TRANSPORT and ROAD
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Department of the Environment
Department of Transport

SUPPLEMENTARY REPORT 663

A BENDING TENSILE TEST TO DETERMINE THE CRUSHING STRENGTH OF SEWER PIPES

by

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Crowthorne, Berkshire
1981
ISSN 0305–1315

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ABSTRACT

A problem which frequently arises in assessing the cause of structural failures in sewers is the difficulty of determining the strength of the pipes. Withdrawal of complete undamaged pipes for testing is often impossible, and all that may be readily available is broken fragments of pipe. This Report describes experience gained with the use of a German DIN test, in which the crushing strength of whole clayware pipes is estimated from tests on small pieces; a modification for estimating the anisotropy of the pipe material is also described. The test is used to examine the relation between the proportion of damaged pipes and the structural integrity of the sewer.

1. INTRODUCTION

A problem which frequently arises in attempting to assess the cause of structural failures or defects in pipe sewers is the difficulty of determining the strength of the pipes. Withdrawal of complete undamaged pipes for testing is often impossible, and all that is readily available may be broken fragments of pipe.

This Report describes experience gained with the use of a German DIN test[1], the 'bending tensile test', in which the crushing strength of whole clayware pipes is estimated from tests on small pieces. An extension of this test to examine the anisotropy of the pipe material is also described. The use of the test is illustrated with site studies of the relation between structural integrity and the proportion of damaged pipes in old sewers.

2. THE BENDING TENSILE TEST

2.1 *Description of test*

Rectangular test pieces are cut from a pipe or fragment of pipe, of length and breadth approximately five and three times the wall thickness respectively, and with the length perpendicular to the axis of the pipe (Figure 1). Each test piece is mounted on the apparatus shown in Figure 1. A line load applied through a steel pressure beam and a rubber strip about 1/10 of the wall thickness of the pipe is increased steadily until the test piece fails.

2.2 *Theory*

The moment/unit breadth at failure may be calculated by treating the test piece as a thin beam;

$$M_{test} = \frac{Fl}{4b} \quad \ldots\ldots\ldots \quad (1)$$

where M_{test} = moment/unit breadth of test piece at failure
F = ultimate load on test piece at failure
l = length of test piece measured along the chord at axis level
b = breadth of test piece.

For a whole pipe, the moment/unit length of pipe at failure in the British Standard crushing strength test is given by[2];

$$M_{pipe} = 0.32\, F_c \, \frac{d+t}{2} \qquad \ldots\ldots (2)$$

where M_{pipe} = moment/unit length of pipe at failure
F_c = crushing strength of a pipe per unit length[3]
d = internal diameter of pipe
t = wall thickness of pipe

If the pipe material is homogeneous, M_{test} is equal to M_{pipe}, and so from equations (1) and (2);

$$F_c = \frac{1.56\, Fl}{b(d+t)} \qquad \ldots\ldots (3)$$

2.3 *Test of theory*

To test equation (3), eleven intact clayware pipes manufactured at various times and of diameters between 229 and 457 mm were obtained. The crushing strength of each pipe was first determined in the usual way[3]. Between three and ten test pieces were cut from the broken pieces of each pipe using a diamond saw, and tested as described above. The results obtained are shown in Figure 2. For three early pipes, probably made by hand about 1850, the bending tensile test greatly overestimated the actual crushing strength. For the eight pipes manufactured between about 1870 and 1930 the discrepancy was less marked and the measured crushing strength averaged 0.88 times the crushing strength estimated from the bending tensile test with a standard deviation of 0.15.

A better estimate of pipe crushing strength can be obtained by multiplying equation (3) by a correction factor of 0.88 to give

$$F_c \simeq \frac{1.4\, Fl}{b(d+t)} \qquad \ldots\ldots (4)$$

This reduction of strength is to be expected since manufactured materials are variable and strength determinations on large specimens (complete pipes in this case) are normally lower on average than those determined on small specimens (the bending tensile test pieces in this case). Using the coefficients of variation found in the test on the small pieces of pipe used in the bending tensile test, Weibull's theory (see Wright[4]) would indicate that the ratio of strengths determined on whole pipes and in the bending tensile test would be in the range 0.85 to 0.90.

The use of the bending tensile test to determine pipe crushing strength is also applicable to pipes of other plain materials like unreinforced concrete but the effect of material variability and hence the numerical factor in equation (4) could be somewhat different.

Over 90 per cent of test pieces failed by fracture at or near the pressure beam. Occasionally pieces failed in such other modes as splitting parallel to the pipe wall but this appeared to make little difference to the load measured at failure. Results were therefore only rejected if they could definitely be ascribed to hairline cracks or other previous damage to the test piece.

One problem that did arise was in the mountings for the test piece. For simplicity, the apparatus used in the present study (Figure 1) departed from the DIN specification in not having one bearing plate free to rotate with respect to the other. It was found necessary to ensure that the test pieces were cut with opposite edges not more than 2 mm out of parallel, to give firm support in the test apparatus. The DIN form of the apparatus would have obviated this problem.

The number of test pieces required for each pipe is discussed later in Section 3.

2.4 *Extension of test to assess anisotropy of pipe material*

Present British standards for clayware[3] and concrete[5] pipes are now being extended to include bending moment resistance[6] (BMR) as well as crushing strength. BMR determines the strength of the pipe against bending moments causing it to fail as a beam. A modified bending tensile test was therefore developed to deal with this mode of failure; the principle is illustrated in Figure 3.

The test piece is cut to the same dimensions as in the bending tensile test (Section 2.1) but in this case with its length parallel to the pipe axis. It is mounted on the test apparatus shown in Figure 3, and loaded to failure as previously described. Again treating the test piece as a thin beam, equation (1) may be used to calculate the bending mount at failure.

A comparison of the bending moments obtained for the bending tensile test, and for the modified bending tensile test, on pieces cut from the same pipe, gives an indication of the anisotropy of the pipe material. No significant evidence of anisotropy was in fact found in tests on 13 clayware pipes manufactured between about 1870 and 1930.

3. EXPERIENCE WITH BENDING TENSILE TEST

The bending tensile test has been used in a preliminary assessment of the structural integrity of old pipe sewers, and the relation between structural integrity and proportion of damaged pipes.

A single pipe will fail by crushing (ie be damaged or deformed by longitudinal cracks along the axis) if the load due to traffic and overburden (W_e) exceeds the in situ strength of the pipe[7]. That is, if: –

$$W_e > W_T \times Fm$$

$$\text{or} \quad \left(\frac{W_e}{W_T}\right) > Fm \qquad \qquad (5)$$

where W_T is the average crushing strength of the run of pipes
Fm is a load factor.

Because of the variation in strength of individual pipe lengths in normal circumstances it is unlikely that a run of pipes laid on a similar bedding will all fail simultaneously and the proportion which fails should be related to W_e/W_T.

To test this possibility, seven lengths of clayware pipe sewers laid beneath roads were examined while they were being excavated and replaced by new sewers. In five cases it was possible to recover a whole pipe for testing, but usually only fragments were obtained. W_T was therefore obtained using the bending tensile test to make estimates of the crushing strength. The load on the pipe, W_e, was estimated using the usual design procedure[7] for the actual trench widths observed. All of these sewers had been laid on the trench bottom with a soil surround, ie Class C or Class D, except for one length with a concrete arch over the crown and sides of the pipe. The proportion of damaged pipes was determined from closed circuit television (CCTV) survey reports, taken some time before reconstruction.

The results obtained from this study are shown in Figure 4 where W_e/W_T is plotted against the cumulative percentage of failure. It can be seen that there is a relation between W_e/W_T and the proportion of damaged pipes. It has been found possible to fit a normal distribution curve with a mean value of 2.8 and a coefficient of variation of 0.25 to the data. Such a relation could prove useful in developing methods of interpreting the results of CCTV surveys in structural terms, particularly if changes in the loading regime are being considered.

It should be noted that the sewers examined in this study were laid between about 1870 and 1930, when methods of pipe production and pipe laying were different from those now employed. While a relation similar to that shown in Figure 4 might well exist for modern sewers, it cannot be assumed that it will be represented by the same curve.

The results of these tests may also be used to examine the number of test pieces required from each pipe to estimate crushing strength from the bending tensile test. For the application considered in this Report, what is needed is an accurate mean crushing strength of all the pipes in a run of sewer. There are therefore two aspects of variability to consider; that between test pieces cut from the same pipe, and that between pipes sampled from the same sewer. Analysis of the present test results[8] shows that the main variation is that between pipes, and that in most cases this is significantly greater than the variation between test pieces (Table 1). An extreme example is Length 5, where manufacturer's marks showed that pipes from two factories had been used in one length of sewer. The variation between test pieces is very similar to that found for the data given in Figure 2.

The more efficient sampling procedure when a length of sewer is being considered is therefore to take about three test pieces per pipe, but to ensure that a sufficiently large number of pipes are sampled. Conversely, if the strength of a single pipe, or a uniform batch of pipes is required, a larger number of test pieces would be appropriate; the DIN standard recommends ten test pieces per pipe.

TABLE 1

Variation of pipe crushing strengths

Length No.	1	2/3	4	5	6	7
Average number of test pieces per pipe	3	4	3	3	3	3
Number of pipes in sample	5	6	9	5	4	6
Total number of pieces tested	14	23	31	16	11	20
Variance estimate for pipe crushing strengths;						
Between pipe variation	1.07	1.98	0.30	6.91	0.33	1.21
Within pipe variation	0.12	0.08	0.10	0.29	0.09	0.08

4. CONCLUSIONS

1. The DIN bending tensile test has been found to be a useful means of estimating the crushing strength of *in situ* clayware pipes, in circumstances where complete pipes cannot easily be recovered.

2. When determining the average strength of a run of pipes, three test pieces cut from each of a number of pipes are probably adequate. More test pieces would be required for estimating the crushing strength of single pipes, or for batches of manufactured pipes.

3. The test has been used to explore the relation between the proportion of damaged pipes and the structural integrity of the sewer.

5. ACKNOWLEDGEMENTS

The work described in this Report was carried out in the Tunnels and Underground Pipes Division (Division Head: Mr M P O'Reilly) of the Structures Department of TRRL.

The author wishes to thank the staff of District Authorities and contractors for their co-operation in the site observations, and Mr C E G Bland of the Clay Pipe Development Association for valuable comments.

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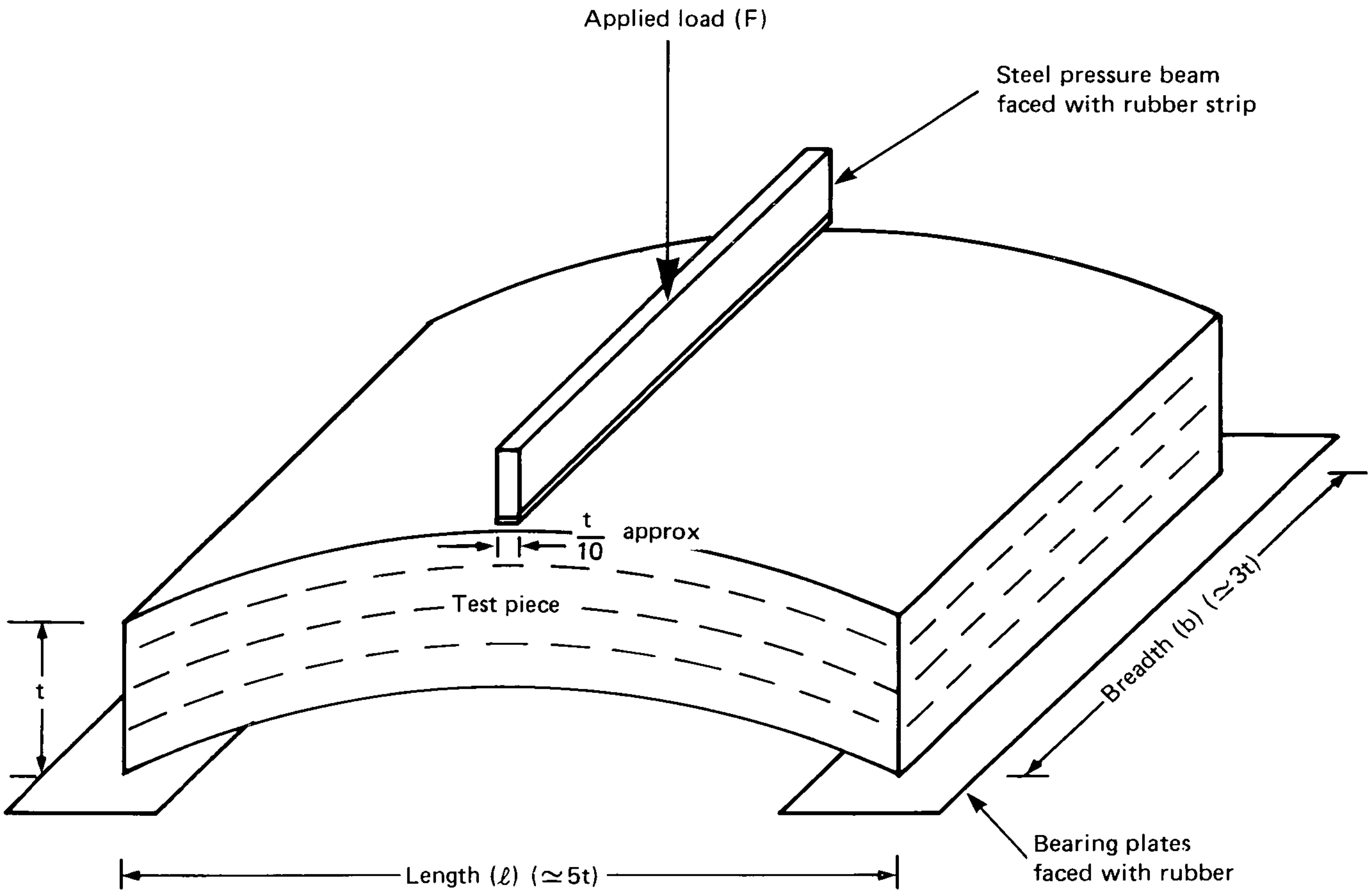

Fig.1 Mounting of test piece for 'bending tensile test'

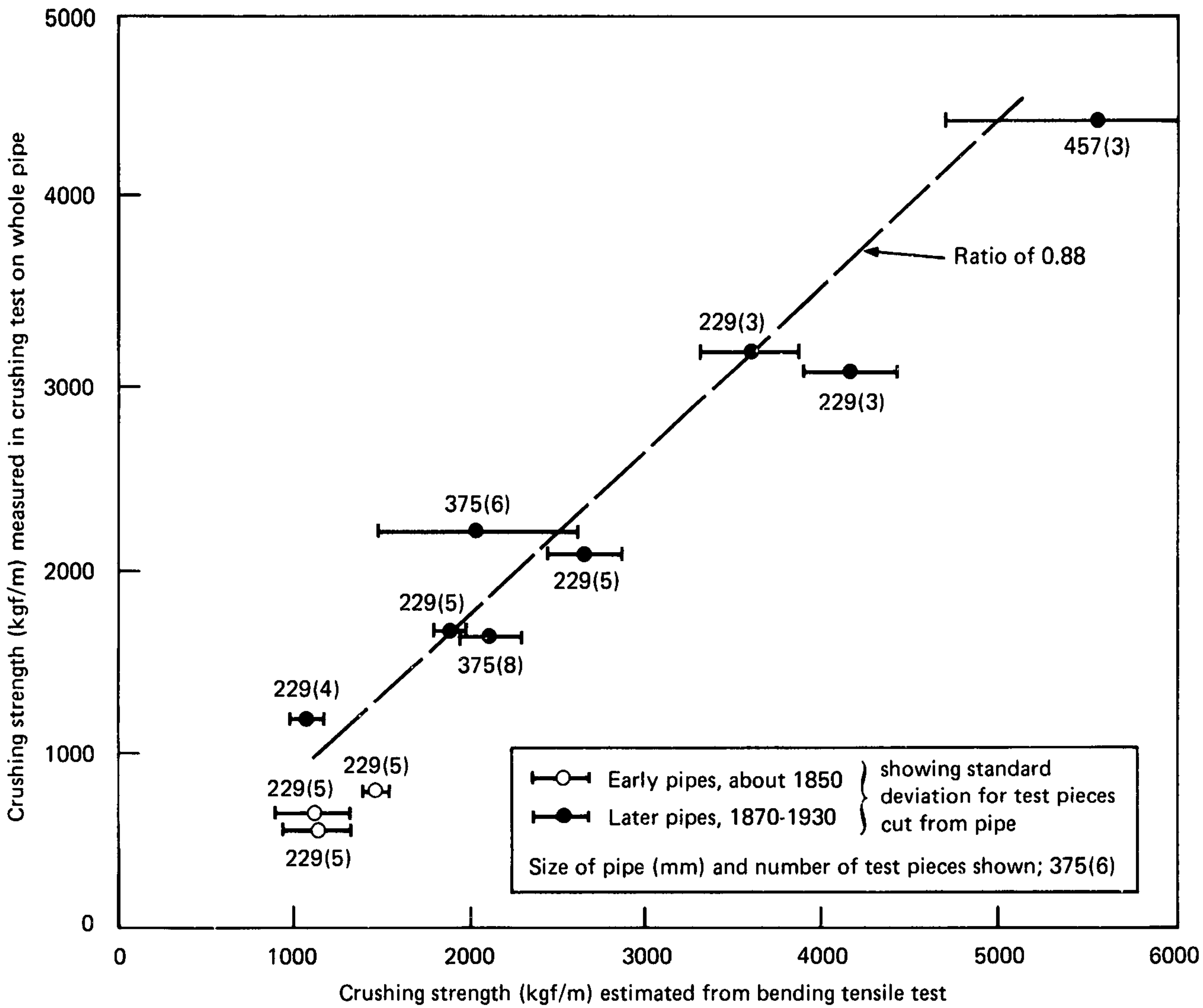

Fig.2 Relation between measured and estimated crushing strength

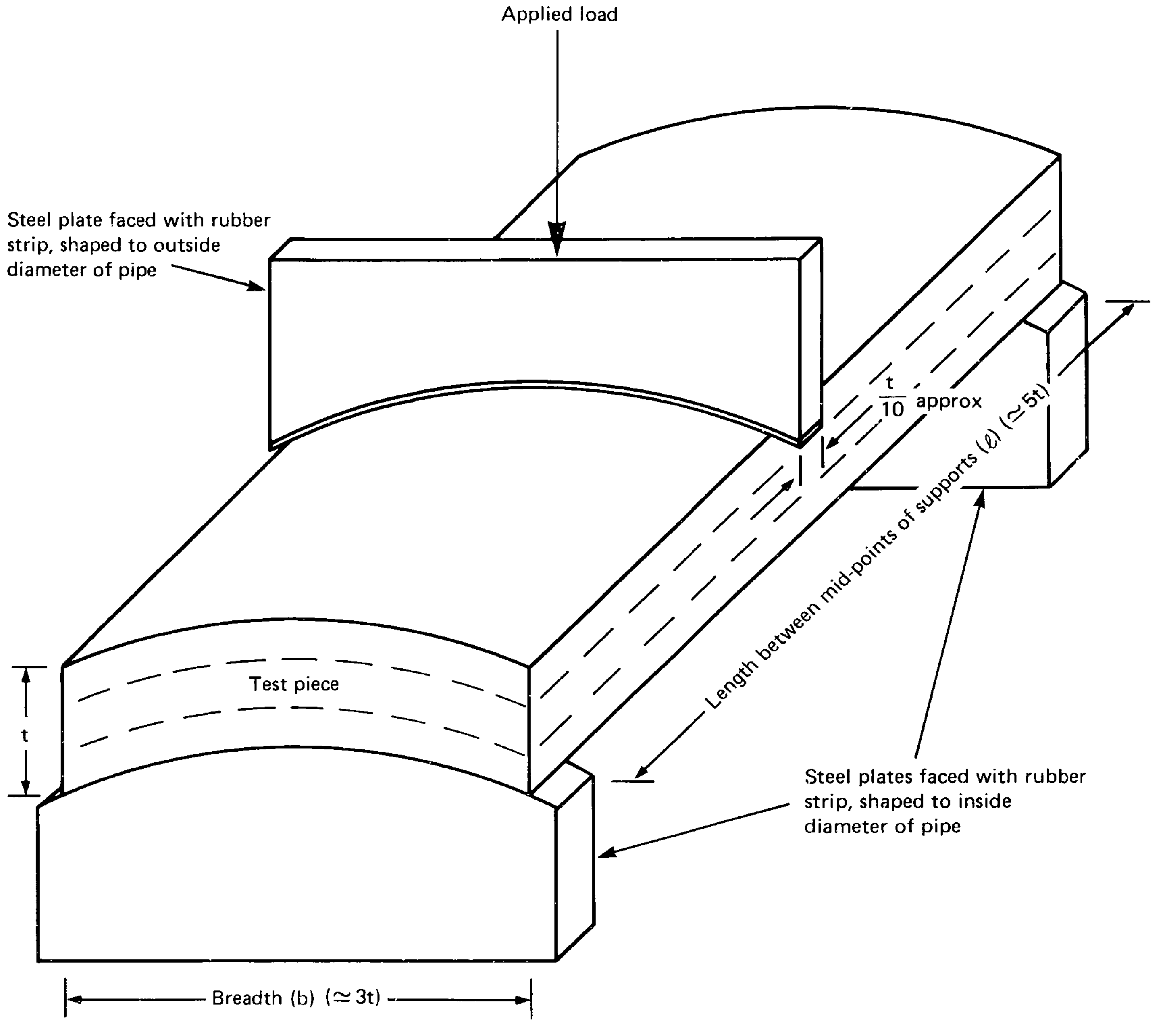

Fig.3 Mounting of test piece for 'modified bending tensile test'

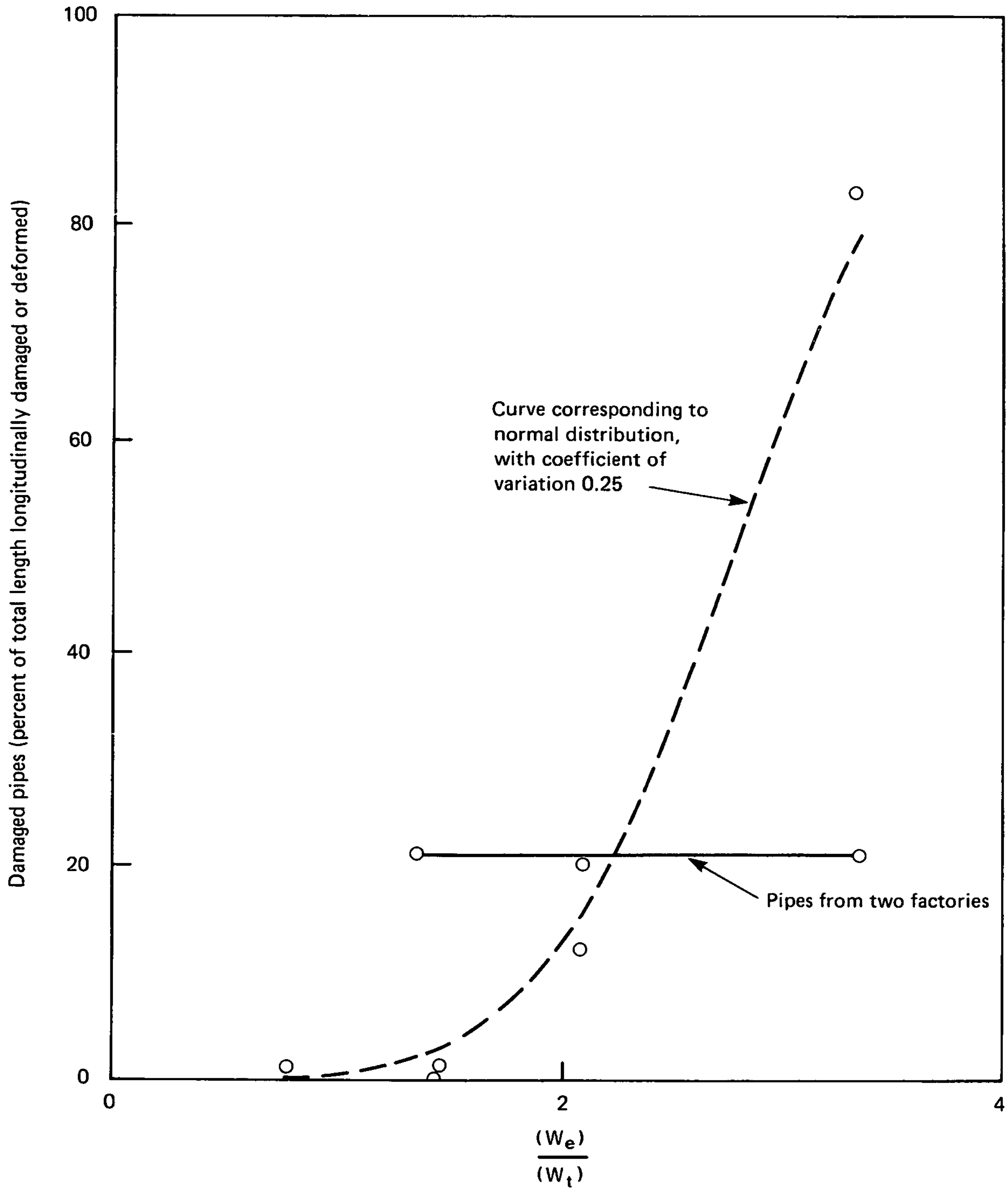

Fig.4 Relation between proportion of damaged pipes and structural integrity of sewers

(1210) Dd8041301 1,400 7/81 H P Ltd So'ton G1915
PRINTED IN ENGLAND

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