

PLAINTIFF'S EXHIBIT

CAP-839

B-ACP-TA
ARTICLE I
ISSUED - 7/15/58
REISSUED - 2/15/65

FLEXURE TESTING

Re: Flexure Testing

The word "flexure" is defined by the dictionary as, "The act of bending". Whenever we speak about our pipe products, invariably the subject of flexural strength creeps into the conversation. As can be seen from the dictionary-definition of the word flexure, the words flexural strength would apply to the product's strength when bending.

Pressure pipe which is not laid to grade, in the majority of instances, is usually assembled using earth pads or some other method. However, one thing common to most methods employed to install pressure pipe is that the bottom of the pipe is seldom in contact with the bottom of the original ditch. It is necessary to replace the earth between the pipe and trench bottom with backfill material and tamp this fill into place to give an even support to the pipe along its entire length. In installing gravity sewer pipe and building sewer pipe we usually find all pipe being laid directly on a carefully prepared trench bottom at a uniform slope. Since the pipe is uniformly supported along its entire length in sewer construction, the subject of flexural strength assumes a position of somewhat minor importance when compared to the pipe's ability to withstand crushing loads. If pipe is installed on an unyielding foundation such as trench bottom, it cannot "bend", to any great extent, and hence, does not normally fall under the definition of flexure. If the installed pipe is properly bedded, the flexure stresses set up would be small in magnitude and would consist primarily of the bending permitted by slight compressing of the earth in the trench bottom directly under the pipe. However, if the trench bottom is not cut true so that it gives an even bearing surface for the installed pipe, then flexural stresses occur. This same situation would occur in cases where the supporting soil under the pipe is washed away or eroded by ground water or some other condition which would force the pipe to support a load over a span from which it could gain no supplemental support.

This brings us to the problem of what, "flexure testing" is in considering pipe strength. Any flexure test is one in which a beam (pipe) is loaded between two supports so that the beam will deflect or bend with the load. As the magnitude of the load is increased, the bending of the pipe will increase until it reaches the ultimate flexural strength, which is that strength attained just before breaking or failing. The flexure test is a measure of the flexural strength of the pipe. The higher the value of the flexural strength, the stronger the pipe will be when forced to act as a supporting beam for the weight of the fill on the top of the pipe.

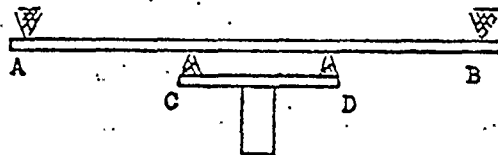
Each length of 6" and 8" gravity sewer pipe and pressure pipe, as well as 4" and 6" building sewer, and 3" and 4" pressure pipe, is tested for flexural strength. To make this test, predetermined loads are chosen based on certain problems and considerations and are established as a guide from which one

Certain-teed Pipe Division

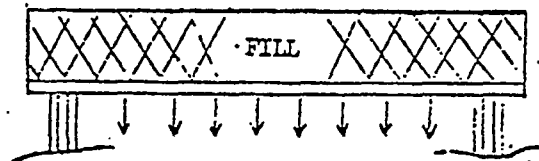
B-ACP-TA
ARTICLE 1
PAGE 2

can determine the flexural strength of the pipe. The table of flexural strengths, which are given in pipe specifications, represent applied loads which each pipe tested must meet in order to be judged equivalent to a given quality standard. The pipe being tested must be capable of sustaining this set of established loads without failure in order to be adjudged at a given strength level.

Since the flexure test is a measure of the flexural strength of the item being tested, the test must be conducted by creating a beam from the pipe. The higher the value of the flexural strength, the stronger the beam will be. As our pipe is manufactured in nominal 13-foot lengths, we use a clear span of 12 feet for test purposes to produce a beam. The flexure machine itself is firmly anchored to the floor so that it cannot deflect from its initial position, and change the load values ascertained from the test. The pipe is placed in the machine on two knife-edge pipe supports spaced 6" from each end of the pipe. The span between these two supports is 12 feet. In the center of the span created, a hydraulic lift is located which applies the load to the pipe. The top of this hydraulic lift is a solid type of support approximately 4 feet in length, to which are attached two additional knife edges which apply a stress against the pipe. Diagram 1 shows these knife edges and their relation to the overall pipe length.

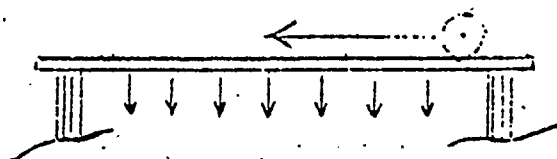


Distributed Load - If a pipe is installed on pilings and then covered with dirt equally distributed to the same height over the pipe, the pipe would have a distributed load or uniform loading. If A/C pipe were installed on a flat trench bottom which provided support for the full length of the pipe, the uniformly distributed load would not produce undue flexural stresses but would mainly exert a crushing action on the pipe due to the weight of the fill material. See Diagram 2.



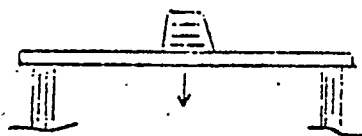
Dynamic Load - If a pipe is installed on pilings, and any man walks on the pipe from one piling to the other, the load caused by the weight of the man would be moving or dynamic in that its location changes as the man moves from point to

point. In the field a dynamic type load on the pipe could occur when the pipe is laid parallel with a road on which some type of vehicle would proceed in a parallel direction with one or more wheels placed over the pipe location. Once again unless the pipe were unsupported on its bottom section, this load would mainly be exerted as a crushing force rather than a flexural stress. See Diagram 3.

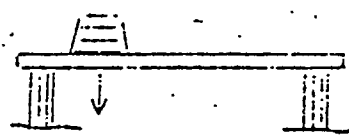


Single-Point Load - If a pipe were installed on pilings, and a weight were to be placed in the middle of the supported section, the load would be center point. If the weight were placed off center, the weight would be single point in that it is being applied at only one point on the beam. See Diagram 4.

Center Point

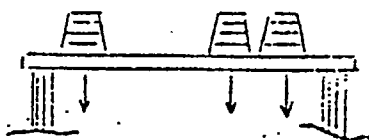


Single Point

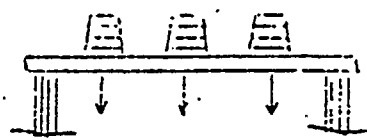


Multiple-Point Loading - If a pipe were installed on pilings and two or three weights were placed at random positions between the supports, the load would be multiple-point, or unevenly distributed loading. If, however, the distance between each weight were equal, the load would be evenly distributed multiple-point loading. See Diagram 5.

Uneven



Even



The apparatus described above the flexure testing develops a type of loading which can be described as, "Third-point loading". Third-point loading would

Certain-teed Pipe Division

B-ACP-TA
ARTICLE I
PAGE 4

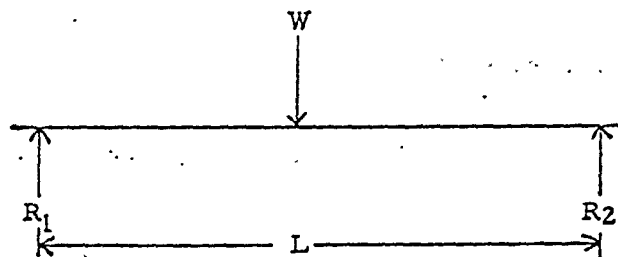
be an evenly distributed multiple-point loading. The total applied load, which has been calculated as a good measure of the pipe's flexural strength abilities, is applied at two points each of which has one-half the total load between the end supports (C and D) so that the distance between the fixed support and a load is equal to the distance between the two loads themselves. This means that the span distance between points A and B has been divided into three equal parts and the load is applied at each third of the span length. From this method we derive an adequate measure of flexural strength for our pipe products.

CPC, as well as other pipe manufacturers, use third-point loading as a flexural test because this type of loading will give the desired stress on as much of the pipe as possible within reasonable limits. The length of pipe between the two load points C and D have the greatest stress exerted upon it but the distances AB and DB are also stressed. We conceivably could use an evenly distributed load to test every foot of the pipe for flexural strength but the difficulties involved in designing the apparatus, and the test procedure would be too detailed for purposes of testing every length on a production basis as is now done. The third-point loading method gives reasonable assurance to the design engineer that the pipe has a degree of flexural strength from which he can calculate the expected limitations of his materials for a given project. However, in construction it is usually a faulty installation which will produce flexural stresses on pipe material. All piping should be either laid on a true and flat trench bottom or if supports are used, should have adequate material tamped under the pipe to produce a supporting strength factor along its entire length. As is evident from the above discussion, this will reduce or remove entirely any flexural stresses on pipe materials.

In recent years many remarks have been made concerning the various lengths of pipe which we produce as compared to lengths produced by our competition. If we were to consider two pipes of equal strength, it should be evident from the above discussion and diagrams that when these pipes are supported over a clear span that the load necessary to produce the ultimate flexural strength would vary with the distance between supports. In essence we may conclude that as the supports are moved further apart, the total applied load necessary to produce the ultimate flexural strength would decrease. For example, there would be no appreciable difference in flexural strength between a 10-foot or a 13-foot pipe length if the pipes were manufactured of equal strength factors and the clear span between supports was identical. However, if we were to apply the third-point loading method to each of these, the 10-foot length of pipe would be supported over a 9-foot span, whereas the 13-foot length would be supported over a 12-foot span. Applying the principles previously discussed, we can readily see that the 9-foot span would permit a higher total load before reaching ultimate flexural strength than the 12-foot span. However, as far as strength would be concerned, both of these pipes could be of equal strength.

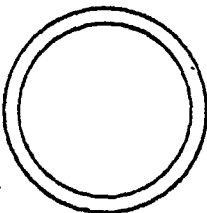
The engineer needs formulas or means by which he can calculate the load or stress that a beam can withstand. These formulas are basic to the engineer, but a knowledge of their meaning is always helpful to others.

The Simple Beam - The simple beam, single point and center loaded, is the most used. Consider a beam, supported at either end, and loaded in the middle by a weight we will call "W". The length of the beam is "L" and the resistances or reactions to the load at each support are "R₁" and "R₂". The value of each



reaction is equal to one-half of the load, "W", or $R_1 = W/2$ and $R_2 = W/2$.

To determine the maximum stress or load which the pipe could withstand we would need to know the section modulus and the moment caused by the load and reactions. (Remember that a moment is the result of a force acting through an arm or some means of connection. Moments are expressed in terms of force or weight-distance. A simple, practical example is a torque wrench expressing the moment of torque in foot pounds.) The section modulus (z) is the moment of inertia of the beam divided by one-half the outside diameter. This relationship applies to the subjects under discussion here.



← D₁ →

← D₂ →

Therefore I = moment of inertia

Z = the section modulus $I / \frac{D_2}{2}$

M = the moment or action caused by the forces involved

And $M = R_1 \times \frac{L}{2}$

or $M = \frac{W}{2} \times \frac{L}{2} = \frac{WL}{4}$ equals the moment at the center of the beam.

In a simple beam the maximum flexural stress, "s" is exerted at the center of the span for single point center point loading and is expressed as a weight per

Certain-teed Pipe Division

B-ACP-TA
ARTICLE 1
PAGE 6

unit area, such as lbs. per sq.in., tons per sq.yd., etc.

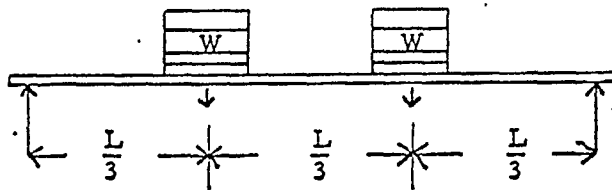
$$S = M \times \frac{1}{z}$$

$$\text{or } S = \frac{WL}{4} \times \frac{1}{z} = \frac{WL}{4z}$$

From this "S" the engineer can calculate load limits for any given size of pipe and its span.

Third-Point Loaded Beam

A beam that is third-point loaded has two loads, "w", of equal value applied at two points so that the distance between the loads and between the loads and the supports are equal. W equals the total applied load, w equals one-half of that value



Proceeding as for the simple beam

$$M = w \times \frac{L}{3} = \frac{wL}{3}$$

Therefore, the maximum stress, "s", to which a third-point loaded beam would be subjected is

$$s = M \times \frac{1}{z}$$

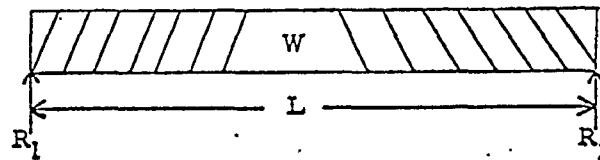
$$\text{or } s = \frac{wL}{3} \times \frac{1}{z} = \frac{wL}{3z}$$

The point to remember that is different between the "single point" and "third point" loaded beams is that the maximum stress in a "single point" loaded beam occurs at the point of loading while the maximum stress of a "third point" loaded beam occurs at any point between the loads. This stress is the same anywhere between the two points of loading. (Refer to previous diagram on third point

loading.)

The Uniformly Distributed Load

A beam that is subjected to a uniformly distributed load is one that has the same amount of weight or load on each unit length of beam between the supports. The total weight on the beam is equal to the weight per unit length multiplied by the total length. The reaction at each support is the same and equal to one-half the total weight on the beam. The moment at the center of a beam is equal the moment of the support times its moment arm less any counteracting moment caused by weights or loads between the support and the center of the beam such as in distributed loads.



Proceeding as before

$$M = (R_1 \times \frac{L}{2})$$

$$M = (\frac{WL}{2} \times \frac{L}{2}) - (\frac{WL}{2} \times \frac{L}{4}) = \frac{WL^2}{8}$$

$(\frac{WL}{2} \times \frac{L}{2})$ = the moment at the center of the beam caused by R₁

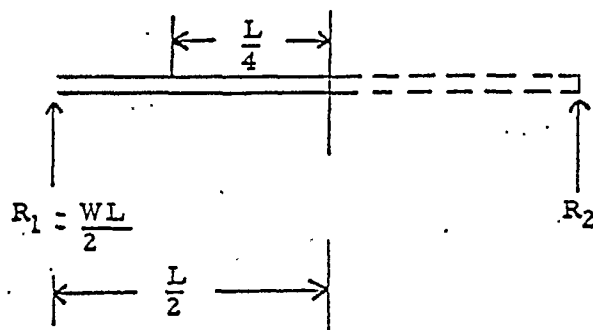
$(\frac{WL}{2} \times \frac{L}{4})$ = the moment at the center of the beam caused by the counter-reaction due to the distributed load along the beam.

$$S = M \times \frac{1}{2} \quad \text{or} \quad S = \frac{WL^2}{8} \times \frac{1}{2} = \frac{WL^2}{16}$$

The point of maximum moment occurs in the center of the beam as in a single point, center-load beam. In determining the maximum moment of this beam the load, being equally distributed, acts to reduce the moment caused by the reaction and its moment arm. Half of the equally distributed load acts against the moment of the reaction.

Certain-teed Pipe Division

B-ACF
ARTICLE 1
PAGE 8



This report is intended to serve as a non-technical discussion of flexure and flexural strength and was prepared through the cooperation of our Research and Development Department. Additional references to flexural strengths and flexural formulas may be obtained from the following reference books:

Mechanical Engineers' Handbook -- Marks
Civil Engineers Handbook
Resistance of Materials -- Fred Seeley.