THE ECONOMIC DESIGN OF WATER PIPE LINES IN SOUTHERN CALIFORNIA.

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INTRODUCTION

In the semi-arid West, and in Southern California particularly, the water-supply problem is one of outstanding importance. A factor in the economic development of the water resources has been the delivery and distribution of the supply.

In the early years of development in this country, capital was relatively limited and the design of pipe lines often had to be adjusted to available means, resulting in the installation of large quantities of light steel pipe, in many instances, however, at the expense of a greatly curtailed life of the pipe lines because of destructive types of soil.

Technical knowledge as to the action of different types of soil on pipe materials or coatings was then only in its preliminary stages. Instances also were numerous where an unanticipated rate of expansion of the enterprise was responsible for untimely obsolescence of undersized pipe lines.

Because of the scarcity and cost of water supplies, lined conduits or pipe lines were used almost from the beginning for the conveyance of irrigation and domestic water. Subsequently, with continued growth of the country, the use of water supplies for combined domestic and irrigation purposes and the necessity of protecting them from pollution, caused the replacement of open or lined conduits with pipe lines on a large scale.

Experience extending over a period of some thirty years of intensive water development has contributed much positive knowledge on soil corrosion, the effect of incrustations and of electric stray currents on the life and carrying capacity of pipe lines.

There has also been a great deal of original research on the subject of corrosion and electrolytic action, both by Federal Agencies and private organizations, so that today we are able to design pipe lines with the assurance that the estimates of carrying capacity and life of pipe are reasonably accurate.

BASIS OF STUDY

This study and the conclusions herein advanced are based upon the following investigations:

(a) Investigation of all available types of pipe, protective coatings and wrappings through a study of trade catalogues and direct inquiry of factories.

(b) Investigation of cost of pipe, pipe laying, trenching and backfilling by inquiry of a great number of municipal water departments and private water companies, both by personal call and circulating of questionnaire.

(c) Investigation of life of pipe in different Southern California soils by direct inquiry of water works engineers, personal inspection, also by study of corrosion tests made by a number of institutions.

FACTORS AFFECTING ECONOMIC DESIGN

The factors which affect the design of a pipe line are classified in the following outline.

I. Economic Limitations of Project.

a - Purpose of Project.
b - Capital available.
c - Obsolescence.

II. Features of Project.

a - Duty of Line.
b - Topography
c - Types of Soil.
d - Stray current electrolysis.
e - Quality of water to be carried (Incrustation of line).

III. Comparison of Available Pipe Materials.

A. Characteristics of Available Pipe.

1. Sizes and thicknesses
2. Resistance to Internal Pressure.
3. Resistance to External Pressure and Vacuum
4. Carrying Capacity and Reduction with age.
5. Effect of corrosion on life of Pipe.
6. Temperature and earthquake resistance.
7. Joints and laying of Pipe.
8. Initial cost (pipe laid).

B. Characteristics of available Pipe Coatings.

1. Description of Available Pipe Coatings.
2. Effect of corrosion on life of Coatings.
3. Cost of Coatings.

GENERAL CONCLUSIONS.

I. ECONOMIC LIMITATIONS OF PROJECT.

The following general conclusions have been reached.

A. Purpose of Project.

The principal classifications of the use of water is for domestic use, power and irrigation. The combination of irrigation with any of the other uses requires special consideration in the design of the pipe line, as this use is limited only to the irrigating season.

B. Capital Available

Relative to organization and financing of the project, there are five classes of water enterprises in California, Private, Municipal, Public Utilities, Mutual Water Companies, and Irrigation or Water Districts. The particular type of organization has a bearing on the method of financing and, consequently, on the life of the project.

C. Obsolescence.

By obsolescence is meant the life of the structure. Hence, this factor is dependent on the general growth of the community and the limitations of the project. In a country like Southern California, where opportunities for development are exceptional, obsolescence has played an important part in the design of pipe lines in the past and still remains a major factor.

GENERAL CONCLUSIONS

II. FEATURES OF PROJECT

A. Duty of Line.

The duty of the line involves the economic relation between the quantity of water to be delivered and the allowable friction loss. For a given quantity of water to be carried, the cost of the pipe line increases with the size, while the friction loss decreases correspondingly with the increase of size of pipe. Several methods have been formulated for determining the economic diameter of pipe in relation to fixed and operating charges.

Arthur L. Adams states that given the quantity of water to be delivered, and the cost and friction loss for various diameters, then a pipe fulfills the requirements of greatest economy if the value of the energy annually lost in frictional resistance equals four-tenths of the annual fixed cost of the pipe line.

Professor W.F.Durand suggests the following solution:

Plotting the value of the operating costs annually as ordinates and the fixed charges annually as abcissae, for various diameters of pipe, the economic diameter is that size at which the slope of the above curve is 45 degrees.

B. Topography.

Relative to the topographic conditions, the goal to be attained in economic design is an alighment resulting in the shortest line consistent with existing conditions and a profile approaching a uniform gradient. This type of alignment usually requires a pipe line under lower pressure, hence of lower cost. The alignment should avoid, as much as possible, any specials except standard and any curvatures that cannot be negotiated in the ordinary process of pipe laying. For all pipe lines, the ruling element of the profile is the hydraulic gradient. Both inverted siphons and summits should be avoided as much as is consistent with the topography.

Conditions of land ownership or right-of-way, of soil types, of stream crossing, the possibility of electric stray currents, and vibrations by trains and other moving loads, may impose limitations of location not associated with topographical conditions.

A summary of several possible routes and estimates of cost may be necessary in determining the economic location of the line. Existing topographic features such as roads, bridges, etc., which might be utilized, may also be important in the economic consideration, both for construction facilities and by reason of available right-of-way.

C. Type of Soil.

Soil surveys are an essential feature in the economic design in order to determine the kind of pipe and necessary protective coating. The various factors used in soil classification are - moisture content, texture, soluble salt content, acidity or alkalinity, and electrical resistivity.

Moisture content is dependent on drainage conditions and can be determined largely from the type of soil and the seasonal rainfall.

Texture classification is made on the basis of the fineness of material and the percentage of sand, clay and silt.

Soluble salt content and the acidity or alkalinity of the soil determine to a large extent the corrosivity of the soil.

Various tests made show the correlation of the electrical resistivity of soils and the amount of corrosion. Soils with electrical resistivities under 10,000 ohm cms generally require some sort of protective coating, the extent of which is dependent on the designed life and the type of soil.

The cost of making soil surveys is relatively small,hence it should be incorporated in the preliminary design of a project.

D. Stray Curremt Electrolysis

In making a preliminary study of the topographic features of a pipe line, the possible sources of stray current electrolysis should be given due consideration. If the source of the current is located, the amount of leakage current to be expected along the pipe line may be measured. In rural areas the trouble will usually occur at the crossing or parallelling of electric railway tracks. In cities, electrolysis is usually more complex because of the large number of electric conductors and pipe lines. Maps can be made of the various pipe line locations showing the amount of leakage currents, making it possible to determine the type of protection necessary, or perhaps the change of pipe line location.

E. Quality of Water to be Carried.

In making a preliminary study of the project, the chemical composition of the water to be conveyed should be given due consideration. Water carried by supply lines usually is treated, consequently the pipe must be protected internally if the carrying capacity is to be maintained with corrosive water. In some instances the use of a chemical treatment may prove to be more economical than the use of a protective lining.

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Available Types of Pipe

The following are the commercial types of pipe available for construction:

Steel Pipe - (Eastern manufacture
(Western manufacture

Wrought Iron Pipe.

Cast Iron Pipe - (Vertical Sand Mold Cast
(Horizontal Sand Mold Cast
(DeLavaud Centrifugal Process
(Sand Mold Centrifugal Process
(Concrete lined

Concrete Pipe - (Plain
(Reinforced

Wood Pipe - (Machine Banded
(Continuous Stave

Steel Pipe.

1. Sizes and Thicknesses: Eastern manufactured steel pipe is either hot rolled or cold rolled. In the hot, lap or butt welded rolled pipe, there are commonly four thicknesses or types made: casing, standard, extra heavy and double extra heavy. The sizes range from 1/8" to 16" in these classes, while seamless pipe is rolled to 24" diameter.

In the cold rolled pipe the manufacture is limited to either riveted or welded pipe from 3" to 132" in diameter and up to 13" diameter for seamless pipe.

Steel pipe is manufactured on the Pacific Coast from sheet steel rolled in eastern mills and made either riveted

Steel Pipe-Sizes and Thicknesses, contd.

or welded. Thin walled pipe may be had in almost any size above 4". The maximum sizes are limited only by transportation facilities, while the maximum thickness is limited by rolling facilities to 1-1/2".

2. Resistance to Internal Pressure: The resistance to internal pressure of steel pipe depends upon the tensile strength of the metal, the efficiency of the seam (if there be any seam), and the efficiency of the field joint. The minimum tensile strength standard specifies 45,000 lbs.per sq.in., with a tendency at present to use a material of 55,000 lbs. per sq.in., giving a higher working stress. The factor of safety commonly used is 3 to 4. For welded pipe, a joint efficiency of at least 100% is attained, while for riveted pipe, the joint efficiencies can be calculated and may be as low as 62.5%.

Since steel pipe can be manufactured in varying sizes and thicknesses it can be adapted to any pressure. This allows the economic use of the metal for all except low pressures, as it utilizes the full tensile strength of the material.

For depths of cover of only 2 or 3 feet, the stresses set up by external pressure can be neglected. For thin walled steel pipe, the depth of cover and the possibility of vacuum pressure must be considered in design. Additional stresses

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Steel Pipe-Resistance to Internal Pressure, contd.

such as those caused by live loads of railway and highway crossings, may affect the thickness of the metal.

4. Carrying Capacity and Reduction with Age: For the computation of the carrying capacity of steel pipe, the formulae suggested by Fred C. Scobey are the most recent and complete. These formulae are based on experiments with both riveted and welded steel pipe and are applicable to the change in capacity with the change in life of pipe. The formulae give proper coefficients of roughness for full riveted, girth riveted and smooth interior pipe.

5. Effect of Corrosion on Life of Pipe:

Atmospheric corrosion is a minor problem because the pipe line can be readily inspected and can be maintained by periodical coating.

Underwater corrosion of steel pipe is a more important problem in fresh water than in salt water and may require the use of some protective coating to increase the life of the pipe.

Soil corrosion of plain steel pipe is dependent on the type of soil. For unprotected #12 gauge steel pipe we can expect a life of -

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

5. Effect of Corrosion on Life of Pipe.

Soil corrosion, contd.

(a) 3 years in Merced Silt Loam

(b) 4 to 5 years in Hanford Very Fine Sandy Loam and Montezuma Clay Adobe

(c) 15 to 20 years in Dublin Clay Adobe and Hanford Fine Sandy Loam

(d) 50 to 100 years in Everett Gravelly Sandy Loam and Ramona Loam.

Internal Corrosion of steel pipe is not a factor as regards the life of the material. The main problem arises from the reduction in carrying capacity due to the growth of tubercules.

The action of stray electric currents is detrimental to the life of steel pipe and must be checked by some type of protection or prevention.

6. Temperature and Earthquake Resistance.

Buried steel pipe do s not require expansion joints. Exposed steel pipe should be protected by the use of expansion joints or allow for the movement of the pipe. Steel pipe is adapted to withstand vibrations and minor settlements and earth movement due to earthquakes.

7. Joints and Laying of Pipe.

Steel pipe can be laid economically because the joints can be made above the trench and pipe subsequently

Steel Pipe-Joints & Laying of Pipe, contd.

lowered into the trench. A large variety of joints permits the laying of curves without the use of special fittings.

8. Initial Cost.

For low pressures, the initial cost of steel pipe is lower than that of cast iron, wrought iron and wood stave pipe.

Generally speaking, steel pipe has the widest range of adaptability, both as to size and internal pressure. It is the most vulnerable for external load and vacuum stresses. It is more susceptible to corrosion than any other type of pipe, but also can be protected at relatively low cost by the use of coatings and wrappings.

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Wrought Iron Pipe.

1. Sizes and Thicknesses:

All wrought iron pipe is manufactured in the east and shipped to the Pacific Coast. The four weights commonly made are casing, standard, extra strong, and double extra strong. This pipe can be had in sizes from 1/8" to 20" in diameter; the sizes above 10" are, however, about 3/8" thick.

2. Resistance to Internal Pressure:

Since wrought iron pipe is all hot rolled, the tensile strength of the metal is the limiting factor in determining the pressure it can withstand. The minimum ultimate tensile strength is specified at 40,000 lbs. per sq.in.

Since the thinnest wall wrought iron pipe is casing, the economic use is limited to the upper range of pressures, namely, above 250 lbs. per sq.in for any size.

3. Resistance to External Pressure and Vacuum:

Wrought iron pipe is made in thicknesses suitable to resist ordinary external pressure or vacuum stresses. Where it is subjected to internal pressures greater than 100 lbs. per sq.in, however, it should be investigated for large external loads.

4. Carrying Capacity and Reduction with Age: The formulae for flow suggested by Scobey for smooth steel pipe can be applied to wrought iron pipe.

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Wrought Iron Pipe, contd.

5. Effect of Corrosion on Life of Pipe:

Atmospheric corrosion of wrought iron pipe takes place but is a slow process. It can readily be prevented by periodical coating.

Under-water corrosion of wrought iron pipe is a problem with fresh water and may require the use of some protective coating.

Soil corrosion of wrought iron pipe depends on the type of soil. For unprotected wrought iron pipe 1/4" thick we can expect a life of:

(a) 10 years in Merced Silt Loam

(b) 20-40 years in Hanford Very Fine Sandy Loam and Montezuma Clay Adobe

(c) 30-50 years in Dublin Clay Adobe and Hanford Fine Sandy Loam

(d) 50-100 years in Everett Gravelly Sandy Loam and Ramona Loam.

Internal Corrosion of wrought iron pipe is less than that occurring im steel pipe but is negligible as far as the life of the pipe is concerned. It is subject to tuberculation similar to steel pipe.

The action of Stray Electric Currents is detrimental to the life of wrought iron pipe and must be prevented.

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Wrought Iron Pipe, contd.

6. Temperature and Earthquake Resistance:

Wrought iron pipe if exposed necessitates the use of expansion joints. It is suited to stand vibrations and a slight amount of earth movement due to earthquakes.

7. Joints and Laying of Pipe:

Wrought iron pipe because of its thickness, can be either coupled or butt welded economically. Screw joints can be used for sizes up to 12 inches.

8. Initial Cost:

For standard weight pipe, the price of wrought iron is slightly higher than steel pipe of the same thickness.

Wrought iron pipe is adapted for large internal pressure and small size pipes. It is capable of withstanding large external loads. Corrosion is a factor to be considered.

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Cast Iron Pipe

1. Sizes and Thicknesses:

Cast iron pipe is segregated according to the methods of casting and for the various sizes and thicknesses, into classes according to the working pressures. Stationary casting is done either in horizontal or vertical molds. The horizontal cast iron pipe (McWane Pipe) is limited to sizes up to 8" in diameter, while the vertical cast pipe is made in sizes of from 4" to 84" in diameter and segregated into 8 classes relative to working pressures.

Centrifugal spun cast iron pipe can be made in either metal or sand core molds. The first method of casting is called the DeLavaud process, for sizes from 3" to 24" and in four classes designated by the working pressure per square inch as classes 100, 150, 200 and 250.

The sand core mold centrifugal spun pipe is made in sizes of from 4" to 24" in diameter and in the same four classes of working pressure.

The range of sizes for cast iron pipe is not as flexible as for steel pipe in sizes above 16"

2. Resistance to Internal Pressure:

The ultimate tensile strength is given as follows:

Vertical Cast	20,000 lbs. per sq. in.
Centrifugal Spun Sand Mold	25,000 " " " "
" " Metal Mold, (DeLavaud)	30,000 " " " "

Cast Iron Pipe, contd.

The economic use of cast iron pipe is limited to the pressures up to 250 lbs. per sq.in. for sizes up to 36". Vertical cast pipe is made up to 84" and centrifugal cast pipe up to 24". It is important to note that the bell and spigot joint does not limit the allowable pressure of the pipe.

3. Resistance to External Pressure and Vacuum:

Since cast iron pipe is made in thicknesses which permit a large factor of safety, it can be utilized to good advantage to withstand stresses from external loads and vacuum. Ordinary vertical cast cast iron pipe, Class C, will withstand, in addition to an internal pressure of 100 lbs.per sq.in., an external fill of 20 feet of soil. For very heavy loads, such as railway and highway crossings, however, the actual stresses should be computed.

4. Carrying Capacity and Reduction with Age:

It has been found that the carrying capacity of cast iron pipe decreases with age because of tuberculation caused by the water, hence this must be taken into consideration in capacity calculations. This fact is considered in the Hazen-Williams formula which gives different coefficients for various sizes and ages of pipe.

Cast Iron Pipe, contd.

To avoid tuberculation, cement linings may be spun inside of the cast iron pipe. Although this reduces the size initially, it more than makes it up by increased carrying capacity over a long period.

5. Effect of Corrosion on Life of Pipe:

Atmospheric corrosion is less for cast iron pipe than for steel pipe and may be considered as negligible in computing the life of pipe.

Under-water corrosion of cast iron in fresh water occurs at about the same rate as for steel and wrought iron pipe. A longer life can be assumed for cast iron because of the greater initial thickness of pipe used for the same pressure. Submerged in salt water, cast iron pipe is more susceptible to corrosion than steel or wrought iron.

Soil corrosion depends on the type of soil. For 20" verticle cast sand mold pipe, .92" thick, we can expect a life of:

(a) 16 years in Merced Silt Loam

(b) 30 years in Montezuma Clay Adobe and Hanford Very Fine Sandy Loam

(c) 75-100 years in Dublin Clay Adobe, Ramona Loam and Hanford Fine Sandy Loam

(d) 100 years in Everett Gravelly Sandy Loam

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Cast Iron Pipe, contd.

For DeLavaud centrifugal spun metal mold pipe of the same thickness, we can expect a life of:

(a) 60 years in Merced Silt Loam

(b) 75 years in Dublin Clay Adobe and Montezuma Clay Adobe

(c) 100 years in Hanford Very Fine Sandy Loam, Hanford Fine Sandy Loam, Everett Gravelly Sandy Loam and Ramona Loam

Internal Corrosion of cast iron pipe is not a factor in determining the life of the pipe line. Tuberculation takes place; however, the pipe can be reconditioned.

Stray current electrolysis is resisted by cast iron to a greater extent than by steel or wrought iron. However, in order to prolong the life of the pipe, protective measures are generally adopted.

6. Temperature and Earthquake Resistance:

With the use of special couplings, expansion joints may not be necessary on exposed cast iron pipe. The bell and spigot joint permits of slight deflections due to earthquakes.

7. Joints and Laying of Pipe:

The use of bell and spigot joints in cast iron pipe makes the laying of the pipe economical and permits of slight curvature. The pipe must be laid in the trench and bell holes are necessary. Coupled joints are ~~not~~ suitable to assemble the pipe on top of the ground and subsequent lowering into the trench.

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Cast Iron Pipe, contd.

8. Initial Cost:

The initial cost of cast iron pipe is higher than the other materials. Its large initial cost, however, may be economical by virtue of its long life.

Cast iron pipe has a relatively large initial cost, offset, however, by long life; hence it is suitable for urban pipe systems. Its capacity to withstand internal pressure is limited, but it is capable of supporting external load and vacuum stresses. Corrosion is a minor factor.

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Concrete Pipe.

1. Sizes and Thicknesses:

Concrete pipe may be divided into plain and reinforced pipe. Plain concrete pipe may be cast by hand in any size. Machine made concrete pipe is manufactured from 6" to 24", the wall thickness varying from 3/4" to 2-1/4". Transportation charges and available materials determine whether the pipe may be economically made at the point of laying or at the factory.

Reinforced concrete pipe may be made with two types of reinforcing, a wire cage called "spider" or a steel shell, or a combination of the two, depending upon the internal pressure. Reinforced concrete pipe may be obtained in standard sizes up to 108" in diameter.

2. Resistance to Internal Pressure:

Plain concrete pipe is limited to heads of 10 feet or less.

For reinforced concrete pipe the steel reinforcing is assumed to take all of the tensile stress. Since the concrete becomes pervious at high heads, it becomes necessary to use a steel shell for reinforcement for heads over 150 ft. The minimum amount of steel to satisfy the working stress may be used. The economic use of reinforced concrete pipe is limited to pressures up to 125 lbs. per sq.in.

GENERAL CHARACTERISTICS OF COMMERICAL PIPE

Concrete Pipe, contd.

3. Resiatance to External Pressure and Vacuum:

Plain concrete pipe cannot withstand much external pressure and hence should not be used where the depth of cover may exceed 6 feet.

Reinforced concrete pipe because of arching action is able to withstand external loads better than any other type of pipe. The combination of steel and concrete permits of a large bending moment in combination with the direct stress to be carried.

4. Carrying Capacity and Reduction with Age:

For determining the carrying capacity of concrete pipe, the formulae suggested by Fed C.Scobey are the most recent and complete. These formulae are based on experiments on different types and sizes of concrete pipe and different coefficients of roughness are given for each of four classes.

5. Effect of Corrosion on Life of Pipe:

Atmospheric corrosion is not a factor with concrete pipe.

Under-water corrosion will not occur in either fresh water or salt water. If laid in salt water and partly exposed to the atmosphere, corrosion takes place above the line of permanent moisture.

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Concrete Pipe, contd.

Soil Corrosion will render concrete pipe useless in 10 years if there is a large percentage of alkaline salts present. In ordinary soils, concrete pipe will have a life of at least 50 years.

Internal corrosion has no effect on the life of concrete pipe unless the water carries sand at velocities sufficiently high enough to cause scour.

Stray current electrolysis will not injure concrete pipe.

6. Temperature and Earthquake Resistance:

Concrete pipe must be placed in firm ground to avoid cracks due to settlement. It is susceptible to slight earth vibrations.

7. Joints and Laying of Pipe:

Plain concrete pipe is made in small sections which necessitates the use of a large number of joints and bell holes. In reinforced concrete pipe the joints can be made on the inside of the bottom half, thus permitting the use of a minimum size trench.

8. Initial Cost:

Plain concrete pipe can be made cheaper than any other class of pipe. The initial cost of reinforced

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Concrete Pipe, contd.

concrete pipe is less than that of thin walled steel pipe for low pressures and compares favorably with that of wood stave pipe.

Concrete pipe is best adapted for low internal pressure and high external load. It has a long life, a constant relatively high carrying capacity and is comparatively cheap.

GENERAL CONCLUSIONS

GENERAL CHARACTERISTICS OF COMMERCIAL PIPE

Wood Stave Pipe

1. Sizes and Thicknesses:

Wood stave pipe is classified as machine banded and continuous stave pipe. Machine banded pipe is made in sizes from 2" to 32", while continuous stave pipe is built from 10" to 16 ft. in diameter.

2. Resistance to Internal Pressure:

The resistance to internal pressure depends on both the tensile strength of the steel bands and the ~~break-~~ bear-ing pressure of the bands on the wood. In order to secure a water-tight joint when the pipe is under load, it is necessary to induce an initial tension into the steel bands. Hence the total load on the band consists of the tensile stress due to water pressure, plus this initial tension.

The ultimate strength of the steel for the bands is 60,000 lbs. per sq.in. and a working stress of 16,000 lbs. per sq.in. can be used in design. The bearing strength of the wood is 650 lbs. per sq.in.

The economic use of wood stave pipe is limited to pressures up to 100 lbs. per sq.in.

3. Resistance to External Pressure and Vacuum:

Wood stave pipe should not be used for fills of more than 6 to 10 feet without additional support of some kind. Air valves are necessary for protection of the

Wood Stave Pipe, contd.

pipe in case of vacuum.

4. Carrying Capacity and Reduction with Age:

For the carrying capacity of wood pipe the formulae presented by Fred C. Scobey are the most recent and complete, and are applicable to both machine banded and continuous stave pipe. Scobey's experiments show no difference in the carrying capacity of wood stave pipe for different ages.

5. Effect of Corrosion on Life of Pipe:

Atmospheric corrosion of wood stave pipe depends on the effect on the steel bands and on the wood. As long as the line is under pressure, the life can be assumed to be at least 25 years in ordinary atmosphere. If exposed to salt water air, the steel bands must be replaced on the average of every five years.

Under-water corrosion of wood stave pipe is measured by the life of the steel bands, hence will be no longer than for steel pipe of the same pressure.

Soil Corrosion of wood stave pipe is determined largely by the life of the steel bands . In soils free from alkaline salts the life of the pipe can be taken as 30 to 50 years, if kept continually full. In alkaline soils, the

Wood Stave Pipe, contd.

life will be limited by the bands to 10 or 15 years.

Internal corrosion of wood stave pipe is negligible as long as the pipe is kept full of water.

Stray current electrolysis does not take place with wood stave pipe.

6. Temperature and Earthquake Resistance:

Because of the flexible joints and the low coefficient of expansion of wood, it can be laid exposed without the use of expansion joints.

7. Joints and Laying of Pipe:

Wood stave pipe can be laid to conform to the topography without the use of special fittings. Banded wood pipe has a bell and spigot or collar joint and must be laid in the trench.

8. Initial Cost:

The cost of continuous stave pipe is slightly higher than that of machine banded pipe. It compares favorably with the cost of reinforced concrete pipe for the same head and with steel pipe and cast iron pipe.

Wood stave pipe is best adapted for rough topography and large quantities of water under low pressure. Machine banded pipe, under certain conditions, may compete with steel and reinforced concrete pipe.

GENERAL CONCLUSIONS

CHARACTERISTICS OF AVAILABLE PIPE COATINGS

Coating materials can generally be divided into the following classification:

A. Bituminous dips or enamels.

 1. Coal tar base

 2. Asphalt base.

B. Wrappings

 1. Felt or Cloth Fabric

 2. Asbestos fiber

C. Hard Emulsions

 1. Asphalt-cement Emulstion

 2. Asphalt-sand mastic

D. Concrete.

E. Metallic Coatings

 1. Foil Wrapping

 2. Galvanizing

A. Bituminous Dips and Enamels

1. Description: Dips or enamels are classified according to the bituminous base, whether of coal tar or asphalt. Asphalt dips manufactured in Southern California are made from California oils. An enamel consists of a specially treated combination of bituminous materials having a higher melting point and a harder but more brittle surface.

GENERAL CONCLUSIONS

CHARACTERISTICS OF AVAILABLE PIPE COATINGS

A. Bituminous Dips and Enamels, contd.

1. Description, contd.: Bituminous dips are applied at the factory by dipping preheated pipe in the heated materials. This gives the best bond between coating and metal. They can, however, be applied in the field by brushing or spraying, although the results are not as satisfactory.

2. Effect of corrosion on Life of Coatings:

Coal gas tar coating has proven to be very effective in resisting the action of atmospheric corrosion.

Coal tar pitch and asphalt coatings are not very resistant to under-water corrosion, either salt or fresh, and at best, last but a few years.

Ordinary bituminous coatings fail in two or three years in corrosive soils. Certain types of enamels, such as Barrett coal tar enamels, withstand corrosive action for at least five years in the most injurious soils.

Bituminous dips resist internal corrosion to a marked degree. New types of enamels recently produced prove to be very resistant to flowing water, but as yet are too brittle for practical use.

Dips and enamels are not resistant to electric stray currents and tend to increase the corrosion by concentrating the pitting action at the punctures.

GENERAL CONCLUSIONS

CHARACTERISTICS OF AVAILABLE PIPE COATINGS.

A. Bituminous Dips and Enamels, contd.

3. Cost of Coatings: Bituminous dips and enamels are the cheapest type of protective coating, costing five to eight cents per square foot.

Bituminous dips and enamels are very useful on exposed pipe lines and for internal linings, can be applied both in the factory and in the field at a very low cost.

B. Wrappings.

1. Description: Pipe wrappings may consist of canvas, burlap, felt, bituminous treated fabrics, or asbestos fiber material. They may be applied in as many layers as needed, although a double wrap has proven to be as effective as is economically justified.

2. Effect of Corrosion on Life of Coatings:

Wrappings are not ordinarily used on exposed lines because the use of various dips has proven satisfactory and also less expensive.

Wrappings are not resistant to under-water corrosion, as they permit the water to penetrate.

In soils, the combination of wrappings and dips has proven to be more effective than dips alone. Wrapping will double the life of the coating. Wrappings are ineffective in resisting stray electric currents. They can easily be punctured and tend to increase the amount of corrosion by concentrating the pitting action at the puncture.

B. Wrappings, contd.

3. Cost of Wrappings: The cost of wrapped coatings depends primarily on the number of layers. In general, a double wrapping costs 60% more than a single wrapping. Asbestos wrap costs about 10% more than paper or fabric wrap.

Wrappings furnish a cheap and satisfactory means of pipe protection in soils, if properly applied. The best results are obtained with machine wrapping.

C. Hard Emulsions.

1. Description: Hard emulsions generally consist of a bituminous material mixed with a hardening material, either sand or cement. In some cases, the bituminous emulsion may be protected by a coat of cement mortar.

2. Effect of Corrosion on Life of Emulsion:

This type of coating is not frequently used for atmospheric protection because of its cost, and also because the use of bituminous dips is satisfactory.

No information is available as to resistance to the action of water when submerged.

For protection due to the corrosive action of soils, this type of coating has proven to be more effective than the bituminous dips and enamels and also the wrapped coatings. In the most corrosive soils, it has a minimum life of five years.

CHARACTERISTICS OF AVAILABLE PIPE COATINGS

C. Hard Emulsions, contd.

2. Effect of Corrosion on Life of Emuslion, contd. Emulsions are not applied for internal protection of pipe.

This type of coating is not resistant to stray electric currents and should not be use for that purpose.

3. Cost of Emulsion: Emulsion coatings are more expensive than the dipped coatings or the ordinary wrapped coatings. It compares favorably, however, with the cost of the heavily reinforced wrapped coatings of two or more layers. Emulsions afford the best protection against soil corrosion, but are relatively expensive.

D. Concrete.

1. Description: Concrete coatings may be placed by hand, by machine, or by guniting, onto a wire netting placed on the outside of the pipe. Inner linings may be spun by machine or else placed by hand.

2. Effect of Corrosion on Life of Concrete Coating:

Concrete coating is not used for atmospheric exposure.

For under-water protection, this coating affords the best type of protection and has a life of at least 50 years.

For protection against soil corrosion, this type of coating has proven to be very effective, except in soils of high alkaline salt content. In ordinary soils, it will maintain the pipe for at least 30 years.

CHARACTERISTICS OF AVAILABLE PIPE COATINGS.

D. Concrete, contd.

2. Effect of Corrosion on Life of Concrete Coating, contd.

Cement lining has proven to be resistant to internal corrosion and also capable of maintaining permanently a high carrying capacity.

Concrete coatings are not resistant to stray electric currents and will not protect the pipe from electrolytic action, because it absorbs water.

3. Cost of Cement Coatings: It is the most expensive of the coatings and exceeds in cost that of the pipe itself. For low heads, it may be cheaper to use reinforced concrete pipe instead of cement coated steel pipe.

This type of coating, although the best type of protection against soil corrosion, is limited by its high cost. It is very adaptable to under-water protection of metal pipe lines.

E. Metallic Coatings:

1. Description: Metallic coatings most commonly used are applied either by foil wrapping or else by galvanizing. Aluminum and copper are common materials used in foil wrapping, while zinc is commonly used in galvanizing.

2. Effect of Corrosion on Life of Metallic Coatings:

Galvanizing is an effective means of protection from atmospheric corrosion.

E. Metallic Coatings, contd.

For under-water protection, this type of coating is not very satisfactory because of electrolytic action between the coating and the pipe.

For soil corrosion, metallic foil wrappings are useful to a limited extent. They add to the thickness of the material, and to some extent resist chemical action better than steel.

The protective effect of galvanizing steel and wrought iron pipe against internal corrosion is generally recognized. Galvanized pipe is universally specified for steel pipe systems in buildings.

Metallic coatings are obviously not resistant to electrolytic action, because of their low resistance.

3. Cost of Metallic Coatings: The cost of galvanizing and other metallic coatings is relatively high and prohibitive for large pipe.

A detailed discussion of the subject of this thesis follows. Special stress was laid upon a study of the effect of various types of corrosion on the life of pipe and protective coatings. The results of the recent tests and special inspections of corrosive action on pipe and coatings made by the U S. Bureau of Standards and the American Petroleum Institute are given.

Pasadena, California,
June, 1933

Harold Roach

I. ECONOMIC LIMITATIONS OF PROJECT

A. Purpose of Project.

The conveyance of water may be for a single or combined purpose. The principal classifications are for domestic use, power and irrigation. In large projects, one or two or all of these purposes may be combined, while in smaller projects the pipe line may serve a single purpose. Domestic water supplies are generally served the year round, so is power supply, while irrigation uses are limited to the irrigation season. The combination of irrigation with any other uses requires special consideration in the design of the pipe line and the quality of the water.

B. Capital Available.

In California there are five classes of water enterprise: private, municipal, public utilities, mutual water companies and irrigation or water districts. The type of enterprise has a bearing on the manner in which capital must be secured, the rate of interest and the period of retirement of invested capital. These factors determine the life of the project and indirectly the type of pipe to be selected.

C. Obsolescence.

Under obsolescence we understand the useful period of life of the structure. The obsolescence of a line is determined by the future development of the enterprise and also the available supply of water. The type of community or organization may determine the necessary life of the line. This is dependent largely on the prospects of a continued market for the products, if an agricultural development, or the permanency of the industrial enterprise upon which the community relies.

In many localities the supply may not be stable, as for example, in some of the foothill regions of Southern California where a protracted dry period may lower groundwater levels to such depths as to make development costs prohibitive or to permit an infiltration of sea water as has occurred in the western coastal plain. These conditions indicate an overdraft on available water supplies, hence a limited development due to curtailed supply of water.

In growing communities the combination of enterprises into one water district may sooner or later prove practicable, so that planning into a far future may not be advisable because of economic considerations. This feature is a common occurrence in the process of annexation of unincorporated territory to cities which operate municipal water works.

The factors here enumerated depend more or less upon local conditions and to some extent upon the judgment of the engineer and they determine the limits of the projected life of the project.

In many cases it may be found advisable to limit the life of the pipe line, even though other features of the project may be planned for a longer period.

II. FEATURES OF PROJECT

A. DUTY OF LINE

The duty of a line involves the economic relation between the quantity of water to be delivered and the allowable friction losses. There is a definite relation between the diameter of the pipe, the velocity of flow and the friction loss, for each pipe material.

The formulas for flow for different types of pipe and the effect of age on the carrying capacity are discussed under the heading "Carrying Capacity of Pipes". If the size of pipe and the allowable friction loss is fixed, then the velocity of flow can be computed.

Velocity may be a limiting factor, as in some cases the water may contain sufficient sand or other particles which require a certain velocity to prevent clogging of the line. Scobey* states that steel pipe lines under 14" showed loss of carrying capacity because of silt in the water with velocities under 5 feet per second. This is very likely to occur in irrigation water obtained from canals. For wood pipe, Scobey** states that silted waters should be carried with a working velocity of from 5 to 10 feet per second, while if sand is present, the line should be designed for a velocity of about 5 feet per second. For concrete pipes, Scobey states that the velocity sufficient to prevent the deposition of silt should be not lower than 3 feet per second.

The friction loss determines the total pressure which must be provided at the source of supply. If the system is a gravity flow, the design is governed by the hydraulic gradient. In the case of a force main, with the head produced by pumps, the cost of pumping is affected by the friction loss. In this case, the economic design must take into consideration the relation between the cost of increased pumping and the saving in pipe cost due to decrease in diameter.

In the Transactions of the American Society of Civil Engineers (Paper 1054,Vol.59,1907) Arthur L. Adams computes graphically that a pipe fulfills the requirements of greatest economy if the value of the energy annually lost in frictional resistance equals four tenths (.4) of the annual cost of the

* Scobey,Fred - "Flow of Water in Riveted Steel and Analogous Pipe"

** Scobey,Fred - "Flow of Water in Wood Stave Pipe

pipe line. This same value of four tenths is computed analytically in the Discussion of Adams' paper by W.E.Buck. His analytical proof is as follows:

The frictional loss according to the Chezy formula:

(1) $S = \left(\frac{V}{C\sqrt{r}}\right)^2$

where: S = frictional loss in feet per foot of pipe
V = Velocity in feet per second
A = Area of pipe cross section in sq.ft.
C = Frictional coefficient
R = Hydraulic radius
Q = Discharge in cu.ft.per second
L = Length of line in ft.
D = Cost of the pipe line
d = Diameter of pipe in inches
b = Value of 1 h.p.
B = Value of the power lost

$A = \frac{\pi d^2}{576}$ in sq.ft.

$V = \frac{576\ Q}{\pi d^2}$

$R = \frac{d}{4} = \frac{d}{48}$ in ft.

$$S = \frac{576^2\ Q^2}{C^2\pi^2 d^4 \times \frac{d}{48}} = \frac{1,613,565\ Q^2}{C^2\ d^5}$$

The total loss of head = SL; the loss of horse power = .1134 QSL, and the total value of the power lost = .1134 bQSL.

Substituting the value of S,

$B = \frac{182,978 Q^3 Lb}{C^2\ d^5}$: let $m = \frac{182,978 Q^3 Lb}{C^2}$ or $B = \frac{m}{d^5}$

If the cost of the pipe line varies as the square of the diameter,

$D = kd^2$; $B + D = \frac{m}{d^5} + kd^2$ and this is to be a minimum.

Equate the first derivative of this equal to zero.

Hence, $\frac{-5m}{d^6} + 2\ kd = 0$

or $d = \left(\frac{5m}{2k}\right)^{1/7}$

Substitute this value in the expression for B & D, and

$$\frac{B}{D} = \frac{m}{\left(\frac{5m}{2k}\right)^{5/7}} \div k \left(\frac{5m}{2k}\right)^{2/7} = \frac{4}{10}$$

A. DUTY OF LINE

Another method of approach of the problem of economic design of the size of pipe is that given by Professor W.F.Durand (Hydraulics of Pipe Lines). His solution is as follows:

Broadly speaking, the annual cost chargeable against a line arises under two heads:

1. Fixed charges proportional generally to investment or to first cost.

2. Operating costs, resulting from the annual operating program.

Let X and Y denote respectively these two classes of cost and the total. Then $u = X + Y$. (1).

The problem is to find the minimum value of u. An increase in size will increase the cost and hence the fixed charges, while it decreases the operating cost or frictional resistance.

Letting x be the diameter of pipe, and differentiating equation (1), then:

$$\frac{du}{dx} = \frac{dX}{dx} + \frac{dY}{dx} \quad (2)$$

$$\frac{d^2u}{dx^2} = \frac{d^2X}{dx^2} + \frac{d^2Y}{dx^2} \quad (3)$$

For a maximum or minimum value of u, $\frac{du}{dx} = 0$

Hence: $\frac{dX}{dx} = - \frac{dY}{dx}$ (4)

Likewise, for a minimum value of u, $\frac{d^2u}{dx^2}$ is positive in sign.

A. DUTY OF LINE

If the functions of X and Y as ordinates with respect to x as abcissa are plotted, then values of

$$\frac{dX}{dx} \text{ and } \frac{dY}{dx}$$

will represent the slopes of the respective curves. This is shown in Figure 1.

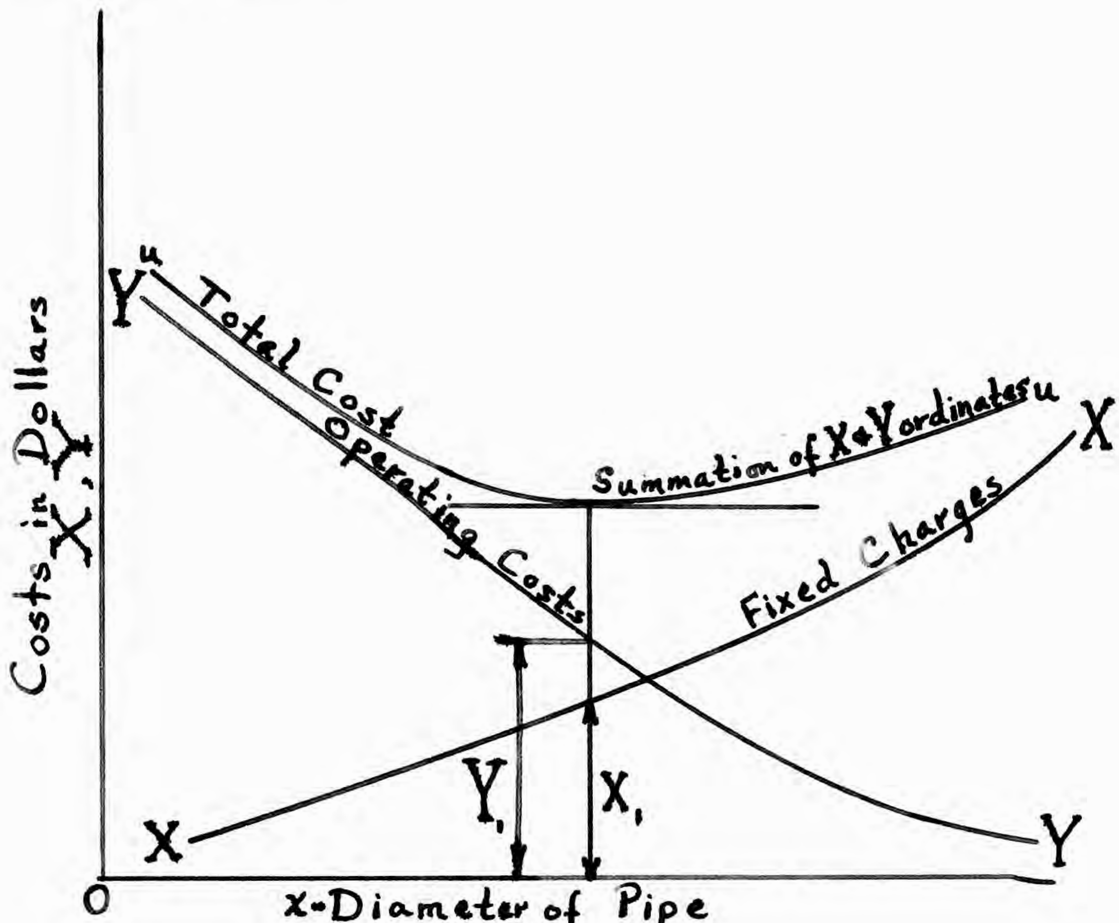


Fig. 1.

Hence, according to equation (4), the economic size of pipe will occur where the slopes are of equal value numerically, but of opposite sign. According to equation (4) $\frac{dY}{dX} =$ -1, hence if X and Y are plotted as abcissa and ordinate respectively, the values which will produce a minimum value of u will be where the slope of this curve is (−1) or where it is 45 degrees.

A. DUTY OF LINE

The actual value of x, the diameter, may be determined from a graphical inspection. In Fig.1 the values of X and Y and their sum u, are plotted for various diameters of pipe for which they have been computed. By inspection, where u is a minimum, the value of x will give the pipe diameter for the economic design.

In each of these methods given, individual calculations are made assuming certain friction losses for certain pipe materials. Hence, the value arrived at will be the most economic size for a particular pipe material. If these curves are made for each material, and the total cost computed for each material, the one giving a total minimum value will be the economic design of pipe to use from the standpoint of duty of line, as herein defined.

FEATURES OF PROJECT

B. TOPOGRAPHY

The general features of a line are determined by the topography between the source of supply and the point of distribution. In large projects, there may be several feasible routes and the final design will depend upon the minimum total of fixed costs and operating expense.

Within broad limits, a pipe line may be laid either parallel to the natural drainage of a country or transverse to it.

In the first instance, the line would be located in the comparatively smooth topography of the bottom lands with a minimum of special structures such as bridges, inverted siphons, bends and curves. The soils to be encountered would be relatively fine and soil drainage might be deficient, thus depositing corrosive salts. The line would likely be under pressure for long distances and require a heavier type of pipe.

In the second instance, the line may traverse the well-drained soils of the foothill areas, which usually are less corrosive. It may have to cross numerous deep incisions in the slopes caused by natural drainage. Pressures are likely to be a minor factor, or nil, except for inverted siphons. Special structures such as bridges, siphons, bends and curves would be a feature of the project.

In both cases, the hydraulic gradient is a governing feature of the profile and determines the depth of cover along the line.

As an example of general location relative to topography, the proposed pipe line of the City of Pasadena, from the San Gabriel Canyon to Pasadena, might be cited.

It is possible to locate this line along the relatively smooth topography of Foothill Boulevard, taking advantage of the right-of-way and the profile of the road, thus necessitating comparatively few structures, but a pipe under heavy pressure along the entire line.

As an alternative, the line might be laid along the foot of the mountains, without pressure but crossing numerous ravines and debris cones, therefore requiring the acquisition of a right-of-way, special structures and heavy grading.

A second example is the 30" line built by the Temescal Water Company from Arlington to Corona. The pipe line conveys 700 miners inches of water by gravity from the terminus of the Gage Canal, located on a steep hillside, to the upper portions of Corona. The route chosen was a private right-of-way along the hillside where a plain cement pipe under no pressure was laid, interrupted, however, by numerous inverted steel siphons, crossing ravines under heads of as much as 250 feet.

The alternative was a pressure line along the Arlington-Corona highway, which is located in the bottom lands in a relatively smooth topography.

The goal generally to be attained is an alignment resulting in the shortest line consistent with topographic conditions and a profile approaching a uniform gradient. The alignment should avoid, as much as possible, any specials except standard, also any curvatures that cannot be negotiated in the ordinary process of pipe laying. However, the cost and facility of excavation may require an irregular horizontal alignment.

Both inverted siphons and summits should be avoided as much as is consistent with the existing topography, because siphons accumulate sand and require special drain valves, while summits must be provided with air valves to admit air in the case of a vacuum and with release valves to dispose of air which is trapped.

Other problems which occur are those of highway and railway crossings, where sufficient resistance to external pressure must be provided. There may also be stream or river crossings where the line will have to be either supported above the stream or else laid on the bottom of the streambed. Salt water lagoons are a characteristic feature of Southern California and may require the construction of trestles or other means of protecting the line from the chemical action of the water.

In cities where pipe lines are laid under the pavements, the cost of repaving becomes an important item and may warrant a larger initial investment for pipe of long life.

FEATURES OF PROJECT

C. TYPES OF SOIL

The most important factor in determining the life of the pipe line is the type of soil encountered. In many cases the shifting of the line, even by a few feet, may avoid a corrosive strata of soil. The types of soils can be classified according to texture, moisture content, soluble salt content, acidity or alkalinity as denoted by the pH value, and electrical resistivity.

After the general features of the line have been studied, a general route of the line can be laid out and soil tests made along the line. A.B.Allyne* refers to several types of severe corrosive conditions which may occur. These are commonly classified as "Hot Spots" and are listed as follows:

1 - Ash or trash dumps.
2 - Previous sites of livery stables.
3 - Decayed vegetation.
4 - Chemical works
5 - Wineries.
6 - Dairies.
7 - Mineral streams.
8 - Alkali swamps and deposits.

These conditions occur mostly in distribution systems,but they may be encountered in a main supply line as well.

A detailed discussion of the different methods of soil classification and their use in determining the life of pipe follows:

Texture

The texture of a soil can be classified by the percentage of sand, clay and silt. This can be obtained by a mechanical analysis of the soil, but an experienced pipe line engineer can usually classify the soil by the color and texture, according to observation. The Bureau of Soils has classified the various soils according to their texture, and valuable information can be obtained on this subject in Bulletin #96 of that organization.

Moisture Content

Different types of soil will have the ability to retain different amounts of water. The moisture content may vary with the season. In Southern California it may be wet for only a few months in the year at most. The most severe conditions of corrosion will occur when the soil is wet,

*Allyne,A.B.: Notes on a Distribution System Soil Survey- Western Gas,August 1932,pg.86.

giving the opportunity for the ions to form in solution and hence setting up an electrochemical action. Efficiency of the soil drainage should also be observed as this is often a good indication of the amount of salts that are deposited in the top soil.

Soluble Salt Content

The amount and type of salts in the soil will often indicate the amount of corrosion that may be expected for bare pipe. It has been found that magnesium salts are among the most corrosive salts and an indication of this constituent will predict the relative corrosiveness of the soil. Usually the depressed portions of the topography will contain the more salts than the slopes, which are better drained. The salt content may also assist in determining on existing pipe lines whether the corrosion is from electrolysis due to stray currents, or from local soil corrosion.

Acidity or Alkalinity

The acidity or alkalinity of a soil is obtained from the Hydrogen ion content, the coefficient of which is given by the pH value. Care should be taken in this measurement that the soil is wet as it would he in the rainy season. The correlation of the pH values to the corrosivity of the soil was brought out by I.A.Dennison* in a survey of an Ohio pipe line and also by the recent Bureau of Standards tests on soil corrosion, and by the American Petroleum Institute tests.

Electrical Resistivity

The correlation of the corrosivity of soils and their electrical resistance has been found by many investigators. E.R.Shepard (Research Paper #298, Bureau of Standards, 1931, pg.708) reaches the following conclusion:

> ".....Soil resistivities of about 500 ohm cms.or less are usually indicative of severe corrosive action. Above about 1000 ohm cms. there appears to be little relation between resistivity and corrosion....."

In a study made by C.E.Weidner and L.E.Davis along 58 miles of pipe line in Oklahoma with the Shepard rods for soil resistivity, and measurements of the pitting depth, the authors conclude that there is a considerable correlation between soil resistivity and the depth of pitting. Soil resistivities of less than 1000 ohms are usually indicative of severe pitting, is another observation.

*I.A.Dennison: "Correlation of Certain Soil Characteristics with Pipe Line Corrosion." Bureau of Stands. Research Paper #363, October, 1931.

C. TYPES OF SOIL

As pointed out by Allyne (Gas Age Record, Aug. 22, 1931) there is a very close correlation between soil resistivity and the life of bare steel pipe in Southern California soils.

~~The~~ To measure the electrical resistivity of the soil, several types of rods have been devised. As pointed out, this means of measurement is satisfactory for the more corrosive types of soils. These tests should be made if possible at two depths, the upper and lower range of the depth the pipe will be buried. This will also disclose whether there is more than one type of soil and if there is apt to be corrosion from the action of two different soils. This electrolytic action of two soils is discussed in the chapter on soil corrosion.

The resistivity readings are usually taken at intervals of from 500 to 1000 ft. along the proposed line. The distance will vary with the type of topography and also the amount of money available for the test.

In a paper by A.B.Allyne, based on experiments in Southern California, he arrives at a method of predicting the life of bare steel pipe in soils of different resistivities; he also suggests the type of protection necessary in various soils. This information is given in Table No.1.

Practical use of the soil resistivity method for determining the protection necessary for pipe lines is given by Frederic A.Hough in the discussion of the design of the Southern Counties Gas Company line to San Diego (Western Gas, July 1932). Here, tests were made at intervals of 600 feet and at a 15" and 30" depth at each location. As a result of this survey, the line was protected in soils having a resistivity of less than 10,000 ohms and was laid bare in soils having a resistivity greater than 10,000 ohms. It was also found advisable in certain locations to move the line from one side of the road to the other in order to avoid corrosive strata of soil.

The economy of such investigations is justified, particularly when considering the small cost involved. A. B. Allyne (Western Gas, August 1931) gives some actual cost data on this method of testing. He states that a single operator can make about 25 to 30 tests per day, depending on the type of soil. The cost per test has been calculated to be 25 to 30 cents: this is the total cost involved.

Considering the cost of protective measures in the construction of water pipe lines, the cost of such surveys is negligible, and desirable.

FEATURES OF PROJECT

D. STRAY CURRENT ELETROLYSIS

In making a survey of the topographic features of a line, the possibility of stray currents for electrolysis should be given due consideration.

The most obvious and the most frequent of these currents are from electric railways and from substation ground returns. No matter how carefully the track is ballasted, there is always some leakage across to the pipe in various portions. Stray currents may also be carried by neighboring pipe lines, which is often the case in the congested areas of large cities.

The experiences encountered with neighboring pipe lines will help to solve the trouble liable to occur and this should be the first source of information.

There have been proposed several methods of bonding the pipe line to the rails of electric railways and these proposals should be investigated. Means can be taken immediately to protect the line or it can be delayed until the line has been installed. In the latter case, surveys can be made along the line to determine the actual leakage and the trouble corrected correspondingly.

The various methods of prevention of corrosion due to stray electric currents are discussed under that heading in the chapter on Pipe Coatings.

FEATURES OF PROJECT

E. Quality of Water to be Carried

It is a fact that most types of water produce incrustation and tuberculation in pipe lines: this is caused by chemical action, depending upon the different constituents contained in the water.

The following statement from Waterworks Handbook (Flyyn, Weston & Bogert, p.772) describes this type of corrosion:

"Pure water dissolves iron to a limited degree. Water otherwise pure, which contains carbonic, organic or other acids, attacks metals, particularly lead and iron, readily. The presence of oxygen increases the action on iron. Soft ground waters containing carbonic acid are the most, and surface waters containing clay and alkalis the least apt to corrode metals...."

The extent of corrosion or deposition depends on both the dissolved oxygen content in the water and also the kind and quantity of dissolved salts. The common scale-forming salts contained in water are the sulphides, chlorides and carbonates of sodium, calcium, magnesium and iron. Most of these salts, if present in harmful quantities, are taken care of at the water treatment plant if the use is domestic. Water carried by supply lines usually is not treated and consequently the pipe must be protected internally if the carrying capacity is to be maintained with corrosive water.

The use of protective linings as an aid to this problem is discussed in the chapter "Corrosion of Pipe Coatings". Chemical methods involve the use of compounds such as hydrated lime, in order to raise the pH value, and eliminate the free carbon dioxide in the water. If a slight excess of lime is present in the water, this deposits calcium carbonate on the pipe walls, which forms a protective coating against corrosion.

The experiences had with pipe lines carrying water similar to that encountered should be investigated in the consideration of this factor in preliminary design. The use of some particular chemical treatment may prove to be more economical than the use of protective linings.

From this description, the chemical analysis of the water to be carried is a prime requisite in the economic design of pipe lines.

III. COMPARISON OF AVAILABLE PIPE MATERIALS

A. CHARACTERISTICS OF AVAILABLE PIPE

1. Sizes and Thicknesses

Steel Pipe

1. Eastern Pipe is generally classified according to method of manufacture, size and thickness.

(a) Hot Rolled Pipe:

Type	Min.Diam.	Max.Diam.	Remarks
Standard	1/8"	12"	
Extra Heavy	1/8"	12"	
Double Ext.Heavy	1/2"	8"	
Large O.D.Pipe	14"	30"	
Mathesen Wt.	3"	12"	
Casing	2"	16"	
Seamless	3/8"	24"	

(b) Cold Rolled Pipe:

Elect.Welded	3"	132"	
Hammerweld	20"	96"	
Seamless	1/8"	13"	
Naylor Spiraldweld	6"	20"	
Riveted Pipe	4"	132"	

2. Western pipe is generally classigied into riveted and welded pipe.

(a) Rivetted Pipe	4"	156"	4" - 16g.
(b) Lock-seamed	4"	11"	20-24g.
(c) Elect.Welded	8"	156"	(8"-16g)-1½" above 24"

Sizes and Thicknesses

Steel pipe obtainable in Southern California is either shipped from eastern mills or rolled locally from sheet steel. Most of the small size pipe, that is, up to 16" is rolled in the East, while in the larger sizes the transportation charges make the locally rolled pipe competitive. Most of the Eastern companies follow the standard sizes, which include a standard weight, an extra heavy, and a double extra heavy thickness. The first two are up to 12", while the last is made up to 8". A thin

Steel Pipe - Sizes & Thicknesses, contd.

walled pipe in the form of casing is made by most companies, but the minimum thickness in this is usually about 1/8".

The above sizes are lap-welded above 2" and are furnished by the Bethlehem Steel Company, the National Tube Co., The Republic Steel Corp., the South Chester Tube Co., Jones & Laughlin Steel Corp., Spang Chalfant Co., Youngstown Sheet & Tube Co., and others. In other hot rolled pipe, certain companies have seamless pipe. This can be had from the National Tube Co. from 2" to 24" and from Jones & Laughlin up to 13". The National Tube Company also furnishes a rolled drawn seamless pipe to 13".

In the large size pipe, the National Tube Co. furnishes a Hammer-weld pipe from 20" to 96". This pipe is made with a maximum thickness of 1-1/2". It is a cold rolled pipe which is heated and welded by hammering. Another type of pipe furnished is the electric welded pipe. This is furnished by the National Tube Co. from 14" to 30", by the Republic Steel Corp. from 3" to 16" and by the Alco Products Co., a division of the American Locomotive Co., in sizes from 30" to 132". The Republic Steel Co. makes a light weight pipe called the Mathewson weight pipe, which is 3/16" thick, from 3" to 12". The Naylor Pipe Co. manufactures a spiral-welded pipe in sizes from 6" to 20". This pipe is made from Toncan Iron.

IN Southern California the Western Pipe & Steel Company can roll pipe from 20" to any size, with a maximum thickness of 1-1/2". This pipe is cold rolled from sheets and is then electrically butt welded. The West Coast Pipe & Steel Co.is a small concern, rolling pipe from 8" to 48", with a maximum thickness, however, of 1/4". This is also electrically butt welded pipe rolled from sheet steel.

Riveted pipe may be had in all sizes from 4" to 36",made locally by the American Steel Pipe & Tank Co. Standard pipe and casing in this type of pipe is from 8 to 16 gauge in thickness. The eastern companies and the other western companies are all prepared to furnish riveted pipe, which has been displaced, to a large extent, by welded pipe because of economy. The American Steel Pipe & Tank Co. also makes a light irrigation pipe from copper bearing steel, from 4" to 11", 20 to 24 gauge in thickness.

The advantage of steel pipe is that it can be had in all sizes and thicknesses, particularly in thin walled pipe,where it is very economical.

III. COMPARISON OF AVAILABLE PIPE MATERIALS

A. CHARACTERISTICS OF AVAILABLE PIPE

Wrought Iron Pipe

All wrought iron pipe is manufactured in the east and shipped to the west. It is all hot rolled pipe and is manufactured in the following sizes and thicknesses.

Type	Min.Diam.	Max.Diam.	Remarks
Standard	1/8"	12"	
Extra Strong	1/8"	12"	
Double Ext.Strong	1/2"	8"	
Large O.D.Pipe	14"	20"	
Standard Casing	2"	15½"	Min. thickness of 3/8"

Sizes and Thicknesses

Wrought iron pipe is all manufactured in eastern mills and must be shipped to the west. This means a delay unless local pipe distributors have a sufficient stock on hand, which is not likely with large sizes. Byers Company and the Cohoes Rolling Mills make lap-welded pipe in the standard weight and extra heavy up to 12" sizes. The Reading Pipe Company makes this lap weld pipe up to 20" in diameter. These companies also make a double extra heavy pipe, but only up to 8" in size. The Reading Pipe Company also makes a thinner walled pipe which is called standard casing: this is made up to 12" diameter.

III. COMPARISON OF AVAILABLE PIPE MATERIALS

A. CHARACTERISTICS OF AVAILABLE PIPE

Cast Iron Pipe - Sizes and Thicknesses

Cast iron pipe is classified first according to the method of casting and then into the various sizes and thicknesses or classes. Each class is either designated by a letter, as A,B,etc., or else by the working pressure, as class 150, 200, etc.

Type	Min. Diam.	Max. Diam.	Remarks
(a) Vertical sand cast			
Classes A,B,C,D	3"	84"	
" E,F	6"	36"	
" G,H	6"	24"	
(b) McWane Horizontal Cast			
Class 150	2"	8"	
" 250	2"	8"	
(c) Centrifugally spun sand core.			
Class 100	14"	24"	
" 150	4"	24"	
" 200	8"	24"	
" 250	4"	24"	
(d) Centrifugally spun metal mold (deLavaud)			
Class 100	14"	24"	
" 150	3"	24"	
" 200	8"	24"	
" 250	3"	24"	

Vertical Cast-Cast Iron Pipe

Vertical cast sand mold cast iron pipe can be furnished in classes A,B,C, and D, from 3" to 84" in diameter. It can also be furnished in classes E,F,G, and H from 6" to 36" in diameter. This type of pipe is made by the American Cast Iron Pipe Co., The United States Cast Iron Pipe & Foundry Co., and the Warren Pipe & Foundry Co. These classes are specified by the standards of The American Water Works Assoc. Class A in this case corresponds to a pressure of 43 pounds per square inch; Class B to a pressure of 86 lbs.per sq.in.; Class C to 130 and Class D to 173.

A. CHARACTERISTICS OF AVAILABLE PIPE

Horizontal-Cast Cast Iron Pipe

This pipe is made under the name McWane Cast Iron Pipe, by the Pacific States Cast Iron Pipe Company. Its manufacture is limited to sizes of from 2" to 8", and in two classes, Class 150 and 250.

Centrifugal Spun Cast Iron Pipe

Centrifugal spun cast iron pipe is furnished by both the American Cast Iron Pipe Co. and the United States Pipe & Foundry Co., the latter under the name of deLavaud pipe. The American Cast Iron Pipe Co. furnishes centrifugal spun pipe in sizes from 4" to 24" in diameter, while the deLavaud pipe is furnished from 3" to 24" in diameter. These are furnished in different classes or thicknesses to follow Federal Specifications or the standards of The American Water Works Association.

The specifications of the American Cast Iron Pipe Company call for a centrifugal spun pipe in a sand lined metal mold. The deLavaud pipe is cast in metal molds horizonally spun, with a sand core to form the bell. These pipes are also formed with special bells which are required in some cases. The de Lavaud pipe is furnished in lengths of 12 or 18 feet while the American Cast Iron Pipe is furnished in lengths of 16 ft.

III. COMPARISON OF AVAILABLE PIPE MATERIALS

A. CHARACTERISTICS OF AVAILABLE PIPE

Plain Concrete Pipe - Sizes & Thicknesses

Type	Min.Diam.	Max.Diam.	Length
Machine Made	6"	24"	
Wet Mix	4" to any size		2 to 4 feet
Dry Mix	4" " " "		

This type of pipe is cast in whatever sizes are needed, in many cases being made by the water company laying the pipe. They are usually cast at the place of laying as transportation charges make the price prohibitive in the larger sizes. The smaller sizes, up to about 36", may be shipped economically.

The American Concrete & Steel Pipe Company, the Independent Concrete Pipe Co., the Newark Pipe Co., and numerous other concerns, manufacture plain concrete pipe, the transportation charges determining whether or not machine made pipe becomes economical. This pipe can be furnished in any size desired, also in any thickness needed. The Newark Concrete Pipe Co. lists as machine made pipe sizes from 6" to 24" with corresponding thicknesses of from about 3/4" to $2\frac{1}{4}$".

The manufacture of plain concrete pipe can be divided into dry mix and wet mix processes. The dry mix pipe is made by tamping the concrete into the forms by hand. The forms are then removed and the pipe is left to cure. This type of pipe can be made economically, but does not have the strength of wet mix pipe. Dry mix pipe is also made by machining. The pipe made by the wet mix process requires a large number of molds and also a longer curing period. This type of pipe has been superceded largely by the machine made pipe of the dry process.

III. COMPARISON OF AVAILABLE PIPE MATERIALS

A. CHARACTERISTICS OF AVAILABLE PIPE

Reinforced Concrete Pipe - Sizes & Thicknesses

Type	Min.Diam.	Max.Diam.	Length
Wire reinforcing	12"	108"	8 feet
Steel Shell	12"	108"	24 ft. up to 36" in diam.

This class of pipe is manufactured with either a plain wire reinforcing, a plain steel shell with a gunited outside coat and spun inner coat, or a combination of both shell and mesh reinforcement. The type used depends on the head under which the line will be used.

In Southern California, the American Concrete & Steel Pipe Company manufacture this type of pipe. Up to heads of 150 ft. the wire mesh alone is used for reinforcement: above 150 feet the combination steel shell and cage reinforcement is used. These pipes are manufactured up to 108" in diameter by both the American Concrete Pipe Co. and the Bonna Pipe Co.

The advantage of the steel shell type is the fact that the lengths of pipe can be made to about 24 ft. The Independent Concrete Pipe Company manufactures reinforced concrete pipe having only cage reinforcing. This is made in four foot lengths from ~~22"~~ 24" to 108" in diameter.

The Newark Concrete Pipe Co. manufactures different types of concrete pipe to meet requirements. Their standard pipe is from 18" to 108" diameters, the wall thickness varying from 3" to 9": these are made with the type of joint required.

The American Society for Testing Materials gives the specifications for the amount of reinforcing and the shell thickness for different sizes of pipe. These specifications are for standard and extra strength reinforced concrete pipe. Specifications for both the type of concrete and for the reinforcing for concrete pipe are also given.

III. COMPARISON OF AVAILABLE PIPE MATERIALS

A. CHARACTERISTICS OF AVAILABLE PIPE

Wood Pipe - Sizes & Thicknesses

Wood pipe is classified as machine banded, continuous stave of bored pipe. It is made in the following sizes and thicknesses:

Type	Min.Diam.	Max.Diam.	Remarks
Continuous stave	10"	16 ft.	Redwood or Fir
Machine banded	2"	32"	" " "
Bored pipe	2"	6"	" " "

Wood pipe is divided into continuous stave, machine banded and bored pipe. The Little River Redwood Company builds continuous stave pipe from 10" to 16 ft. in diameter, while the Pacific Tank & Pipe Company furnishes this pipe from 10" to 14 ft. in diameter. This pipe is shipped in knocked-down staves to the field and is assembled along the line. Both of these companies make this continuous stave pipe out of redwood, although fir and other materials have been used.

Machine banded pipe is made also from either redwood or fir and can be had from 2" to 32" diameters. The length of sections averages 12 feet.

Bored pipe is as the name indicates, bored from logs and is furnished from 2" to 6" inside diameter.

2. RESISTANCE TO INTERNAL PRESSURE

1. Resistance to internal pressure depends upon the tensile strength of the material, the efficiency of the seam (if there be any seam) and the efficiency of the field joint. Other things being equal, the tensile strength of the material is the governing factor in design. With this in view, the sequence of materials to be considered in the economic design relative to internal pressure, as given for each make of pipe by the manufacturer in Table No. 3, is as follows:

Material	Ultimate Tensile Strength Lbs. per in.	Working Stress ~~Pressure~~
Steel	45,000	15,000
Wrought Iron	40,000	13,300
Cast Iron (Vert.& Horiz. Cast) sandmold	20,000	6,500
Cast Iron deLavaud (Centrifugal Spun)	30,000	9,000
Cast Iron sand mold (centrif. spun)	25,000	8,000
Plain Concrete	250	40
Reinforced Concrete-Reinforcing Rods	60,000	18,000
Wood Stave-Steel Reinforcing Bands	60,000	16,000

2. A second feature in the economic design arises from the fact that graduation in thickness of commercial pipe is not the same for all materials and that for certain types of pipe material there may be a considerable difference between the theoretically required thickness and that commercially available.

Steel. For a given diameter, steel pipe is obtainable in thicknesses varying from 20 gage with small gradations in thickness up to such thickness as can be rolled.

Wrought Iron. Wrought Iron pipe can be obtained in casing, standard, extra strong, and double extra strong thicknesses.

Cast Iron. Cast iron pipe is made in 8 grades of thickness known as classes A-H.

RESISTANCE TO INTERNAL PRESSURE

Reinforced Concrete and Wood Stave. Reinforced concrete and wood stave pipe both depend upon the strength of the steel to withstand the internal pressure, hence are adapted to a considerable range of pressure for a given diameter.

3. Because of limits in the tensile strength of the materials and the limiting features in the manufacture, the available types of pipe can be segregated into three classes according to their economic use.

It will be generally found that the most economical use of the pipe material is when it approaches the maximum practicable internal pressure. With a given factor of safety for a particular material, the following classification can be made of the various pipe materials considering the available sizes and thicknesses manufactured.

Class	Pressure	Kind of Pipe
Pipe suitable for high pressure	250 to 500 lbs.per sq.in.	Steel, Wrought Iron
do. medium pressure	100 to 250	Steel, Cast Iron
" low "	0 to 100	Steel, Cast Iron, Wood Stave, Reinforced Concrete

Steel Pipe: For steel pipe, with the new processes of welding, a joint of greater strength than the pipe can be obtained, hence the tensile strength of the material governs the design.

In the ordinary hot rolled pipe of Eastern manufacture, ultimate strength and yield point, together with the chemical characteristics and other physical characteristics, can be obtained from the manufacturer. As shown on Table No. 3, the ultimate strengths of the material have a minimum of 45,000 lbs. per sq.in. Allowing a factor of safety of 3 to take care of water hammer, initial stresses and other unknown factors, a working stress of 15,000 lbs. per sq.in is arrived at.

If the pipe is rolled from sheet steel, the manufacturer's standards ~~are~~ for the various grades of steel are given, also the ultimate strength and yield point. The western rolled pipes, which are all made from sheet steel, are electrically butt welded, giving a joint of more than 100% efficiency. The minimum grade has an ultimate strength of 45,000 lbs. per sq.in. from which a working stress of 15,000 lbs. per sq.in. may be used with a factor of safety of 3. In this type of pipe as well as in the eastern pipe, the present tendency is to use a better grade of material giving a higher ultimate and consequently a higher working stress.

In riveted steel pipe, the strength of the joint governs the design. It is possible to compute the efficiency for the various types of joints, both transverse and longitudinal factory joints, and of riveted or driven field joints. This depends on the number of rivets, the rows and the strength of the rivets as well as the pipe. Large pipe made from sheet steel may be butt strap welded at the joints. The efficiency of this joint can also be computed. A diagram prepared by the Baker Iron Works (now Consolidated Steel Co.) giving the allowable head for relatively small diameter pipes with various joint efficiencies and various factors of safety for an ultimate strength of 50,000 lbs. per sq.in. is shown on Plate No.11.

Since steel pipe can be obtained in all of these different sizes, it can be economically designed <u>for all classes of pressure</u>. The internal pressure which a pipe of a given thickness can carry can be computed from the ultimate strength of the material, the efficiency of the joints, and an allowable factor of safety.

The following formula can be used to obtain the allowable pressure of steel pipe:

Let t = thickness of pipe wall, in inches
f = factor of safety
p = internal pressure in lbs. per sq.in.
S_t = ultimate tensile strength in lbs.per sq.in.
e = efficiency of joint
d = internal diameter in inches

$$pd = \frac{S_t e}{f} : 2t$$

or $$p = \frac{2tS_t e}{fd}$$

Wrought Iron Pipe

Wrought iron pipe is all hot rolled and of eastern manufacture. The various physical standards such as ultimate strength and yield point, and the chemical analysis of the material, is given by the manufacturers. The four thicknesses, casing, standard, extra strong, and double extra strong limit the allowable pressure for any given diameter pipe. As shown on Table No. 3 , the ultimate strength of the material is 40,000 lbs. per sq.in. Allowing a factor of safety of 3, a working stress of 13,300 lbs. per sq.in. is arrived at.

Since the thinnest pipe manufactured is the casing in wrought iron pipe, the economic use is limited to only the upper range of pressures. With a factor of safety as indicated above, the casing will carry a pressure of 500 lbs. per sq.in. The manufacturer's test pressures give a good indication of the factor of safety which is being allowed. Hence, this should be taken into account when making the design. The allowable pressure for various sizes of wrought iron pipe can be obtained from the formula:

$$p = \frac{2_t S_t e}{f d}$$

where:

p is the pressure in lbs.per sq.in.
t " " thickness in inches
S_t " " ultimate tensile strength in lbs. per sq.in.
e " " seam efficiency
f " " factor of safety
d " " internal diameter in inches.

Cast Iron Pipe.

For cast iron pipe the tensile strength of the material varies with the method of casting the pipe. Centrifugal spun pipe is guaranteed for a higher tensile strength than the vertical or horizontal cast pipe. This spinning tends to give a more uniform and compact lining to the pipe.

Tests by Professors F.N.Menefee and A.E.White of the University of Michigan in 1928 show an average tensile strength of 31,150 lbs. per sq.in for centrifugal spun deLavaud pipe, which is cast in a metal mold. Tests made by the Board of Fire Underwriters show an average tensile strength of 35,658 lbs. per sq.in. These two tests show a decided advantage in tensile strength for the centrifugal spun pipe. The ultimate strengths guaranteed by the manufacturers is given in Table No. 3 . This shows a large variation in the guaranteed ultimate strength of the material. The American Cast Iron Pipe Co. centrifugal spun pipe, which is spun in a sand mold, has an ultimate of 25,000 lbs. per sq.in. The vertical cast sand mold pipe has an ultimate strength of 20,000 lbs. per sq.in.

The economic use of cast iron pipe is limited to the two lower classes of pressure, namely up to 250 lbs. per sq.in.

RESISTANCE TO INTERNAL PRESSURE

First of all, the classes of greater thickness are made only in limited sizes. Classes A to D are the only classes made in all sizes up to an 84" diameter. Class D pipe is given a manufacturer's test of 300 lbs. per sq.in. Classes E and F are made up to 36" diameter, while classes G and H are made up to 20". In these larger sizes, the excessive thicknesses also limit the economic design because of the cost.

The bell and spigot joint does not limit the pressure on the pipe. In high pressure pipe, as those above class D, it is common practice to use a flanged joint.

Since the pipe is cast as a unit, there is no seam efficiency which must be taken into account. Hence, various formulas have been developed which tend to take into consideration all of the factors entering into the stress of the pipe. These can be given as follows:

1. Fanning's formula for cast iron pipe as given on page 193, Durand-Hydraulics of Pipe Lines -

$$t = \frac{(p+97.2)d}{7220} + \frac{1}{3}$$

where:

t is the thickness in inches
p " " pressure in lbs.per sq.in.
d " " diameter in inches

This formula provides for the following combination:

(a) A working pressure p with a working stress of 3610 lbs. per sq.in.
(b) An excess pressure of 97.2 lbs.per sq.in as a result of shock or other unusual conditions and with the same working stress.
(c) An excess thickness of 1/3" to allow for corrosion and wear, accidents of manufacture,etc.

2. Fanning's formula for cast iron pipe as given by Flinn, Weston & Bogert, page 385, W.W.handbook)

$$t = \frac{(p+100)d}{1.6\ S_t} + 1/3\left(1 - \frac{d}{100}\right)$$

where:

S_t is the ultimate tensile strength

3. The following formula can be used, with the factor of safety governed by the conditions of the pipe line.

$$t = \frac{p\ d\ f}{2\ S_t}$$

where:

f is the factor of safety

RESISTANCE TO INTERNAL PRESSURE

Plain Concrete Pipe

For plain concrete pipe the concrete must take some tensile stress. The strength of the concrete in tension depends on the mix of the pipe, together with the type of aggregate used. In building designm the concrete is usually taken to carry a tensile working stress of 40 lbs. per sq.in. The ultimate tensile strength is commonly taken as 10% of the ultimate strength in compression. This gives an average ultimate tensile strength of about 250 lbs. per sq.in. This relatively low strength of concrete in tension limits the use of plain concrete pipe to heads of about 10 ft. or less.

Table No. 2 gives the results of tests at the University of California on plain concrete pipe. The head for various mixes and diameters is given at which the concrete will have a factor of safety of 2 before excessive leakage will occur.

The thickness required for various heads assuming a working stress of 40 lbs. per sq.in can be obtained from the following formula for plain concrete pipe:

$$t = \frac{d\,p}{80}$$

where:

t is the thickness in inches
d " " inside diameter in inches.

Reinforced Concrete Pipe

For reinforced concrete pipe the steel reinforcing is designed to take all of the tensile stress, although the inner surface of the concrete must stand its share of the stress if it is to transfer the stress to the steel. The company manufacturing the pipe may furnish minimum specifications or they may follow certain standards for both the concrete and the steel. The American Society for Testing Materials lists specifications for reinforced concrete pipe. These cover both Standard and Extra Strength reinforced concrete pipe, from 24" to 108" in diameter. The amount of steel and the shell thickness are given for ultimate strength of concrete of three grades. The steel reinforcement follows the standards of reinforcing steel which are listed in another set of standards of the Society.

Reinforcing is divided into two different types, the wire reinforcing, commonly called the "spider", and the steel shell. For heads above 250 feet, it has been observed that the concrete becomes pervious, causing the pipe to leak, or as it is commonly termed, to "sweat". Hence, it is common practice to use a steel shell, in addition to two wire cages of reinforcement, for heads above 150 feet. These wire cages are placed, one inside of the shell and the other outside.

RESISTANCE TO INTERNAL PRESSURE

Since the steel is protected by the concrete, the minimum steel to satisfy the tensile strength with an allowable factor of safety may be used. The economic use of reinforced concrete will be in pressures up to about 125 lbs. per sq.in.

The joints are made as strong as the rest of the pipe by lapping over the reinforcement and also putting in circular reinforcing at the lap.

Three gr ades of reinforcing steel wire are listed for reinforced concrete pipe by the American Society for Testing Materials: these are as follows:

If cold drawn steel wire is used, a working stress of 27,500 lbs. per sq.in. shouad be used. If reinforcing bars of billet steel of intermediate or hard grade are used, a value of 20,000 lbs. per sq.in may be used. If billet steel of structural grade is used, a value of 18,000 lbs.per sq.in should be used.

For the steel shell reinforcement, 12,000 lbs.per sq.in. is used as the working stress in Hume steel pipe. The ultimate strength of this steel is 55,000 lbs. per sq.in. The same stress is used in the wire reinforcing for the Hume centrifugal concrete pipe, which does not have the steel shell. For the last named type of pipe, the wall thickness of concrete is obtained from the following formula:

Hume Concrete Pipe.

$$T = \frac{P\,R}{S}$$

where:

T = the wall thickness in inches.
P = the internal pressure in lbs. per sq.in.
R is the internal pipe radius, in in.
S " " allowable concrete stress, depending on the conditions of the line

Considering the steel reinforcing to take all of the tensile stress, the following formula may be used to determine the amount of reinforcing per lineal inch of pipe:

$$t = \frac{p\,d}{2\,f_s}$$

where:

t is the area of steel per lineal in.
p " " pressure in lbs.per sq.in.
d " " inside diameter in inches
f_s " " working stress of the steel.

RESISTANCE TO INTERNAL PRESSURE

Wood Stave Pipe

In order to secure a water-tight joint when the pipe is under load, it is necessary to induce an initial tension in the steel bands. Hence, the total load of the band is composed of the tensile stress due to water pressure and of this initial tension.

The resistance to internal pressure depends on both the tensile strength of the steel bands and the bearing pressure of the bands on the wood.

The various manufacturers of wood stave pipe specify a minimum tensile strength of steel and the working stress at various heads. This steel may also be referred to the standards of the American Society for Testing Materials if listed so by the manufacturer. The ultimate strength for steel as shown on Table No. 3 is 60,000 lbs. per sq. in. The working stress under this strength is taken as 16,000 lbs. per sq.in. by the manufacturers. The spacing depends on the size of the bands and the internal pressure. A minimum spacing of 12" is usually specified.

Page 282 in Etcheverry, Vol. II states the experimental results of D.C.Henny on the allowable bearing loads of bands on wet redwood. Ther permissible loads vary from 600 to 747 lbs. per sq.in for bands from 3/8" to 7/8" in diameter. Arthur L.Adams* uses an average value of 650 lbs. per sq.in. for the bearing value. For this value he computes the required thickness of wood stave for various pipe diameters. The bearing strength of the wood also determines the allowable spacing of the bands and Adams also computes these values for different pipe diameters.

The economic use of wood stave pipe is limited by these two requirements to pressures of the lowest class; that is, up to 100 lbs. per sq.in.

Various formulae have been offered for the band spacing for different pressures and sizes of pipe. Some of these are as follows:

*Proceedings, A.S.C.E., 1897

RESISTANCE TO INTERNAL PRESSURE

1. A.L.Adams - Assuming 100 lbs. per sq.in initial tensile stress in bands because of swelling of wood and also one and one-half times the actual stress due to band compression:

$$f = \frac{S}{(R+1.st)p + 100t}$$

where:

- f is the band spacing in inches
- S " " tensile load in bands in lbs.
- R " " internal radius in inches
- t " " stave thickness " "
- p " " water pressure in lbs. per sq.in.

2. H.C.Henny-Neglecting the 100 lbs. per sq.in initial tension:

$$f = \frac{S}{(R+1.5t)\,P}$$

3. Considering the bearing stress of the band on the wood:

$$B\,(R+t)\frac{d}{2} = S$$

where:

- B is the bearing stress in lbs.per sq.in.
- R " " internal radius, in inches
- t " " stave thickness, " "
- d " " band diameter, " "
- S " " tensile load in the band, in lbs.

3. RESISTANCE TO EXTERNAL LOADING

External loading on pipe may be divided into four general classes:

1st - The dead local of backfill and of such structures as may be superimposed upon the backfill.

2nd - The life load which may be transmitted to the pipe as from vehicular or engine loading through the backfill.

3rd - External loading such as an empty pipe submerged in water or the loading caused by air pressure on an uncovered pipe line in which a partial or nearly complete vacuum has been produced.

4th - Where pipe line is supported on pier or a trestle or on cradles, resulting in bean action.

The stresses caused by such external pressures involve tension, compression and torsion. From the standpoint of external pressure, therefore, a pipe with heavy walls and a relatively large moment of inertia capable of withstanding buckling, bending or torsion, will be found to meet the requirements. From this point of view, the pipe materials enumerated in order of resisting these forces are as follows:

1. Reinforced Concrete Pipe
2. Cast Iron Pipe
3. Wrought Iron Pipe
4. Thin Steel Pipe
5. Wood Stave Pipe

Load on Buried Pipe

The distribution of loading on a buried pipe depends upon the size and shape of the pipe trench with reference to the diameter of the pipe, the depth of fill, and method of backfilling. In order to effect a distribution of a concentrated live or dead load onto the full length and width, pipe should be buried under two or more feet of soil, depending on its diameter.

Various tests have been made to determine the amount of load on the pipe for different soils under various ditch conditions. Tests for cast iron pipe of 27" diameter and clay pipe of 12" and 36" diameters are given in Bulletin #45, Iowa State College, 1932, by W.S.Schlick. For a 27" cast iron pipe in a 39" ditch, the load taken by the pipe for the particular soil studied was about 5/8ths of the weight of the soil above the pipe, indicating that the arch action of this

Load on Buried Pipe, contd.

soil had taken up 3/8ths of the load.

Marston and Anderson in Bulletin #31 of Iowa State College, 1913, present the most comprehensive study of the load taken up by various soils for different widths of ditches. This study resulted in the following formula:

The weight on the pipe $W = c\,w\,B^2$

c = constant depending on type of soil and ratio of depth to width of trench
w = weight of soil per cubic foot in pounds
B = the width of the trench in feet

For depth of cover of only 2 or 3 feet, the stresses set up by external pressure of the fill alone may be neglected, but for depth of cover over this amount the design may be considerably affected if thin steel pipe is to be used.

Prof. Etchevery, in his work on Irrigation, page 242, recommends the use of Professor Talbot's formula for the bending moment of external earth loads. This formula was obtained from experiments on Cast Iron Pipe:

Maximum moment $M = 1/16\ W\ d$

W = total vertical load on pipe in pounds per inch of length
d = diameter of pipe in inches.

A method of computing the stress in the materials due to external loads is given in University of Illinois Bulletin #22. The moment at the top of the pipe due to a uniform vertical load:

$M = 1/16\ W\ d$

Where:
M is the moment at top of the pipe
W is the total load per inch of pipe
d is the pipe diameter in inches.

For pipes, the relation $f = \frac{Mc}{I}$ can be assumed as nearly true.

Then considering the stress from bending alone,

$f = \frac{6M}{t^2}$

Where:
t is the pipe thickness in inches
f is the stress in lbs.per sq.in.

Load on Buried Pipe, contd.

Example:

Assume 100 lbs. per cubic foot as the soil weight on the pipe and 20 feet of cover.

$$\text{Then } M = \frac{1}{16}\left(\frac{100xh}{12} \times \frac{d}{12}\right) d = \frac{h}{16} \times \frac{100}{144} d^2 = \frac{t^2 f}{6}$$

and:

$$f = \frac{6hd^2}{16t^2} \times \frac{100}{144} = \frac{.26hd^2}{t^2}$$

where: h is the depth of soil cover in feet.

Assuming further a pipe of 20" diameter necessary to withstand an internal pressure of 100 lbs. per sq.in., the above formula can be used to find the stress for various pipe materials due to bending alone, with a cover of 20 feet of the assumed soil.

(a) 20" #12 gauge steel pipe

$t = .109"$

$$f = \frac{.26 \times 20 \times 400}{.109^2} = 175{,}000 \text{ lbs. per sq. in.}$$

(b) 20" 3/8" wrought iron pipe

$$f = \frac{.26 \times 20 \times 400}{.375^2} = 14{,}800 \text{ lbs. per sq. in.}$$

(c) 20" Class C - cast iron pipe

$t = .87"$

$$f = \frac{.26 \times 20 \times 400}{.87^2} = 2{,}760 \text{ lbs. per sq. in.}$$

External Loading from Water or Air Pressure.

Cases of pipe failure caused by external pressure of air or water are recorded. In the former, the creation of a vacuum causes atmospheric pressure to come into play with a maximum pressure of 15 lbs. per sq. in. possible, and in the latter, an empty line may be subjected to an external pressure of 62.5 lbs. per sq. foot for each foot of the depth of submergence.

3. RESISTANCE TO EXTERNAL LOADING

Pipe Lines supported on Pier or Trestle

If a line is supported as a continuous beam on piers, cradles or a trestle, a different set of stresses is set up than that resulting from earth cover and the maximum fiber stress may be computed by the formulas:

Maximum moment $M = W L/12$

W = load in lbs.
L = length of section between supports in inches

Maximum fiber stress $f = Mc/I$

M = moment in inch lbs.
c = distance to outer fiber
I = moment of inertis

In large pipe lines supported on saddles, local stresses will be produced at the points of support. If the wall thickness of the pipe is relatively small in comparison to the diameter, additional support in the form of girth rings may be required. This type of support was found necessary in several places in the construction of siphons on the Los Angeles acqueduct, and accomplished by using a steel channel and filling the space to the pipe with concrete.

Herman Schorer* presents an exact theory of design of large pipe lines based on the use of ring girders. He states in the synopsis to his paper:".....Theory and experience show that a pipe line so designed does not require any intermediate stiffening angles, even in the case of comparitively thin shells. Much larger spans than those permitted by the customary saddle supports are entirely feasible and considerable savings in steel and excavation may be realized with a larger factor of safety....."

Testing of External Loading: Common Practice

Various tests have been devised to determine the strength of different pipe materials to external load. That most commonly used is the three point tests. These tests are usually specified for steel, cast iron and reinforced concrete pipe. For reinforced concrete pipe, the American Society for Testing Materials and the Joint Committee of various organizations have both prepared standards on shell

*Herman Schorer-"Design of Large Pipe Lines":A.S.C.E.Proceedings, September,1931

Testing of External Loading: Common Practice, contd.

thickness and amount of reinforcement for various external loads and have also specified the minimum requirements in the three point loading tests.

Conclusions.

Cast iron pipe, wrought iron pipe, standard steel pipe and reinforced concrete pipe have relatively thick walls and large moments of inertia and are capable of supporting vacuum pressure as well as a heavy over-burden of earth. External loading, therefore, may become a minor factor in the design with these types of pipe, while with light steel pipe and wood stave pipe, the external load may become the deciding issue.

4 CARRYING CAPACITY OF PIPES

The carrying capacity of pipes is a function of the radius, the slope, and the frictional resistance. The basic formula used for determining the velocity of water in pipes is the Chezy formula.

$v = C\sqrt{rs}$, where v is the velocity in feet per second, r the hydraulic radius in feet, s the hydraulic slope, and c a coefficient depending upon the roughness of the pipe. This coefficient c was assumed to be a constant. Subsequent investigations showed that c is a function of roughness as well as of the radius and slope. This multiple function of c is taken into consideration in Kutter's formula*. However, because roughness generally increases with the age of the pipe, c, as a matter-of-fact, is a variable quantity for a given type of pipe. This factor is recognized in the formulae evolved by Williams & Hazen and also in those by Fred C. Scobey.

The investigations by Scobey, made for the U.S.Dept. of Agriculture and published in its bulletins, are the most up-to-date and complete. They bear specifically on the effect of age, and separate formulae are presented for steel, concrete and wood pipe. Many of the experiments were made in Southern California so that the results are applicable to the studies presented in this thesis. Scobey's formulae, therefore, were adopted for computations of relative capacity of steel, concrete and wood pipe, while Williams & Hazen formula has been used in connection with cast iron pipe.

Various enamels have been recently spun as linings on the inside of metal pipes. These promise to give high flow coefficients in the Williams & Hazen formula. A recent test in Los Angeles on a straight section of new steel pipe with no projecting seam, and a spun lining, gave a value of 158 in the Williams & Hazen formula. Another spun coating is the Talbot lined pipe which also gave very high flow coefficients. The resistance of these enamel linings to age will determine their economic benefit on pipe lines.

The following general remarks are submitted on the carrying capacities of different types of pipes:

Steel Pipe

Scobey** suggests the following general formula of flow for steel pipe, based on his experiments:

* "Flow of Water in Rivers and Other Channels", by Ganguillet & Kutter.

** The Flow of Water in Riveted Steel and Analogous Pipe, by Fred Scobey, U.S.Dept.of Agriculture, Bull.150, Jan.1930.

CARRYING CAPACITY OF PIPES

Where:

$$H = \frac{K_s^1 V^{1.9}}{D^{1.1}}$$

$$V = \frac{H^{.53} D^{.58}}{K_s^{1}\,^{.53}}$$

$$Q = \frac{.78 H^{.53} D^{2.58}}{K_s^{1}\,^{.53}}$$

H = the head loss in ft. per 1000 foot length

K_s^1 = coefficient of flow

V = the mean velocity in ft. per second

D = inside diameter of pipe in in.

Q = capacity in cu.ft.per second

Steel pipe is divided, by Scobey, into three classes:

Class 1 - Full riveted pipes, having both longitudinal and girth seams held by one or more lines of rivets with projecting heads. From a capacity standpoint, pipe with countersunk rivets on the interior belongs in class 3.

Class 2 - Girth riveted pipe, having no retarding rivet heads in the longitudinal seams, but having the same girth seams as the full riveted pipe.

Class 3 - Continuous interior pipe, having the interior surface unmarred by plate offsets or by projecting rivet heads in either longitudinal or girth seams. Not necessarily described as smooth. This class also applies to welded pipe.

The coefficient K_s^1 is given for the three classes as follows:

Class 1.

(a)	K_s^1 ----.38	New metal to 3/16" thick	
(b)	.44	" " " 7/16" thick, taper joint	
(c)	.48	" " above 1/2" thick taper joint	
(d)	.52	" " " 1/2" thick butt strap	

Class 2. K_s^1 ----.34

Class 3. K_s^1 ----.32

Scobey divides the effect of age on carrying capacity into two parts, one for eastern waters and one for western waters, the latter he terms "relatively inactive".

CARRYING CAPACITY OF PIPES

For the eastern waters, Scobey suggests the following change in the flow coefficient, assuming K_s' for a new pipe:

$$K_s = K_s' \, e^{.015t}$$

For western waters known to be relatively inactive, the following formula for change in coefficient is presented:

$$K_s = K_s' \, e^{.01t}$$

where:

K_s is the flow coefficient for a particular condition.

K_s' " " value of K_s for new pipe

e " " base of naperian logarithims equal to 2.718

t " " age of the pipe in years

Scobey states the following facts as some of the conclusions in the experiments on steel pipe:

"There is a material difference in the carrying capacities of steel pipes. Other things being equal, the difference is due to the type of unit assembly and the field joints.

"Present indications, based on the performance of pipes of various ages, are that all iron and steel pipes lose capacity progressively when in use. Time alone will determine the extent of immunity afforded by some of the newer coatings.

"Assuming the capacity of full riveted pipe with plate less than ½" thick as 100%, then continuous interior pipe (class 3) without rivet heads will carry about 18% more, and girth riveted pipe, but continuous on the straight seams (class 2) will carry nearly 15% more. With the same base, thin sheet (gage metal) pipes with flat rivet heads will carry 8% more; heavy plate pipe of cylinder or taper joints will carry about 4% less; and heavy plate, butt strap pipe will carry about 8% less....."

Wrought Iron Pipe

For all purposes of computation, the carrying capacity of wrought iron pipe can be taken the same as steel pipe, the different flow coefficients depending on the class of pipe, the same as those for steel.

CARRYING CAPACITY OF PIPES

Cast Iron Pipe

The following general formula for the flow of water in pipes is given by Williams & Hazen:*

$$v = CR^{0.63} S^{0.54} 0.001^{-0.04} = 1.318 CR^{.63}S^{.54}$$

In this formula, v is again the velocity in feet per second, S the hydraulic slope, R the hydraulic radius in feet and C the coefficient of roughness.

Relative to cast iron pipe, the following remarks are made by the authors -

> "The gradual roughening of the interior of cast iron pipe is one of the most familiar of water works phenomena. It is also one of the most difficult to compute. In a general way it may be said that in a series of years, which is not long compared with the total life of the pipe, the roughening of the surface and the reduction of the area through rusting and tuberculation reach such an extent that twice as much head is consumed in sending a given volume of water through it as was the case when the pipe was new."

The coefficient c, as determined by the experimenters, becomes larger with increasing diameter for pipes of like age as indicated by the following examples:

Age in Years of Cast Iron Pipe
to which C applies
Williams & Hazen Tables

C	DIAMETER 4"	10"	20"	30"
140	Very best pipe new, perfectly straight	do.	do.	do.
130	New pipe	"	"	"
120	4	5	5	6
110	-	10	-	-
100	13	17	19	19
90	-	-	28	30
80	26	35	41	43
60	45	68	-	-
40	75	-	-	-

*Hydraulic Tables, by Gardner S. Williams and Allen Hazen.

It is further stated in regard to these classifications:

> "It must be understood that these are necessarily very rough approximations, based on the best data available, which are principally for soft and clear but unfiltered river-waters. Hard waters and lake waters will often attack the pipe less rapidly, and the figures must then be increased. Sometimes they must be multiplied by two or more. Other waters will corrode the pipes more rapidly than the average, and for them the values will be reached more quickly than the figures indicate."

Tests made by the City of Pasadena with Cast Iron Pipe gave the following value for C in the Williams & Hazen formula:

10" C.I.Pipe laid in 1887, tested in November, 1932, average of three tests c = 95

12" C.I.Pipe laid in 1921, tested in November, 1932, mean of three tests c = 87

8" C.I.Pipe laid in 1921, tested in November, 1932, c = 93.5

Concrete Pipe

Scobey offers a new formula of flow based on his experiments with concrete pipe.*

$$V = C_s H^{.5} d^{.625}$$

$$H = \frac{V^2}{C_s^2 d^{1.25}}$$

$$Q = .00546\, C_s d^{2.625} H^{.5}$$

where:

Q is the carrying capacity in cu.ft. per second
H is the head loss in feet per 1000 foot length
V is the velocity in ft.per sec.
C_s " " new coeff.of retardation
d " " mean diam.of pipe, in in.

where the following coefficients are recommended:

Class 1. C_s = .267

Class 2. C_s = .310

Class 3. C_s = .345

Class 4. C_s = .370

Since Q is a direct function of C, the carrying capacity increases gradually from Class to Class 4.

*F.S.Scobey: The Flow of Water in Concrete Pipe: U.S.Dept.of Agriculture Bulletin #852, October, 1920.

Concrete Pipe, contd.

Formulas for the flow in concrete pipe are divided into four classes:

Class 1. For old California cement pipe lines.

Class 2. For modern dry mix concrete pipe and monolithic concrete pipe or tunnel linings made over rough wood forms.

Class 3. For small wet mix pipes in short units; for dry mix pipe in long units; for average monolithic pipe made on steel forms.

Class 4. For glazed interior pipe lines; for large cement lined iron pipes; for monolithic pipe lines where joint scars and all interior surface irregularities are removed.

Some of the conclusions of Scobey on concrete pipe are listed as follows:

".....A concrete surface is not subject to a progressive roughening influence like the tuberculation found in iron and steel pipes, though tuberculation of the reinforcement may occur if too near the surface. Roots may affect a poorly made or poorly laid pipe, but will not influence a hard, well jointed pipe.....

".....In considering various kinds of pipes, it is not sufficient to compare concrete with wood, concrete with steel or iron, concrete with vitrified clay, or even concrete with concrete. This is true not only from a capacity standpoint, nut also from the standpoint of strength, life, and operation. One particular class of concrete pipe must be compared with the pipe of the other materials or with concrete pipe of the other classes. Two estimates or bids for a concrete pipe may differ 20%, yet from a capacity standpoint alone, the higher in cost may be the more economical......

"Waters of the Southwest are less liable to develop retarding growths than those of the East and Northwest".

For the change in carrying capacity of concrete pipe, three reasons of deterioration are listed. These are as follows:

(1) The invasion of rootlets from neighboring trees.
(2) Scour from the water.
(3) The accumulation of lime or other deposits

The same can be said for concrete pipe as for wood pipe in this respect: that is, if there is any possibility of any of the above three factors deteriorating the line, then they shoukd be taken into account.

Wood Stave Pipe

Scobey offers the following general formula for wood stave pipe based on the experimental data* -

$$H = \frac{7.68\ V^{1.8}}{d^{1.17}} = \frac{.419\ V^{1.18}}{D^{1.17}}$$

$$V = 1.62\ D^{.65}\ H^{.555}$$

$$Q = 1.272\ D^{2.65}\ H^{.555}$$

where:

D is the pipe diameter in ft.
H " " head loss in feet per 1000 ft.
Q " " quantity of flow in second ft.
V " " mean velocity in ft. per second.

Since the experimental data shows an average of steady carrying capacity with age, no correction need be made unless the chemical composition of the water or impurities in the water warrant it.

Tests were made and abstracted by Scobey covering both machine banded and continuous stave pipe. These were put into one classification, however, and not divided according to type of pipe. Some of the conclusions arrived at by Scobey are as follows:

> "....That the data now existing do not show that the capacity of wood stave pipe either increases or decreases with age. This statement, of course, does not consider sedimentation, a purely mechanical process.... That if silted waters are to be conveyed the pipe shall be designed for a working velocity of from 5 to 10 feet per second...... That if sand is present in the water, the design should be for a velocity of about 5 feet per second, which will be high enough to carry out a large part of the sand and at the same time not so high as to seriously errode the pipe. The better method, of course, is to remove the sand by sumps or other means...

*F.C.Scobey-"The Flow of Water in Wood Stave Pipe", U.S.Dept. of Agriculture, Bulletin #376-1916

CARRYING CAPACITY OF PIPES

"...That wood pipe will convey about 15% more water than a 10 year old cast iron pipe or a new riveted pipe and about 25% more than a cast iron pipe 20 years old, or a riveted pipe 10 years old......"

In the first of these statements listed above, the data obtained by Scobey showed that for wood pipe 22 of the lines decreased in capacity, while 20 of the lines increased in capacity along the same range of age. It seems reasonable that each line will have its own features which in time will determine whether the capacity will materially decrease with age. If the line is laid in an agricultural region, and is buried, it is likely that the roots of plants and trees will penetrate into the pipe and retard the flow, after a long period.

CARRYING CAPACITY OF PIPES

Effect of Commercial Sizes of Pipes on Actual Carrying Capacity

In the economic design of a pipe line, a further factor presents itself in that the computed size of pipe must be adjusted to commercial specifications. This may require the adoption of a larger diameter than computation would indicate, resulting in lesser friction losses, or vice versa.

In the following tabulation, the commercial sizes of pipe are indicated by a cross:

Diam. in in.	Riveted Steel Pipe	Welded Steel Pipe	Wrought Iron Screw Pipe	Vert. Sand mold Cast	Horiz. Cast	Cent. Spun	Mach. Banded	Cont. Stave	Plain Concrete	Rein. Concrete
2	-	x	x	-	x	-	x	-	-	-
3	-	x	x	x	x	x	x	-	-	-
4	x	x	x	x	x	x	x	-	-	-
6	x	x	x	x	x	x	x	-	x	-
8	x	x	x	x	x	x	x	-	x	-
10	x	x	x	x	-	x	x	x	x	-
12	x	x	x	x	-	x	x	x	x	x
14	x	x	x	x	-	x	x	x	-	x
15	x	x	x	-	-	-	-	x	x	x
16	x	x	x	x		x	x	x	-	x
18	x	x	x	x		x	x	x	x	x
20	x	x	x	x		x	x	x	x	-
21	-	x	-	-		-	-	x	x	x
22	x	x	-	-		-	x	x	x	-
24	x	x	-	x		x	x	x	x	x
26	x	x		-		-	x	x		-
28	x	x		-		-	x	x		27
30	x	x		x		-	x	x		x
32	x	x		-		-	x	x		-
34	-	x		-		-	x	x		33
36	x	x		x		-	x	x		x

CARRYING CAPACITY OF PIPES

For the purpose of illustration, the relative carrying capacities and friction losses of a pipe of 20" inside diameter after 20 years service has been graphically presented on the curves of Plate No. 6. The following materials are included in the order of relative smoothness:

Wood Stave Pipe.
Glazed Concrete (spun linings in metal pipe)
Welded Steel and Wrought Iron.
Concrete
Cast Iron
Riveted Steel

These curves have been plotted from computed values, using capacity in second feet as absissa and friction loss in feet of head as ordinates.

For steel, wood stave, and concrete surfaces, the formulae and coefficients suggested by Scobey have been used in the computations. For the cast iron, the Hazen-Williams equation and coefficients were used.

It should be noted that these values have all been computed on the basis of relatively "inactive" water, which is the reason for the comparitive smoothness of the welded steep pipe. It is noted that the various pipe materials have little divergence for low carrying capacities. However, when the flow exceeds 10 sec. feet, the friction loss varies considerably for the different pipe materials.

5. EFFECT OF CORROSION ON LIFE OF PLAIN PIPE

The life of a plain pipe line is a direct function of the rate of corrpsion. Frank N. Speller has divided corrosion into five classifications:

1. Atmospheric
2. Underwater
3. Soil
4. Internal
5. Stray Electric Currents

A detailed discussion of each of these types of corrosion in relation to water pipe lines in Southern California will be given. The types of materials included in this discussion are those commonly used in pipe lines, namely; steel, wrought iron, cast iron, wood and concrete.

The purpose of this discussion is to determine the life of these materials under each of the conditions of corrosion listed above. Hence, the conclusions will present an estimated life of material based on practical experiences as obtained from personal inspection of lines by the writer; information obtained directly from water superintendents; data from various engineering journals, pipe manufacturers, and from tests performed by various investigators.

5. EFFECT OF CORROSION ON LIFE OF PLAIN PIPE

1. Atmospheric Corrosion

Atmospheric corrosion varies with the type of material used, the amount of moisture in the atmosphere, and the type of atmosphere.

The atmosphere, for the sake of convenience, can be classed as either fresh water or salt water air. No tests of atmospheric corrosion on pipe lines have been made, the only criteria available being the experience obtained from inspections of lines and experiments with test specimens. With many pipe lines, atmospheric corrosion is a minor factor, because a major portion of the pipe may be buried underground. Atmospheric corrosion is less problematical than other types because the pipe line is exposed and subject to periodical inspection and recoating.

Along the sea coast we find many sections of line exposed to the salt water air. This may prove more corrosive than immersion in sea water because of the alternate moistening and drying to which the pipe is subjected.

Various experiences with different pipe materials in Southern California exposed to the atmosphere and also the different types of coatings used for protective purposes will be presented. Coating inspections on exposed pipe lines have been made under the direction of American Petroleum Institute and these are given under the chapter on Coatings. Examples of plain pipe exposed to air are few, because coating offers a relatively inexpensive method of protection.

Attached Table #13 gives a summary of tests by various investigators and presented in Speller's "Corrosion, Causes & Prevention", made with various materials relative to atmosphere and under-water corrosion.

Steel Pipe

A summary of the various experimental data shown on Table #13 indicates an average penetration of .005" per year for steel pipe under ordinary atmospheric conditions. Modern investigation indicates that a steel containing a small percentage of copper of .2%± is more resistant to corrosion than ordinary steel. This fact has led to the manufacture of steel pipe with a small percentage of copper, such as Toncin iron pipe and also of "copper" steel sheet piling.

Referring to Table # 4 the results of the inspection

Atmospheric Corrosion, contd.

of the Los Angeles Aqueduct siphons are given: these are for coated steel pipe.

The Oxnard Drainage District has a 60" #10 gauge copper bearing steel culvert pipe extending into the ocean, which is continually exposed to alternate wetting and drying. This pipe has an accumulated coat of rust on the outside, but the remaining metal underneath is still sound. The rust acts as a protective coating for a time, decreasing the rate of rusting.

Wrought Iron Pipe

Speller, in comparing the relative corrosion of wrought iron and steel in the atmosphere, draws the following conclusion: "....In the atmosphere, wrought iron seems to have some advantage in certain cases. However, in industrial air, steel containing more than .15% copper is more durable than wrought iron or pure iron carrying the same amount, and decidedly more durable than ordinary wrought iron or pure iron which generally carries less than .03%. This also appears to hold true in the air of other localities......"

The conclusions from the summary presented in Table #13 show that the corrosion rate of wrought iron pipe is practically the same as for steel pipe. The average rate of penetration is .045" against that of .049" for steel pipe, for ordinary air conditions.

Cast Iron Pipe

There is no standard make of cast iron pipe that is not dipped, hence the conclusion here cited refers to standard dipped pipe.

Table #13 shows that the rate of corrosion of cast iron in ordinary atmosphere is only .001" per year, which is a great deal less than with steel or wrought iron pipe. This relatively low rate of corrosion is also borne out by various exposed sections of cast iron pipe used by the Los Angeles Water Department.

Flynn, Weston & Bogert (Waterworks Handbook) state that cast iron pipe laid above the salt marshes in New Jersey in 1862 was still in good shape in 1925. A number of sewer outfalls along the ocean front in Southern California have been in service for 20 years and are still in apparently good condition.

Atmospheric Corrosion, contd.

Concrete Pipe

Concrete pipe, plain or reinforced, under ordinary atmospheric conditions of Southern California appears to be unaffected, because of the absence of freezing temperatures.

The Temescal Water Company has installed a 24" line from Arlington to Corona which has been in service for 7 years, to date. This line is exposed in many sections and is in satisfactory condition.

Wood Stave Pipe

The atmospheric corrosion of wood stave pipe depends on both the corrosion of the steel bands and of the wood itself. For the corrosion of the steel bands, the life will be longer than for ordinary steel pipe, because of the concentrated thickness of the steel. The corrosion of the wood takes place with the formation of plant growths on the pipe. These growths occur at the leaks, usually at the joints in machine banded pipe.

Etchevery P.288 writes that the expected life of continuous stave pipe of either redwood, pine or fir, supported above the ground, has a useful life of at least 25 to 30 years.

Exposure to sea water air means alternating moistening and drying of the pipe. This condition seems to have a more corrosive effect than ordinary exposure. A recent inspection by the writer of a 16" continuous stave wood pipe line at Carlsbad, California, owned by the Oceanside Mutual Water Company, revealed severe corrosion to the steel bands. The pipe line was built on a trestle support over the estuary of a small water course about a hundred yards from the ocean. After five years' service the wood was in good condition but the steel bands were rusted to about half their original diameter. These steel bands are renewed periodically at intervals of 5 to 10 years, a few at a time, thus keeping the line in continuous operation.

5. EFFECT OF CORROSION ON LIFE OF PLAIN PIPE

2. UNDERWATER COOROSION OF PLAIN PIPE

Underwater corrosion is a problem not frequently encountered, since instances of lines submerged because of high water tables or laid in sea water and across streams are relatively few. Such cases do exist, however, and must be considered as important as other problems of corrosion wherever they appear.

The problem can be divided into corrosion in fresh water and corrosion in salt water. Many accelerated tests have been made to determine the corrosive rates for various materials under these two conditions. These tests have been combined in Table #13 and the average values are given for the two cases of corrosion for different materials.

The effect of underwater corrosion on pipe coatings is explained in the chapter "Corrosion of Pipe Coatings".

Steel Pipe.

A summary of the tests in Table #13 reveal the following corrosion characteristics of steel pipe in both fresh and salt water. For fresh water the average corrosion is .00185" per year. For salt water the average corrosion is .00243" per year.

The Arden Salt Works at Newark, California, operate a 48" x 1/4" steel siphon which is installed in marsh ground and subject to the action of salt water. This line was installed in 1926 and inspected in 1930 and showed that the section completely immersed had suffered no corrosion. The section partly submerged, and therefore exposed to alternate wetting and drying, showed that corrosive action had begun.

The Spring Valley Water Company operates four wrought steel lines which are installed under the San Francisco Bay and are completely submerged. These lines were installed in 1887 and 1903. As reported by their engineers, the pipe lines were still in good condition in 1930 and are still in service.

Wrought Iron Pipe

The summary of the corrosion tests in Table #13 shows that the corrosive rate of wrought iron is about the same as for steel pipe. The value in fresh water is .00169" per year, while that in salt water is .00302" per year.

Underwater Corrosion of Plain Pipe, contd.

Cast Iron Pipe

The summary of the corrosive tests in Table #13 for cast iron pipe are as follows:

In fresh water the rate is .00183" per year. In salt water the rate is .00194" per year. This is about the same as for both steel and wrought iron pipe.

Flynn, Weston & Bogert state that cast iron rusts slowly in air or fresh water, but is rapidly corroded in salt water, in which it rapidly becomes soft. They also state that a cast iron pipe line was in service for 50 years in sea water before corroding.

Pugh states (Transactions of the American Society of Civil Engineers for 1915) that cast iron pipe is very susceptible to corrosion in salt water and that it may be rendered useless in from 7 to 20 years if laid in salt marshes.

In the Journal of the American Water Works Association for April, 1931, J.R. Tanner states that 16" cast iron pipe was removed after being submerged in salt water for 10 years, from 1920 to 1930. He states that the deterioration on the outside of the pipe was almost negligible.

In Laguna Beach, California, a cast iron pipe line is laid in a salt water lagoon. This line has been in service since 1926 and is still in good condition.

Concrete Pipe

Fresh Water: The corrosion of concrete pipe in fresh water is practically negligible. Concrete piles and other concrete structures have withstood the submergence in fresh water without any apparent ill effects.

Salt Water: The same may be stated of concrete permanently submerged in salt water. Numerous examples are available of concrete which has been submerged in tide water for long periods without being affected, in any way.

A reinforced concrete pipe partly submerged will suffer corrosion of the steel rods above the water-line. Capillary water will evaporate above the water line and leave a deposit of salt on the steel. This deposition causes the rusting of the steel and the breaking of the concrete. This conclusion has been borne out by the action of the sea water on concrete piles above the line of permanent moisture, which causes the rusting of rods andthe spalling off of the concrete. (Report on Concrete Piling, Los Angeles Harbor, November 1926, by R.Bennett and A.L.Sonderegger).

Wood Stave Pipe

The corrosion of wood stave pipe in water depends on two factors, the corrosion of the steel bands and of the wood. Flynn,Weston & Bogert state that wood pipe is best suited to convey water through salt water or salt marshes. Also that salt water has no decaying effect on wood and if the pipe bands are made of copper it will last much longer in salt water than cast iron or steel.

In Carlsbad, California, the Oceanside Mutual Water Company installed a 16" machine banded wood stave line in 10 feet of salt water. After 15 years in salt water, the line is still in service and an inspection by the writer showed the line to be in fairly good shape. Within the last few years the estuary has been drained and the line is now exposed to salt air.

EFFECT OF CORROSION ON LIFE OF PLAIN PIPE

3. Soil Corrosion on Plain Pipe

Soil corrosion is the main problem with which to cope because a large percentage of pipe lines is buried.

The great number of different types of soils and lack of uniformity of soils in any particular location makes a general formulation of specifications not feasible, each case presenting its own particular problem. The individual experiences of water superintendents and others who have occasion to observe the effect of soils over long periods have never been collected and relatively little systematic discussion of soil corrosion is available. Besides, the pipe materials and coatings have changed considerably during the last 20 years, which makes final conclusions more difficult to arrive at.

Discussions on soil corrosion are numerous in the engineering journals, but refer to the general problem of proving the advantage of one pipe material over another, rather than to cases in specific soils. Examples of such discussions are cited by Speller, Birkinbine and Redington in the Journal of the American Water Works Association, November, 1931, pg. 1664.

Systematic tests of soil corrosion on various types of metal pipe have been carried out by the United States Bureau of Standards. These tests include 47 different soils and their effect on the different materials investigated, over a period to date of eight years. Included in the test soils were seven Pacific Coast soils. The locations of these test sites are distributed along the coast, but the experimental results bear close to the actual experience of similar soils in Southern California. The test speciments were buried in 1922, and include Bessemer steel, open-hearth steel, cast iron, both sand cast and deLavaud, and copper bearing steel. These tests will be discussed in detail.

A special problem arises when the pipe comes in contact with two strata of different soils, because of the electrolytic action set up on the pipe, due to the potential difference of the two soils. This case will also be discussed in detail.

Combining the results of the tests of the Bureau of Standards with the experiences of existing lines, we can arrive at a close figure for the estimated life of each pipe material in the particular type of soil considered.

EFFECT OF CORROSION ON LIFE OF PLAIN PIPE

Discussion of Tests by Bureau of Standards.*

Since the purpose of the tests was to determine the amount of corrosion in pipe lines, without that due to electrolysis by stray electric currents, extensive tests were made previously of the test sites. Commercial materials, obtained from the manufacturers, were used in the tests and buried at depths corresponding in each case with the practice of the local public utility organization Specimens of each material have been removed at two year intervals, the total period of the test being planned to take ten years. Each speciment was carefully weighed before being placed in the trench and tagged for identification. In addition, the pH values, the soil resistivity, and the soluble salt content were determined for a number of soils.

The pH values indicate the acid or alkaline condition of the soil. These are coefficients of the Hydrogen ion content in the soil. The pH value for pure water is 7 since the hydrogen ion concentration is 10^{-7}. The soil resistances were measured in the trench, by means of a McCollum earth current meter. The soluble salt content of the soils were measured at three depths, the upper, middle and lower portions; the lower portion being at an average depth of about 30". The corrosive action of the particular soil is determined both by loss in weight and the maximum pitting.

The results of the tests are shown graphically in Plates 1 to 5 and numerical tables 5 to 8. The materials tested here are plain steel pipe, wrought iron pipe, vertical cast sand mold cast iron pipe, and deLavaud centrifugal process cast iron pipe.

Description of Soils

The soils chosen by the Bureau of Standards can be readily associated with similar soils encountered in Southern California. The seven considered and their characteristics are listed here, with the Bureau's classification number used.

(5) Dublin Clay Adobe, "....In the site selected for this study the soil is of silty clay or clay texture, is sticky when wet, and during the dry summer season the typical adobe, exhibiting the usual surface checks and cracks, is well developed...."These adobe soils, because of their tendency to stick when wet and check during the summer, tear off the coating and dip from the pipe, leaving it exposed to the soil action. These soils occupy level to gently rolling alluvial slopes, fans and alluvial valleys traversed by minor streams. There is nearly always a perceptible slope and drainage is, in most cases, well established. Alkali salts are occasionally noted over small areas....."

*Technologic Paper T-368, Bureau of Standards, 1928

Discussion of Tests by Bureau of Standards

(6) Everett Gravelly Sandy Loam. "....The surface soil consists of a light brown gravelly sandy loam containing practically no organic matter. The subsoil is a light gray or grayish brown compact sandy loam containing considerable gravel and small fragments of firmly cemented soil material. Drainage is usually excessive and the soils are subject to drought." The soils of this series have been mapped only in Western Washington but similar soils, such as those occurring along river beds, can be found in Southern California.*

(12) Hanford Fine Sandy Loam. "....The soil here consists of a light brown fine sandy loam with a grayish cast which passes into a very fine sandy loam of the same color at a depth of 28 inches. The topography is practically flat. This soil differs from the Hanford very fine sandy loam in that it does not contain soluble carbonates or 'black alkali' in appreciable amount....."

(13) Hanford Very Fine Sandy Loam. "....The heavier members of this soil carry considerable organic matter. These soils are occasionally subject to accumulation of alkali salts, due to the fact that they are not very well drained."

(23) Merced Silt Loam. "....The soils are frequently poorly drained and subject to overflow during times of high water and often contain injurious amounts of alkali salts. This soil has been previously called white alkali soil. The location of the speciments is in a flat topography with poor drainage and a high concentration of alkali."

(28) Montezuma Clay Adobe. "....This soil is found in Central and Southern California. The clay adobe is very sticky when wet and checks extensively when exposed to periods of drought. Surface drainage is very good, but subdrainage is restructed and the soil and subsoil are retentive of moisture."

(35) Ramona Loam. "....These soils are found only in Southern California. The subsoils are nearly always compact and are heavier in texture than the surface materials. The series is usually low in organic matter and generally contains a small amount of mica. The topography of the Ramona loam is typically gently sloping to undulating, but locally the surface may be steep and eroded or disected by streams. Drainage is well developed....."

The pH values and percentages of soluble salts in these soils is shown on Table #9.

Discussion of Tests by Bureau of Standards.

Plain Steel Pipe

The life of unprotected steel pipe in various soils can be determined from the curves of Plate #2, which give the relation of age to the accumulative maximum pitting. These curves contain the data shown in Table #5, which was computed from the data on recent tests on corrosion by the Bureau of Standards in Research Paper 329;1931. The specimens used for the tests on steel pipe consisted of three inch samples of open hearth steel, buried in 47 soils throughout the United States. The seven soils considered here are those which can be suitably associated with similar soils found in Southern California.

The action of the soils falls into four clearly defined groups:

The first group consists of soil #23, Merced Silt Loam. This soil is the most corrosive to steel pipe because of the large amount of sodium sulphate or 'white alkali'. It is very poorly drained, which is responsible for the accumulation of alkaline salts, indicated by a high soluble salt content of 2.100%, as shown in table #9. The rate of corrosive action in this soil is sufficient to destroy a 12 gage pipe inside of three years unless some protective measures are taken. This life is arrived at from the curves on Plate #2, which give the accumulative pitting. The water content of the soil is the basic cause of corrosion as it affords the ions the opportunity to form and produce electrolytic action. This water content is the result of a lack of drainage.

The second group of soils consists of Nos.13 and 28, Hanford Very Fine Sandy Loam, and Montezuma Clay Adobe, respectively. These soils are similar in that the drainage for both is very poor. The Hanford Very Fine Sandy Loam contains considerable black alkali as sodium carbonate. From Table #5 it can be seen that an ordinary 12 gauge pipe would last about 4 or 5 years before being destroyed. Although the original pitting rate is rather heavy, the curve characteristically flattens out. While the life of the pipe in these two soils is considerably longer than in the Merced Silt Loam, they are still very destructive to the life of the pipe.

Group three consists of soils 5 and 12, Dublin Clay Adobe and Hanford Fine Sandy Loam, respectively. These soils differ from the previous group in that they afford better drainage, as shown by the smaller amount of alkaline salts present. The corrosion is a great deal less because of these reasons, and we find from Plate #2 that a 12 gauge pipe would last from 15 to 20 as a minimum without any protective coating.

Group four consists of soils 6 and 35 which are, respectively, Everett Gravelly Sandy Loam and Ramona Loam. These two soils, though of different fineness, afford effective drainage, hence no alkaline salts are present. These soils have no corrosive effect on steel pipe. Experience has proven that the life of the pipe may be from fifty to one hundred years.

Plain Steel Pipe

Conclusions.

The corrosive action of unprotected steel pipe is dependent largely upon the drainage conditions of the soil in which it is buried, which in turn determines the acidity and alkalinity present in the soil.

For unprotected #12 gauge steel pipe we can expect a life of:

(a) 3 years in Merced Silt Loam
(b) 4-5 " " Hanford Very Fine Sandy Loam and Montezuma Clay Adobe
(c) 15-20 " " Dublin Clay Adobe and Hanford Fine Sandy Loam
(d) 50-100 " " Everett Gravelly Sandy Loam and Ramona Loam

Referring to (d), this conclusion is borne out by the experience of the Los Angeles Water Department, which has a 40" steel pipe line buried in a well-drained sandy loam. This soil was formerly the Los Angeles River bed. The pipe has been in service for forty years, with only an ordinary pipe dip coating, and recent inspection shows the pipe to be in excellent condition, which is ascribed to perfect drainage.

In Pasadena, the Pasadena Water Department uncovered a 20" #14 gauge riveted steel pipe line which, in 1928, had been in service for 36 years and was still in good condition.

The Montebello Land & Water Company operates a 20" #12 gauge steel line which, to date, has been in service for 33 years. This line is laid in clay soil and is still operating satisfactorily.

The Newport Heights Irrigation District operates an 18" #12 gauge riveted wrapped steel pipe which, to date, has been in service for 11 years in adobe, clay and sandy soils.

Discussion of Tests by Bureau of Standards.

Wrought Iron Pipe

Wrought iron pipe shows practically the same grouping of curves as does steel pipe for the soils here shown, but with different degrees of resistance. On Plate #4, data for which is given in Table #7, we find the accumulative pitting for the various soils tested. While the corrosive rate of steel pipe and wrought iron pipe are practically the same for the good soils, there is a marked difference in the action in the more corrosive soils. Here we find that the wrought iron pipe is slightly more resistant than the steel, probably due to the chemical composition of the materials in resisting the electro-chemical action of the soils.

Again following the general curve showing the pitting rate for all materials, the life of wrought irom pipe can be extrapolated for each of the soils. Soil #23, or Merced silt loam, id the most corrosive soil, showing practically the same corresponding action as for steel pipe. For example, a quarter inch thick wrought iron pipe would last about ten years in this type of soil, before being destroyed. This figure is quite a great deal less for steel pipe of the same thickness, being about 6 years.

The next group of soils consists of soils Nos.13 and 28, which are Hanford Very Fine Sandy Loam and Montezuma Clay Adobe. The corrosion rate here is also much less than for steel pipe. A quarter inch thick wrought iron pipe would last from 20 to 40 years in these soils, whereas a steel pipe of the same thickness would corrode inside of ten years, sufficiently to be destroyed.

The third group consists of soils Nos.5 and 12, being respectively Dublin Clay Adobe and Hanford Fine Sandy Loam. The life in these soils is practically the same as for steel pipe, with very little corrosion. Here, quarter inch thick wrought iron would have a life of at least 30 to 50 years. As we have previously noticed, these soils are well drained, showing very small quantities of alkaline salts present, which accounts for the long life.

Group four consists of soils Nos.6 and 35, which are Everett Gravelly Sandy Loam and Ramona Loam, being well drained soils with no alkaline content. Here we find practically no corrosion whatever as in the case of steel pipe. The life in these two soils can be taken as from 50 to 100 years as a minimum, with the small corrosive rate present.

Tests of Wrought Iron Pipe

Conclusions.

The corrosion of wrought iron pipe as indicated by the tests in the soils studied shows a longer life than steel pipe for the more corrosive soils, but practically the same for the better soils.

For unprotected wrought iron pipe one-quarter inch thick, we can expect a life of:

(a) 10 years in Merced Silt Loam
(b) 20-40 years in Hanford Very Fine Sandy Loam and Montezuma Clay Adobe.
(c) 30-50 years in Dublin Clay Adobe and Hanford Fine Sandt Loam
(d) 50-100 years in Everett Gravelly Sandy Loam and Ramona Loam.

Etcheverry (P.266) states that wrought iron is less susceptible to corrosion than steel pipe because it is in general more homogeneous than steel. He cites the case of the City of Rochester Water Works System where, in clay soil, wrought iron pipe 24" diam. and 1/8" thick, lasted 36 years and was still in good condition, while steel pipe in the same line of 38" diam. and twice as thick lasted only about ten years before serious corrosion had started.

He also cites the case of the Coolgardie line in Australia which lasted only three years before serious cor o sion, because of alkaline salts in the soil, was apparent. This type of soil corrosion can be prevented if the line is left uncovered in alkaline soils.

Discussion of Tests by Bureau of Standards

Vertical Cast Sandmold Cast Iron Pipe

The tests concerning corrosion of Vertical Cast Sandmold Cast Iron Pipe are given in Table #6, the data of which is presented in graphical form in Plate #3. Here we notice a different grouping than was presented in the curves on steel and wrought iron pipe. There are four groupings here, but the last two groups are not as well defined as in the other materials.

For the first group, soil #23, or Merced Silt Loam, is again the most corrosive soil. The large content of "white alkali" present seems to be more injurious to cast iron than to either steel or wrought iron pipe. This does not show the relative life of the different pipe materials, as cast iron pipe is usually constructed with a greater thickness than the other two. Using 20" cast iron pipe with a thickness of .92", or Class C, for a pressure of 100 lbs. per sq.in., we are allowed an excess thickness of .87" as compared with #12 gauge steel, with a factor of safety of one and an ultimate tensile strength of 20,000 lbs.per sq.in. On this basis we arrive at a life in soil #23 of 16.years.

The next group are soils No.s28 and 13 which are, respectively, Montezuma Clay Adobe and Hanford Very Fine Sandy Loam. The corrosion for cast iron is shown to be slightly more than for steel or wrought iron. Computing the life of Class C cast iron pipe in these soils on the same basis as above, we arrive at a figure of about 30 years. This relatively high figure is the result of the excessive thickness of the cast iron pipe as compared with #12 gauge steel and wrought iron.

The next group can be taken as a combination of the three soils Nos. 5,35 and 12, which are Dublin Clay Adobe, Ramona Loam, and Hanford Fine Sandy Loam, respectively. Here the corrosion is about the same as in steel and wrought iron, but with a longer life because of the added thickness. Using Class C cast iron on the same basis as above, we arrive at a life of from 75 to 100 years.

Group four consists of soil #6 which is Everett Gravelly Sandy Loam. As in the case of both steel and wrought iron pipe, because of excellent drainage, this soil has no appreciable corrosive effect on cast iron. According to Table #5, the percentage of soluble salts contained in this soil is .0077%, which is the lowest figure for the seven soils discussed here. The life of cast iron pipe in this soil can be taken at 100 years as a minimum.

Discussion of Tests by Bureau of Standards

Vertical Sandmold Cast Iron Pipe

Conclusions

Vertical Sandmold cast iron pipe has a higher corrosive rate than either steel or wrought iron in the more injurious soils, but is the same in the better soils. The high corrosive rate is offset by the greater thickness for the same internal pressure.

For 20" cast iron pipe with a thickness of .92", we can expect a life of:

(a) 16 years in Merced Silt Loam
(b) 30 years in Montezuma Clay Adobe and Hanford Very Fine Sandy Loam
(c) 75-100 years in Dublin Clay Adobe, Ramona Loam and Hanford Fine Sandy Loam.
(d) 100 years in Everett Gravelly Sandy Loam

DE LAVAUD CENTRIFUGAL PROCESS CAST IRON PIPE

Reference is made to Table #8 and Plate #5.

Most of the specimens of the deLavaud cast iron pipe were buried two years later than the other materials, hence there is only a six year record of their corrosibility. The tendency thus far, however, shows the same type of grouping as with the other materials. The rate of corrosion as a whole is much less than that for the vertical-cast cast iron, there being a large difference in the corrosive soils, while only a small difference in the less corrosive ones. By extrapolating the data, four groups can be made.

Soil #23, or Merced Silt Loam, which is the most corrosive. Comparing the rate of corrosion in this soil to the vertical-cast cast iron, at the end of three years the pitting is less than a third as much. Using 20" Class C pipe which has a thickness of .92", we arrive at a life of about 60 years in this soil.

The second group consists of soils Nos.5 and 28 which are, respectively, Dublin Clay Adobe and Montezuma Clay Adobe. For the same pipe as above, we arrive at a life of about 75 years in these two soils.

deLavaud Centrifugal Process
Cast Iron Pipe, contd.

The third group consists of soil #13, or Hanford Very Fine Sandy Loam. The pitting rate in this soil is very much less than for vertical-cast cast iron and much less than steel pipe. On the same basis as above, we arrive at a life of at least 100 years for this soil.

The last group consists of soils Nos.12,6 and 35, which are Hanford Fine Sandy Loam, Everett Gravelly Sandy Loam and Ramona Loam. These are the best drained soils of those considered and consequently the corrosion is the lowest for all the materials considered. For all practical purposes, 100 years is a satisfactory figure for the life in these three soils.

Conclusions

For 20" deLavaud cast iron Class C pipe, we can expect a life of:

(1) 60 years in Merced Silt Loam
(2) 75 " " Dublin Clay Adobe and Montezuma Clay Adobe
(3) 100 " " Hanford Very Fine Sandy Loam, Hanford Fine Sandy Loam, Everett Gravelly Sandy Loam and Ramona Loam.

In a paper by C.P.deJonge, in Western Gas, August 1932, the relative merit of centrifugal and common pit cast iron is discussed, applicable to Southern California soils. Some of his observations are as follows:

(a) An analysis similar to that of the Bureau of Standards by Corfield shows a great superiority for centrifugal cast iron in five Southern California soils. He finds that the expected life, deduced from penetrations at various periods, of centrifugal cast iron is about twice that of pit cast.

(b) In an inspection of 33 cast iron pipe mains in a severe adobe soil, by the San Diego Consolidated Gas & Electric Co., it was found that assuming a constant rate of penetration, the annual penetration for sand cast pipe was .0432" and for the centrifugal cast pipe was .0223". Eleven samples of cast iron were brought in from the field and in every case the samples with a coarser graphite structure showed the least resistance to corrosion.

Discussion of Tests by Bureau of Standards

deLavaud Centrifugal Process
Cast Iron Pipe.
Conclusions, contd.

Referring to the Bureau of Standards tests, this same ratio of corrosion between centrifugal and pit cast iron pipe holds true for Montezuma Clay Adobe, although the pitting rates presented in the San Diego tests are slightly higher than the average rate of the Bureau of Standards tests. This is probably because the rate of observation was of less length and the fact that the rate of corrosion decreases with time.

CONCRETE PIPE

In all soils except those containing a large percentage of alkaline salts, concrete pipe has been known to have a life of at least 50 years. In soils of alkaline content, it has been found that the salts in solution enter into the concrete. On crystalizing, these salts expand, both cracking the pipe and exposing the steel to the soil.

Speller* states that concrete coatings will give good protection where severe corrosive conditions are encountered, as where the soil may be acid. He also states that cement coatings cannot be used in localities where the ground water contains salts or alkalis, which attack this material.

It is stated in Water Works Practice** for 1925, that good concrete pipe is generally regarded by engineers as practically safe against deterioration.

The Beardslee Ditch Company in Monrovia, Calif., operates a 14" cement pipe line which has been in service since 1922. This line is laid in sandy gravelly soils, and is in good condition.

Conclusions

The life of concrete pipe can be taken in ordinary soil conditions at least 50 years. Where there are alkali salts in the soil, the life should be estimated at not more than ten years.

* Speller, F.N.; "Corrosion-Causes & Prevention" P.539
** Water Works Practice, 1925, A.W.W.A. P.292

Discussion of Tests by Bureau of Standards

Wood Stave Pipe

The life of wood stave pipe buried in soil depends on the corrosion of the wood and of the steel bands. The steel bands will corrode in the same rate per unit exposed as the Bureau of Standards tests indicate for unprotected steel pipe, assuming no coating on the bands. The steel, however, is concentrated at the band, giving a greater thickness than with ordinary steel pipe. Hence, the total corrosion will be less and consequently the life longer.

The corrosion of the wood depends on whether or not the pipe is kept full of water. It has been found that with lines that are alternately wet and dry the wood begins to rot, whereas in lines kept under pressure the wood remains sound. The use of redwood has proved to be of great benefit to the life of wood stave pipe. This wood shows a life of from 50 to 100 years under the most severe conditions, considering the life of staves.

Etcheverry (P.288, Irrigation Practice & Engineering) states that:

(a) Continuous wood stave pipe, either pine, redwood or fir, not coated, buried in tight retentive clay loam or fine silt soils, free from alkalis constantly full, has a useful life of from 40 to 50 years and probably greater when the pressure is not less than 50 feet.

(b) Continuous stave pipe of either pine, fir or redwood, supported above the ground constantly full will have a useful life of from 20 to 30 years.

(c) The durability of the bands is greater than that of the staves except in alkaline soils, in which case the bands may have to be renewed after 10 or 15 years.

(d) Machine banded pipe with a good coating placed in good soil will have a useful life of from 20 to 30 years, but in bad soils, of from 10 to 15 years.

PIPE CORROSION DUE TO THE ACTION OF TWO SOILS.

It has been found that an electrolytic action is set up when a pipe is buried in contact with two strata of dissimilar soils.

Joseph F.Putnam* gives the various factors which cause an electrolytic action to set up on the pipe. For simplicity it will be taken up for a pipe buried in one soil alone and then extended to the more complicated case.

In Figure 1, we have a section of pipe buried in one soil.

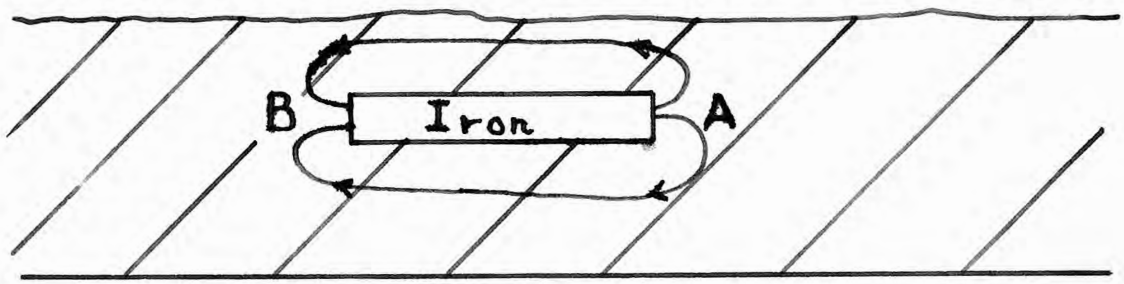


Fig. 1

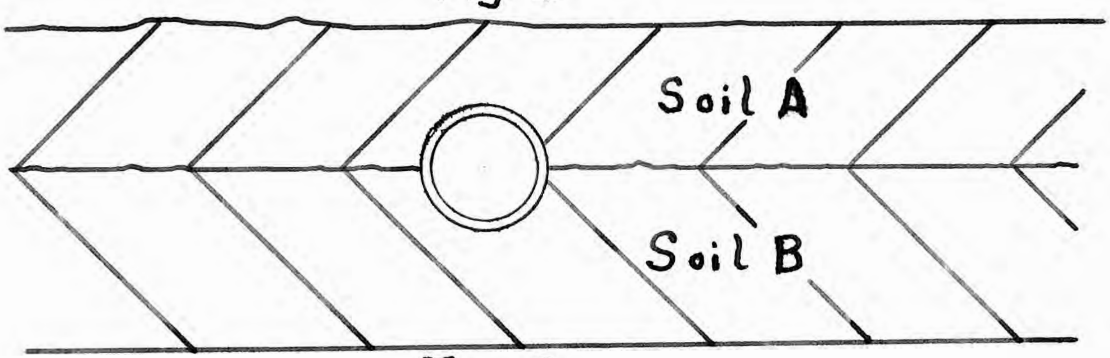


Fig. 2

Between points A and B there is a potential difference. This potential difference may come about in several ways but is explained by the fact that one of the substances is cathodic to the other by a certain potential difference. This sets up a cell with iron as the anode. The cathode may be ferric hydroxide or it may be a gas of a certain concentration. The potential caused by various factors are as follows:

1. Mill scale on point B .45 volts
2. Red rust at B .65 volts
3. Segregations of impurities at B to .275 volts
4. Electrolytic differences to .3 volts
5. Differences in salt concentration to .1 volt
6. " " gas " to 1.4 volts

*Joseph F.Putnam-"Soil Corrosion-Causes & Predetermination" A?P.I.Proceedings, December/1930

Pipe Corrosion Due to the Action of Two Soils

Referring now to Figure 2, we can consider the case of a pipe in two dissimilar soils. There will be a difference in potential between the top and bottom of the pipe because of the different chemical composition of the soils. Putnam explains the following actions if the soils are of the same chemical composition.

....."If now the two sections A and B have the same chemical composition, but one section contains more moisture than the other, again there will be a potential difference between the top and bottom of the pipe due to a difference in concentration of the dissolved salts (item 5). Even if the salt content and concentration of the two sections is the same, if the dissolved air or other gases in the soil moisture differs, there will be a potential set up (item 6). This gas concentration potential is, it is believed, most important of all potential difference and may reach a value as high as 1.4 volts when there is dissolved air on one section and no air on the other. The efficiency of this reaction probably depends on soil texture, drainage, etc...."

F.N.Speller quotes Scofield and Stenger in their experiments in 1914, showed that certain dissimilar soils, when kept moist in contact with the same metal, caused active local corrosion and generated a considerable difference in potential due to the difference in the soluble constituents forming an electrolytic cell consisting of two different electrolytes in contact with the same metal.

A practical experience of this phenomena was encountered by the Department of Water & Power in the City of Los Angeles in 1930. This experience will be discussed later in detail. Another occurrence of this same condition was encountered by the Southern Counties Gas Company.

Quoting from F.A.Hough's paper on Soil Surveys in Western Gas Journal, August 1932: ".....Here the deep pitting of the bottom of the 12" transmission line while the upper half remained in perfect condition was caused by a difference in soils in which the two halves of the lines were located. The lower half is located in soil having a resistivity of 1800 ohm cms. while the upper half is located in soil having a resistivity of 5000 lhm cms. Strata 6" thick of inert soil such as sand are occasionally found immediately above strata of very corrosive alkaline soils. Such strata may be found in one area at varying distances from the surface....."

Pipe Corrosion Due to the Action of Two Soils

In this case, the corrosive action took place on the bottom of the pipe, while in the Los Angeles line the pitting was concentrated on the top.

In the City of Los Angeles, a steel water line was found to be badly corroded after eight years of service, which necessitated its removal. It was found that the pipe was corroded at the top section only, the bottom of the pipe showing little, if any, corrosion. Tests were made to determine whether electrolysis due to stray electric currents had been the cause. These tests revealed that there was no fluctuation of the current as would occur if the currents had leaked from the street car line nearby. Electrical apparatus was set up and it was found that a large difference in potential existed between the two soils in which the pipe was located. The test showed that the difference in potential between the two soils had set up a deposition current sufficient to corrode the top of the pipe.

The potential differences and the conditions of the pipe in the soil are shown in Fig.3 Here we see that the difference in potential between the top of the pipe and the grey clay was 120 millivolts, while the difference in potential between the top of the pipe and the greay tan clay was 95 millivolts.

The remedy for the Los Angeles line was to encase the pipe in a box coating of concrete. This coating has been on for about two years and no further trouble has been encountered. The Southern Counties Gas Company, when encountering this problem, uses a protective coating, or else shifts the line.

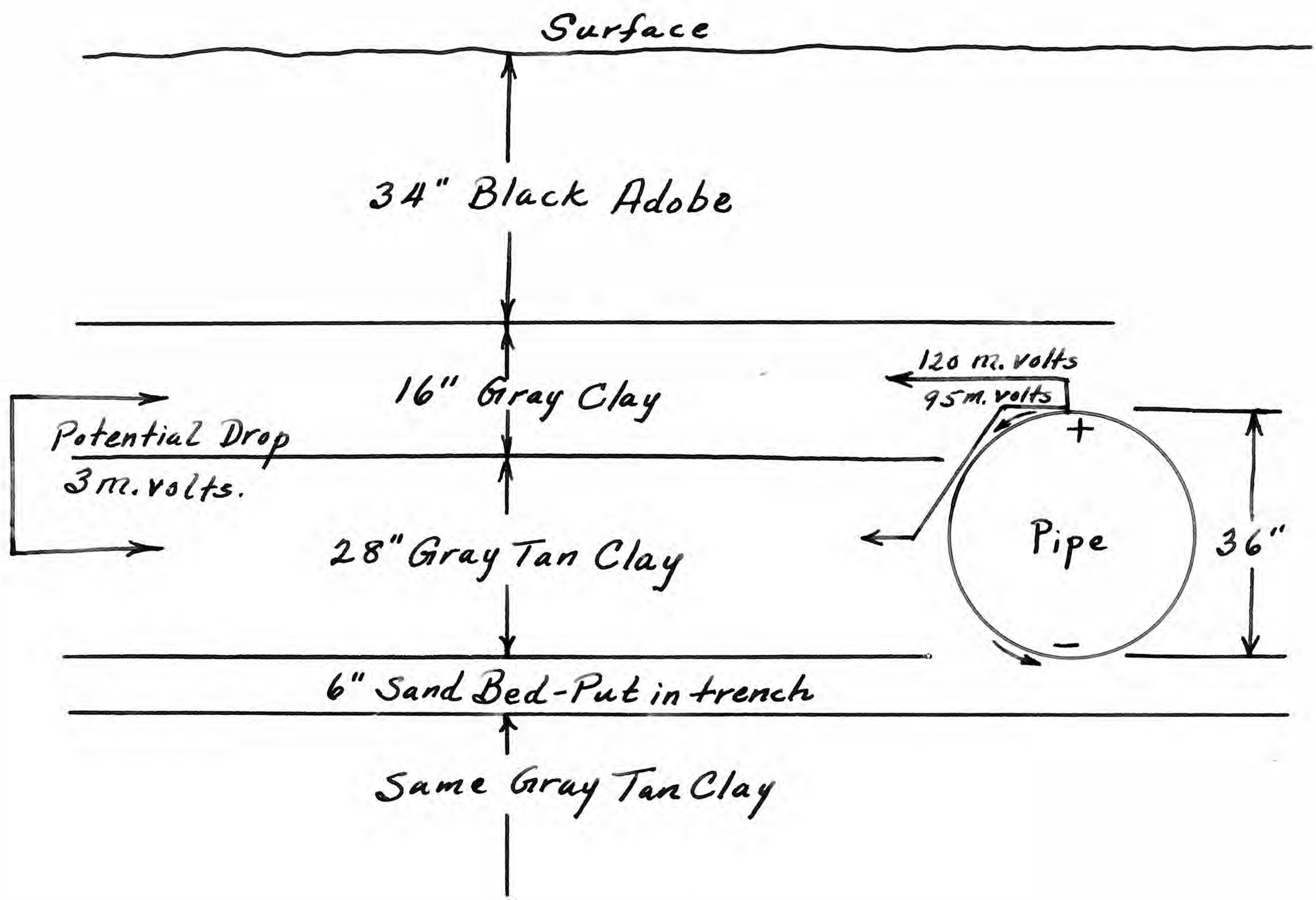

Surface
34" Black Adobe
16" Gray Clay
Potential Drop
3 m. volts.
28" Gray Tan Clay
6" Sand Bed-Put in trench
Same Gray Tan Clay
120 m. volts
95 m. volts
+
Pipe
−
36"

Figure 3

EFFECT OF CORROSION ON LIFE OF PLAIN PIPE

4. INTERNAL CORROSION OF PLAIN PIPE

Internal corrosion of plain pipe depends upon the chemical quality of the water carried and the mechanical abrasion by the particles carried, such as sand. The result of the chemical action of the water on the metal is the formation of knobs, called tuberculation. The tubercules are formed largely of feric hydrate and grow as the age of the pipe increases. If the pipe is coated, the action starts first where the pipe becomes exposed and gradually builds up around the surface of the pipe. The depth of these tubercules may reach a size of as much as one inch in height.

This formation does not have a very great effect on pitting the pipe internally. The main problem, due to tuberculation, is the reduction of carrying capacity due to increased roughness and decreased area of flow. Pipes which have tubercular growths are reconditioned by scraping the inside of the pipe and recoating. The metal in most cases has been found to be pitted less than 1/16 of an inch.

The action of water on the various types of internal coatings is discussed in the chapter on "Corrosion of Pipe Coatings". On non-metal pipes such as concrete and wood stave pipe, there is no chemical action of the water on the pipe internally and no corrosion takes place.

In ordinary velocities of from 1 to 3 feet per second, the mechanical action of the particles carried by the water is very slight. At the bottom of siphons, which frequently are operated at high velocities, however, there may be sufficient abrasion by sand to errode the pipe. In the Pine Tree Siphon of the Los Angeles Aqueduct (9 ft.diam.), the rivet heads at the bottom of the siphon were worn to half their original size. The velocity with a discharge of 400 second feet is 6.31 feet.

In concrete siphons in Southern California this type of corrosion has also been found to occur at the bottom of the pipe. This condition is reported by Fred C. Scobey in bulletin entitled "The Flow of Water in Concrete Pipe"

5. CORROSION OF PLAIN PIPE DUE TO STRAY ELECTRIC CURRENTS

The purpose of this discussion on corrosion due to stray electric currents is, first, to present briefly the reason of transferrence of such currents; secondly, the methods of prevention, and third, the effect on the different pipe materials.

The result of the passage of electric current through metal pipe is to pit the pipe at the points of departure of the current. By Faraday's law, the total corrosion is proportional to the total amount of electricity passing between the conductors. The total quantity of electricity can be defined as a certain number of amperes flowing for a certain length of time. Ohms law gives the relation between the potential drop, the current and the resistance to flow. Therefore, the total amount of corrosion varies directly as the potential drop and inverselt as the resistance to flow of the current.

Electrolysis due to stray electric currents comes as a result of the pipe having the ability to carry the current that is transferred from the conductor through the soil. These currents may come from many sources; from street car rails, sub-station supply lines, adjacent pipe lines carrying stray currents, telephone lines and other current carrying devices. The amount of current which the pipe will carry depends upon the ability of the soil to carry the current to the pipe. This ability is called the resistivity of the soil and depends on several variables, such as soil moisture, dissolved salts and acidity.

If a pipe line parallels a street car rail, there are various leakage currents transferred between the two conductors, depending on the soils encountered and also on the potential drop between the two at various points along the line. At the source of the current the pipe line will usually be absorbing current from the conductor. This will continue along the line until the potential drop between the two is zero. From this point on, the pipe will be discharging its current back to the original conductor to complete the circuit. The point at which the direction of the current changes, or the flex point, is found to occur both mathematically and actually, about 40% of the distance from the source of current on the line. This center point is usually rather a region of activity, of a few feet to several hundred feet in length.

Corrosion of Plain Pipe Due to Stray Electric Currents

When a pipe line parallels another pipe line, the current distribution along the two lines will vary depending on the variance of potential drop between the two lines. Thus, if there are a large number of lines paralleling one another, the problem becomes extremely complicated. In the country, the problem is usually one of a single pipe line and a return current conductor, but in urban areas there may be numerous pipe lines, rails and other conductors, paralleling and crossing, making the current distribution along each pipe line very complex. Current surveys in cities will reveal the areas where the current will leave the pipe and also the areas where it will enter.

Prevention.

There are four methods of prevention of corrosion due to stray current electrolysis. These will be discussed in general in relation to metal pipes, without any differentiation as to the relative merits of the pipe materials.

The first preventative is the use of protective coatings on the pipe. The object is to cover the pipe line completely, thus preventing the passage of current. The ability of coatings to do this will be discussed under the heading of pipe coatings.

The second preventive measure is the bonding of the pipe line to the return current conductor supplying the leakage current, at the point where the current leaves the pipe. This has proved to be a help in some cases, but is not a complete solution to the problem. The difficulty lies in maintaining proper voltage regulation in the original current conductor.

The third method of preventing this type of corrosion is the use of insulating joints at various intervals along the line. This tends to decrease the amount of localized corrosion, but with large currents there will be corrosion at each joint, the current tending to go around the joint.

The fourth method* used is that termed "cathodic protection. This involves supplying current at the points where the leakage current tends to leave the pipe. The current supplied is in the opposite direction to the leakage current, hence neutralizes it. This involves the installation of a

*"Corrosion Mitigation on Gas Lines of the Pacific Gas & Elec. Co." by W.R.Schneider. Western Gas, August 1932, p.74

Prevention, contd.

conductor in the soil which will transfer the excess current supplied by the booster back into the pipe line. Thus, instead of the current leaving the pipe it will be entering as long as the potential furnished by the booster is in excess of that in the line.

This method of cathodic protection has been tried on a line in San Francisco and has proved to be very successful. Instead of 100 amperes per sq.ft. leaving the main as was previously the case, 40 amperes per sq.ft. now enter the main. This type of protection was also planned for the Southern Counties Gas Company gas line to San Diego. Estimated cost* of protection for this 12" line is $7.70 per year per mile of pipe protected.

The economics of the type and amount of protection for this type of corrosion can be determined by a survey of the actual leakage currents along the pipe line. Small amounts of leakage currents can be successfully solved by the use of insulating couplings. With proper voltage regulation by electric railway companies, the use of bonding will be successful. With large amounts of stray currents, the use of "cathodic protection" may be warranted because of its relative low cost in the long run.

Effect on Different Pipe Materials

(a) Steel Pipe: Steel pipe is one of the best conductors of electricity and hence does not offer much resistance to the passage of electric currents through this type of pipe line. Therefore, if any corrosion due to stray current electrolysis is encountered it must be met immediately by some means of prevention.

(b) Wrought Iron Pipe: Wrought iron has practically the same current carrying properties as steel and hence is as ineffective as steel in preventing this type of corrosion.

* "Soil Survey & Protection Measures for the So.Counties Gas Co., San Diego Natural Gas Line". Frederic A.Hough, Western Gas, July, 1932

(c) Cast Iron Pipe: The silicide coat of sand cast cast iron has been found very effective to resist the effects of stray current electrolysis. This experience has been found to be true, particularly in cities. This type of cast iron is not totally resistant to the passage of current, but is much more effective than the metal mold cast cast iron, steel, or wrought iron pipe. Wherever severe conditions arise, they must also be met by some means of prevention even with this type of cast iron, if long life is to be guaranteed.

(d) Concrete Pipe: Both reinforced concrete and plain concrete pipe are resistant to the corrosion by electric current. This is because the reinforcing is discontinuous and hence prevents the flow of current.

(e) Wood Stave Pipe: Wood stave pipe is resistant to this type of electrolysis because the steel is discontinuous, in both the machine banded and continuous stave pipe, hence preventing the flow of current.

III. COMPARISON OF AVAILABLE PIPE MATERIALS

A. CHARACTERISTICS OF AVAILABLE PIPE

6. TEMPERATURE AND EARTHQUAKE RESISTANCE.

Temperature

Pipe lines, both buried and exposed, are subject to temperature variations. The variations of the soil temperature are slight compared to the atmospheric variations. With exposed lines it becomes an important problem. Stresses are produced by temperature changes when the pipe line is prevented from moving.

Etcheverry states (Conveyance of Water p.242) that in a buried pipe line the following condition is true: ".....A short pipe of large diameter when full will have a range of temperatures nearly equal to that of the water, while a long pipe line of small diameter will have a temperature range nearly equal to that of the soil..." For exposed lines the following statement applies: ".....A short steel pipe line left uncovered, when full of water will have a range of temperature nearly equal to that of the water, but if of small diameter and of large length, with the water flowing slowly or stationary, the range of temperature may be much greater and approach that which the exposed line would have when empty....." This statement is borne out by the Los Angeles Aqueduct steel siphons which are 7 to 10 diameter and of a length of 1/2 mile, more or less. They are not provided with expansion joints.

Steel Pipe, Wrought Iron, Cast Iron.

Assuming a temperature range of 30° F.$\pm$ in the soil, the unit stress for steel pipe:

$$F = 30 \times .0000065 \times 30{,}000{,}000 = \underline{5{,}850 \text{ lbs.per sq.in}}$$

This would be an extreme range for buried pipe in Southern California.

The range of temperatures of the soil in Southern California is not of sufficient magnitude to produce large stresses at 2 or 3 foot depth, as borne out by the experiences with numerous steel pipe lines.

In pipe lines used partly for irrigation water, the line may not be full the year round, hence the temperature changes may produce large stresses in exposed lines unless expansion joints are provided.

Temperature, contd.

Concrete Pipe: Since plain concrete pipe cannot take much tensile stress, it will crack very easily with temperature changes. For a change in temperature of 30° F., the tensile stress will be

$$F = 30 \times 3,000,000 \times .000006 = 540 \text{ lbs. per sq. in.}$$

Reinforced concrete pipe lines are generally buried and avoid temperature stresses and cracking.

Wood Stave Pipe: Because of the low coefficient of expansion of wood, expansion joints are not necessary for wood stave pipe. The principal factor is to keep the wood saturated continuously. The kerfs joining the staves allow for slight longitudinal movement.

Earthquake Resistance.

In Southern California attention must be paid to the effect of earthquakes and the location of pipe lines should tend to avoid fault lines and filled ground. It has been found that the greatest damage to pipe lines occurs in soft, or filled ground.

This is borne out by the following statement (Transactions of the American Society of Civil Engineers-1907) on the San Francisco earthquake: "....As far as the committee has been able to ascertain, no considerable damage resulted to any pipe line which had been laid in firm ground...."

In the recent earthquake in Long Beach, the most severe damage to pipe lines occurred in the filled ground of the Naples district. The majority of the breaks occurred in the mains at the point of service connections. This damage can be avoided to a large extent by a new type of connection which permits a vertain amount of movement at the fitting, and makes the service the weaker link so that the break will occur in the service pipe instead of the main.

In locating supply pipe lines, soft alluvial terrain should be avoided.

There is no type of pipe material that is immune to earthquake movements. Concrete pipe is more susceptible to slight shocks than the other materials and should not be used in filled ground, in particular. Settlement of the earth under-

Earthquake Resistance, contd.

neath the pipe, due to leakage or earthquake vibrations, will cause large tensile stresses in concrete pipe, and cracking. This is borne out by the experience with a concrete pipe line in California near the Lytle Creek fault in Reche Canyon, near Colton, which was leaking after every earthquake.

For the Oceanside-Carlsbad District, it has been a common occurrence that vibrations due to battleship target practice were sufficient to cause concrete lines to break.

III. COMPARISON OF AVAILABLE PIPE MATERIALS

A. CHARACTERISTICS OF AVAILABLE PIPE

7. JOINTS AND LAYING OF PIPE

Laying of Pipe.

From the standpoint of economic design, the comparative ease of laying and handling various classifications of pipe is important. The difficulty connected with handling and laying is affected by the following conditions:

1. Length and weight of standard sections of pipe.

2. Type of Joint.

3. Adaptability of a pipe to assembling on surface alongside of trench or on cradles over the trench and its subsequent lowering to the required grade, as compared with laying directly in the trench.

4. The ease with which the pipe may be laid to conform with irregularities in alignment and breaks in profile, including the adaptability of various types of joints to be laid in curves and permissible angles of deflection of such joints.

7. JOINTS AND LAYING OF PIPE

Laying of Pipe, contd.

1. Length and Weight of Pipe Sections for Different Types of Pipe.

Type of Pipe	Length of Standard Sections	Number of Joints per mile		Weight per Section in Lbs. 12" #12 gage	24" 1/8" thick	36" 1/4" thick	48" 3/8" thick
Steel:							
Riveted) Driven) Welded)	20 ft.	264		100	700	2200	4140
Wrought Iron:							
Standard	20 ft.	264		900	-	-	-
Casing	20 "	264		700	-	-	-
Cast Iron:			Class	C	C	C	C
Vertical S.Mold	12 ft.	441		1100	3350	6550	10,900
			Class	150	Cl.150		
DeLavaud 12 or 18'	18 "	294		1116	3360	-	-
American Centrif.	16 "	330		1055	3245	-	-
Concrete:							
Plain	3 ft.	1760		270	600	1520	2500
Low head, reinf.	8 "	660		950	2120	5350	8800
Hume (steel shell)	24 "	220		300	6750	8800*	14,900*
						*12 ft.	
Wooden Pipe:							
Machine Banded	12 ft.	441					
Continuous Stave	No sections	-		-	-	-	-

2. Type of Joints

Steel Pipe: The hot rolled pipe is made either plain end for welding or else threaded or beveled for different types of couplings. Welding in the field has come to be both the most suitable and economical means of making joints in steel pipe.

Screw couplings tend to weaken the pipe and also are apt to leak if the pipe settles, and strains the joint. Butt welding overcomes the disadvantages of the screw coupling in the economy, but it still does not permit sufficient freedom of the joint.

The slip joint lap welded pipe can be used to the most advantage under all conditions. It furnishes as tight a joint

Laying of Pipe, contd.

2. Type of Joints - Steel Pipe, contd.

as the butt weld and still allows a freedom of the joint. This is very important in Southern California as in many localities, as for example along the San Andreas rift, there is a constant vibration of the earth which necessitates a certain amount of give in the joint.

Another advantage of the slip joint is that a two or three degree curve can be made on the line by merely offsetting one side of the pipe as it is fitted into place. This same advantage is obvious in soft or filled ground, which permits a certain degree of settling.

Patented couplings, such as the Dresser or Vitaulic couplings, embody some of the advantages of the slip joint. They require less labor to install but weaken the pipe to a certain extent and are rather expensive. These patented joints can be used on the spiral weld pipe also.

For low heads and thin walled pipe, as in irrigation practice, the drive joint is commonly used and very economical. Riveted field joints are also in use, on both welded and riveted pipe for sizes which admit access to the pipe.

2. Type of Joints - Wrought Iron Pipe

The pipe is furnished either threaded for threaded couplings or else beveled for welding. Vitaulic Couplings require a groove at the ends which must be machine cut. Other patented couplings can also be fitted.

2. Type of Joints - Cast Iron Pipe.

The most widely used joint on cast iron pipe is the bell and spigot type. This requires packing with cement, cement and jute, or lead and jute. In fills or in soft earth it is advisable to use lead to make the joint flexible.

The pipe may also be made plain end for different types of couplings, such as the sleeve coupling, the Victaulic coupling, the threaded coupling and other patented types. There are also many variations of the bell and spigot joint as the Doublex Simplex joint, the flexible type, Metropolitan type, and others. Furthermore, there is the flanged pipe which is fastened together with bolts and made water-tight by gaskets.

With the bell and spigot joint, a several degree curve can be laid without any special fittings. This is done by slacking about an eighth of an inch on one side of the pipe while laying.

7. JOINTS AND LAYING OF PIPE

2. Type of Joints - Concrete Pipe

This type of pipe may be made with a bell and spigot joint with a concrete collar, or with a lock-joint, or other similar type of joint. The lock-joint is a patented joint which has a semi groove on both sections of the pipe fitting together. On the lower half of the pipe, the pipe can be cemented on the inside and on the upper half it can be cemented on the outside. This eliminates the use of bell holes and permits the use of a narrower trench.

The Newark Pipe Company in their standard specifications require the end of the pipe to be cemented when fitting into a bell so as to prevent leakage. In some types of joints the reinforcement is carried through the joint and connected to the next section. This idea is carried out in the Hume Steel pipe, which has a combination of both the steel shell and cage for reinforcement. In this pipe the steel shell of one pipe is lapped over the shell of the other pipe. The mesh reinforcing is carried through in the same manner.

Concrete collars are reinforced in the same manner as the pipe. This type of joint permits a small amount of expansion and contraction without any leakage, which is not the case with bell and spigot or lock-joints.

2. Type of Joints - Wood Pipe.

Continuous stave pipe is made by breaking joints of alternate staves, making a continuous pipe throughout. The staves are held together by steel bands which are individually fitted on the pipe. Joints between staves are made water-tight by means of grooves and steel kerfs.

The machine banded pipe sections are joined by collars made of redwood. The collar is first driven onto one section of the pipe and then the other section of the pipe is joined in the same manner. The sections are driven tight and when the water enters the line, the wood swells and consequently the joint is made water tight. This type of joint permits of slight deflections.

Another form of collar for machine banded pipe is constructed in the same fashion as the rest of the pipe, only in this case the steel bands are individually placed on the collar in the fashion of the continuous stave pipe. Cast iron collars may also be had for high pressure lines. They are driven in the same manner as the wooden collars.

Laying of Pipe, contd.

3. Adaptability to Assembling on surface, as compared laying directly in trench.

Certain pipe joints, like driven joints, bell and spigot joints, or sleeve joints which, while capable of taking up internal and external pressure, are not suitable to take up tensile stresses as they develop in pipe exposed to expansion and contraction, or in the lowering of the pipe into the trench. Pipes with such joints must, therefore, be laid in the trench and suitable bell holes excavated, which give access to the entire circumference at the joint. Because of impeded access to the joint and cost of special bell holes, the cost of laying is greater as compared with pipe fitted together on the surface.

On the other hand, steel pipe with welded joints, screw joints, or with riveted joints within certain limits of diameter and weight, may be laid on top of trench and subsequently lowered either as continuous pipe or in sections of 150 to 250 feet. The latter system applies to the larger steel pipe which, being subject to expansion and contraction, is lowered in sections of such length. These sections are then covered with earth, before being permanently joined together, to permit the pipe to adapt itself to normal earth temperature.

Continuous wood stave pipe is not subject to contraction and expansion from temperature. It may be laid permanently on the surface of the ground, resting on wooden cradles or on the ground. It is essential that such pipe be continuously under water pressure, which process keeps the wood staves soaked up and insures the tightness of the line.

With concrete pipe of a diameter to be accessible for cementing, it is feasible to cement the joint from the inside, so that a trench can be dug with a nominal clearance of 6" on both sides of the pipe and without special bell holes.

Laying of Pipe, contd.

4. Adaptability of Pipe to be Laid in Curves and Permissible Angles of Deflection at Joints.

The adaptability of pipe to be laid in curves generally decreases with diameter and thickness of materials.

n Screw pipe in sizes up to 6" can be laid in curves, but with diameters of 8" or more the bending curves become difficult and may injure the joint.

Continuous wood stave pipe is laid in curves limited by the manufacturer, as follows:

Diam. of Pipe Inches	Economic Radii			Minimum Possible Radii		
	1½"	2½"	3½"	1½"	2½"	3½"
20	84			59		
24	100			70		
30	125			88		
36	150	225		105	150	
48	200	300		140	200	
60	250	375		175	250	
72	-	450	600	-	300	450
84	-	525	700	-	350	525

Certain types of materials such as driven joints and welded slip joints of steel pipe, also bell and spigot joints of C.I. and Hume concrete pipe permit of deflections as much as 3° per length of section of 20 feet. This deflection corresponds to a radius of 380 feet. Such deflection is not feasible with welded butt joints without special cutting, which makes butt joints less adaptable for curvdd alignment.

8. INITIAL COST OF PIPE LAID

The cost of pipe lines generally segregates itself into the following items:

Cost of Pipe

Transportation to and Distribution of pipe along trench

Trenching and Bell Holes

Laying

Backfilling

Paving

Incidentals

Overhead

Extensive data on the cost of pipe lines are available and cover almost any normal problem of design. Quotations on the cost at factory and transportation to trench and cost of laying can be obtained from the manufacturer.

The cost of trenching and backfilling depends upon the possibility of using trenching machinery, the labor market, type of soil, condition of surface of trench, whether paved or not, and the existence of other pipe crossing the trench particularly water, gas and electric house services. Hence, no set rules can be evolved to cover cost estimates and each case must be treated with reference to the special conditions and circumstances which prevail.

There are many problems involved in laying pipe in city streets, such as the repaving of streets and the installation of safety devices against electrolysis, and of numerous valves and fittings in the line. Trenching machinery, while reducing cost of excavation, may not be adapted to excavation in city streets where numerous service connections are encountered.

In rural areas, the surface of the ground is generally unpaved. The use of trenching machinery may depend upon the magnitude and location of the work.

Cost Data: The data here presented is actual cost data from engineers, water companies, and water districts, relative to pipe lines that have been laid in Southern California.

8. INITIAL COST OF PIPE LAID

Cost Data, contd.

The information on steel pipe is given on Table No. 11 and covers pipe lines from 6" to 40" in diameter.

The information for cast iron pipe is given on Table No. 12 and covers lines from 6" to 30" in diameter, assuming 250 lbs. per sq.in. working pressure for the pipe. The data presents the average costs of a large number of pipe lines.

The cost records for concrete pipe given in Table No. 13 cover sizes from 16" to 48" in diameter, including both plain and reinforced concrete pipe.

The data on wood stave pipe lines was obtained from the manufacturer and by adding the trenching and backfilling charges. For comparison with other pipe materials, the costs are given for both machine banded and continuous stave pipe lines of 20" and 24" diameters, for pressure heads of from 50 feet to 300 feet and are shown on Table No. 14a

On Table No. 14b is given the cost of lining cast iron pipe with cement per foot of pipe for sizes from 4" to 48" in diameter.

In Table No. 14c is shown data for the width of pavement cut, and the corresponding trench width for different sizes of steel or cast iron pipe; also costs for re-surfacing with different types of material.

B. CHARACTERISTICS OF AVAILABLE PIPE COATINGS

1. Description of Available Coating Materials

Coating Materials can generally be divided into the following classifications:

A. Bituminous dips or enamels

1. Coal tar base
2. Asphalt base

B. Wrappings

1. Felt or cloth fabric
2. Asbestos fiber

C. Hard emulsions

1. Asphalt-cement emulsion
2. Asphalt mastic

D. Concrete

E. Metallic Coatings

1. Foil wrapping
2. Galvanizing

There are a great number of paints, greases and miscellaneous types of coatings which should be included to make the list complete, but these have been intentionally omitted in favor of the coatings which are in general use and about which we have more information.

In selecting a particular coating, it should be borne in mind that its sole purpose is to protect the pipe from corrosion and hence increase the life of the pipe. It has been found that the care with which the coating is applied on the pipe is perhaps the most important feature involved and while a coating may give satisfactory test results, care must be taken that the pipe is covered completely and with a uniform thickness of coating. Furthermore, that the coating is not injuried or abraided in transport or during the process of laying pipe and backfilling of trench.

A. Bituminous Dips or Enamels.

In Table # 29 are listed the characteristics of some of the available bituminous dips and enamels, together with the

Bituminous dips or enamels, contd.

method of application and pipe treatment during coating application. Most of these materials are applied at the factory on preheated pipe. This insures a more effective bond between the pipe and the coating material. If the coating is applied in the field, a primer of the same base as the dip is applied in order to secure a better bond.

As a result of practical experience in the use of the materials, standard specifications have been developed for coating materials. The use of materials with high melting points is desirable because the coating may "run" while it is exposed to the sun before the pipe is laid in the trench. However, coatings should not be brittle, otherwise the coating material may chip off if subjected to shocks.

As seen on Table #29, the enamels and dips may be of either an asphaltic or coal tar base, or else a combination of both materials. In each case, the particular dip or enamel can be applied either at the factory or in the field. In the factory, the present practice is to vertical dip the pipe into tanks producing a coating of from 1/32" to 1/16" for a single dipping, and to dip at least twice. In the field, the pipe is either brushed, wiped, or sprayed by machine.

B. Wrappings

Pipe wrapping material may consist of canvas, burlap, felt, bituminous treated fabrics, or asbestos fiber material. The wrapping is generally applied by machine at the plant, although it can be done in the field. The pipe usually receives one or two dips of bituminous coating and then is wrapped.

Relative to wrapping, there are two opinions concerning the best method. One method advocates the use of a hot liquid coating while the pipe is being wrapped, contending that it bonds the wrapping better to the pipe. The other method is to wrap the pipe cold, the advantage being that it allows the wrapping some movement to resist "soil stress" without injuring the bituminous coating next to the pipe. Spiral wrapping is the general practice, as it affords a tighter wrap than any other method.

The number of layers of wrapping depends on the amount of protection needed and also the cost involved. If two wrappings are used, there is usually placed a layer of bituminous material between the two coats as a filler and also to produce a better bond.

Available Coating Materials

Wrappings, contd.

The wrappings in general use in Southern California are those of the Paraffine Co's, Inc., known as "Pabco" and of the Johns-Manville Company called "Asbestos Pipeline Wrap". The general description of the pipe coatings manufactured by these two companies is presented in the following pages. Other combinations of common coatings and dips are presented on the price lists of the General Paint Corporation, which also does the wrapping.

The Paraffine Co's, Inc.
Floatine and Pabco Covering.

A. Standard:
1. Hot dip of Floatine (a Pabco asphaltic product)
2. Cold Machine wrap of Pabco pipe covering (mica finish)
   The covering shall be cemented to the pipe by Floatine @ 300-340° F.

B. Double Cover
1. Hot dip of Floatine
2. Second layer of Pabco cemented by hot Floatine
   Second layer to break joints with first.

Johns-Manville Asbestos Pipe Wrap

Analysis of Wrapping

Asbestos content	92-95%
Hair "	5- 7%
Binder (either asphalt or tar base)	3% max.
Tensile strength	= 30 lbs.

No cracking at 77° F. around a 3" Mandrel

A. Standard:
1. Primer (coal tar)
2, 1/16" (coal tar base) J.M. enamel
3. Second coat of enamel and wrapping of Asbestos pipe line felt put on simultaneously

B. Double Standard:
1. Primer (coal tar base)
2. Hot coat 1/16" (coal tar base) enamel
3. Second coat of enamel and wrap~~ped~~ simultaneously
4. Third coat of enamel
5. Fourth coat of enamel and wrap simultaneously

Available Coating Materials.

C. Hard Emulsions.

Hard emulsions generally consist of a bituminous material mixed with a hardening material, either sand or cement. The bituminous material used renders the pipe waterproof, while the hard material combines with the bitumen to resist mechanical action of the soil on the coating.

In some cases, the coating may consist of a bituminous emulsion applied to the pipe with a protective coating of mortar.

The standards of the Shell Oil Company, for this type of coating are as follows:

"...The protective coating which has been adopted as a standard by this company for the protection of underground steel pipe lines, consists of a two-coat application of asphalt chromated emulsion, covered by a rigid cement armor. The asphalt emulsion is applied with a coverage of 12.3 square feet per gallon, giving a set thickness of approximately 1/8". The cement armor consists of a mixture of one volume of Calavaras Cement Company early hardening cement to two volumes of clean-sharp plaster sand which will pass a seven mesh screen. In order to obtain the maximum strength, the consistency of the mortar is kept as low as possible in obtaining a workable mixture, an average of 3.75 gallons of water being used for each sack of cement.

"The cement armor is applied with a curved hand trowel to a thickness of three-eighths to one-half of an inch, without reinforcing, and is cured by spraying on a coat of Hunt Process"

D. Cement or Concrete Covering.

Cement coatings have been used in many instances in Southern California where severe corrosive conditions are encountered. In places where electrolysis from the action of two different strata of soil is liable to occur, concrete coatings are satisfactory.

The coating on the ~~inside~~ outside may be put on by hand, by machine, or else gunited, on a wire netting placed on the outside of the pipe. For inside linings, the cement may be spun on for practically all sizes of pipe. Large inner linings may be placed by hand or by machine. The lining and coating may be done either at the factory or at a plant set up in the field, the economy depending on size of pipe and cost of transportation.

Cement or Concrete Covering, contd.

The Cement Wrapped Pipe Co. of San Francisco does the outside covering by machine. Their application is on a woven wire cloth having a width of 12". On the Hetch Hetchy line, coated by this Company, the coating applied was 1/2" thick, with the exception of one mile, which was especially protected by a 2" coating. The curing was accomplished by the use of the Hunt process by spraying the sections. The Portland Cement Association recommends a minimum thickness of 1" to be applied on a wire mesh reinforcement.

The mix recommended depends a great deal on the experience of the individual in the use of a wrapping machine. The Portland Cement Association recommends a mixture of one part of sand, one and half part of gravel and three parts of cement. For inner linings a mix of one part of sand to three parts of cement has been used successfully in many cases.

E. Metallic Coatings.

Metallic coatings most commonly used are applied either by foil wrapping or else by galvanizing, which consists of hot dipping. Aluminum and copper are common materials used in wrappings, the layers being usually about 20 gauge thickness.

In the galvanizing process zinc is the most commonly used material. Most of the steel pipe which is hot rolled is specified by the manufacturers to be delivered either coated black or else galvanized. Hence, galvanizing can be done at almost any factory. The thickness of zinc coating depends on the corrosive conditions encountered. Speller* states that: "Water pipe for underground service should be hot-galvanized with not less than 2 ounces of zinc per square foot of coated surface, and be further protected against the soil in localities where the soil corrosion is known to be severe."

*Speller, F.N.-"Corrosion-Causes & Prevention" P.522

B. CHARACTERISTICS OF AVAILABLE PIPE COATINGS.

2. EFFECT OF CORROSION ON LIFE OF COATING.

The same segregation in the types of corrosion can be made relative to coatings as to plain pipe, namely:

1. Atmospheric
2. Under water
3. Soil
4. Internal or chemical
5. Electrolysis

A detailed discussion of the effect of each of these types of corrosion on plain water pipe is given in the chapter headed "Corrosion of Plain Pipe".

The purpose of this section is to determine the life which will be added to the pipe under various corrosive conditions for different types of coatings.

The information as to the life of coatings was obtained from Water Superintendents, personal inspection of lines by the writer, data from various engineering journals, from coating manufacturers, pipe manufacturers, and from tests performed by investigators, in Federal and private employ. Chief among these tests are those by the U.S.Bureau of Standards and inspections and tests by the American Petroleum Institute, which are discussed herein in detail.

1. ATMOSPHERIC CORROSION

The field inspections of the American Petroleum Institute (pg.139, A.P.I.Proceedings, January 1930) relative to the effect of atmospheric exposure on pipe coatings, includes 7 inspections of coatings on exposed pipe lines. Five of the inspections recorded in this group refer to enamel coatings, and two to emulsion coatings. Neither of these coatings prevented the pipe from corroding.

As shown in Table #19 of the Chapter on Soil Corrosion of Coatings, the average age of all the exposed inspections was 2.43 years. The average age of those corroded is given as 1.17 years.

In a discussion of the protective coating on the Southern Counties Gas Company's steel line to San Diego, Frederic A. Hough (Western Gas, July, 1932) states that pipe, which will be suspended on bridges, will be of standard weight, and will be galvanized. This line is located close to the ocean and this type of protection was used in this case for salt air.

At the Redondo Beach plant of the Southern California Edison Company, three 56" steel inlet pipes, carried on bents above the ocean surface, have been in service since 1907. These pipes have been maintained by painting the outside each year with two coats of bitumastic solution. A recent inspection showed the outside of these pipes to be in good condition.

The Los Angeles Aqueduct siphons, which are constructed of riveted steel plate, furnish a good example of atmospheric corrosion. This line has been exposed to the desert air for 21 years to date, and has been inspected this year.

The original external protective coating consisted of a water gas tar primer, followed by a coat of coal gas tar. The priming coat was very thin and was applied cold. The total thickness of both coats was from 1/16" to 1/8" thick. The outer coat was applied hot and brushed on, as was the primer. In 1933 the external coating was scraped off and no pitting was found on the pipe. The pipe was then recoated with the same coating as originally used.

Speller states that (p.304, Corrosion causes and Prevention) Bituminous coatings such as ordinary coal tar pitch or asphalt, unless reinforced with a fabric or a suitable filler, are too susceptible to deterioration and changes in temperature for use under most atmospheric conditions.

Conclusions: Since a pipe line exposed to the atmosphere is open to inspection, it can be periodically examined and coated, hence any spots appearing on the surface can be brushed over and readily protected.

The experience of the Los Angeles Aqueduct indicates that coal tar coatings with the use of primers can maintain proper protection, under ordinary atmospheric conditions. Also the experience with the Edison Company line at Redondo Beach shows that periodically applied coatings are satisfactory in salt water air.

EFFECT OF CORROSION ON LIFE OF COATINGS.

2. UNDERWATER CORROSION

The effect of underwater corrosion on the life of coatings can be devided into the effects of fresh water and that of sea water.

The effect of exposure to fresh water of bituminous coatings is relatively slight and such materials are used for pipe protection in contact with water. Coal tar pitch gives better results than asphalt. Metallic coatings, applied by spraying, are considered by Speller as too thin to afford protection under water. Speller also states that - "....Zinc applied by the hot dip process is the best known and most generally used metal coating for iron and steel in contact with water...." Concrete coatings are satisfactory in fresh water and should prove suitable in Southern California because not subject to frost action which is injurious to this type of coating. In the construction of the Hetch Hetchy line crossing the San Joaquin River, a concrete jacket 6" thick was placed on the outside of the 58" steel line. This line has been in use since 1925 and has proved to be satisfactory.

In regards to salt water protection, Frederic A. Hough, in a discussion of the Southern Counties Gas Co.line (Western Gas,July,1932) states the following: ".....At several points the line is to be located in the bottom of salt water lagoons. In these places 5/8" wall galvanized steel pipe is to be used. The very heavy wall provides weight to prevent the line from floating and also insures a long life even if the galvanizing fails to protect. A very heavy coat of galvanizing is to be used. Our previous experience with galvanized lines in the Los Angeles Harbor has been quite satisfactory. The use of galvanized pipe rather than coated pipe permits welding sections on the banks of the lagoons and dragging them into position. Welds in these galvanized sections are to be sprayed with molten zinc...."

The City of Ventura Outfall sewer pipe, which is a 24" 3/8" copper bearing steel pipe, extends into the ocean. This pipe is protected by a gunite coating of concrete on the outside and since its installation, in 1926, it has remained apparently in the same condition.

It is concluded that ordinary bituminous dips give good protection under salt water if applied properly, and with the use of a primer. Concrete coatings also give good service in salt water, if they are properly submerged.

EFFECT OF CORROSION ON LIFE OF COATINGS

3. SOIL CORROSION

The discussion on soil corrosion here presented includes the characteristics of various coatings and the effect thereon of different soils. Within the last few years numerous tests have been made on pipe specimens and also on sections of operating pipe lines to determine the protective action of various types of coatings.

Three series of tests will be discussed here separately in an attempt to determine the life of various types of coatings under different soil conditions:

1 - Tests of the Bureau of Standards, performed in conjunction with the plain pipe tests.

2 - Inspections of existing pipe lines by Dr. Gorden N. Scott, which were presented in the American Petroleum Institute Proceedings of January, 1930.

3 - The tests of American Petroleum Institute on test specimens and test lines, 1929.

The practical value of these tests may be seen in this statement from the Bureau of Standards* , "......In applying the data derived from these specimens to practical pipe protection it is well to bear in mind that the tests only show the action of the soil on the coating, and that the specimens were more carefully coated and handled than pipe lines could be. The failure of a coating indicates that probably a similar coating would be unsatisfactory in the soil involved, but a satisfactory specimen coating might give unsatisfactory service if it could not be properly applied to or maintained on a pipe line......."

*Logan, K.H.; Ewing, S.P.; Yomens, C.D.: Bureau of Standards "Soil Corrosion Studies", Technical Paper #368, p/533

EFFECT OF CORROSION ON LIFE OF COATINGS.

CONCLUSIONS

The conclusions of the various tests on pipe coatings give the results obtained by carefully followed procedure and also the results of actual pipe line inspections. These tests serve to eliminate to a large extent the coatings which are unsatisfactory for pipe line protection. The Bureau of Standards tests and the American Petroleum Institute tests serve to eliminate the unsatisfactory ones, but do not give a satistactory comparison for the general class of coatings, as, for example, the advantages of single or double wrappings. These facts can be obtained from the American Petroleum Institute inspections, which cover a longer period of exposure.

The advantages of "Kraft" paper on coatings can be seen from a statement by Dr.G.N.Scott in the A.P.I.Proceedings for December,1931,p.106. He states, "......The principal advantages may be listed as follows:

"1. Prevention of undue rise in coating temperature, due to an absorption of solar radiation.
"2. As an exterior indicant or of possible mechanical abrasions, due to shipment, handling,etc.
"3. Prevention of coatings on adjacent pipe lengths sticking together during transportation.
"4. Reduction of distortion due to soil stress....."

It has been found that the action mainly responsible for the failure of coatings is the mechanical action of the soil on the coating, commonly called "soil stress". This action is more evident in clay or adobe types of soils. In certain Southern California soils, which, on the whole, are not very moist, there is a great percentage of adobe. Practical experience has shown that a coat of enamel, or similar dip outside of the covering or wrapping, is not effective in adobe soil. This is because the tendency of the soil to adhere to this outer coat and pull it off when the soil becomes dry. It is, therefore, advisable to have the outer coating in the form of a wrapping of some sort for this particular soil condition.

From tests of the Bureau of Standards, the American Petroleum Institute and others, it has been found in general that soils having resistivities of less than 10,000 ohms require some sort of protection for the pipe. It is also shown in Table No.   that the soil corrosivtivity has a fair correlation to the number, or percentage, of coatings corroded. Hence, the effectiveness of the coating can be approximated by the resistivity of the soil. This can be justified because of the various tests which have shown that soil resistivity depends on the salt content, acidity, and rainfall. Reference is made to H.D.Holler, Industrial & Engineering Chemistry, p.750, August 1929. Also by I.A.Dennison in the Bureau of Standards Journal of Research paper 363, October 1931.

The use of these types of tests in the selection of the most econmic type of protective coating is shown in the selection of coatings for the Southern Counties Gas line to San Diego in a paper by Frederic A. Hough in the Western Gas of July, 1932. He states, ".....There are several reasons for selecting the particular design of coal-tar coating we have specified. The specified coating is particularly adapted to field application. By using two coats of enamel next to the pipe without a reinforcing material between, a thick dense coating of bitumen is obtained free from pin holes or holidays. The wrapper, since it is not bonded to the second coat, can be applied at any time prior to the laying of the pipe in the trench. Since this wrapper is made of asbestos felt, shown by the tests of the American Gas Association to be unaffected by soils, it is not necessary to use an outer coat of tar to protect the wrapper. The wrapper is in direct contact with the soil and free to move slightly as the soil moves. Applied in this way, the wrapper protects adequately from soil stress and still does not destroy the imperviousness of the second coat of bitumen as it would if it were included between the two coats of bitumen....."

A detailed discussion of the various tests and inspections on pipe coatings by the Bureau of Standards and the American Petroleum Institute will be presented in pages 133 to 145.

SOIL CORROSION OF PIPE COATINGS.

1. Discussion of Tests by Bureau of Standards.

In the Bureau of Standards tests, many types of coatings were used and their characteristics are listed on Table No.15.

Quoting from the test paper*: "....Six ashpalt coatings and three tar or pitch coatings were considered sufficient for ascertaining the value and usefulness of bituminous dipped pipe coatings. The asphalt coats were made from the straight residue from Mexican, Texas and California crude petroleums, and from mid-continent asphalt combined with gilsonite and stearine pitch, and with the residue from Illinois crude oil....." Further, ".....The tar or pitch coatings were of three different kinds. The first was a low melting, soft coal tar pitch produced from high carbon coal tar, the second was low carbon coal tar from coke ovns, and the third was refined water gas tar manufactured especially for coating cast iron pipe....."

Bituminous coatings applied to steel pipe in 1922 in 31 soils, included asphalt dip, asphalt impregnated fabric wrapping, coal tar pitch dip, and coal tar pitch impregnated wrapping. Coatings applied in 1924 and 1926 to steel pipe in 46 soils were asphalt impregnated fabrics, asphalt dip and coal tar dip. Other wrappings applied to steel pipe which were buried in six to ten soils in 1924 and 1926, consisted of asphalt impregnated felt wrapping, sulphur impregnated cloth wrapping asphalt dips, and asphalt mastics.

The pipe specimens used for the coating tests were butt welded Bessemer steel, 1½ inches in diameter and 17 inches long. The description of the coatings and application is given in Table No.15, greater care being taken than would ordinarily be followed in the field or factory. The pipes were dipped twice, at intervals of one minute. After being cooled, they were dusted with Portland cement dust, wrapped in thin waxed paper, followed by ordinary brown wrapping paper. Specimens were removed in 1926, some being buried for two and one-half years and others for four years.

The soils referred to on Tables 15, 16 and 17, are those referred to in the chapter - "Soil Corrosion of Plain Pipe" and are listed as follows:

*Logan,K.H.;Ewing,S.P. & Yomans,C.D.-"Bureau of Standards: Soil Corrosion Studies, Tech.Paper #368,pg.521

Discussion of Tests by Bureau of Standards

Soil Number	Type of Soil
5	Dublin Clay Adobe
6	Everett Gravelly Sandy Loam
12	Hanford Fine Sandy Loam
13	" Very Fine Sandy Loam
23	Merced Silt Loam
28	Montezuma Clay Adobe

CONCLUSIONS

The corrosive action of soils on coatings is not necessarily the same as on plain pipe. The action on the coating is mostly a mechanical action of the soil, rather than a chemical one as in the case of pipe corrosion. Adobe and clay soils, which are alternately wet and dry, have the effect of tearing the coating off the pipe, as a result of contraction during the process of drying. Temperature changes have a large effect on coatings, causing them to flow in hot weather and to become brittle, and crack in cold weather.

The conclusions of this test are given on Table No.16, together with the criteria used to judge the action of the various coatings.

The tests are divided into two groups, those examined after two and one-half years and those after four years. Since the tests were not made complete to date, an approximate life of the coatings not reported can be interpolated from the other results. The actual results reported are shown on Table #16. On Table #17 is presented the summary of all the coatings, together with the assumed life according to the tests for the various soils.

These coatings can be divided into two groups, the plain dip coatings such as coal tar or asphalt compounds, and the fabric reinforced coating. Coatings 10,13 and 14 are those coatings which have a fabric reinforcement, while the others are plain dips.

The average life of these two groups can be seen by referring to Table No. 17. The life of the reinfofced coatings averages about 12 years, while the plain dips average about 2 and one-half years.

Discussion of Tests by Bureau of Standards

Conclusions (cont'd.)

The following conclusions are those presented in the Bureau of Standards paper on these tests.

"....The thin bituminous coatings add somewhat to the life of a pipe, but in many soils they deteriorate and do not furnish adequate protection against soil corrosion.

"The bond between the coating and the pipe seems to hold better in the pitch coatings, but certain of these coatings are friable and easily scraped from the pipe.

"The thick pitch coating has a tendency to creep or flow, to leave the upper part exposed, and to allow stones and pebbles to penetrate the coating. It also tends to become brittle, but this may not affect its protective value when the protected pipes are not exposed.

"Reinforcing the pitch coating by wrapping the pipe with a loosely woven fabric which can be impregnated with the pitch adds materially to the value of the protection by keeping the coating in place.

"There is some evidence of deterioration of the bituminous materials in some soils, and in such soils a bitumen-impregnated fabric coating will not afford protection against soil action.

"A coating better than any of the dip coatings under test is needed for a number of soil conditions."

SOIL CORROSION OF PIPE COATINGS.

2. Discussion of A.P.I. Inspections of Pipe Lines.

In 1929, four hundred and forty nine field inspections were made in different States of protective coatings on oil and gas lines. The results of these inspections are given in the American Petroleum Institute Proceedings of January 2, 1930 by Gordon N. Scott.

Most of these inspections were of ordinary coatings on actual lines, while the remainder were test coatings placed at various places to compare their action. Ordinarily, these inspections considered a four to eight foot section of pipe which was uncovered and examined.

Corroded means that the coating was rendered unfit regardless of the manner in which it took place.

Group 1 of the inspections as shown hereafter, included exposed pipe lines only, while all the rest of the inspections were on buried lines.

The Distribution of Inspections by States was as follows:*

State	Number of Inspections Made
California	205
Illinois	40
Indiana	5
Kansas	12
Louisiana	23
Missouri	12
Oklahoma	62
Texas	90

Soil Quality was arbitrarily chosen from the corrosibility of bare steel pipe as follows:

Excellent	- Standard 8" Steel Pipe lasting	24 years
Good	do	18-24 years
Fair	"	12-18 "
Bad	"	6-12 "
Very bad	"	less than 6 yrs.

* A.P.I.Proceedings,-.136 Jan.1930,Table 2.

Description of Coating Inspections

Group 1. Coatings on Exposed Lines.

This group includes inspections made on coated pipes which crossed gulleys, creek bottoms, etc., which consequently were not buried. The inspections recorded in this group are enamel coatings, with the exception of two emulsion coatings neither of which prevented the pipe from corroding. These were referred to under discussion of atmospheric corrosion of coatings.

Group 2. Miscellaneous Treatments.

This group includes 23 inspections and is composed of a collection of coatings which could not be placed under one of the other groups. It includes 7 inspections of either enamel, coal,tar,asphalt or asbestos filled cut-back bituminous material, wrapped with a heavy woven unsaturated fabric, such as burlap or canvas; 1 inspection of concrete; 13 inspections of enamels protected by either uncemented, loosely applied fabric wrap (4), wood veneer (1), or uncemented and loosely applied Sisal Kraft paper (8); and 2 inspections of coatings for which an adequate description was not available.

Group 3. Asphalt-emulsion Coatings.

This group is composed of 4 inspections of two coats of emulsion, brushed or sprayed on the pipe, and 14 inspections in which the emulsion coat was followed by dry cement dusted or sprayed on the coating.

Group 4. Grease Treatments.

This group consists of 12 inspections of one or more coats of grease, 14 inspections of greases wrapped with a saturated woven fabric, and 6 cases of grease treatments protected with a bituminous saturated wrapper. In four cases only the grease contained no inhibitor. Three cases of a grease-saturated asbestos pipe line felt wrapped treatment have been included under Group 8.

Group 5. Enamels.

Three makes of coal tar base enamels are included in this group. The numbers of inspections of the three makes are, respectively, 1, 75 and 81.

Group 6. Unreinforced Materials Applied Hot.

Treatments involving paints or primers as first coats for the subsequent hot applications of coal tar materials and asphalts have been included in this group. A few of these applications have been followed by a wrap of Kraft paper which is not considered a protection against corrosion.

Group 7. Paints and Cut-back Bituminous Materials

This group contains a large variety of coatings applied cold, such as paints or primers alone or followed by an application of cut-back bituminous material. Five cases of an asbestos filled cut-back bituminous material are included, as well as three cases of a cut-back bituminous material followed by a wrap of impregnated woven fabric.

Group 8. Single-ply Felt Wrapped Treatments

This group includes 29 inspections of treatments using asphalt, coal tar, and enamels, applied hot as cementing materials for various saturated and coated felts; five cases of cementing materials applied cold, three of which are greases wrapped with a grease saturated asbestos pipe line felt; and three inspections of treatments using combination of cementing materials applied both cold and hot.

Group 9. Double-ply Felt Wrapped Treatments

This group is similar to Group 8, except that two plies of fabric are incorporated in the coating. It contains 31 inspections of coatings using bituminous materials applied hot; 11 cases of cut-back bituminous materials, 9 of which showed the pipe to be corroded; and 1 case where both hot and cold applied bituminous materials were used.

Group 10. Triple-ply Felt Wrapped Treatments.

This group is similar to the two previous groups, except that only bituminous materials applied hot have been used and three layers of fabric. Four of the fifteen heavily reinforced treatments in this group have been further protected from distortion by applying an outer layer of a sand and sulphur mix, asphalt-emulsion and cement and sheet iron longitudinally wrapped and wired on over the coating.

Discussion of A.P.I. Inspections of Pipe Lines

Conclusions

The composite results for all the groups of coatings inspected are shown on Table #19.

This Table gives the average age of each group of coatings, the average soil quality in which the particular group was inspected and which is explained on Table #20, and the percent of inspections of each group which were found corroded; also the average age of the coatings which were corroded. Hence, if allowances are made for errors in observation, an approximate life can be calculated for each of the groups of coatings inspected in the various types of soils, as represented by the soil qualities.

This has been calculated and is presented in the last two columns of Table #19, for a soil quality of 20, assuming that an average life can be determined when half the inspections were corroded.

This is an approximate solution, because, as indicated in the discussion to this test, the soil quality gives an indication of the soil action on bare pipe, which is not always the same as the action on the coating. However, this calculation places all the coatings on an equal basis and a sound comparison can be made.

In Table #20 is presented the number of corroded inspections for each of the various soil classes. This is also shown graphically on Plate #7.

In Table #21, the coatings are divided into two classes: Division I consisting of groups 3-7 inclusive, and Division II, which is composed of groups 8,9 and 10. From the description of the various groups it can be seen that Division I is made up of the unreinforced coatings, while Division II is made up of the fabric supported coatings. In the last two columns of this Table is shown the percent corroded, for each division, at the age of 1 to 18 years, which has been calculated assuming an average soil quality of 20. On Plate #9 is shown the graphical presentation of the data on Table #21 for varying soil qualities. This is given for the coatings combined and also for each of the divisions. On Plate #10 is shown the data computed from Table 21 for an average soil quality of 20. This is also shown for all the coatings and for each of the divisions.

Discussion of A.P.I. Inspections of Pipe Lines

Conclusions

On Table #18 is shown the computed life of each group of coatings for each soil quality. This summary is also presented in graphical form on Plate #8. On the page following is shown the method of computation of the life of each of these groups.

Since the data originally presented was for various percentages corroded in each group, the first correction to be made was to determine the age at which 50% of the coatings in each group would be corroded. Then the next step was to use this standard of 50% corroded and determine the life in each soil quality for each of the groups. This was done with the use of Plates #7 and #10, as shown in the calculations.

As seen in Plate #8, the reinforced coatings have a life of from 2 to 50 years in the various types of soils, as compared with a variation in life of from 6 months to 7 years among the reinforced coatings. The information from this data is not necessarily valuable for predicting the life of coating, but is important in showing the relative life of the different groups of coatings under the same soil conditions.

Discussion of A.P.I. Inspections of Pipe Lines.

Average Life of Coating in Years in Various Soils.

Sample Calculation of Table #18

In column 3 of Table #19 is given the average soil qualities of the inspected groups. In column 7 of the same table is given the average of the life of any particular group considering that soil quality.

In order to get the life of a group for different soil qualities, this age must be multiplied by the ratios of soil qualities. Since the ratio for soil quality to age does not vary as a straight line, this ratio has been plotted on Plate #7. Hence this ratio can be taken from this plate in computing the estimated life of a group of coatings for the different soil qualities.

Example for Group 2.

From table 3, the average soil quality is 10.3
" " " " age is 2.04 years

(a) To find the life in a soil quality of 10

From Plate 7, the ratio of soil quality to age for the 10.3 and the 10 is 1.14 to 1.12

Hence, the life in soil quality 10 is $\frac{1.12}{1.14}$ x2.04 or 2.0 years.

(b) To find the life in a soil quality of 5.

From Plate 7 the ratio of soil qualities to age for the 10.3 and the 5 is 1.14 to .67

Hence, the life in soil quality of 5 is $\frac{.67}{1.14}$ x 2.04 or 1.2 years.

SOIL CORROSION OF COATINGS

3. Discussion of A.P.I. Tests - 1930

The tests by the American Petroleum Institute* on test lines and pipe specimens were performed at 15 different locations, given in Table No.22. These tests were started in 1930 and the results of two years observation are available, and are discussed herewith.

The various soils studied and their characteristics are listed in Table No.22. Three of the test locations are in California and are hence applicable to this study.

Two groups of tests were made. The first group was the test of 19 different coatings on test pipe lines. Both the thickness and description of these coatings are listed in Table No.23 and the results in Table No.24. In many cases primers were also used, which are also described, together with the coating.

The second test group consists of short pipe specimens, the results of which are shown on Table No.26. These specimens were 2 foot lengths of 3" pipe and were buried in the same localities as the specimens in the first test. This second involved the study of 46 different coatings. Because of the great number of coatings studied in this second test, only those which showed the pipe to be unaffected by corrosion in not less than 11 sites will be described. The description of these coatings is given in Table No. 26.

Test Criteria

Two types of tests were used to determine the corrosion of the coating. The first involved the inspection of the pipe under the coating. The results were classified by the following symbols:

- U - That the pipe is unaffected.
- R - Shows definite surface rust.
- M - Shallow metal attack.
- P - Pit Depth - Figures indicating the deepest pit in excess of .010" in the pipe beneath the coating.

* "Progress Reports of A.P.I.Coating Tests" - Dr.G.N.Scott, A.P.I. Proceedings, December, 1932

A.P.I. Tests

The second crireria involved the making of an electric pattern of the coating to determine if there were any holes in the coating. A positive pattern showed that the coating had been punctured, while a negative pattern showed that the coating was in good shape.

In regard to the accuracy of the pattern tests as true indicators of coating failure, the following statement from the A.P.I. Proceedings of Dec. 1932, p.121, will suffice -

> "If, in testing a simple unreinforced coating, not too thick, a negative pattern is obtained, it may be assumed that the pipe underlying the coating is free from corrosion. If a negative pattern is obtained with a reinforced or heavy coating, it may be assumed that there are no direct ruptures in the coating; but it cannot be inferred that corrosion either has or has not occurred. On the other hand, if a positive pattern is obtained, it is almost certain that corrosion has occurred, although the extent of the corrosion can only be determined by an examination of the pipe. This latter statement is true regardless of the structure of the coating, but is more exact the longer the coating has been in service..."

Conclusions of A.P.I. Tests

The conclusions of these two tests are given in Tables Nos. 24 and 26.

The first set of tests, that on test lines, the results of which are shown on Tables Nos. 24 and 25, is the more important of the two from a practical point of view. These coatings were subjected to the actual conditions to which coatings are exposed on pipe lines, hence the results are more valuable.

The second group of tests, the results of which are indicated on Table No.26, although they were but two foot specimens, nevertheless show the effects of the particular soils on the coatings. It is apparent that if a coating failed under the conditions of this test, it would stand up for a lesser time on an actual pipe line.

Table No.27 gives the relative corrosive effect on coatings of the different soils studied in the tests. Although most of the soils are about equal in this respect, there are a few instances where the soil does not exert much action on the coating and only the weaker coatings were corroded. This table is uniform, however, showing the same degree of corrosion for a particular soil in both tests and with both the pipe examination and the pattern indication.

The thickness of the various coatings should be noticed very carefully. If a thin coating is used without a substantial wrapping for protection, it will have an opportunity to be broken by rough handling or by backfilling. Also, a thicker coating may flow to a certain extent on the pipe and still cover every portion of the pipe.

The results of the tests of the various coatings on the test lines can be seen in Table No.24. Coating O, which is an asphalt mastic, was the only coating to remain unaffected. This coating, as shown on Table No.23, is the thickest of the coatings tested, being approximately one half an inch thick. Coating F, which was a coating of practically the same thickness, but consisting of an asphalt emulsion covered by a mortar coat, showed no pitting underneath, but did show indications of rust in about half the cases tested.

The thin, single coats of coal tar or asphalt enamels and dips showed no effect of corrosion in only 25% of the tests. The fabric reinforced materials were better than this, although showing only 35% to be unaffected, and showed a small percentage of the pipe to be pitted.

In the second test group, which consisted of coatings on two foot specimens, 46 coatings were tested. Out of these 46 there were 15 which were unaffected in at least 11 sites out of the 15. The actual percentage is higher than this, because all the coatings were not tested in all of the locations. These coatings and their composition are listed on Table No.26.

In a summary on the page following Table No.26, it can be seen that there are four groups of coatings unaffected. The first consists of dips with no fabric protection. The three dips in this first group, although made by different companies, are all coal tar enamels.

In the second group were two coatings of bituminous dips placed on a base of lead paint. Other similar coatings made by different companies failed, showing that here, as in the case of all materials, the particular composition has a large difference in the action.

Conclusions of A.P.I. Tests

In the third group, which consisted of single wrapped coatings, both coal tar and asphalt dips were equally effective. There were more successful coatings in this group than those not wrapped, showing the added protection of the wrapping.

In the fourth group, which consisted of the double wrapped materials, the action was about the same as the single wrapped materials. A longer test period will reveal more information as to the advantages or disadvantages of double wrapped coatings as compared to single wrapped coatings.

One coating composed of 20 gauge strip steel on a double reinforced asphalt coating was satisfactory for pipe protection. Another coating, consisting of a double dipped asphalt coating wrapped with aluminum foil, was not satisfactory. This type of covering seems to be not as practicable as the bituminous coatings, and less effective.

EFFECT OF CORROSION ON LIFE OF COATINGS

4. Internal Corrosion

The internal corrosion of coatings depends on two factors, the scouring action of the water and material it carries, and the corrosive properties of the water.

In the first case, it is purely a mechanical action of errosion, merely one way of wearing away the coating to permit the corrosion of the metal to take place.

In the second case, a direct chemical decomposition of the coating may occur, or the perviousness of the coating may allow the rusting of the pipe inner surface.

Pipe coatings applied by immersion are coated on the inside as well as on the outside. This method of dipping applies to most of the western rolled pipe, which is dipped at the factory. Field coated pipe requires application inside at the factory if the pipe is too small to permit access in the field. Cast iron pipe is usually dipped at the factory and consequently is also coated on the inside. This also applies to galvanized pipe, which is coated by the hot dip process.

Spun bituminous linings furnish very impervious surfaces and experience with this type of lining shows that it is satisfactory as far as protecting the pipe, but is as yet too brittle for practical use.

In Table No. 4 is shown the results of the recent inspection of the Los Angeles Aqueduct steel siphons. The internal coating consisted of a primer coat of water gas tar followed by a coat of coal gas tar. After being in service for 21 years the coating was scraped off, together with the tubercules which had formed, and the pipe appeared to be in good condition. This inner surface was then recoated with the same type of coating as that originally used.

At the Redondo Beach plant of the Edison Company three 56" steel lines carry salt water from the ocean and have been in service since 1907. These lines were painted on the inside with an asphalt dip originally, and have not been painted since. A recent inspection showed these lines to be in excellent condition on the inside.

Concrete and cement spun linings in metal pipes have been the most recently used internal protection. This type of lining has proven to be very successful, as has concrete pipe, against internal corrosion.

EFFECT OF CORROSION ON LIFE OF COATINGS.

5. Electrolysis

It has been found that the ability of coatings of bituminous materials or wrappers to resist electrolysis, due to stray electric currents, is negligible. The elctrical resistivity of the dry coating is not the true indication of its value under actual operating conditions. Here the coating is immersed in what, for all practical purposes, is an electrolyte. It may, at best, resist the passage of current for a few hours, but where the soil is moist to any degree, the coating will furnish no resistance whatever. This experience has been found to be true by the Los Angeles Department of Water & Power, in testing and trying both one and two coats of bituminous and other basic enamels and paints.

Wrappings delay the effectiveness of the current because of their thickness but they are not resistant to the passage of current to the pipe for any length of time. A further difficulty with wrapping is that it is discontinuous in many places along the line, which serves to concentrate the amount of corrosion at these points, because the current may leave the pipe through these openings. This is also true of all kinds of coatings wherever punctures occur.

The tests performed by the Bureau of Standards in 1914 (Surface Insulation of pipes as a means of Preventing Electrolysis) Technologic Paper #15, bear out the fact that paints bituminous dips, wrappings, enamels, and cement mortar or concrete coatings, do not offer any resistance to the passage of electric current.

Speller (p.539, Corrosion, Causes and Prevention), states that concrete coatings are not proof against electrolysis.

3. COST OF PIPE COATINGS

The cost of coating depends on the type of material used and the number of dips and wraps. Large lines, such as aqueducts, are usually brushed in the field, although spraying is also used a great deal. On Table No. is given the price data per foot for three sizes of pipes, with different coatings.

Costs are also given for an interior lining of coal tar enamel which is applied by spinning.

For field application, coating primers are usually necessary. They are applied very thin and cost about 2¢ per foot of pipe for a 20" pipe.

Costs on concrete coatings are not quoted by the companies. An 18" steel line 2453 feet long, was dug up by the Los Angeles Water Department in 1931: this was given a concrete lining and coating and replaced in the trench. The total cost was $4.56 per foot.

Pasadena, California
June, 1933

Harold Roach

Notes on A Distribution System Soil Survey
By - A.B.Allyne
Western Gas, Aug.1932, pg.87

Class of Soil	Descriptive Terms	Rod Reading ohms - cms.	Estimated Life of Bare Steel Pipe years	Specifications for Mains
1	Excellent	10,000-6,000	25 or more	Steel pipe with no protective coating.
2	Good	6,000-4,500	17 - 25	Steel with a protective coating, cost of which will not constitute more than 10% of entire cost of job.
3	Fair	4,500-2,000	10 - 17	Cast Iron, copper or heavily protected steel, depending on local conditions. If steel, cost of protective coating shall not exceed 20% of entire cost of job.
4	Bad	0 - 2,000	0 - 10	Cast Iron or copper. No steel installed in this classification of soil.

ALLOWABLE PRESSURE FOR PLAIN CONCRETE PIPE

The following table is given on page 303, Etcheverry, based on tests at the University of California for plain concrete pipe, which will not leak or sweat excessively for pressures at least twice those given in the table and whose bursting pressure is about four times the value given in the table.

Diam. of Pipe in Inches	Maximum Safe Head in Feet		
	1 to 2 Mix	1 to 3 Mix	1 to 4 Mix
12	20	15	10
14	20	15	10
16	18	12	8
18	18	12	8
20	18	12	8
24	15	10	6
30	15	10	6

Table No.3

<u>MANUFACTURERS STANDARDS FOR PIPE MATERIALS</u>

<u>A. STEEL PIPE</u>

Company	Ultimate Strength	Standards	Test Pressures	Efficiency & Seam	Type of Material	Yield Point	Chemical Analysis
Western Pipe & Steel Co.	50,000	A.S.T.M. A-78 Gr.B.	to 18,000 stress	100 % Elect.weld	A.S.T.M. Grade B.	27,000	
West Coast Pipe&Steel Co.	46,000	Am.St.Man. Ass.Grade B to stands.		Elect.weld	Grade C.	23,000	
National Tube Co.-Hammerweld	45,000	A.S.T.M. A-78-23 T	to 15,000 stress	Hammerweld		24,000	Carbon below .15% Mn.-.35-.60% P-below .06% S-below .05%
National Tube Co.-Seamless	45,000		$p=\frac{32,000t}{D}$	100% Seamless	Open Hearth	24,000	Carbon below .20 to .10% Mn.-.30-.60% P-below .04% S-below .05%
National Pipe	45,000		Manuf. Standards		Open Hearth	.25,000	
Jones-Laughlin Steel Co.	45,000		"		"	25,000	Ph.below .06%
Spang-Chalfand Co.	45,000		"		"	25,000	Mn.from .3 to .6% S.-below .06%
Naylor Pipe	(39,100)				Toncan Steel	(24,400)	Cu-.40% Carbon below .04%

<u>B. WROUGHT IRON PIPE</u>

Company	Ultimate Strength	Standards	Test Pressures	Efficiency & Seam	Type of Material	Yield Point	Chemical Analysis
Reading Pipe	42,000		Manuf.Stands.	Lap Weld		24,000	
Byers Co.			" "	" "			.02%C. .14%P. .03%Mn. .02%S. .16%Si.
Cohoes Mills	40,000	A.S.T.M.	" "	" "		24,000	" " " " "

C. CAST IRON PIPE

Company	Ultimate Strength	Standards	Test Pressures	Efficiency & Seam	Type of Material	Yield Point	Chemical Analysis
Warren Fdy.Co.	20,000			100%	Vertical Cast		
Amer.C.I.Pipe	20,000			"	" "		
U.S.Pipe Co.	20,000			"	" "		
McWane Pipe	20,000			"	Horizontal "		
deLavaud Pipe	30,000			"	Centrifugal Spun Metal Mold.		
Centrif.Spun A.C.I.P.Co.	25,000			"	Centrifugal Spun Sand Mold		

D. WOOD STAVE PIPE

Company	Ultimate Strength	Standards	Test Pressures	Efficiency & Seam	Type of Material	Yield Point	Chemical Analysis
Pacific Tank & Pipe Co.	60,000 (Steel Bands)				Both Continuous Stave & Machine Banded.		
Little River Redwood Co.	"				"	30,000	

E. REINFORCED CONCRETE PIPE

Company	Ultimate Strength	Standards	Test Pressures	Efficiency & Seam	Type of Material	Yield Point	Chemical Analysis
Amer.Conc.Pipe (Hume Steel)	55,000 (Steel)					33,000	
Independent Concrete Pipe		A.S.T.M.					
Bonna Pipe Co.							
Newark Concrete Pipe Co.							

LOS ANGELES AQUEDUCT STEEL SIPHONS

INSPECTION* JUNE 1931

Installed 1912-1913

Siphon	Diam.	Head	Buried or Exposed	Soil
Nine Mile	9'6"	175 ft.	Exposed-piers	Sandy Loam.
No Name	9'3"	365	" "	" "
Sand Canyon	8'6"	455	2/3 on piers. 1/3 partially buried.	Decomposed Granite.
Grapevine	9'3"	355	Partially buried	
Jawbone	10'0" to 7'6"	850	Exposed-piers	Sandy Loam.
Pine Canyon	9'0"	480	" "	
Antelope	10'0"	200	Partially buried	Clay Loam.
Deadman	11'0"	245	Exposed-piers	Sanstone.
Soledad	11'0"	260	" "	"
Quigley	11'0"	67	" "	Gravel Loam.
Placerita	11'0"	105	3/4 on piers exposed.	Sandy Gravel.
Dove Spring	9'0"	105	Buried	Sandy Loam.
San Antonio	9'0"	72	"	" "

LOS ANGELES AQUEDUCT SIPHONS

INSPECTION JUNE 1931

General Remarks

Original paint throughout-water gas tar primer and coal gas tar finish.

Pipe somewhat tuberculated($\frac{1}{2}$" max.)in some siphons due to relatively soft well water.Water neutral.

To scrape inside of pipe,wire brush,and apply water gas and coal gas tar paints-cost 8-$\frac{1}{2}$ ¢ per sq.ft.

For outside of buried pipe,same work plus all excavation work cost 17¢per sq.ft.

Have tried Arcomastic paint (cold) on inside of Grapevine. Water gas and coal gas tar paints applied hot at 400°F.Black paint used throughout,although aluminum would be better color on the outside.For buried pipe,uncover two rings at a time for painting.

Water temperature-minimum of 40°F.;maximum of 79°.

Atmospheric temperature-min.of 25°F.;max.of 110°.Pier space of 24 feet.

Steel plate in excellent condition throughout;buried pipe has very occasional spot with slight pitting;pipe breaths considerably,but has caused no trouble;sweating at occasional points very slight;no expansion joints used;pipe bears directly on saddle; anchors only at horizontal bends and at ends;dual lines favored by some engineers;pipe laid on piers because cost of trench and bell holes more than offset cost of piers;boiler plate steel used.

Friction test as follows;after 20 years of service and before applying new paint,all of the riveted steel siphons had a William and Hazen "C" of 86;after cleaning and repainting,"C" became 108.

Present practice of Power department in painting pipe is to apply two coats of Detroit graphite outside,and a primer coat of Bitumastic solution and a finish coat of Bitumastic enamel on inside.In past,have tried use of water gas tar,Ferrum,Krodeproof,Valdura,Biturine,etc.varying degrees of success.

OPENHEARTH STEEL PIPE-UNPROTECTED

CORROSION LOSSES IN VARIOUS SOILS

BUREAU OF STANDARDS-JOURNAL OF RESEARCH-PAPER 329

Soil No.	Name	Weighted Maximum Rates of Pitting-Mils, Of in. per yr. 2 yr.	4 yr.	6 yr.	8 yr.	Av.#20
5	Dublin Clay Adobe	2.6	7.2	9.9	5.8	6.4
6	Everett Gravelly Sandy Loam	2.6	3.3	2.3	1.9	2.5
12	Hanford Fine Sandy Loam	2.6	9.5	8.7	2.1	5.7
13	Hanford Very Fine Sandy Loam	31.6	12.6	13.4	---	19.2
23	Merced Silt Loam	40.8	29.1	17.0	19.7	26.7
28	Montezuma Clay Adobe	23.3	---	12.7	(14.0)	18.0
35	Ramona Loam	2.6	4.0	1.6	3.0	2.8

COMPUTED ACCUMULATIVE PITTING

Soil No.	Total Pitting-Accumulative of Max.Rates-Mils of Inches 2 yr.	4 yr.	6 yr.	8 yr.	Total at aver.rate
5	5.2	19.6	39.4	51.0	51.2
6	5.2	11.8	16.4	20.2	20.0
12	5.2	24.2	41.6	45.8	45.6
13	63.2	88.4	115.2	153.6*	153.6
23	81.6	139.8	173.8	213.4	213.6
28	46.6	82.6*	108.0	136.0	144.0
35	5.2	13.2	16.4	22.4	22.4

*Usw average rate in missing years

VERTICAL SANDMOLD CAST IRON PIPE-SOUTHERN ORE-UNPROTECTED

CORROSION LOSSES IN VARIOUS SOILS

BUREAU OF STANDARDS-JOURNAL OF RESEARCH-PAPER 329-1931

Soil No.	Name	Weighted Maximum Rates of Pitting-Mils of in.per yr. 2 yr.	4 yr.	6 yr.	8 yr.	Av #20
5	Dublin Clay Adobe	2.6	6.2	11.9	8.3	7.2
6	Everett Gravelly Sandy Loam	2.6	2.4	1.6	1.2	1.9
12	Hanford Fine Sandy Loam	2.6	11.1	9.3	1.2	6.0
13	Hanford Very Fine Sandy Loam	31.0	24.6	30.0	---	28.5
23	Merced Silt Loam	82.0	67.8	41.8	41.8	57.3
28	Montezuma Clay Adobe	28.8	---	---	(31.0)	28.8
35	Ramona Loam	20.2	7.6	2.5	1.2	7.9

COMPUTED ACCUMULATIVE PITTING

Soil No.	Total Pitting-Accumulative of Max.Rates-Mils of Inches 2 yr.	4.yr.	6 yr.	8 yr.	Total at aver.rate
5	5.2	17.6	41.4	58.0	57.6
6	5.2	10.0	13.2	15.6	15.2
12	5.2	27.4	46.0	48.4	48.0
13	62.0	111.2	171.2	228;2*	228.0
23	164.0	299.6	383.2	466.8	458.4
28	57.6	115.2	172.8	234.8	230.4
35	40.4	55.6	60.6	63.0	63.2

* Use average rate in missing years

Table No.7

HAND-PUDDLED WROUGHT IRON PIPE-UNPROTECTED

CORROSION LOSSES IN VARIOUS SOILS

BUREAU OF STANDARDS-JOURNAL OF RESEARCH-PAPER 329

Soil No.	Name	Weighted Maximum Rates of Pitting-Mils of in.per year 2 yr.	4 yr.	6 yr.	8 yr.	Av.#20
5	Dublin Claay Adobe	2.6	6.6	6.5	4.3	5.0
6	Everett Gravelly Sandy Loam	2.6	3.0	2.1	1.2	2.2
12	Hanford Fine Sandy Loam	2.6	10.4	10.4	2.4	6.4
13	Hanford Very Fine Sandy Loam	23.1	8.6	9.6	---	13.8
23	Merced Silt Loam	23.4	22.3	14.4	19.6	1919
28	Montezuma Clay Adobe	16.5	---	9.8	---	13.2
35	Ramona Loam	2.6	4.7	3.3	2.1	3.2

COMPUTED ACCUMULATIVE PITTING

Soil No.	Total Pitting-Accumulattive of Max.Rates-Mils of Inches 2 yr.	4 yr.	6 yr.	8 yr.	Total at aver.rate
5	5.2	18.4	31.4	40.0	40.0
6	5.2	11.2	15.4	17.8	17.6
12	5.2	26.0	46.8	51.6	51.2
13	46.2	63.4	82.6	110.2*	110.4
23	46.8	91.4	120.2	159.4	159.2
28	33.0	59.4*	79.0	105.4*	105.6
35	5.2	14.6	21.2	25.4	25.6

*Use average rate in missing years

Table No.8

DE LAVAUD CENTRIFUGAL PROCESS CAST IRON PIPE UNPROTECTED

CORROSION LOSSES IN VARIOUS SOILS

BUREAU OF STANDARDS- JOURNAL OF RESEARCH-PAPER 329

Soil No.	Name	Maximum Rates of Pitting- Mils of Inches per Year 2 yr.	4 yr.	6 yr.	8 yr.	Av.#20
5	Dublin Clay Adobe	17.7	---	8.9	---	13.3
6	Everett Gravelly Sandy Loam	4.5	---	1.6	---	3.0
12	Hanford Fine Sandy Loam	4.5	---	1.6	---	3.0
13	Hanford Very Fine Sandy Loam	13.2	12.2	1.6	---	9.2
23	Merced Silt Loam	16.4	30.4	2.2	20.5	22.7
28	Montezuma Clay Adobe	18.0	---	7.0	(8.0)	12.5
35	Ramona Loam	4.5	---	1.6	---	3.1

COMPUTED ACCUMULATIVE PITTING

Soil No.	Total Pitting-Accumulative of Max.Rates-Mils of Inches 2 yr.	4 yr.	6 yr.	8 yr.	Total at aver. rate
5	35.4	62.0*	81.8	108.4*	106.4
6	9.0	15.0*	18.2	24.2*	24.0
12	9.0	15.0*	18.2	24.2*	24.0
13	26.4	50.8	54.0	72.4*	73.6
23	32.8	93.6	98.0	139.0	181.6
28	36.0	61.0*	75.0	91.0	100.0
35	9.0	15.2*	18.4	24.6*	24.8

*Use average rate in missing years

Table No.9

pH VALUES AND PERCENT OF SOLUBLE SALTS IN SOILS

BUREAU OF STANDARDS- TECHNICAL PAPERS- 1928

Soil No.	Name	Depth	pH	Soluble Salts
5	Dublin Clay Adobe	10"-30"	5.9	.044%
6	Everett Gravelly Sandy Loam	" "	5.6	.007%
12	Hanford Fine Sandy Loam	28"-36"	7.6	.023%
13	Hanford Very Fine Sandy Loam	8"-24"	9.0	.342%
23	Merced Silt Loam	10"-24"	9.2	2.100%
28	Montezuma Clay Adobe	---	---	----
35	Ramona Loam	8 "-26"	7.2	.061%

Note: pH means the index of the hydrogen ion content. Pure water has a hydrogen ion value of 10^{-7}, hence the pH value is 7.0. If the solution is acid, the pH value will be below this, or 5.0 etc. If the solution is alkaline, the pH will be above this or 8.5 etc.

SUMMARY OF TESTS ON STEEL, WROUGHT IRON, & CAST IRON SUBJECT TO CORROSION

IN AIR AND WATER

Average Penetration in Inches per Year

	-Air			Fresh Water			Sea Water		
	Steel	Wrought Iron	Cast Iron	Steel	Wrought Iron	Cast Iron	Steel	Wrought Iron	Cast Iron
Mean of Data 1838 - 1900	.00252	.00301	.00100	.00185	.00169	.00138	.00278	.00302	.00184
Other Tests	.0049	.0045	.----	.00116	-----	.00229	.00206	----	.00205
	.0109	.0067		.00190					
Average	.0049	.0045	.00100	.00185	.00169	.00183	.00242	.00302	.00194

Data: Speller, F.N.- Corrosion, Causes and Prevention

Table No.11

COST DATA-ACTUAL LINES IN SOUTHERN CALIFORNIA

STEEL PIPE

Diam. in.	Head #/in.²	Thickness	Type of Soil	Type of Pipe	Date	Length in ft.	Total cost per.ft.	Surface Condition
6	--	Stand.	---	---	1932	1,362	$ 2.60	Paved±Hand dug.
8	--	Stand.	---	---	1932	1471	2.72	" "
16	--	#10 ga.	---	Welded & welded joints	1933	400	1.50	Earth-Hand dug.
16	70	#12 ga.	Rocky	Riveted	1931	3,072	1.76	" "
16	90	#12 & 14 ga.	Gravelly Loam	Riveted joints	1928	8,700	1.08	" "
16	40	#12 ga.	Sand & Rock	---	1932	7,300	1.54	Paved and Unpaved
16	--	3/8"	---	Welded	1931	1,518	4.47	Earth-Machine dug.
16	--	3/8"	---	"	1931	415	3.41	" "
20	140	#8 ga.	Gravelly	---	1920	20,142	5.37	Paved "
24	---	3/8"	---	---	1928	4,976	8.56	" "
24	---	3/16" &#10 ga.	Clay	Double riveted	1925	6,452	3/16=3.39 10 ga.=2.75	
30	---	3/8"	---	Welded	1932	785	12.63	Paved-Hand dug.
30	---	3/8"	---	"	1931	20,189	8.29	" Machine dug.
30	---	3/8"	---	"	1931	12,950	10.53	" "
30	---	3/8"	---	"	1932	5,405	8.78	" "
36	---	7/16"	---	"	1931	6,541	11.72	" "
36	---	7/16"	---	"	1931	4,217	10.69	Paved partly "
40	---	3/8"	---	"	1932	2,598	12.30	Paved "
40	---	3/8"	---	Welded± slip joint	1931	1,750	10.99	Paved partly "
40	---	3/8"	---	Welded	1932	2,948	10.04	Paved "
40	---	3/8"	---	"	1932	3,696	10.65	Paved partly "

Note: Total cost includes cost of pipe and installation and overhead, and all other costs.

SCHEDULE USED FOR ESTIMATING PIPE LINE COSTS

Nov.1932

CAST IRON PIPE - BELL & SPIGOT JOINT

COST PER FOOT

Size-250#	6"	8"	12"	16"	18"	20"	24"	30"
Pipe	$ .65	$ .95	$ 1.60	$ 2.40	$ 3.50	$ 4.30	$ 5.05	$ 7.40
Labor	(.26	.32	.35	.65	.85	1.00	1.10	1.25
Misc.Material	(		.20	.25	.25	.25	.30	.35
Equipment	(		.15	.15	.20	.25	.35	.50
Transportation	(.24	.28	.12	.15	.18	.20	.24	.30
Shop Service	(		---	.05	.08	.09	.10	.10
Indirect	(		.21	.39	.49	.56	.65	.81
Total	1.15	1.55	2.63	4.04	5.55	6.65	7.79	10.71

COST DATA-ACTUAL LINES IN SOUTHERN CALIFORNIA

CONCRETE PIPE

Diam. in.	Head #/in.^{2}	Thick- ness	Type of Soil	Type of Pipe	Date	Length in ft.	Total cost per.ft.	Surface Condition
16"	15	2"	Alkaline	Concrete	1929	6,600	55¢	Earth-Hand& Machine dug
16	Gravity	--	Gravelly	"	1932	3,300	65¢	Unpaved- Hand dug.
18	--	1-1/2"	Clay	Hume Reinf. Concrete	1928	2,640	$4.00	Earth-Machine dug.
24	Up to 86	---	Clay	Reinforced Concrete	1925	14,322	2.11-3.04	Unpaved-Hand& Machine dug.
24	--	2-1/4"	Clay	Concrete	1932	2,573	1.68	Earth-Hand dug.
30	Gravity	--	Clay	Plain Concrete	1925	20,845	1.75	Unpaved-Hand& Machine dug.
39	25	3-1/2"	Gravel	Hume Reinf. Concrete	1930	1,243	8.65	Unpaved*Machine dug.
42	55	3-3/4"	Sandy Loam	Hume Reinf. Concrete	1927	40,000	8.62	" "
48	10	4-1/8"	Decomposed Granite	Hume Reinf.Conc.	1930	5,420	8.75	" Hand dug.

COST DATA-1932 PRICES

REDWOOD WOOD STAVE PIPE

Cost per Foot

Size	Head in Feet	Cost of Pipe Alone		Total Cost-Pipe Buried	
		Mach.Band.	Cont.Stave	Mach.Band.	Cont.Stave
20"	50	$ 1.46	$ 1.80	$ 2.73	$ 3.30
	100	1.66	2.17	2.93	3.67
	150	1.86	2.57	3.13	4.07
	200	2.06	2.97	3.33	4.47
	250	2.26	3.31	3.53	4.81
	300	2.47	3.71	3.74	5.21
24"	50	1.73	2.63	3.28	4.38
	100	2.01	3.13	3.56	4.88
	150	2.30	3.63	3.85	5.38
	200	2.61	4.13	4.16	5.88
	250	2.92	4.63	4.47	6.38
	300	3.26	5.13	4.81	6.88

CEMENT LINED CAST IRON PIPE

AMERICAN CAST IRON PIPE CO.

COST FOR LINING ONLY- UNDER 500' LENGTHS

Size	Cost per ft.
4"	5¢
6	8
8	12
10	16
12	21
14	22
16	23
18	28
20	33
24	44
30	50
36	68
42	89
48	$ 1.13

Table No.14c

TRENCHING AND RESURFACING DATA

Size of Pipe	Trench Width	Pavement Width
2"	1.5 ft.	2.0 ft.
3	"	"
4	"	"
6	"	"
8	"	"
10	"	"
12	"	"
14	1.7	2.2
16	1.9	2.4
18	2.0	2.5
20	2.5	3.0
22	2.7	3.2
24	3.0	3.5
27	3.25	3.75
30	3.5	4.0
36	4.0	4.5
40	4.3	4.8
42	4.5	5.0
48	5.0	5.5
52	5.5	6.0
60	6.0	6.5
68	6.7	7.2

RESURFACING COSTS

Type of Pavement	Cost per Sq.Ft.
Asphalt	40¢
Bitulithic	40
Brick	40
Granite Block	30
Concrete	30
Macadam	30
Cement Walk	28
" Gutter	28
Concrete Base (only)	22
Asphalt Surface "	18
Gravel or Oil Surface	12
Dirt Surface	01

SOIL CORROSION OF PIPE COATINGS

Description of Bituminous Pipe Coatings
Used in Bureau of Standards Tests.

From p.520, Technological Papers, Vol.22, 1927-28 U.S.Bur.Stds.

Coating No.	Coating Thickness	Penetration Low	Penetration Normal	Penetration High	Ductility at 77° F.	Melting Point B & R Method	Solubility in CS_2	Application Temperature	REMARKS
1	.013"	21	31	47	1.6 cm	216° F.	99.9%	370° F.	Coating soft & greasy. Rubs off & chips on impact
2	.024"	14	19	34	2.0 "	210° F.	98.5%	355-380°	Hard, tough coating. Rubs off; poor adhesion to metal
3	.007"	33	49	89	2.5	181°	99.8%	400° F.	Soft, greasy Ctg. Pushed off by impact. Spreads out. Good adhesion;
4	.011	13	20	48	3.0	185°	99.8%	350-365°	Smooth, waxy Coating. Chips easily. (Resists abrasion.
5	.008"	23	33	66	3.0	174°	99.9%	400° F.	Smooth Ctg. Spalls on impact. Smears out on abrasion.
6	.01	14	28	80	5.0	156°	99.9%	400° F.	Smooth Rubbery Ctg. Spalls on impact. Smears out on abrasions.
7	.007"	(Free Carbon 17%	Distillation @ 355°C 24% Distil. & 76% Res.			106° F.		250-260°	Hard glossy Ctg. Resists abrasion. Chips on impact
								260° F.	Hard glossy Ctg. Resists abrasion. Chips on impact
8	.005"	10.5%	31% Dist.@ 355°C			177° F.			
9	.004"	2%	55% Dist.@ 355°C			320° F.		250° F.	Hard glossy Ctg. Chips on abrasion
10									Cloth impregnated with asphalt #1
11						96° F.		250° F.	Double dipped coal tar
12		7-10	25-30	60-70		215-225° F.	99.3%		Heavy Coating of #1
13						150° F.		350° F.	Single dipped with #11 & 6 oz.cotton impreg.with coal tar
14		7-10	25-30	60-70		215-225° F.	99.3%		No.1 impreg. fabric, 3½ oz.cotton
15	1."		25-35				99.5%		Mastic Coating: 55-56% sand: 18-25% Limestone Dustor Cement 14-18% California Asphalt

BITUMINOUS COATINGS

Coating No.	Description
1.	Mid-continent asphalt - Gilsonite
2.	" " " " - stearine pitch
3.	Illinois " Mexican asphalt - Gilsonite
4.	Mexican "
5.	Texas asphalt
6.	California asphalt
7.	High carbon coal tar
8.	Low " " " (cake-oven tar)
9.	Water gas tar
10.	Mid-continent asphalt - Gilsonite impregnated fabric

Bituminous Coatings, contd.

Coating No.	Description
11	High carbon coal tar
12	Mid-continent Asphalt - Gilsonite
13	High Carbon Coal Tar impregnated Fabric
14	Mid-continent asphalt - Gilsonite impreg.fabric

SOIL CORROSION OF PIPE COATINGS

Bureau of Standards Tests

Rating of Bituminous Coatings on Pipe in Various Soils.

From: Tech.Papers, U.S.Bureau of Standards - Papers T-368,Vol22,1928

Coat-ing No.	SOIL NUMBERS 5	6	12	13	23	28	35
		2-1/2 Years					
1				Cce		Cce	
2				Cc+e		Cce	
3				C+ce		Cce	
4	Bc+e+	Aa-s	B+as	C+c+e+		Cce	B+as
5				C+c+e+		Cce	
6				Cce		Cce	
7	Bb-e+	Bb+s-	C+a-s-	Cce+		Cce+	Ba-s-
8				Ccs-		Cce	
9				Cce+		Cce	
10	Ab+e+r+	Aaeg	Aasg	A-ber		A-ber+	Aae+g
			4 Years				
11				C+ce+	Cce+		Cce+
12				B+be+	B+as-		B+as
13				Aasg	Aasg		A-asg
14				A-a-s-g	A-a-gs		B+asg-
15*	Aas	--	Aas	Aas	---	Aas	---

*No.15, Mastic Coating (Asphalt Mastic)-Crushed Rock, Sand and asphalt filler.

Note: Soil numbers refer to the following classification:

Soil No.	Name
5	Dublin clay adobe
6	Everett gravelly sandy loam
12	Hanford fine sandy loam
13	" very fine sandy loam
23	Merced silt loam
28	Montezuma clay adobe
35	Ramona loam

SOIL CORROSION OF PIPE COATINGS

Bureau of Standards Tests.

TEST CRITERIA

From: U.S.Bureau of Stds., Technologic Papers, Vol. 22,p.529

BITUMINOUS COATINGS

The following letters were selected as representing certain distinctions in the appearance of the specimens.

These letters are used in the test ratings of Table No.16

1. As to condition of coating:

   A. Coating apparently about as when buried.

   B. Coating somewhat deteriorated

   C. Coating dried out or brittle and porous

2. As to condition of pipe.

   a. No indications of corrosion
   b. Slight general rusting or small shallow pits
   c. Some pitting or corrosion

3. As to adherence of coating to pipe

   s. Bond good
   e. Coating does not adhere well

4. As to condition of impregnated fabric

   g. Fabric strong
   r. Fabric rotted

SOIL CORROSION OF PIPE COATINGS.

Interpolated Computed Life of Bituminous
Coatings in Various Soils (in years).
From U.S.Bur.Standards Tech.Paper T-368, Vol.22,1928

Coating No.	Soil Numbers 5	6	12	13	23	28	35
				2-1/2 years			
1	2.2	3.0	2.5	1.0	1.0	1.0	3.5
2	2.5	3.5	3.0	1.2	1.2	1.0	3.5
3	2.5	3.5	3.0	1.2	1.2	1.0	3.5
4	2.0	7.5*	3.0	1.2	1.2	1.0	4.0
5	2.5	3.5	3.0	1.2	1.2	1.0	3.5
6	2.5	3.5	2.5	1.0	1.0	1.0	3.5
7	2.0	2.5	2.5	1.0	1.0	1.0	3.5
8	2.2	3.0	2.5	1.0	1.0	1.0	3.5
9	2.2	3.0	2.5	1.0	1.0	1.0	3.5
10	2.5	7.5*	15.0*	2.5	2.5	2.5	10.0*
				4 years			
11	4.0	6.0	5.0	2.0	2.5	2.5	2.5
12	8.0	12.0	10.0	4.0	5.0	5.0	5.0
13	12.0	15.0	15.0	16.0x	16.0x	16.0	12.0
14	10.0	10.0	18.0	12.0x	12.0x	12.0	5.0

* Multiply 2½ yr.coatings,unharmed,by 3 to get approximate life
x Multiply 4 " " " " 2 " " " "
Interpolated figures appear in red.

Table No.18

A.P.I. INSPECTIONS OF PIPE LINES

Average Life of Covering in Years in Various Soils.

Data:A.P.I.Proceedings,January 1930-Using Trend of Plate #7

AGE IN YEARS ASSUMING 50% OF INSPECTIONS CORRODED

Coating Group	Excellent 30 Years	Good 20 Years	Fair 15 Years	Bad 10 Years	Very Bad 5 Years	Exposed Years
1						2.04
2	7.9	3.8	2.8	2.0	1.2	-
3	1.8	0.9	0.7	0.5	0.3	-
4	5.1	2.5	1.8	1.3	0.8	-
5	4.4	2.2	1.6	1.1	0.7	-
6	5.4	2.6	1.9	1.4	0.8	-
7	2.3	1.1	0.8	0.6	0.4	-
8	10.0	4.9	3.6	2.5	1.6	-
9	8.7	4.3	3.2	2.2	1.4	
10	53.3	25.9	19.1	13.5	8.3	

Coating Groups refer to those listed in the Discussion.

Table 19

A.P.I. INSPECTIONS OF PIPE LINES

COMPOSITE DATA ON COATING INSPECTIONS BY GROUPS

Group	Number of Inspections	Average Soil Quality	Toatal Average Age	Percent Corroded	Average Age Corroded	Computed on Straight Line Basis: Average Age 50% Corroded	Computed on Straight Line Basis: Average Age-50% Corroded-Soil Q=20
1. Coatings on exposed lines.	7	---	2.43	28.6	1.17	2.04	---
2. Miscellaneous treatments	23	10.3	1.29	43.5	1.78	2.04	3.96
3. Asphalt emulsion Treatments	18	12.8	1.23	88.9	1.21	0.68	1.03
4. Grease treatments	32	10.6	2.36	90.6	2.47	1.36	2.56
5. Enamels	157	19.4	2.47	71.4	3.00	2.10	2.17
6. Unreinforced bituminous materials applied hot.	51	21.3	5;99	100.0	5.99	3.00	2.82
7. Paints and cut-back bituminous material	54	15.7	1.60	94.5	1.65	0.87	1.11
8. Single ply felt wrapped treatments	37	21.2	6.06	64.8	7.16	5.52	5.21
9. Double ply felt wrapped treatments	43	17.9	3.00	46.5	3.53	3.79	4.24
10. Triple ply felt wrapped treatment	15	14.1	1.82	6.7	2.42	18.10	25.70
Totals and averages	437	17.8	2.99	72.3	3.43		

Note: Average soil qualities are as rated in table 20

Table No.20

A.P.I. INSPECTIONS OF PIPE LINES

*Relation of Soil Quality to % of inspections showing corrosion

Soil Quality	Total No.of Inspections	Percent Total	Percent Corroded	Average Age Years	Computed on Straight Line Basis: Av.Age 50% Corr'd Years	Computed on Straight Line Basis: Assumed Soil Qualities
Excellent	100	30.4	66.0	5.82	4.41	27
Good	54	16.4	70.4	3.02	2.15	20
Fair	93	28.2	71.0	2.25	1.58	15
Bad	67	20.4	89.6	2.00	1.12	10
Very Bad	15	4.6	73.4	1.01	.69	5
Total	329	100.	73.3	-		
No Data	101	-	58.3			
Total	430	-	72.1			

* P.140 A.P.I.Proceedings,January 1930.

Note: The assumed soil qualities listed in Column 7 refer to the various quality soils as listed in the Discussion.

Table 21

A.P.I.INSPECTIONS OF PIPELINES

RELATION TO AGE OF COATINGS TO PERCENT OF INSPECTIONS SHOWING CORROSION

			Division I Groups 3,4,5,6,7.		Division II Groups 8,9,10			Computed on Straight Line % corroded-soil quality		
Age limit in years	Total no.of inspections	Percent corroded	Total no.of inspections	Percent corroded	Total no.of inspections	Percent corroded	Average soil quality	Total groups	Groups 3,4,5,6,7.	Groups 8,9,10
0- 1	91	55.0	70	61.4	3	---	14.8	40.7	45.4	---
1- 2	166	71.7	134	81.4	29	24.1	16.9	60.6	68.8	20.4
2- 3	65	69.2	37	97.3	28	32.2	18.6	64.4	90.5	30.0
3- 4	17	94.2	11	100.0	5	---	15.9	74.8	79.4	---
4- 5	20	90.0	9	---	11	81.8	19.1	86.0	---	78.2
5- 6	19	89.5	16	100.0	3	---	14.6	65.3	73.0	---
6- 18	52	94.2	36	100.0	15	80.0	24.9	100.0	100.0	99.5
Total	430		313		94					

Note: Soil quality refers to that given on table 20 in columns 7&8.

Data: P.140 A.P.I.Proceedings-Jan.1930

Table No.22

A.P.I. PIPE COATING TESTS

Page 114, A.P.I.Proceedings,December,1932.

Site No.	Location	Type of Soil	Size of Specimen Inches	Av.Soil Resis-tivity ohm cms
I	Temple, Texas	Bell clay	10	492
II	Arkansas City,Kans.	Heavy black clay	8	945
III	Beaumont, Texas	Lake Clarles clay	8	494
IV	League City,Texas	Brown clay loam	8	1140
V	Preble, Ind.	Miami clay loam	8	1934
VI	Council Hill,Okla.	Clay loam	10	2975
VII	Kaney, Kans.	" "	8	-
VIII	Spindletop Gulley, Tex.	Heavy brown clay	8	377
IX	Long Beach,Calif.	Sandy clay loam	6	945
X	Mt.Auburn,Ill.	Muscatine clay loam	8	1412
XI	Skiatook, Okla.	Brown sandy loam	6	1170
XII	Mendota, Calif.	Merced clay loam	8	1327
XIII	Bunkie, La.	Miller clay	8	826
XIV	Chambersburg,Pa.	Hagerstown clay	6	3310
XVI	Cholame Flats,Calif.	Heavy black clay	8	204

A.P.I. PIPE COATING TESTS

Proceedings, December, 1931

Symbol	Thickness	Description of Coatings
A	.0647"	Two coats of asphalt emulsion
B	.1072"	One coat of grease, spiral wrap of grease saturated fabric and outer coat of heavier consistency grease.
C	.0206"	Two coats of filled cut-back coal tar
E	.1506	Asphalt primer, followed by sling coat of asphalt compound, spiral wrap of coal tar-saturated Osnaburg fabric, outer coat of asphalt and Kraft paper.
F	.4185	Two coats of asphalt emulsion, followed by rigid shield of sand and cement mortar.
G	.0625	Coal tar primer, followed by coal tar enamel, and unbonded wrap of asbestos pipe line felt
H	.0807	Coal tar primer, followed by coal tar enamel and unbonded wrap of wood veneer
K	.0685	Coal tar primer, followed by coal tar enamel
L	.0798	" " " " " " " "
M	.0576	" " " " " " " "
N	.0596	" " " " " " " "
O	.5186	Asphalt primer, followed by a hot coat of priming asphalt, and spiral wrap of asphalt mastic carried on pipe with tissue and sheathing paper.
R	.1427	Asphalt primer, followed by two coats of asphalt enamel; spiral application of asbestos pipe line felt; flood coat of enamel and Kraft paper.
S	.1502	Asphalt primer, followed by two coats of asphalt; spiral application of rag base pipe line felt; flood coat of asphalt and Kraft paper.
T	.3507	Coal tar primer, followed by two straight-away rag base pipe line felt applications on the inner faces of which coal tar enamel wrapped on; sling coat of coal tar enamel, and whitewash.
U	.1709	Coal tar primer, followed by two coats of coal tar enamel; spiral application of asbestos pipe line felt; flood coat of enamel and Kraft paper.

A.P.I. Pipe Coating Tests

Symbol	Thickness	Description of Coatings
X	.2302	Hot asphalt primer, followed by double spiral wrap of unsaturated fabric drawn through molten asphalt, and spiral butt wrap of 20 gauge strip steel.
Y	.0287	Asphalt primer, followed by one coat of asphalt cut-back; one coat of asphalt adhesive, and field wrap of aluminum foil.
Z	.2062	Hot asphalt primer, follwwed by double spiral wrap of unsaturated fabric drawn through molten asphalt and Kraft paper.

The coatings have been arbitrarily divided into 4 groups:

1. (A,C,K,L,M,N,O.) - Neither reinforced nor shielded.
2. (G and H). - Shielded and corresponding to (N & L).
3. (B,E,R,S,T,U,X,Z) - Fabric reinforced Coatings.
   X is shielded but otherwise the same as Z.
4. (F,Y) - Cement and aluminum.

Table No. 24

A.P.I. PIPE COATING TESTS

Results of 2 Yr. Tests on Test Lines.

Coating	Number of Pipes Affected				Percentages of Nos.of Pipes Affected			
	U	R	M	P	U	R	M	P
A	0	2	4	12	-	11.	22	66
B	0	10	7	3	-	50	35	15
C	0	0	3	13	-	-	19	81
E	7	5	7	1	35	25	35	5
F	9	8	3	6	45	40	15	-
G	7	7	3	5	32	32	14	22
H	7	8	2	5	32	36	10	22
K	4	1	6	7	22	6	33	39
L	5	3	5	7	25	15	25	35
M	0	2	3	15	-	10	15	75
N	2	5	7	6	10	25	35	30
O	23	1	0	0	96	4	-	-
R	5	6	6	5	23	27	27	23
S	4	5	6	1	25	31	38	6
T	7	12	1	0	35	60	5	-
U	7	7	9	1	29	29	37	5
X	9	15	0	0	37	63	-	-
Y	3	13	6	8	10	43	20	27
Z	4	10	9	1	17	42	37	4

U - denotes pipe is unaffected
R - " definite surface rust
M - shallow metal attack
P - Pit depth in thousands of one inch

Letters in first column refer to description of coating given in Table No.23

A.P.T. TESTS ON TEST LINES - 1932

Page 117, A.P.I.Proceedings, December, 1932

Coating	(+)	(-)
A	17	1
B	19	0
C	16	0
E	10	10
F	5	15
G	13	9
H	14	8
K	14	4
L	15	5
M	20	0
N	18	2
O	0	24
R	17	5
S	7	9
T	4	16
U	14	10
Y	16	4
Z	16	7

Letters in first column refer to coatings described in Table No.23

(-) shows coating to be unaffected
(+) " " " " corroded

Table No.26

SOIL CORROSION OF PIPE COATINGS

Results of Tests at 2 Yr.Period* on 2 Foot Specimens

Out of 46 Coatings Tested, in 15 sites, the following showed no electrical pattern and also showed the pipe to be unaffected under the coating in at least 11 sites.

Coating Symbol	Sponsor	Average Thick-ness Inches	Description
A	American Tar Products Co.	.054	Pyrmax primer, followed by one coat of Komac P.C. Enamel (coal Tar)
D	The Barrett Co.	.342	Barrett coal-tar primer, followed by two coats of rag-base roofing felt to inside face of which hot Barrett pipe line enamel (coal tar) was mopped on, and an outer coat of enamel followed by whitewash.
G	Eagle Picher Lead Company	.069	Priming coat of baked sublimed blue lead, followed by bitumastic primer (coaltar) and bitumastic XX14 (coal tar enamel)
K	Hill, Hubbell & Co	.075	Biturine primer, followed by sling coat of biturine #212 enamel (coal tar)
KK	Hill, Hubbell & Co	.165	Biturine primer, followed by 2 coats of biturine #212 enamel (coal tar) spiral wrap of J.M. 15# asbestos pipe line felt, flood coat of enamel and Kraft paper (machine applied)
NN	McEverlast, Inc.	.337	Asphat primer, followed by hot coat of priming asphalt and spiral wrap of somastic (asphalt mastic) carried on pipe with tissue and sheating paper (machine applied)
P	Lead Industries Association	.071	One coat of baked red lead paint followed by bitumastic primer and bitumastic XXH (coal tar enamel)

*American Petroleum Inst.Proceedings, December, 1932

Coating Symbol	Sponsor	Average Thickness Inches	Description
PP	National Tube Co.	.216	Hot Robertson asphalt, followed by double spiral wrap of unsaturated fabric (Osnaburg type) drawn through molten Robertson asphalt, and 20 gauge strip steel (machine applied)
SS	Resistcor Eng. Corporation	.041	Resistcor primer (coal tar), followed by sling coat of Resistcor enamel (coal tar) and unbonded wrap of J.M.15# asbestos pipe line felt.
V	Standard Oil Co. of California	.337	Same as NN, using asphalt mastic pipe coating
WW	Johns-Manville and Std.Oil of N.J.	.170	Asphalt primer, followed by one coat of Standard pipe coating (asphalt enamel) spiral application of J.M.15# asbestos pipe line felt; flood coat of enamel and Kraft paper (fabric machine applied)
YY	The Texas Co.	.199	Texaco primer (asphalt) followed by 2 coats of Texaco #30 asphalt pipe coating, spiral wrap of Texaco pipe line felt; coat of asphalt, second ply of felt, and Kraft paper (machine applied)
YYY	The Texas Co.	.259	Same as coating YY, excepting a flood coat of Texaco #30 asphalt pipe coating over 2nd ply of felt. Outer wrap Kraft paper
Z	Wailes Dove-Hermiston Corp.	.077	Bitumastic primer, followed by sling coat of bitumastic XH enamel (coal tar) and whitewash
ZZ	Wailes Dove-Hermiston and Basket & Box Co.	.072	Bitumastic primer (coal tar) followed by sling coat of Bitumastic XXH enamel (coal tar) and unbonded wrap of Becker's sewed wood veneer

The dips given in Table #26 are classified as follows:

1. Dips with no fabric wrappings:

   A,K,Z

2. Dips over a priming coat of lead paint

   G, P.

3. Single wrapped coatings

   KK,NN,SS,V,WW,Z

4. Double wrapped coatings

   D, GG, YY, YYY

A.P.I. TESTS*

Relative Corrosion of Soils

Soil Res. ohms	Soil No.	Test Line Results						Test Specimens					
		Percent				Patterns		Percent (See page 127)				Patterns	
		U	R	M	P	(+)	(-)	U	R	M	P	(+)	(-)
492	I	21	33	25	21	14	12					60	40
945	II	29	33	25	14	13	13					54	46
494	III	12	12	23	53	21	2					74	26
1140	IV	28	52	4	16	16	8					60	40
1934	V	42	27	12	19	13	11					34	66
2975	VI	19	4	31	46	20	6					53	47
-	VII	19	15	42	20	17	9					62	38
377	VIII	31	20	19	29	19	5					-	-
945	IX	38	29	20	13	11	13					34	64
1412	X	31	50	15	4	13	12					43	57
1170	XI	22	13	30	35	16	6					58	42
1327	XII	58	38	4	-	11	13					31	69
826	XIII	12	24	32	32	19	5					49	51
3310	XIV	21	42	25	12	16	6					44	56
204	XVI	15	27	27	31	16	8					48	52

Note: U - denotes that pipe is unaffected
R - " definite surface rust
M - " shallow metal attack
P - " pit depth in mills of 1 inch
(+) Pattern means: electrical test shows hole in coating
(-) " " " " " coating unaffected
Letters I to XVI refer to test sites given in Table #22

*American Petroleum Inst.Proceedings,December,1932

AVAILABLE COATING MATERIALS — INFORMATION FROM MANUFACTURERS

Company	Standard Oil Co.				Union Oil Co.			Johns-Manville Co.
Coating material	Petrolastic Cement				Union 1a,1b,1c.			Water Works Pipe Enamel.
Petroleum base	California Asphalt				Asphalt			Coal Tar
Grade	X	XX	XX	XX	1a	1b	1c	---
Penetration 100 gr.77°	16-20	21-30	25-35	31-40	5-10	10-15	15-20	---
Melting point	170° F.	155	150	145	240-215	210-185	185-170	210° F.
Solubility in CS_2	99.8 %				99.7 %			---
Ductility	2.0	3.0	4.5	6.0	0-4	1-6	2-15	---
Loss on Heating	1.5%	2.0%	2.0%	2.0%	.7%	.7%	.7%	---
Other Properties	Add Calol Asphalt as flux 1 to 4.				% fixed carbon 15.5	15	15	Not less than 20% mica filler.
Flash Point	350° F.				420° F.			---
Specific Gravity	1.01				1.03	1.03	1.025	1.67 @ 25°C.
Penetration of Residue	min.of 60%				Reduction of 4-20%			---
Coating Thickness	Single 1/16"-1/8"				Single 1/16"-1/8"			Single 1/16"
Application	Dipping or application hot. 300-325°F.				Dipping or Application			Applied at 330-350°F. Vertical dip in shop.
Pipe Treatment	Preheated to 325°F. For cold application use Oronite primer.				----			Preheated for shop to 300°F. Primer used in field.

General Paint Corp.		The Parrafine Co's.Inc.	WailesDove Hermiston Co.	
Biturine enamel Coal Tar	Biturine pipe dip Asphalt	Floatine Asphalt	Bitumastic enamel Coal Tar	Hermastic pipe dip Asphalt
No.7003	No. 7005			
	25-30	35°		
180-190	205-215	Softening Point 133°F.		170°F.
	99.5%	99.25%	---	---
---	---	5	---	---
---	---	---	---	---
---		---	---	---
---		400°F.	---	
---	1.015	---	---	
---		---	---	
1/8"-1/16"	360°-1/8" 380°-1/16" 400°-1/32"	Single .1010 min.	1/16"	1/32"
Dipping or field application. Hot @ 360-400°F.		Hot dip. Dip temp.350-375°F.		Dip@ 400-450°F.
Pipe preheated.360-400°F. Use Biturine enamel primer		Pipe may be preheated to 275-425°F.		Pipe heated in furnace to 900°F.

COST OF COATINGS - 1932

Cost per Foot

Coating	Field or Fcty. Applied	10"	16"	24"
1. Coal Gas Tar & Primer	Field	15¢	24¢	30¢
2. Johns-Manville Asbestos Felt Wrapping & J.M. Coal Tar Enamel				
(a) Single Wrap Double Dip-Asbestos Felt		18¢	29¢	36¢
(b) Double wrap-triple dip " "		34¢	55¢	68¢
3. Pabco Felt & Floatine Dip.				
(a) Single wrap-double dip		13¢	20¢	25¢
(b) Double wrap-triple dip		21	32	40
4. Biturine Enamel-Pabco Wrap & Kraft Paper.				
(a) Single wrap-double dip		16¢	23¢	29¢
(b) " " triple dip		19	28	34
(c) Double " " "		24	35	42
(d) " " 4-coats of enamel		27	39	48
5. Texaco Asphalt-Pabco Wrap & Kraft Paper.				
(a) Single wrap-double dip		13¢	18¢	22¢
(b) " " triple "		14	20	24
(c) Double " " "		19	27	33
(d) " " 4 coats of asphalt		20	28	35
6. Asphalt Emulsion with Cement. Mortar lower coat.		29¢	44¢	55¢
7. Johns-Manville Coal Tar Enamel Interior lining spun		13¢	21¢	26¢

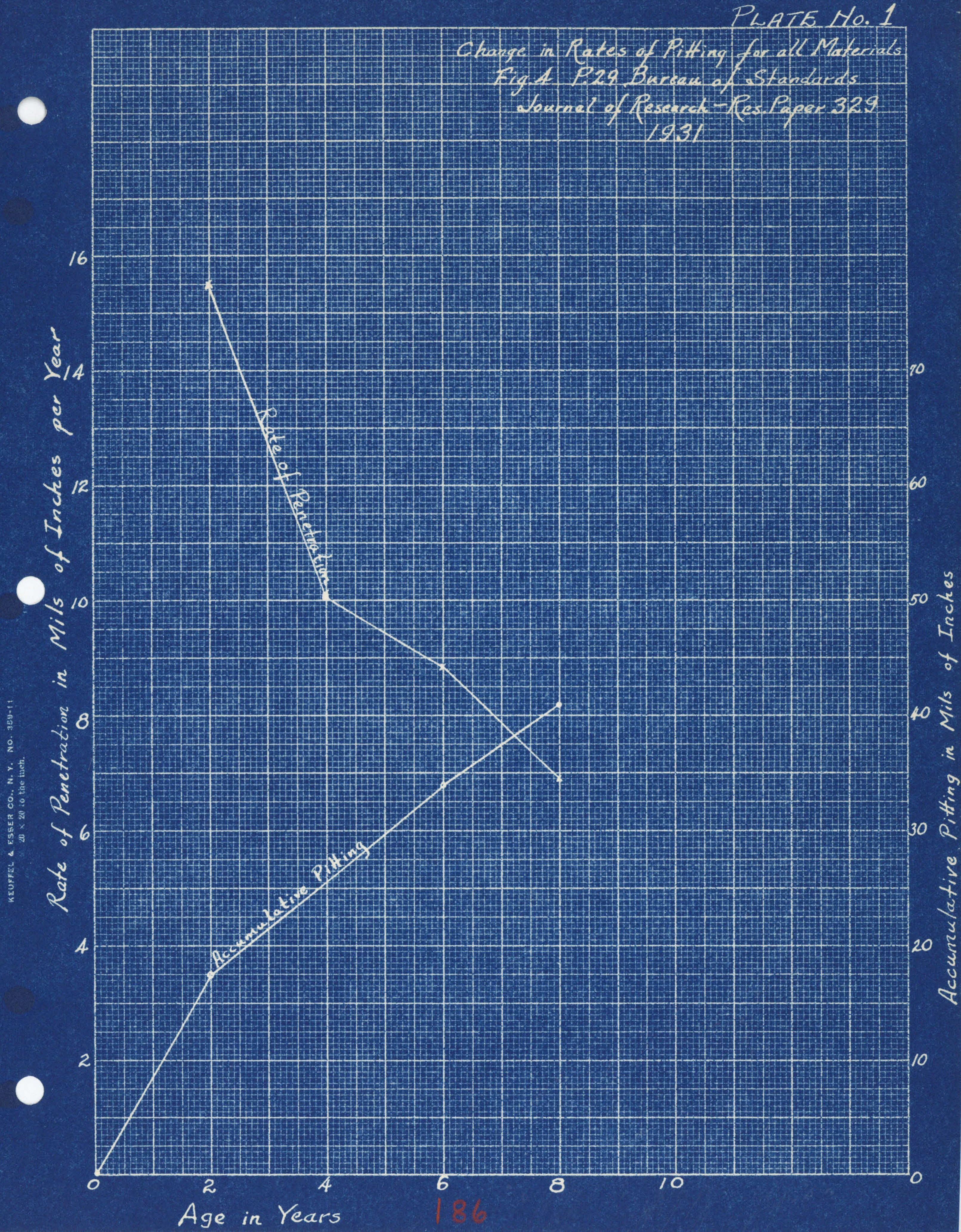
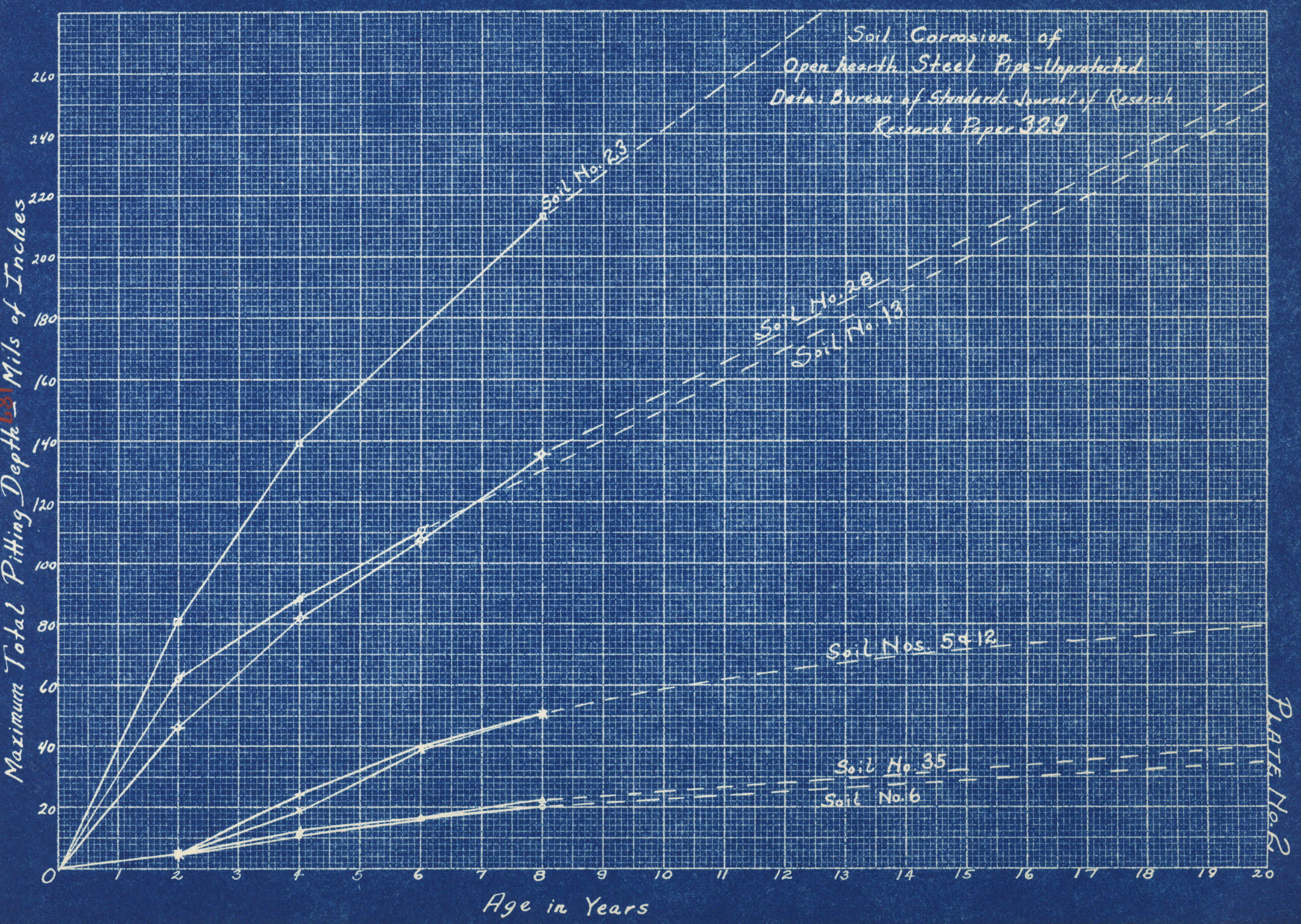
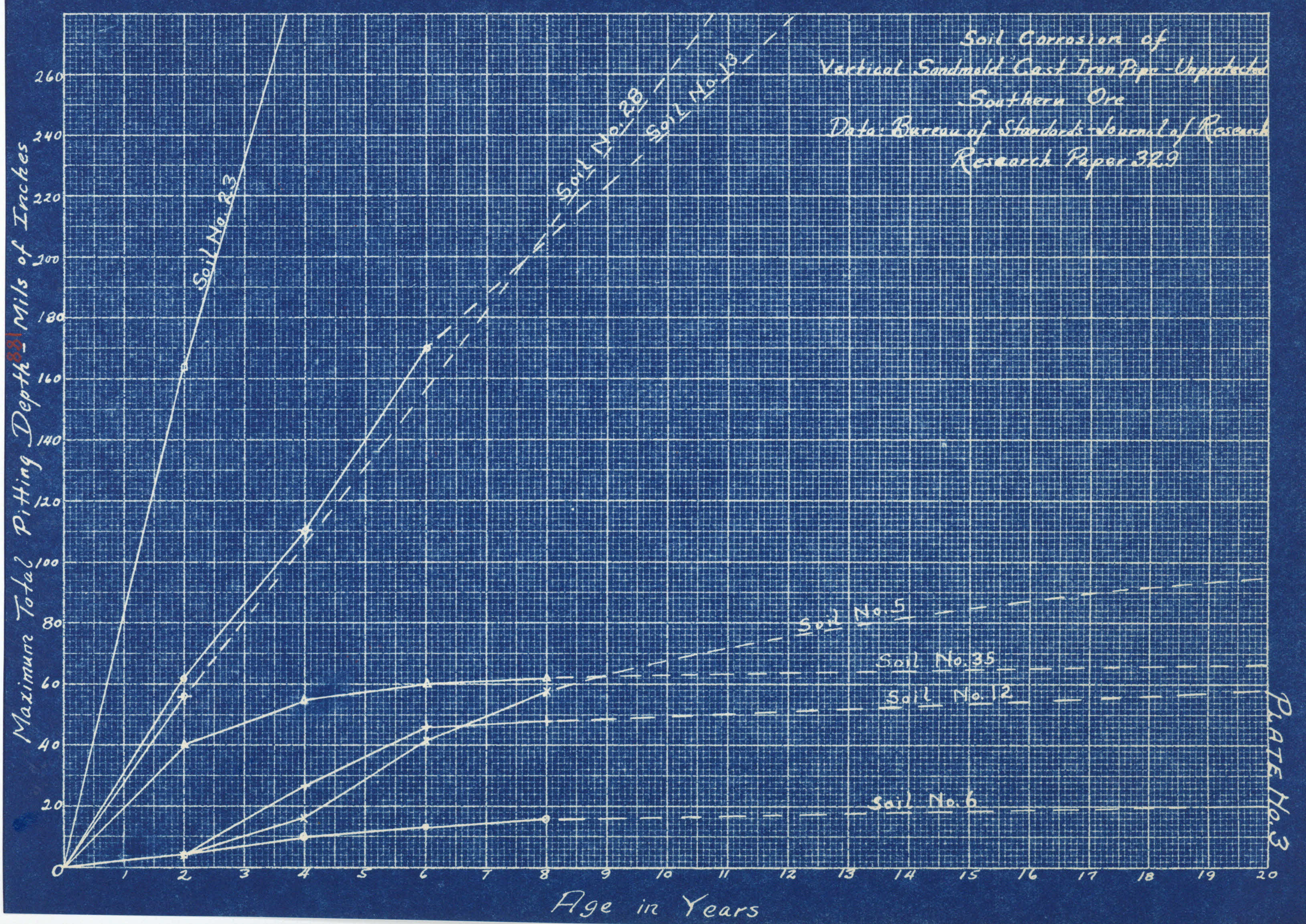


PLATE No. 1
Change in Rates of Pitting for all Materials
Fig. 4 P. 29 Bureau of Standards
Journal of Research - Res. Paper 329
1931
Rate of Penetration in Mils of Inches per Year
Accumulative Pitting in Mils of Inches
Age in Years
Rate of Penetration
Accumulative Pitting
0
2
4
6
8
10
12
14
16
20
30
40
50
60
70
KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 × 20 to the inch.

186


Soil Corrosion of
Open hearth Steel Pipe-Unprotected
Data: Bureau of Standards Journal of Research
Research Paper 329
Soil No. 23
Soil No. 28
Soil No. 13
Soil Nos. 5 & 12
Soil No. 35
Soil No. 6
Maximum Total Pitting Depth Mils of Inches
Age in Years
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
20
40
60
80
100
120
140
160
180
200
220
240
260
PLATE No. 2

181


Soil Corrosion of
Vertical Sandmold Cast Iron Pipe - Unprotected
Southern Ore
Data: Bureau of Standards Journal of Research
Research Paper 329
Soil No. 23
Soil No. 28
Soil No. 13
Soil No. 5
Soil No. 35
Soil No. 12
Soil No. 6
Maximum Total Pitting Depth Mils of Inches
0
20
40
60
80
100
120
140
160
180
200
220
240
260
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Age in Years
PLATE No. 3

881

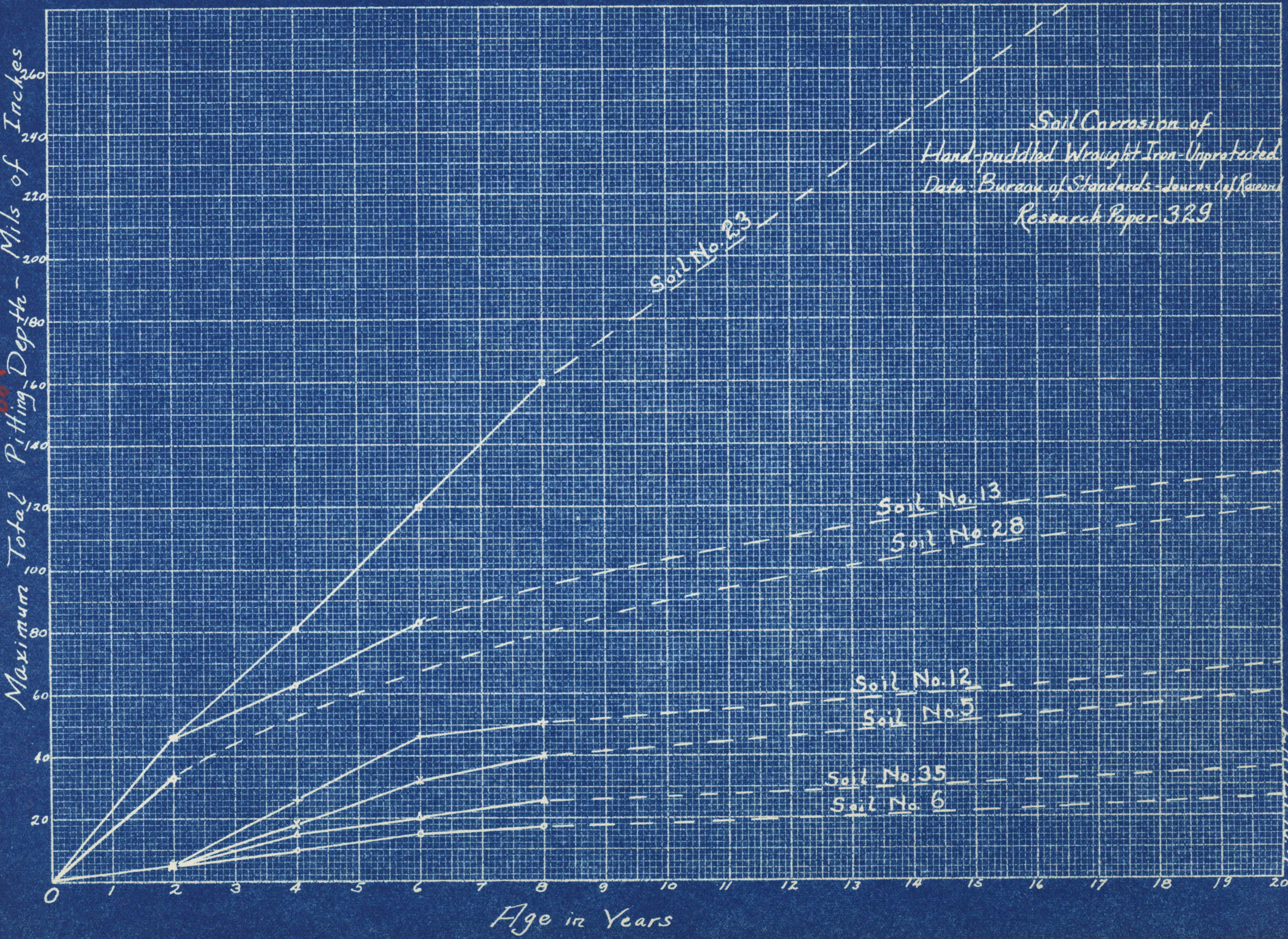

Soil Corrosion of
Hand-puddled Wrought Iron-Unprotected
Data: Bureau of Standards-Journal of Research
Research Paper 329
Soil No. 23
Soil No. 13
Soil No. 28
Soil No. 12
Soil No. 5
Soil No. 35
Soil No. 6
Maximum Total Pitting Depth - Mils of Inches
Age in Years
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
40
60
80
100
120
140
160
180
200
220
240
260

PLATE No. 4

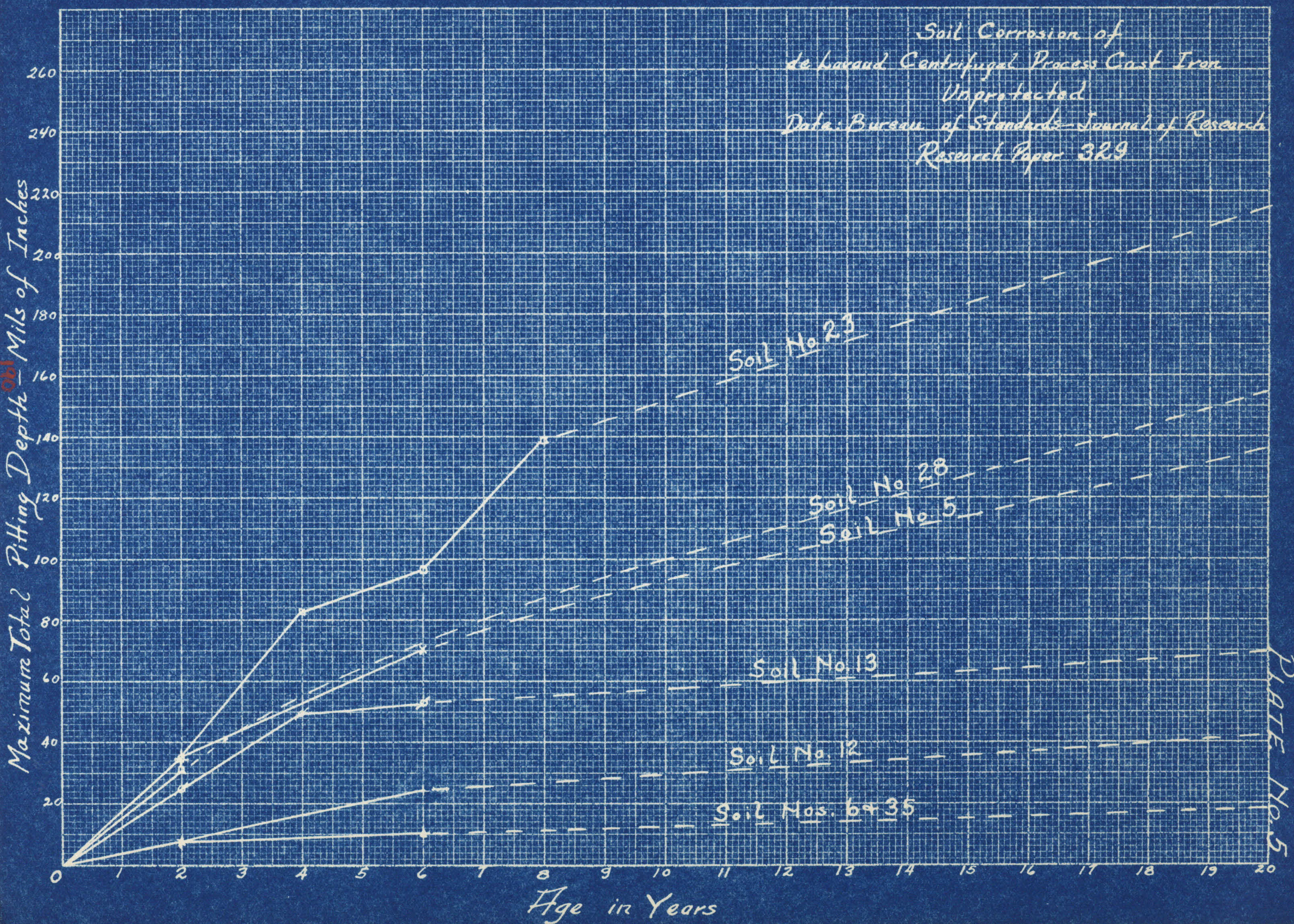


PLATE No. 5
Soil Corrosion of
de Lavaud Centrifugal Process Cast Iron
Unprotected
Data: Bureau of Standards – Journal of Research
Research Paper 329
Soil No. 23
Soil No. 28
Soil No. 5
Soil No. 13
Soil No. 12
Soil Nos. 6 & 35
Maximum Total Pitting Depth – Mils of Inches
Age in Years
0
20
40
60
80
100
120
140
160
180
200
220
240
260
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 × 20 to the inch.

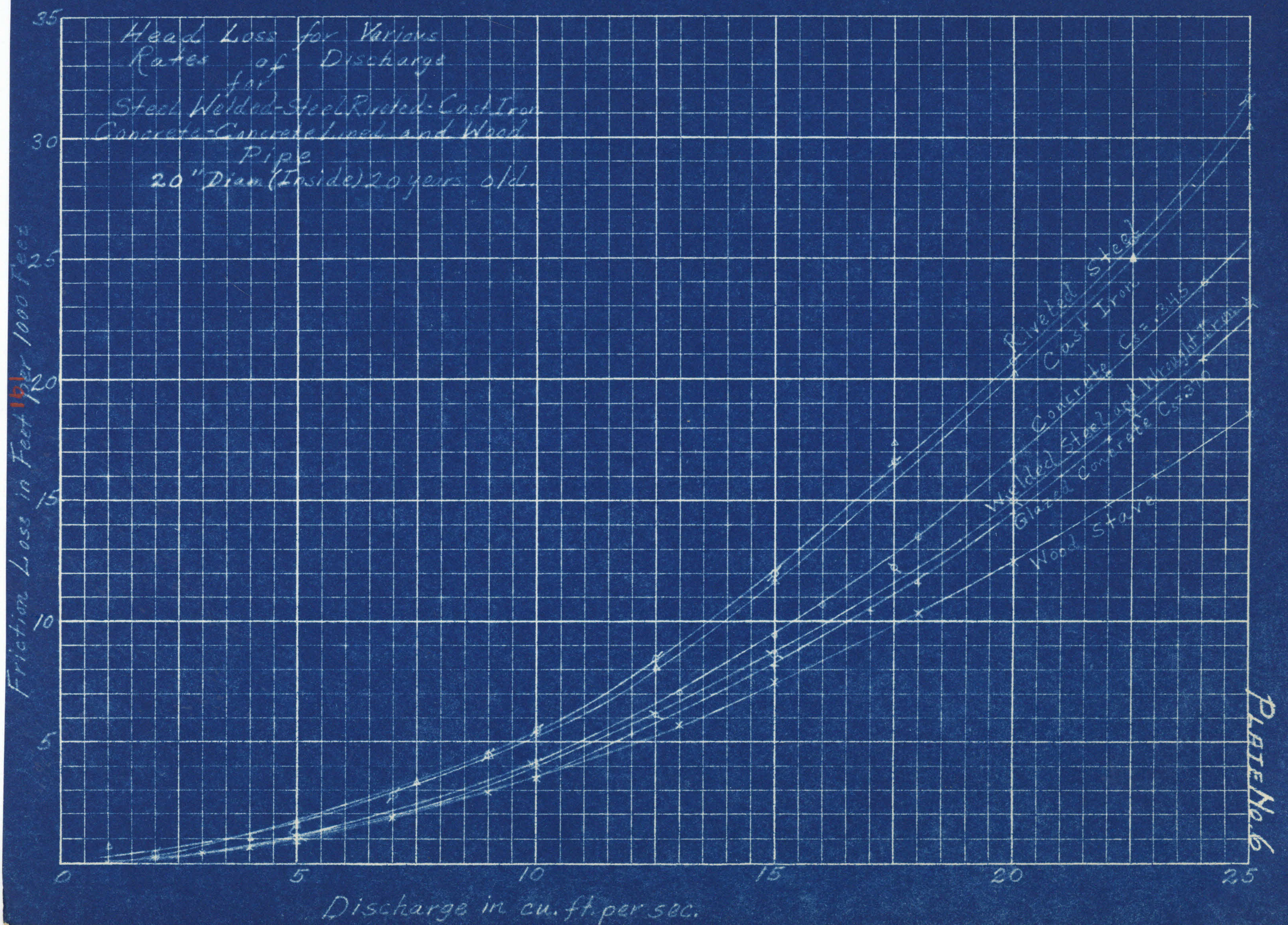

Head Loss for Various
Rates of Discharge
for
Steel Welded-Steel Riveted-Cast Iron
Concrete-Concrete Lined and Wood
Pipe
20" Diam (Inside) 20 years old.
Riveted Steel
Cast Iron
Concrete Cs=.345
Welded Steel and Wrought Iron
Glazed Concrete Cs=.370
Wood Stave
0
5
10
15
20
25
30
35
Friction Loss in Feet per 1000 Feet
Discharge in cu. ft. per sec.
PLATE No. 6

PLATE No. 7

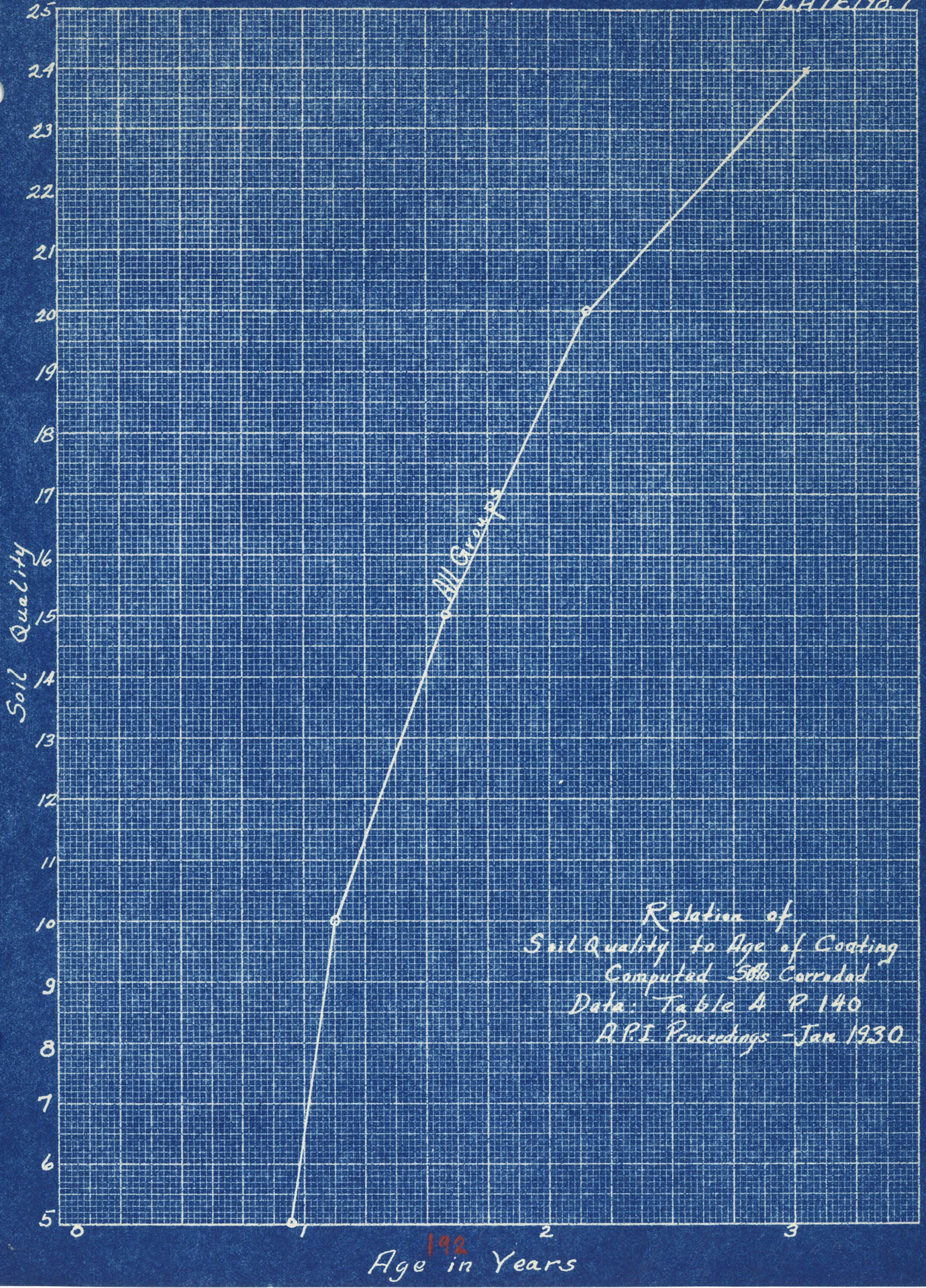
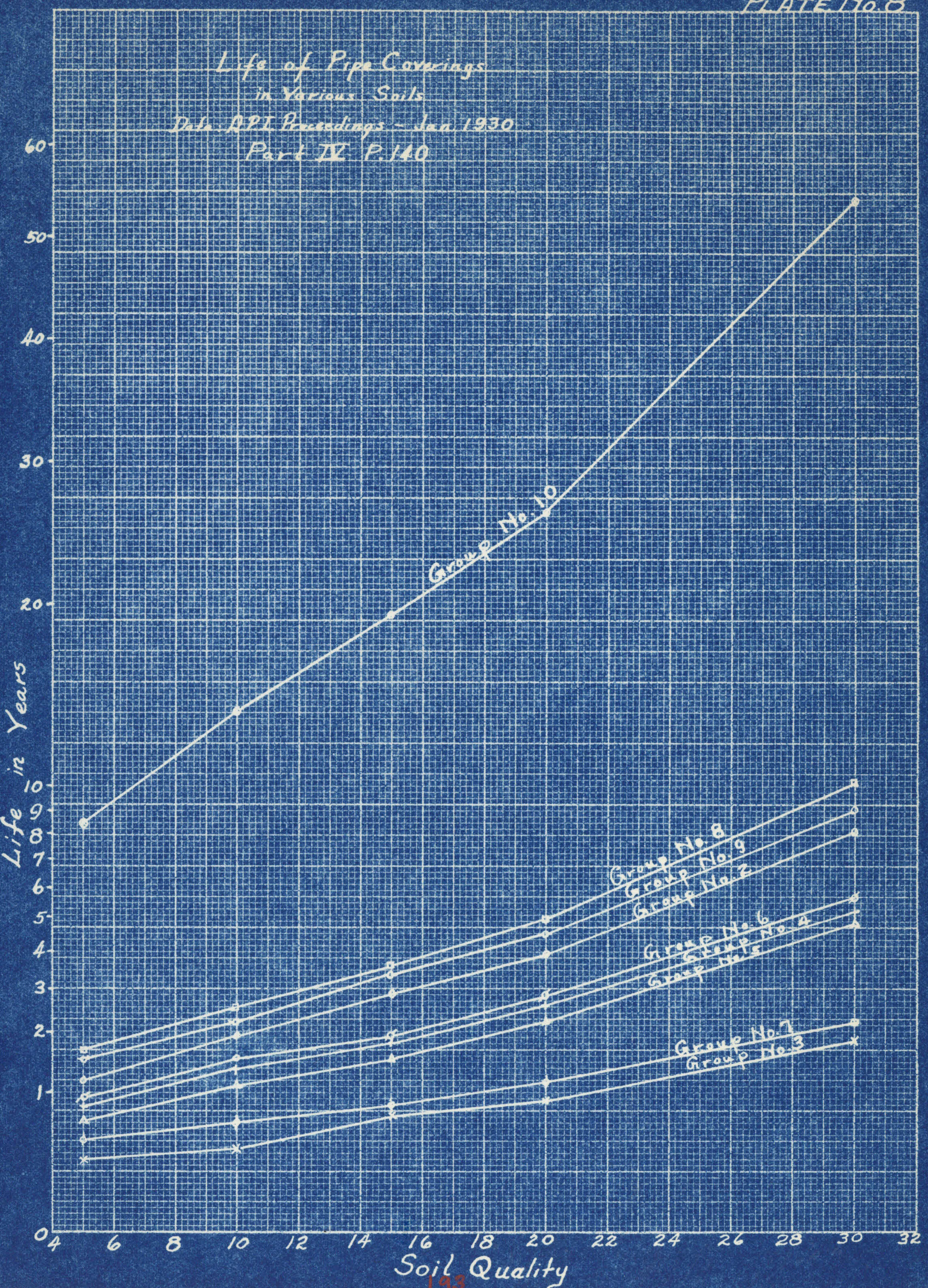
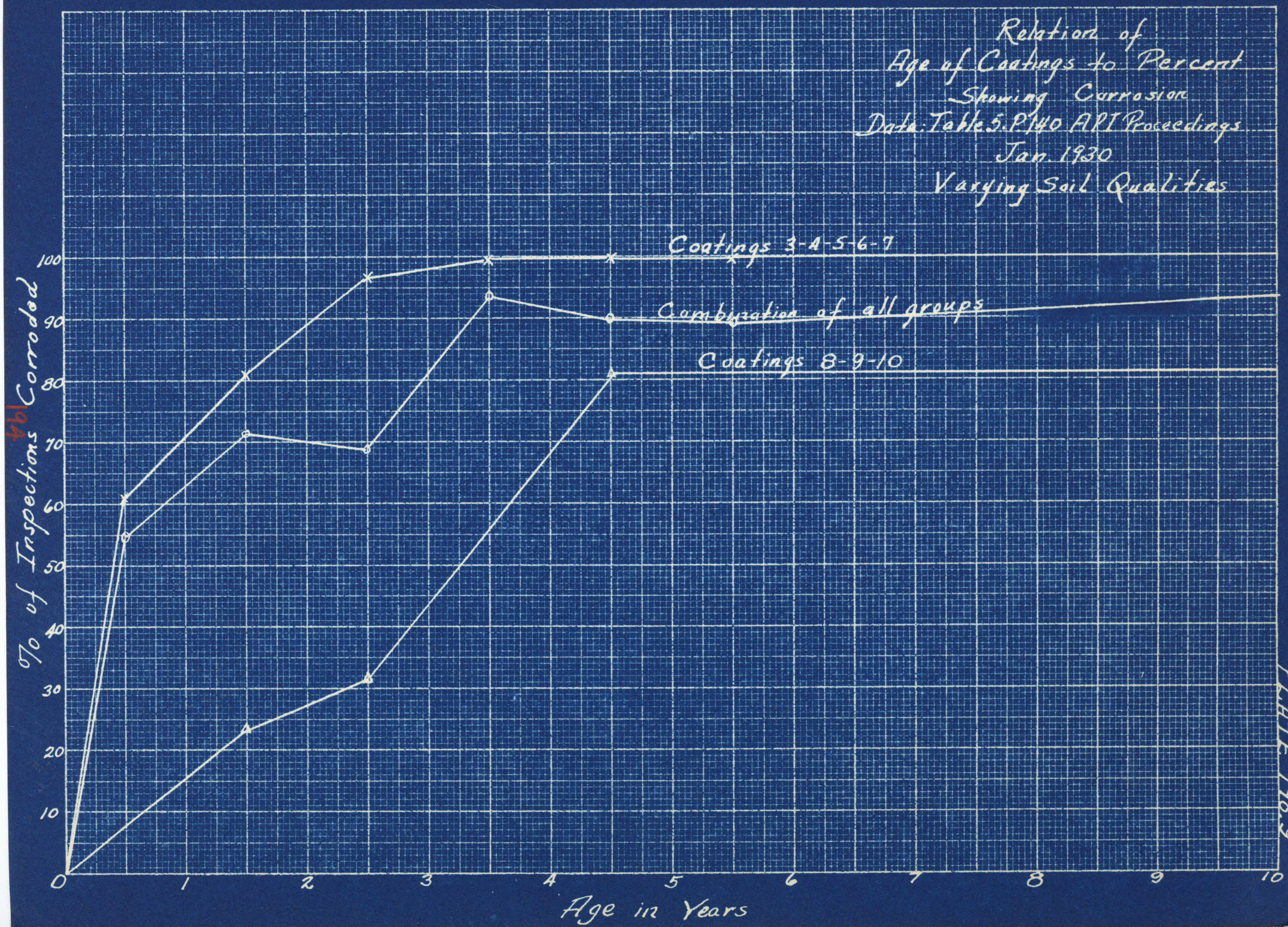

Soil Quality
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
0
1
2
3
Age in Years
All Groups
Relation of
Soil Quality to Age of Coating
Computed 50% Corroded
Data: Table A P. 140
A.P.I. Proceedings - Jan 1930

PLATE No. 8



KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 × 20 to the inch.



KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 × 20 to the inch.
Relation of
Age of Coatings to Percent
Showing Corrosion
Data: Table 5. P.140 API Proceedings
Jan. 1930
Varying Soil Qualities
Coatings 3-4-5-6-7
Combination of all groups
Coatings 8-9-10
% of Inspections Corroded
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10
Age in Years
PLATE No. 9
194

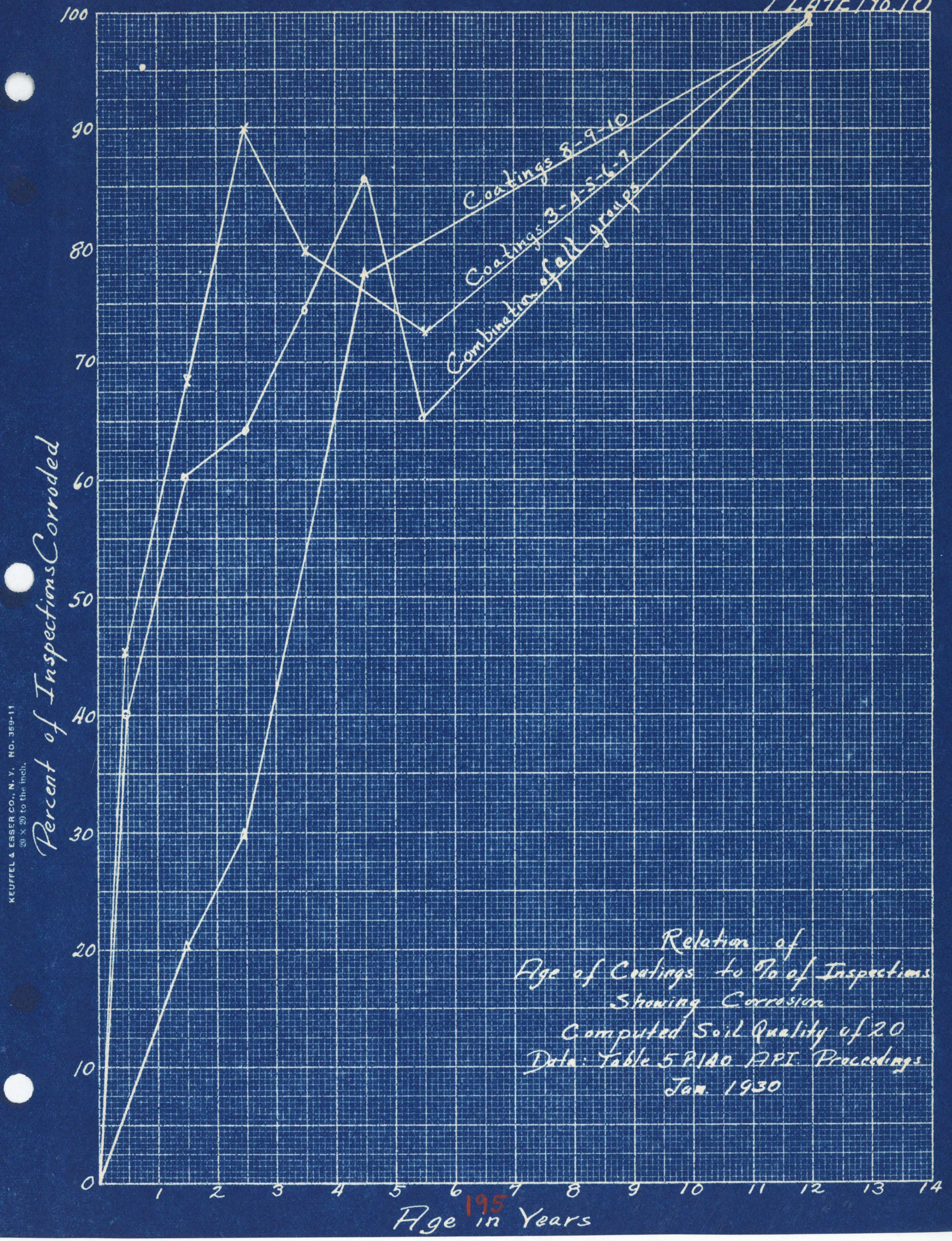

Coatings 8-9-10
Coatings 3-4-5-6-7
Combination of all groups
Percent of Inspections Corroded
Age in Years
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Relation of
Age of Coatings to % of Inspections
Showing Corrosion
Computed Soil Quality of 20
Data: Table 5 P. 140 API Proceedings
Jan. 1930
KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 × 20 to the inch.

PLATE No. 11

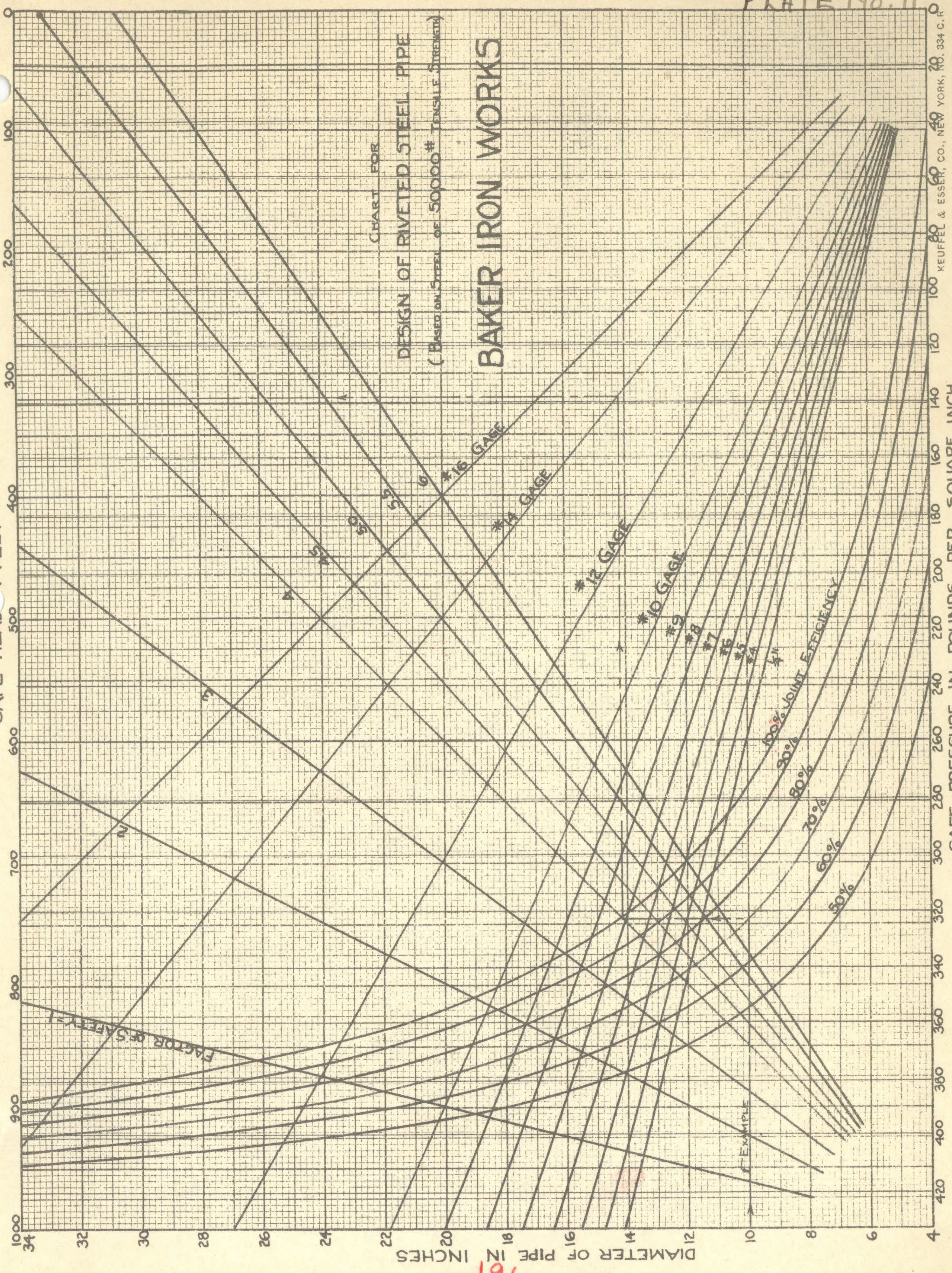


CHART FOR
DESIGN OF RIVETED STEEL PIPE
(BASED ON STEEL OF 50000 # TENSILE STRENGTH)
BAKER IRON WORKS
SAFE HEAD IN FEET
SAFE PRESSURE IN POUNDS PER SQUARE INCH
DIAMETER OF PIPE IN INCHES
FACTOR OF SAFETY-1
#16 GAGE
#14 GAGE
#12 GAGE
#10 GAGE
#9
#8
#7
#6
#5
#4
1/4"
100% JOINT EFFICIENCY
90%
80%
70%
60%
50%
EXAMPLE
KEUFFEL & ESSER CO., NEW YORK, NO. 334 C.R.

PLATE No. 12

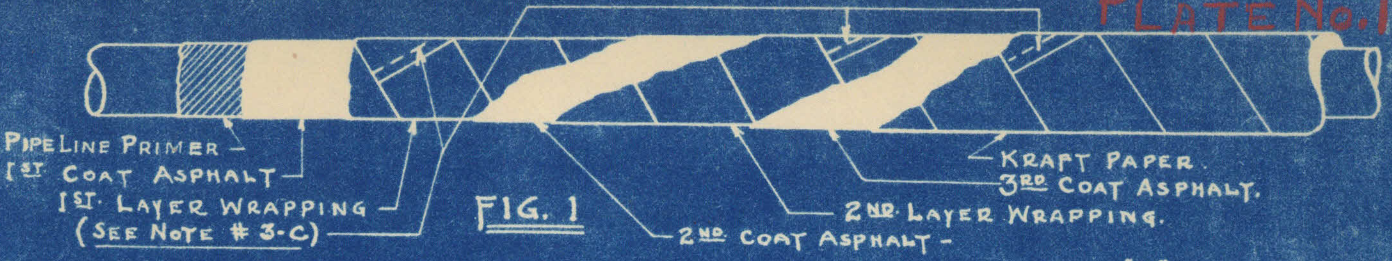


FIG. 1

FIG. 2

METHOD OF CUTTING ENDS OF ROLLS - UPON COMING TO COLLAR TEAR WRAPPING OFF AT RIGHT ANGLES AND FINISH WITH PIECE "A"

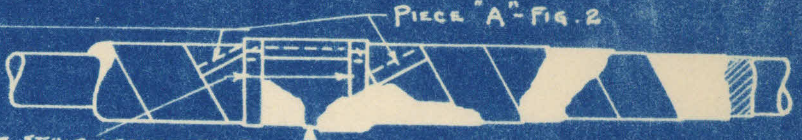


FIG. 3

WRAP 3" WIDE STRIP AROUND PIPE ENOUGH TIMES TO BUILD TO FULL HEIGHT OF COLLAR. WRAPPING APPLIED AT COLLARS TO BE THOROUGHLY SEALED WITH ASPHALT BETWEEN EACH LAYER.
(KRAFT PAPER NOT SHOWN IN THIS FIGURE)

SINGLE LAYER WRAPPING
6" WIDE FOR 2" PIPE
9" " " 3" TO 6" PIPE
11" " " 8" " 12" "

- QUANTITIES PER 1000 LINEAR FEET OF PIPE -

SIZE OF PIPE	"A" PRIMER 1 COAT GALLONS	"B" WRAPPING - 2 LAYERS		"C" ASPHALT 3 COATS BARRELS	"D" KRAFT PAPER - 1 LAYER		CIRCUMFERENCE OF PIPE - "C"
		6" WIDE LINEAR FEET	9" WIDE LINEAR FEET		6" WIDE LINEAR FEET	9" WIDE LINEAR FEET	
2"	1.25	2750		2.00	1400		7½"
3"	1.80	4000		2.75	2035		11"
4"	2.35		3350	3.50		1700	14⅛"
6"	3.55		4800	5.00		2435	20⅞"
8"	4.60		6200	6.00		3150	27⅛"
10"	5.85		7700	8.00		3915	33¾"
12"	6.75		9050	9.00		4600	40"
14"	7.45		10000	10.00		5100	44"
16"	8.50		11400	11.00		5800	50¼"

INSTRUCTIONS FOR APPLYING:-

1-AFTER THOROUGHLY CLEANING PIPE PAINT IT WITH ONE COAT OF PIPE LINE PRIMER & ALLOW TO DRY THOROUGHLY.
2-APPLY ASPHALT & WRAPPINGS AS SHOWN - FIG. 1. - ASPHALT TO BE HEATED TO 275°F.
3-IN WRAPPING:- (a) - THE FABRIC & KRAFT PAPER SHOULD BE APPLIED IMMEDIATELY AFTER THE HOT ASPHALT SO AS TO GET GOOD ADHESION.
(b) - THE EDGES SHOULD BE BUTTED NOT LAPPED. THE SPIRAL JOINTS SHOULD BE STAGGERED IN APPLYING A DOUBLE WRAP. A SNUG JOB SHOULD BE DONE.
(c) - LAP ENDS OF ROLLS AT TOP OF PIPE.
4-REMOVE CLODS, ETC. FROM TRENCH SO COATINGS WILL NOT BE PUNCTURED WHEN LINE IS LOWERED.
5-UPON LOWERING LINE:- (a) - PATCH ALL SCARRED SPOTS WITH ASPHALT & KRAFT PAPER.
(b) - CAREFULLY TAMP SOIL UNDER PIPE SO AS TO PREVENT SAGGING OF COATING. (USE SPECIAL CARE IN PLACES WHERE OIL IN LINE WILL BE HOTTEST)
6-COATING WORK TO BE DONE ONLY WHEN PIPE IS PERFECTLY DRY.

MATERIALS:-

"A" - GILSONITE PIPE LINE PRIMER - "B" - J.M. ASBESTOS OR PABCO PIPE LINE FELT - "C" - UNOLOX # 2A - "D" - KRAFT PAPER.

APPROVED FOR CONSTRUCTION

A. F. E.	DATE	SIGNED

REVISED

DATE	REV. BY	APP'D.

DRAWN BY E. C. B.
CHECKED BY
APP'D.
APP'D. Z.K.
SCALE NONE
DATE 1-20-32

STANDARD
SPECIFICATION
PROTECTIVE COATINGS
UNDERGROUND PIPE LINES

UNION OIL COMPANY OF CALIFORNIA

197

DRAWING NO.
SPECIFICATION # 326
1 SHEETS. SHEET 1

THIS SPECIFICATION SUPERSEDES # 326 - DATED 11-19-28 - REVISION OF 5-23-29 -

FORM M247A