP	Miss. Terrace	25 Yrs	5.6	6788
Structural	Miss. Terrace	20-25 Yrs	5.6	6788
BCCMP	Flatwoods	20-25 Yrs	5.8	7076
Concrete	Flatwoods	>25 Yrs	5.8	7076
ABCMP	Flatwoods	25 Yrs	5.8	7076
Structural	Flatwoods	20-25 Yrs	5.8	7076
BCCMP	Recent Alluvium	20-25 Yrs	5.5	3050
Concrete	Recent Alluvium	>25 Yrs	5.5	3050
ABCMP	Recent Alluvium	25 Yrs	5.5	3050
Structural	Recent Alluvium	20-25 Yrs	5.5	3050
BCCMP	Coastal Plain	20-25 Yrs	5.4	10,000
Concrete	Coastal Plain	>25 Yrs	5.4	10,000
ABCMP	Coastal Plain	25 Yrs	5.4	10,000
Structural	Coastal Plain	20-25 Yrs	5.4	10,000

TABLE 1

DISTRICT 02

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
BCCMP	Recent Alluvium	20			100		6	7.1-8.3	550-1700
Concrete	Recent Alluvium	20	100				6	7.7-8.2	600-2000
ABCMP	Coastal Marsh	3	100				10	8.3-8.7	200-400
Concrete	Coastal Marsh	8	100				10	8.3-8.9	800-1450
BCCMP	Coastal Marsh	25	100				4	7.0-7.7	800-1400
BCCMP	Coastal Marsh	15				100	20	7.2-7.7	900-2450

TABLE 1

DISTRICT 03

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
ABCMP	Coastal Marsh	12		100			30	6.3	7605
ABCMP	Coastal Marsh	5	100				30	4.9-8.0	650-2100
Structural	Coastal Marsh	11		100			2	6.3	4000
Structural	Coastal Marsh	5	100				2	7.3	1100
Concrete	Coastal Marsh	14	100				20	7.1-7.9	1000-1200
BCCMP	Coastal Marsh	11			100		37	6.8-8.0	1000-1300
Structural	Mississippi Terrace	12		100			5	6.0	3900
ABCMP	Coastal Prairies	10	100				10	7.2-7.7	1000-1600

TABLE 1

DISTRICT 03

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
ABCMP	Coastal Prairies	5	100				60	7.5	2571
Concrete	Coastal Prairies	3	100				18	6.1-7.9	1000-1900
Concrete	Coastal Prairies	15	100				30	6.6-7.6	550-2000
Structural	Recent Alluvium	12		100			13	4.7-7.5	1846-8300
ABCMP	Recent Alluvium	13-16		100			10	4.5-7.5	1500-3390
ABCMP	Recent Alluvium	5	100				50	6.9-7.5	7750
Concrete	Recent Alluvium	5	100				50	7.0-7.5	900-1450
BCCMP	Recent Alluvium	13			100		10	7.5	3390

TABLE 1

DISTRICT 04

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
Concrete	Flatwoods	10	100				5	5.9-8.1	2000-10500
Concrete	Flatwoods	16-18	100				40	4.7-6.7	1367-30000
BCCMP	Flatwoods	10			100		10	4.6-10.9	400-120000
BCCMP	Flatwoods	16			100		4	4.8-5.8	12000
Structural	Flatwoods	11		100			3	4.4	30000
BCCMP	Coastal Plain	16-17			100		5	6.0-6.2	6200-16000
BCCMP	Coastal Plain	9-10			100		4	4.8-5.1	11000-18000
Structural	Coastal Plain	10-11			83.3	16.7	6	4.3-6.6	1700-18000
Structural	Coastal Plain	4	100				9	4.3-6.6	600-5000
ABCMP	Coastal Plain	4	100				12	4.5-7.9	1200-16000

TABLE 1

DISTRICT 04

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
Concrete	Coastal Plain	18	100				3	6.2-7.7	2200-7000
BCCMP	Coastal Plain	16			100		4	6.0	1600

TABLE 1

DISTRICT 05

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
BCCMP	Mississippi Terrace	11		100			3	5.2-6.2	2000-4600
Structural	Mississippi Terrace	15-17		40.0	60.0		10	5.8-7.0	1000-7000
BCCMP	Recent Alluvium	16-17			100		2	6.1	1600-4200
Structural	Recent Alluvium	13-17			33.3	66.7	3	4.9-5.2	9000-11000
BCCMP	Mississippi Terrace	15		100			2	6.0	4100
BCCMP	Coastal Plain	11-14		21.05	78.95		19	5.5-6.5	2800-3000
BCCMP	Recent Alluvium	11			100		63	6.1	4200
BCCMP	Recent Alluvium	11		100			11	4.2-6.5	1023

TABLE 1

DISTRICT 05

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
Concrete	Coastal Alluvium	11	100				20	5.0-6.7	2800-9000
BCCMP	Coastal Plain	16-17		12.5	25	62.5	16	3.9-6.5	2200-9000
BCCMP	Coastal Plain	5	100				15	4.2-7.3	1600-18000
Concrete	Coastal Plain	17	100				30	5.0-5.8	3780-9000
Structural	Coastal Plain	15-17		71.4	28.6		7	3.0-7.6	1500-10000
BCCMP	Coastal Plain	25				100	5	4.6-5.9	1200-30000
BCCMP	Mississippi Terrace	11		100			3	5.2-6.2	2000-4600

TABLE 1

DISTRICT 07

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition: Excellent	Condition: Good	Condition: Fair	Condition: Perforated	Total Observed	pH Range	Rest Range
Structural	Flatwoods	10		100			1	7.6	3000
BCCMP	Coastal Prairies	8-9		100			11	5.2-7.2	2000-14000
Structural	Coastal Prairies	8		100			1	5.4	4800
ABCMP	Coastal Prairies	9	100				1	7.1	1950
Concrete	Flatwoods	5	100				10	5.5-7.3	3100-72000
ABCMP	Flatwoods	5	100				4	5.3-7.3	1350-8000
Structural	Flatwoods	5	100				2	6.3-8.3	2250-8000
Concrete	Coastal Marsh	1[illegible]-21	100				20	6.9-9.2	225-8000

TABLE 1

DISTRICT 08

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
Concrete	Mississippi Terrace	30	100				5	4.8-7.3	1350-26000
Concrete	Mississippi Terrace	14-17	100				8	5.2-7.1	1200-7950
Concrete	Recent Alluvium	10	100				9	7.1-8.1	600-2400
BCCMP	Recent Alluvium	8-10		100			49	5.2-7.7	550-5200
Structural	Recent Alluvium	14-17		100			6	6.9-8.3	1800-3790
BCCMP	Coastal Plain	9-12		100			46	4.9-8.3	2300-12000
BCCMP	Recent Alluvium	14		100			8	5.6	5500
ABCMP	Coastal Plain	5	100				6	4.1-6.3	4800-12000

TABLE 1

DISTRICT 08

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
BCCMP	Coastal Plain	16		100			27	5.7-8.2	2400-5000
BCCMP	Coastal Plain	21			100		2	5.7	5000
Structural	Coastal Plain	11		100			2	7.6	6000
Structural	Coastal	16			100		14	7.6	4300

TABLE 1

DISTRICT 58

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
BCCMP	Coastal Plain	16-17		40	60		15	5.6-6.0	1550-14000
BCCMP	Coastal Plain	11-13		100			32	5.5-5.6	5400-14000
Structural	Coastal Plain	17		14.3	85.7		14	5.2-6.4	2600-18000
Structural	Coastal Plain	11			100		1	5.5	5400
BCCMP	Recent Alluvium	14		100			5	7.0	1200
Structural	Recent Alluvium	19			100		2	6.5-6.9	680-800
Structural	Mississippi Terrace	16			100		6	6.2-6.3	4100-5200
BCCMP	Mississippi Terrace	12-15			100		24	5.3-7.7	1100-5000

TABLE 1

DISTRICT 58

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
Concrete	Mississippi Terrace	15-17	100				12	6.4-6.9	1100-7500
Structural	Recent Alluvium	12			100		6	6.0-6.2	1450-2200

TABLE 1

DISTRICT 61

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
Concrete	Mississippi Terrace	5	100				9	5.2-7.0	650-2500
BCCMP	Mississippi Terrace	5		100			6	6.0-7.8	800-3800
ABCMP	Recent Alluvium	4	100				1	7.1-7.5	550-800
Structural	Recent Alluvium	15		90	10		10	5.7-7.9	500-1200
Structural	Recent Alluvium	4	100				3	7.1-7.9	500-700
Concrete	Recent Alluvium	4	100				9	6.4-7.8	475-2000
BCCMP	Recent Alluvium	11-15		94.11		5.89	17	5.7-6.0	1100-2400

TABLE 1

DISTRICT 62

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
Structural	Coastal Alluvium	7	100				4	4.3-6.2	1300-8000
Structural	Coastal Alluvium	11	33.3		66.7		3	6.2-7.4	650-1300
Concrete	Coastal Alluvium	3-7	100				18	5.2-9.3	900-19000
BCCMP	Coastal Alluvium	7-11	36	48	16		25	5.8-7.3	950-12000
BCCMP	Coastal Alluvium	15		100			1	4.9-5.0	1000-1350
Concrete	Mississippi Terrace	3-5	100				15	5.0-6.9	1100-8875
ABCMP	Mississippi Terrace	3-5	100				8	4.5-6.6	1325-20000
Structural	Mississippi Terrace	5	100				2	5.5-7.2	720-12000

TABLE 1

DISTRICT 62

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
ABCMP	Flatwoods	3	100				1	5.7	11400
Structural	Flatwoods	5	100				2	5.9-6.8	1500-6400
Structural	Recent Alluvium	7			100		2	5.8	3300
BCCMP	Recent Alluvium	11-14		100			10	5.0-6.1	2800-3800
ABCMP	Coastal Alluvium	3	100				2	5.1-11.1	3800-17000
ABCMP	Coastal Plain	5	100				6	5 1-6.1	18000-30000
Structural	Coastal Plain	5	100				3	5.3-6.0	3300-12000
Concrete	Coastal Plain	5	100				6	5.1-6.5	10000-30000
BCCMP	Mississippi Terrace	18	100				3	4.6	3000

TABLE 1

DISTRICT 62

PERCENT OF OBSERVED PIPE IN

Type of Pipe	General Soil Area	Years Submerged	Condition				Total Observed	pH Range	Rest Range
			Excellent	Good	Fair	Perforated			
Concrete	Flatwoods	3-5	100				15	4.4-6.7	3000-20000
BCCMP	Flatwoods	5		75		25	12	4.9-6.5	1300-8000
BCCMP	Mississippi Terrace	11		100			4	5.5	8000
Structural	Mississippi Terrace	11			100		1	5.5	8000
BCCMP	Coastal Plain	10			100		6	4.3-6.3	6100-30000
Concrete	Coastal Plain	10	100				6	4.4-7.6	5800-30000
BCCMP	Flatwoods	11-14	30.56	58.33	11		36	4.0-6.3	1200-20000
Structural	Flatwoods	11			84.62	15.38	13	4.0-6.8	6990-12000
Structural	Flatwoods	3	100				7	5.1-7.3	2450-14000