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A PROCEDURE FOR CALCULATING THE COST OF LAYING RIGID SEWER PIPES

by

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A PROCEDURE FOR CALCULATING THE COST OF LAYING RIGID SEWER PIPES

ABSTRACT

The Transport and Road Research Laboratory is engaged on research into the design and construction of underground pipelines. In order to assess the economic consequences of any changes in present practice which may be recommended, it is essential to have a detailed knowledge of the materials and operations involved and their costs.

This Report describes a procedure for calculating these costs, for rigid sewer pipes not exceeding 600 mm internal diameter, which is based upon site observations of the operations involved and published cost data. Costs obtained by this procedure are in reasonable agreement with costs in a limited number of tenders, and with other estimates. Its scope is at present limited by lack of data on some construction operations and by its simplified approach to site management problems.

1. INTRODUCTION

The Transport and Road Research Laboratory is engaged on a programme of research into the structural design and construction of underground pipelines, with the object of reducing the cost of construction and maintenance by improved design, specification and site practice. Research is being conducted into methods of analysing soil structure interaction, the structural performance of buried pipes, and site practice in laying pipes.[1,2]

An essential part of this programme is a detailed study of the materials and operations involved, and their costs, to enable the economic consequences of any recommended changes in design, specification or construction procedure to be determined. A partial breakdown of costs can be obtained from an analysis of tender prices, but these suffer from the disadvantages that the breakdown of costs is not very detailed (usually 4 or 5 items), and that no insight is obtained into the contractor's method of working or real cost distribution. This Report describes an alternative method of estimating costs, based upon the results of site observations of the time taken to carry out the operations involved in installing rigid pipes not exceeding 600 mm internal diameter for foul and surface water sewers, and the use of the results in conjunction with published cost data to develop a procedure for estimating the cost of these operations.

2. DATA

2.1 *Timing of elements*

Observations have been made at a number of sewerage contracts, in which the individual elements in the job of installing rigid pipes with flexible O-ring joints were timed, and the plant and labour employed were noted.

The observed times for excavating the trench are shown in Fig 1a, in the form of volume excavated per unit time. The wide range of rates of excavation appears to be determined primarily by the ease of operation of the excavator. The lowest rates were observed in the confined volume of sheeted trenches. Rates were lower in roads, where working width was usually restricted, than in fields. Rates could not be directly related to trench dimensions (Fig 1a), but much larger rates were measured in trenches with battered sides and large cross-sectional areas. Because the excavator was usually working below its maximum capacity, rates of excavation could not be related to the size of the machine (for bucket or backhoe capacities of 0.3 - 0.6m^3).

The observed times for laying and levelling the pipes are shown in Fig 1b. For the smallest pipe diameters, manual handling takes less time than using the excavator to lower in the pipe. If an excavator is used for this purpose, the time for pipe-laying does not appear to vary greatly with size of pipe. The time could not be related to the number or type of joints.

The observed times for all of the elements are summarised in Table 1. It was not possible to obtain reliable times for certain elements that should have been included, in particular the laying of concrete bedding and excavation in rock and some other difficult ground conditions. Soil compaction (item 12 in Table 1) is usually to a standard less than that specified[2]. A limited number of the elements involved in manhole construction are included in Table 1 because of their relevance to the method of synthesising the elements described in Section 2.2.

These observations were made by an observer during regular visits over the duration of the various contracts studied. It was not possible to make detailed observations of the utilisation of plant or labour, and the method that was used to assess this indirectly is described in Section 2.2.

The impression of the observers was that the utilisation of labour was high, since men could change their duties quickly to suit the sequence of operations, and work was stopped only during heavy rain. The utilisation of plant was more variable. The excavator was the only machine to have a permanent operator, and appeared to have a high degree of utilisation in many operations. The utilisation of smaller machines, such as dumpers and compaction equipment, appeared to be much lower.

Among the factors which did affect operations, and reduce utilisation, were tea breaks, heavy rain, mechanical breakdowns, interception of existing services, and movement of plant and materials between sites. No allowance is made for these in Table 1.

2.2 *Synthesis of elements*

The times given in Table 1 do not give any indication of variability or of time lost on non-productive work. The method that has been used to synthesise the elements and obtain an indication of the overall performance of the pipe-laying gang is to compare the 'productive time' with the 'actual time'.

The 'productive time' is the time that would be taken to complete the work cycle if all the elements took the time given in Table 1, ie if there were no interruptions or variations. This time can be calculated from the sequence involved, ie excavation, a pause while the bedding and pipe are laid, and back-filling. The excavator is usually also used for manhole construction. Sufficient labour is usually available to ensure that ancillary operations, such as road-breaking and compaction, can be carried out without holding up the excavator.

The 'actual time' is the time actually taken by the gang, including all delays and difficulties experienced on the site.

The 'productive time' and the 'actual time' are compared in Fig 2, for three contracts where the method of working, hours worked and rate of progress were known. The ratio of these times is an indication of the performance achieved. Contract 'X' was an off-road site with problems of plant mobility on wet ground, and limited access and working width; the ratio of productive to actual time was only 35 per cent. Contract 'Y' was a road site, with good access and only slightly affected by road traffic; at this site a ratio of 65 per cent was achieved. Contract 'Z' was initially on an off-road site, but one with no problems of access or mobility, and later on a road site with problems of access and working width; in this case the ratio was initially 70 per cent, but fell to 45 per cent.

Because the excavator is used in most of the critical operations in pipeline construction, the ratio of productive to actual time is largely an indication of the degree of utilisation of the excavator. As was pointed out in Section 2.1, the utilisation of smaller machines is likely to be lower, and the utilisation of labour higher.

2.3 *Cost of materials, plant and labour*

Table 2 gives the cost of supplying some pipes typical of the diameters and types employed in sewerage contracts. These costs are based upon manufacturers' list prices for complete loads delivered to site. Apart from variations with delivery distance, prices negotiated for a particular contract may depart by at least 20 per cent from list price. Some pipes larger than 600 mm diameter are included in Table 2 for completeness.

The costs of contractor's plant, materials and labour are given in Table 3. These costs are based upon the 'Daywork and Prime Costs' rates given by Spon[4], including the recommended additions for costs and profits, and are for 100 per cent plant utilisation as defined in Section 2.2. The costs of materials are necessarily approximate and will vary with transport costs in a particular locality.

All the costs in Tables 2 and 3 are for January 1975, the original costs being corrected to this date where necessary by the appropriate Baxter[5] or Osborne[6] indices.

3. CALCULATION OF PIPE-LAYING COSTS

3.1 *Cost data*

The cost of the operations involved in laying sewer pipes may be determined by combining the times given in Table 1 with the costs given in Table 3. The cost of providing pipes, labour and materials may be obtained from

Tables 2 and 3. In addition, the following assumptions are made:

(a) The utilisation of plant is taken to be 50 per cent, and of labour 75 per cent (ie the costs given in Table 3 are multiplied by 1/0.5 for plant and 1/0.75 for labour).

(b) Pipelaying runs are sufficiently long for the cost of bringing plant on to the site to be negligible.

(c) The rate of laying pipes is not affected by the length of pipe or type of joint.

(d) An allowance of £2 per hour of productive time, as defined in Section 2.2, is made for the cost of ancillary plant (part use of a van, small pumps, traffic lights, etc). This would not be sufficient for a site where extensive de-watering was required.

The costs obtained with these assumptions, and used in the calculations, are given in Table 4.

3.2 *Method of calculation*

Fig 3 shows a flow chart giving the principal steps in calculating the cost of laying sewer pipes with the Class B bedding commonly used in this work and with a typical cost of pipe. The procedure given could be readily modified to deal with any other construction procedure for which the time of operation and costs are available.

3.3 *Input*

The data required for each calculation of the cost of laying a pipe-line is given in Table 5.

3.4 *Output from calculation*

An example of the calculated costs obtained, for a typical set of data giving the required dimensions and method of working, is given in Table 6. The total cost of laying the pipeline is divided into eight elements, which are further sub-divided into costs of materials and of work done.

4. COMPARISON WITH OTHER DATA

Estimates of the costs of laying sewer pipes were obtained from the published and unpublished sources listed below. Where necessary, these estimates were adjusted to January 1975 by using the mean of the Baxter indices for labour, plant, aggregates and cement:

(a) Tender prices. Prices were obtained from eight successful tenders submitted during 1974 and 1975. We were informed that no major difficulties have arisen with claims on these contracts. 'Preliminaries' on six of these contracts were between 0 and 30 per cent of total bill and averaged 12 per cent. The 1975 adjusted prices were used without any allowance for claims or preliminaries.

(b) 'Civil Engineering'[8]. The 'measured rates' given in this journal for June 1975 were used. These rates make no allowance for 'preliminaries'.

(c) Boden et al[1]. This paper gives a partial breakdown of the cost of laying sewer pipes at a depth of 2 m. These prices were based upon tender prices (not those of (a) above) for the early part of 1975.

(d) Banks[9]. This paper, presented in January 1976, gives some typical prices which include 'preliminaries' and other works incidental to pipeline construction as well as compensation.

(e) Local Government Operational Research Unit[10]. A partial breakdown of costs for May 1971; it is emphasised that the costs are not necessarily representative of the whole of the United Kingdom.

(f) Consultant's estimate. The average rates used by a consultant for estimating the costs of sewerage schemes were made available to us.

Some costs obtained from these sources, for runs of three diameters of pipe at a range of depths, are compared in Fig 4 with those calculated by the procedure described in this Report.

Reasonable agreement is obtained between tender prices and calculated costs, although the number of tenders considered is small and not necessarily representative. The analysis in Table 7 shows that the mean of the ratios of tender price to calculated cost does not depart significantly from unity. There are appreciable variations in individual prices, reflecting possible discrepancies between an individual contractor's actual and assumed methods of working and in his method of pricing.

Reasonable agreement is also obtained between the estimated prices given in (b), (c), and (e) above, and the calculated costs. The estimated prices given by Banks and the consultant ((d) and (f) above) are, however, consistently higher; these prices include allowances for preliminaries and other items incidental to pipeline construction, and the higher prices presumably reflect the magnitude of these allowances.

Some of the sources listed above give partial breakdowns of the total cost of pipe-laying. Figure 5 shows the effect of depth of invert and of pipe diameter upon costs, and compares prices given in (b) and (c) above with calculated costs. Reasonable agreement is again obtained, the results showing the dominance of construction costs over cost of supplying the pipe, for smaller and deeper pipelines[1].

These comparisons show that it is feasible to estimate contractor's costs in laying sewer pipes from a study of site operations. The procedure described in this Report can be used to calculate costs which are detailed, and in reasonable agreement with other estimates and with a limited number of tender prices. The present procedure is, however, a very simple one and does suffer from a number of drawbacks:

(a) Adequate site observations have not been carried out for some operations, in particular excavation in rock and other difficult ground conditions, and de-watering operations.

(b) The present Report is limited to pipes not exceeding 600 mm internal diameter. The operation costs given would generally also be applicable to pipes of greater diameter, but the cost of providing cranage for pipes weighing more than about 1 Mg would have to be allowed for[3].

(c) Site management problems have almost certainly been over-simplified. For example, the utilisation of plant and labour is likely to vary with type of plant, site conditions, and sequence of operations. These difficulties have also been identified in the study of construction operations for bridges[11].

(d) The costs relate solely to the direct pipeline construction operations and do not include for the cost of preliminaries and other works incidental to pipeline construction (for example, flow diversions) or for the cost of design and supervision. The comparison with Bank's data in Fig 4 suggests that these items might increase the total cost by up to 50 per cent in extreme cases. An analysis of tender sums and final accounts would provide information on the magnitude of these items[12].

Bramwell[13] has studied contractor's operations in laying sewer pipes in a manner which deals to some extent with the first three of the above drawbacks, and this work is being extended by Aston University and Bryant (Civil Engineering) Ltd under a TRRL contract.

5. INFLUENCE OF COSTS ON DESIGN

The interaction between costs, site practice, and design has been discussed in a recent paper[2]. An example of this interaction is shown in Fig 6.

Figure 6a shows the cost of laying pipes in an unpaved area at two depths (2 m and 4 m to invert), and in two types of ground (weak and unstable; see Table 1). It is apparent from this example that the type of ground can have a very great effect on the cost, and that any method of estimating costs must take account of ground conditions.

Figure 6b shows the same examples, but gives the cost of providing the pipe as a percentage of the total cost. This graph demonstrates that for smaller diameter pipes the cost of providing the pipe is almost always less than half the total cost of construction. Any significant savings in total costs are therefore more likely to arise from improvements in construction operations rather than from economies in pipe costs. Conversely, for pipes of larger diameters than those considered in this Report both construction costs and pipe costs offer opportunities for savings.

6. CONCLUSIONS

1. The results of site observations on contracts for laying rigid sewer pipes not exceeding 600 mm diameter have been used, in conjunction with published cost data, to develop a simple procedure for calculating the costs of the operations involved.

2. Costs obtained by this procedure are in reasonable agreement with those obtained from a limited number of tenders, and with other estimates of construction costs based upon tender prices.

3. Although this procedure has been shown to be feasible, its present scope is limited by lack of data on some construction operations and its simplified approach to site management problems. The cost of preliminaries, and other items additional to actual pipeline construction costs, should be added to obtain the total cost to the client.

7. ACKNOWLEDGEMENTS

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Thanks are due to the staff of Water Authorities, Consultants and Contractors for permission to carry out observations and for valuable discussions, and for provision of cost data.

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TABLE 1

Times of elements involved in sewer construction

	Operation	Plant employed	No. of men (1)	Output
	Pipe lines			
1	Break road surface	Compressor, 2 breakers	2	0.2 m^2/min
2	Excavate trench by hand	-	2	0.02m^3/min
3	Excavate trench by machine:			
	Close sheeting (unstable ground (2))	Excavator	2	0.04m^3/min
	" " (weak ground)	"	2	0.1 m^3/min
	Road	"	2	0.2 m^3/min
	Field	"	2	0.4 m^3/min
	Field (battered sides)	"	2	1.0 m^3/min
4	Unload and distribute pipe	Excavator/dumper	2	1 m/min
5	Place & subsequently remove open trench sheeting	Excavator	2	0.5 m run/min
6	Place & subsequently remove closed trench sheeting	"	3	0.1 m run/min
7	Lay granular bed	Dumper	3	0.25m run/min
8	Lay and test pipes by hand (< 300mm dia)	-	2	0.3 m run/min
9	" " " " " machine	Excavator	3	0.2 m run/min
10	Replace soil by hand	-	2	0.2 m^3/min
11	" " " machine:			
	From material in heap	Excavator	2	0.5 m^3/min
	From material being excavated	Dumper	2	0.2 m^3/min
12	Compact soil	Rammer	1	0.1 m^3/min
13	Lay concrete or tarmac	Dumper	3	0.3 m^2/min
14	Compact concrete or tarmac	Vibratory roller	1	0.5 m^2/min
15	Excavate short heading by hand (3)	Excavator	2	0.03m run/min
16	Backfill " " " " (3)	"	2	0.05m run/min
	Manholes			
17	Place concrete foundation	Dumper (10 mins)	2	50 mins
18	" ring and joint	Excavator	3	15 mins
19	" concrete road segment	Dumper	2	15 mins
20	Benching	Dumper (10 mins)	1	300 mins

(1) Excluding site supervision, but including driver and ganger.

(2) Excavator bucket cannot work its own length ahead of sheeting.

(3) Not normally exceeding 2 m in length, eg under an existing pipe.

TABLE 2

Cost of supplying pipes for sewerage contracts
(January 1975)

Material	Class	Cost (£/m run) of pipe diameter					
		150mm	300mm	450mm	600mm	900mm	1200mm
Concrete	STD	2.6	4.1	6.8	11.9	32.0	39.5
	M			9.1	15.8	32.1	61.0
	H		5.3	9.7	16.9	35.4	68.8
Clay	ES **	1.3	4.4	11.1			
Asbestos cement	L(AC)			6.5	10.9	22.1	
	M(AC)			7.2	12.0	27.1	
	H(AC)	1.9	4.0	7.9	13.7	30.5	
uPVC*	B	2.7	7.7	16.0	30.0		
	C	3.3	10.9	20.1	42.8		
Pitch fibre		1.2					
Grey iron	1	3.7	8.6	15.6			

* Unplasticised polyvinyl chloride

** Extra strength

TABLE 3

Estimated costs of plant, labour and materials
(January 1975)

Item	Cost
Plant	
Compressor ($4m^3$/min) and 2 breakers	2.7 £/hr
Wheeled excavator ($1m^3$ shovel)	3.5 £/hr
Tracked excavator ($0.6m^3$ bucket)	6.0 £/hr
Dumper ($0.8m^3$)	1.1 £/hr
Power rammer (100kg)	0.6 £/hr
Pedestrian operated vibratory roller (0.7Mg)	0.8 £/hr
Van (1 Mg)	2.1 £/hr
Labour	
General operative	1.6 £/hr
Material	
Granular bedding material	3 £/m^3
Concrete	11 £/m^3
Tarmacadam	7 £/m^3
Trench sheet and struts	0.05 £/m length/day
Other	
Removal of surplus material from site	1.0 £/m^3

TABLE 4

Estimated costs of pipe laying operations
(January 1975)

Operation	Cost	
Break out road surface (< 200mm thick concrete)	0.79	£/m^2
Excavate trench by hand	3.13	£/m^3
Excavate trench by machine **	0.22*	£/min
Place and subsequently remove open trench sheeting	0.44*	£/m run
Place and subsequently remove closed trench sheeting	2.52*	£/m run
Place Class B granular bedding	0.69	£/m run
Place pipes by hand (< 300mm dia)	0.48	£/m run
Place pipes by machine	1.38*	£/m run
Replace soil, using excavator	0.44*	£/m^3
" " " dumper	0.53	£/m^3
Compact soil, using power rammer	0.54	£/m^3
Place and compact concrete or tarmac	0.56	£/m^3
Remove surplus soil from site	1	£/m^3
Supply granular material	3	£/m^3
" concrete	11	£/m^3
" tarmacadam	7	£/m^3
" rigid pipe (d metres internal dia)≁	$(1+4d^2)$	£/m run
" trench sheet and struts	0.01	£/m length

* Multiply by 1.3 if tracked excavator ($0.6m^3$ bucket) used, to allow for greater cost of machine.

** Rates of excavation as in Table 1.

≁ Typical costs, assuming clay pipes used for small diameters and 'M' concrete for larger diameters. Actual cost could be substituted if known.

TABLE 5

Data required for calculation of cost of laying a sewer pipe

Question	Answer	Condition assumed (unless other information available)
Surfaced?	Yes/No	Temporary re-instatement of 300 mm concrete, 75 mm surfacing. Permanent reinstatement consists of replacing 75 mm surfacing, if this is carried out by contractor.
Road?	Yes/No	Road; backfill placed by dumper & compacted. Field; backfill placed by excavator, not compacted.
Tracked excavator?	Yes/No	Tracked excavator for all off-road sites, and trenches deeper than 3 m to invert.
Pipes laid by hand?	Yes/No	Pipes less than 300 mm internal diameter and less than 1.5 m to invert laid by hand.
Trench sheeting?	No	Trenches less than 1.5 m to invert.
	Open	Trenches 1.5 - 3.0 m to invert
	Close	Trenches more than 3 m to invert.
	Battered sides	Trenches in field only.
Rate of excavation?	0.04	Close sheeting (unstable ground)
(m^3/min)	0.1	" " (weak ground)
	0.2	Road
	0.4	Field
	1.0	Trench with battered sides
Pipe diameter?	(m)	
Depth to invert?	(m)	
Width of trench?	(m)	As in Simplified Tables[7]; minimum width 0.75 m.

TABLE 6

Example of calculated costs for laying a sewer pipe

Data (See Table 5)

Surfaced?	Yes
Road?	Yes
Tracked excavator?	Yes
Pipes laid by hand?	No
Trench sheeting?	Close sheeting
Rate of excavation?	0.1 m^3/min
Pipe diameter?	150 mm
Depth to invert?	3.5 m
Width of trench?	0.75m

Calculated costs (£/m run)

	Work	Materials	Total
Breaking surface	0.59	0	0.59
Excavation	7.77	0	7.77
Sheeting	3.27	0.23	3.51
Bedding pipe	0.69	0.39	1.08
Laying pipe	1.79	1.90	3.69
Backfilling trench	2.43	0	2.43
Surfacing	1.90	3.26	5.17
Remove surplus soil	0.44	0	0.44
TOTAL	18.90	5.79	24.70

TABLE 7

Comparison of tender prices and calculated costs

Internal diameter (mm)	Mean value of; $\frac{\text{Tender price}}{\text{Calculated cost}}$	Standard deviation
150	1.06	0.18
300	1.11	0.16
600	1.08	0.11

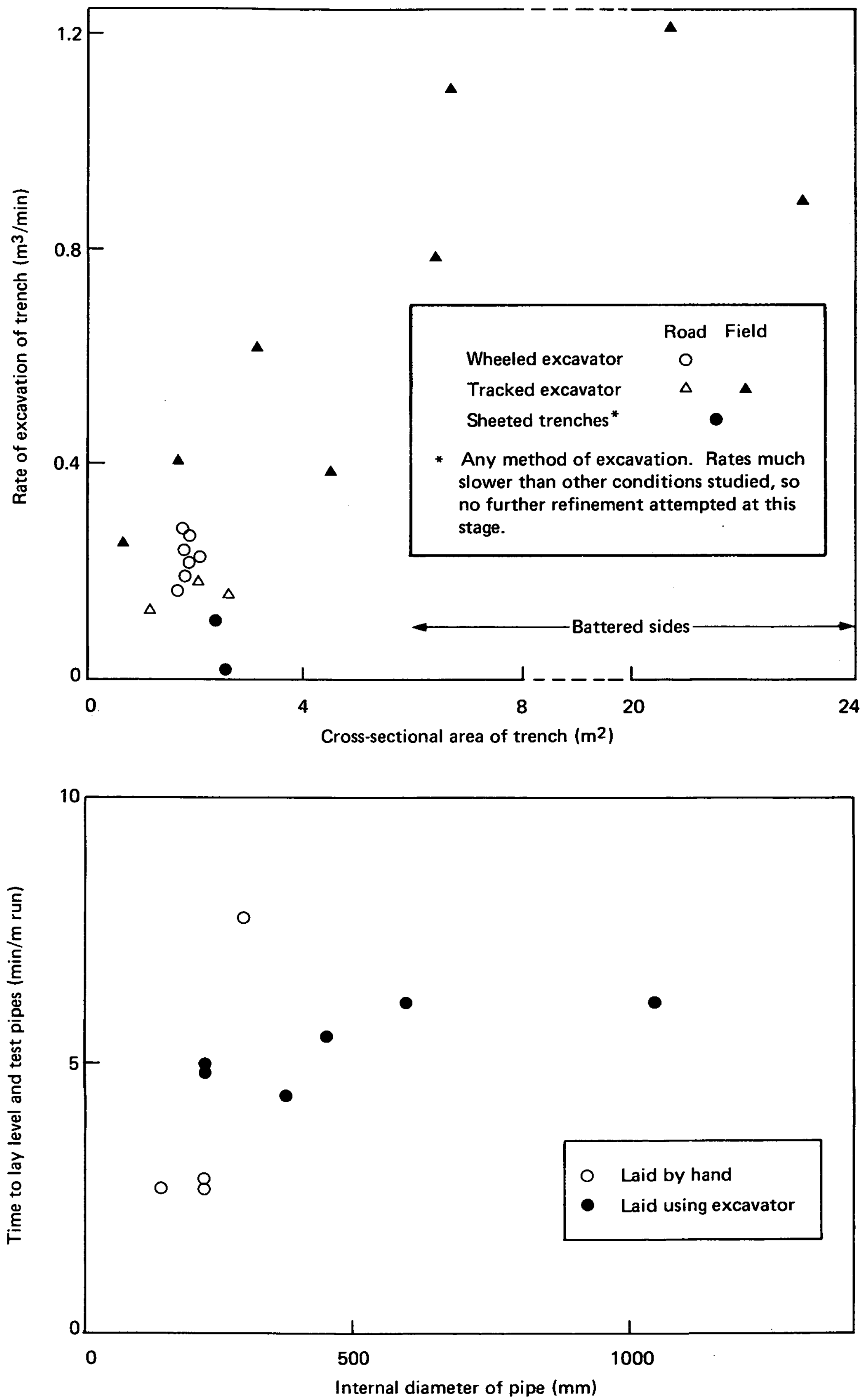

Fig. 1 MEASURED TIMES FOR EXCAVATION OF TRENCHES AND LAYING OF PIPES

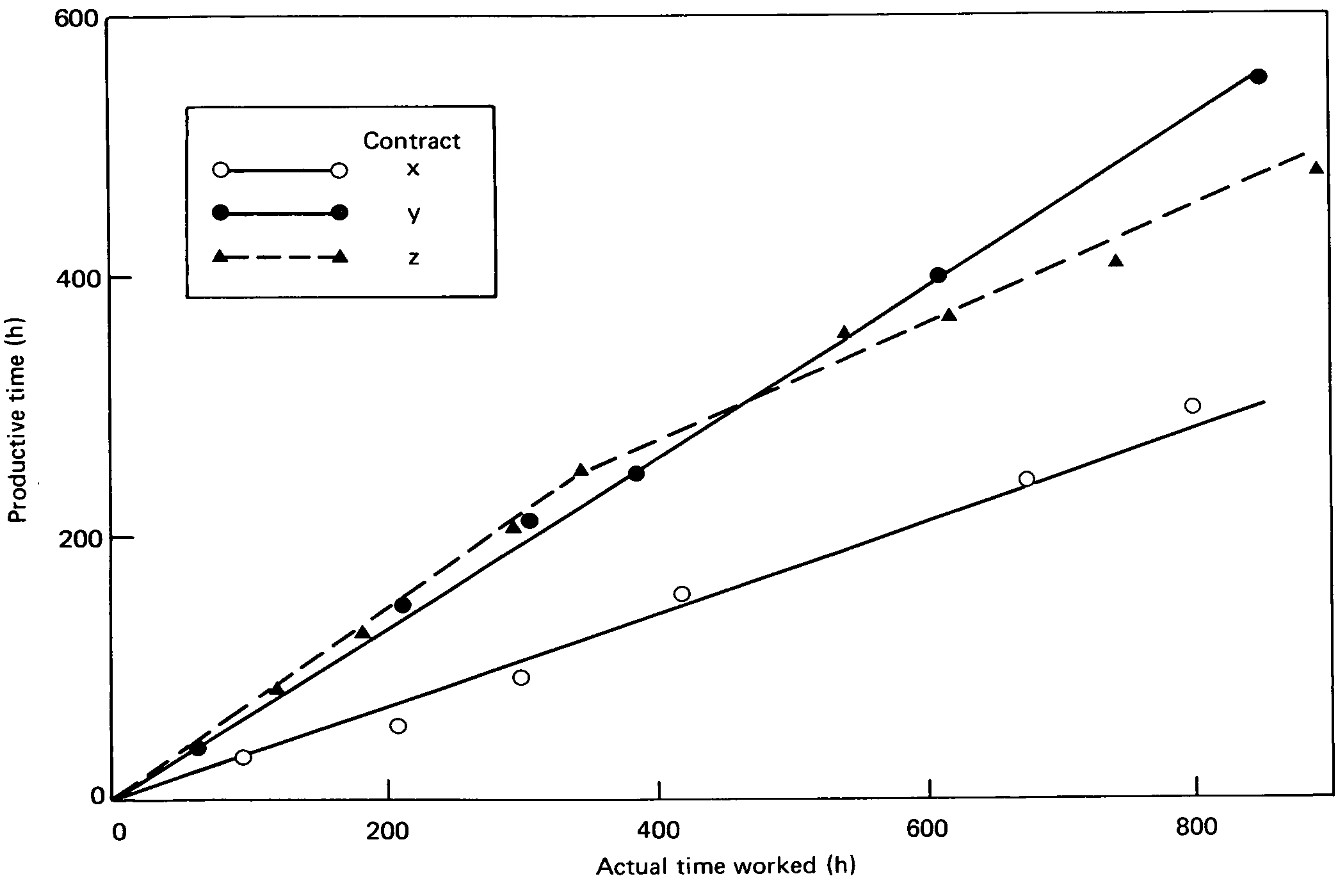

Fig. 2 COMPARISON OF 'PRODUCTIVE TIME' AND 'ACTUAL TIME' FOR THREE SEWERAGE CONTRACTS

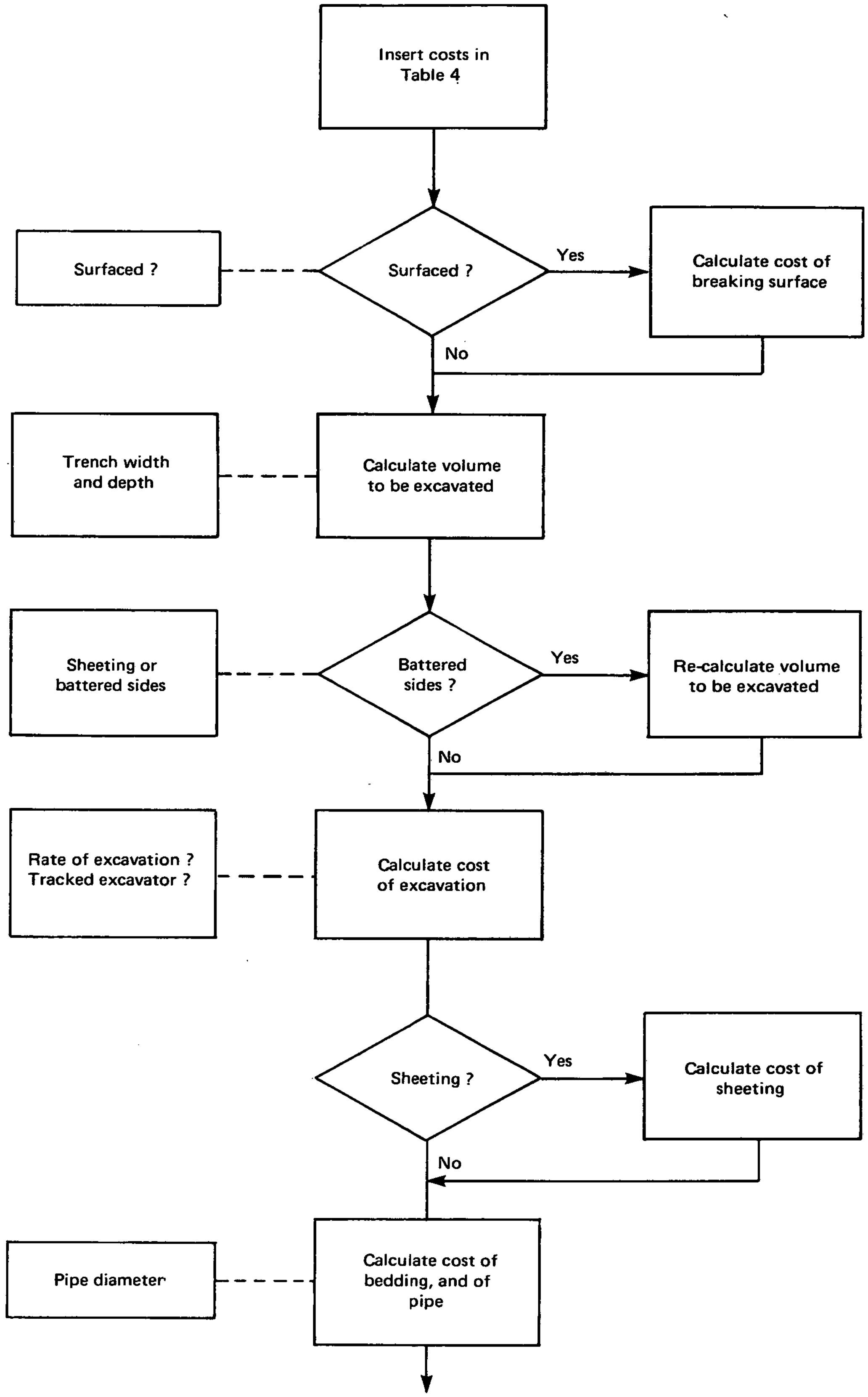

Fig. 3 FLOW CHART FOR CALCULATION OF COSTS OF SEWER PIPELINES

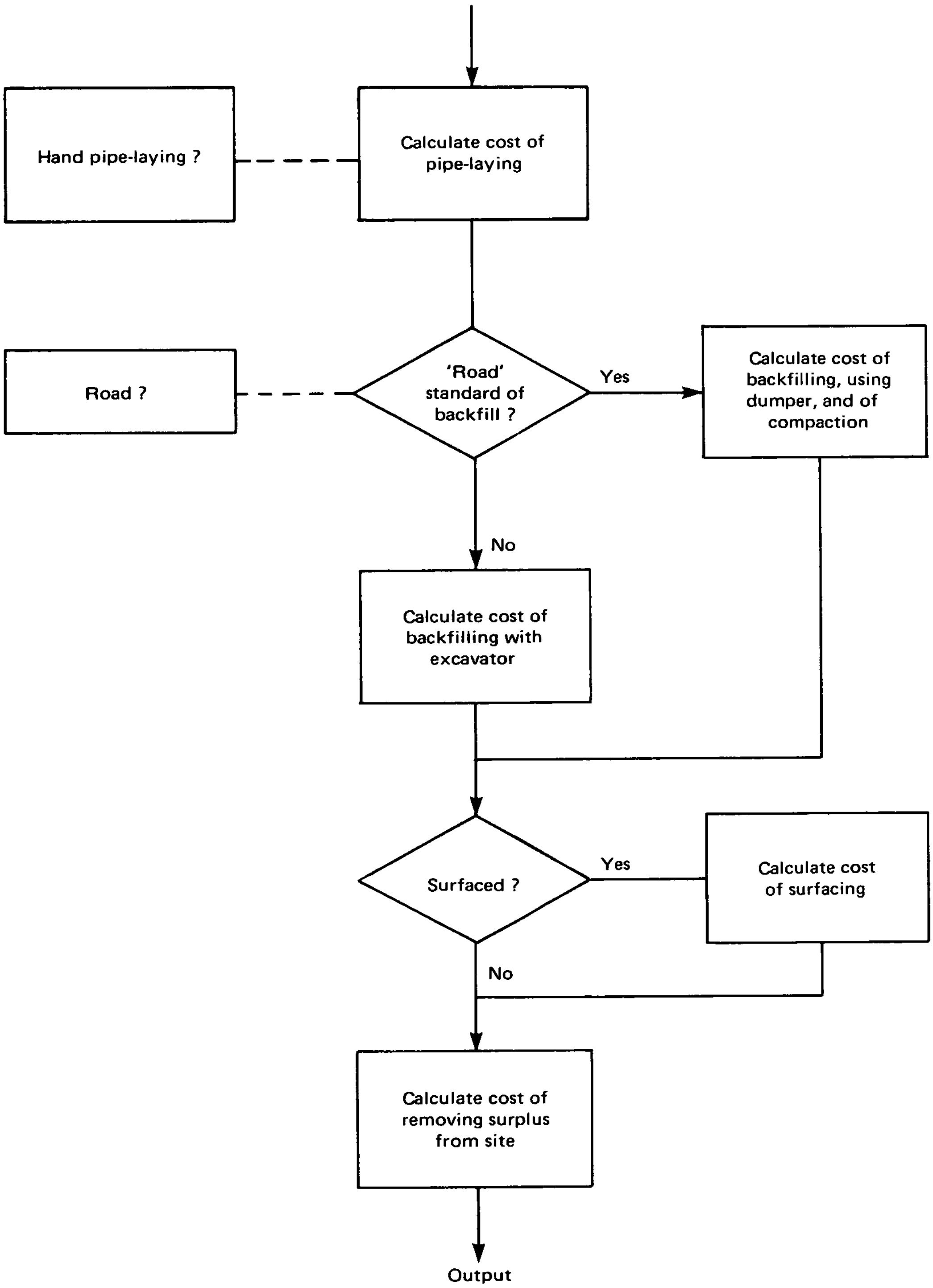

Fig.3 (Cont.) FLOW CHART FOR CALCULATION OF COSTS OF SEWER PIPELINES

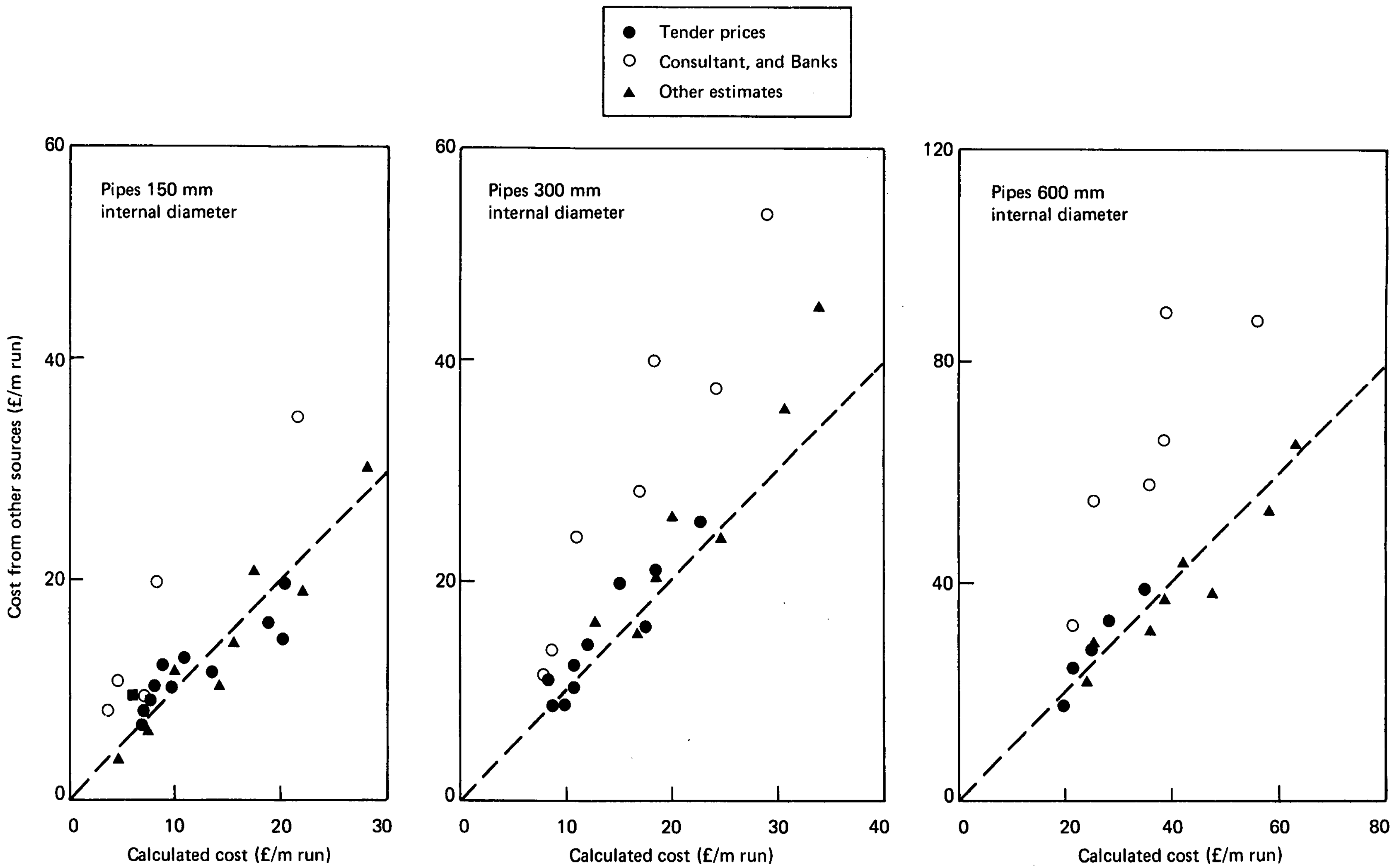

Fig. 4 COMPARISON OF CALCULATED COSTS OF RIGID SEWERS WITH COSTS FROM OTHER SOURCES

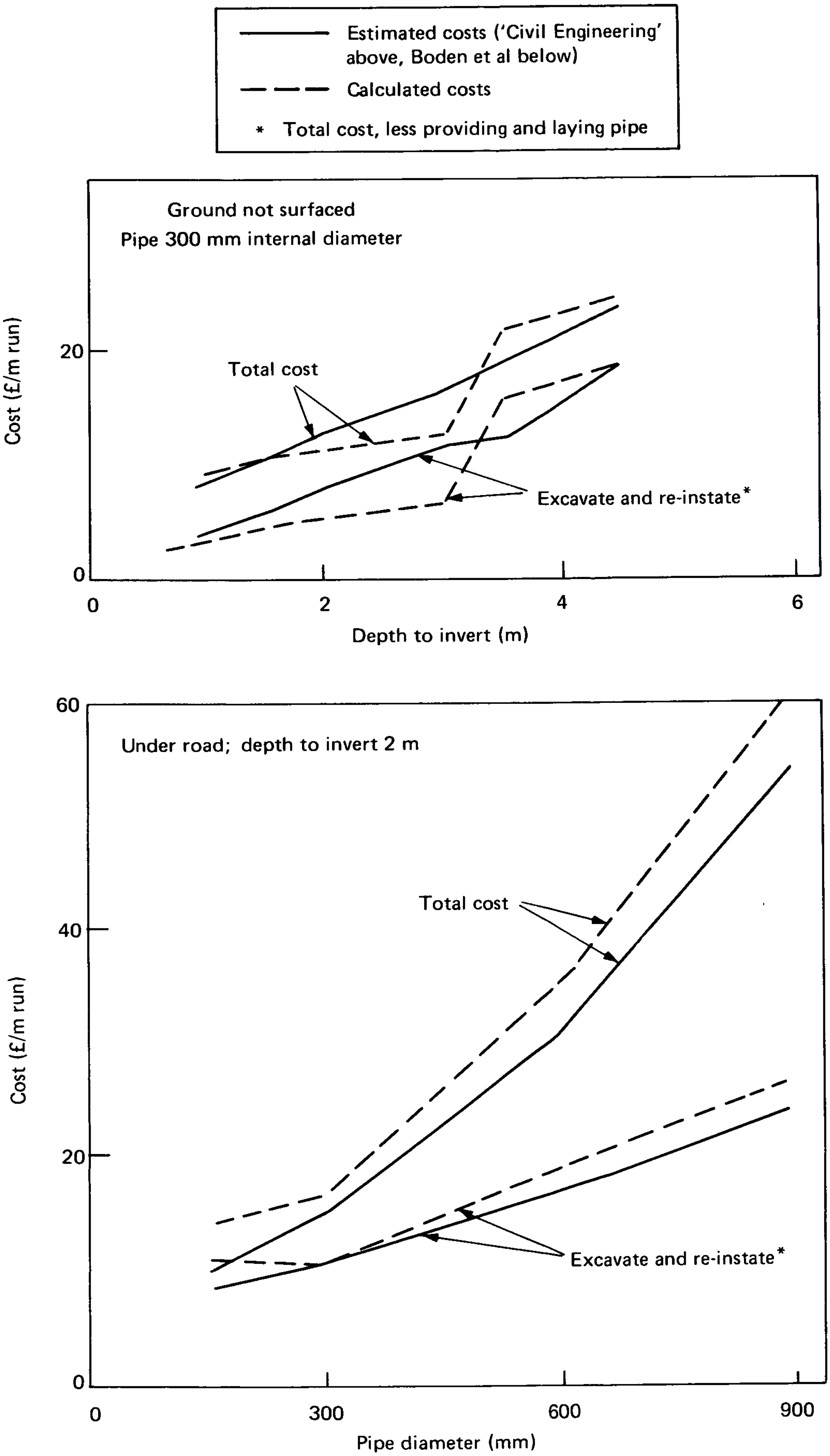

Fig. 5 EFFECT OF DEPTH AND DIAMETER ON COST OF SEWER PIPELINES

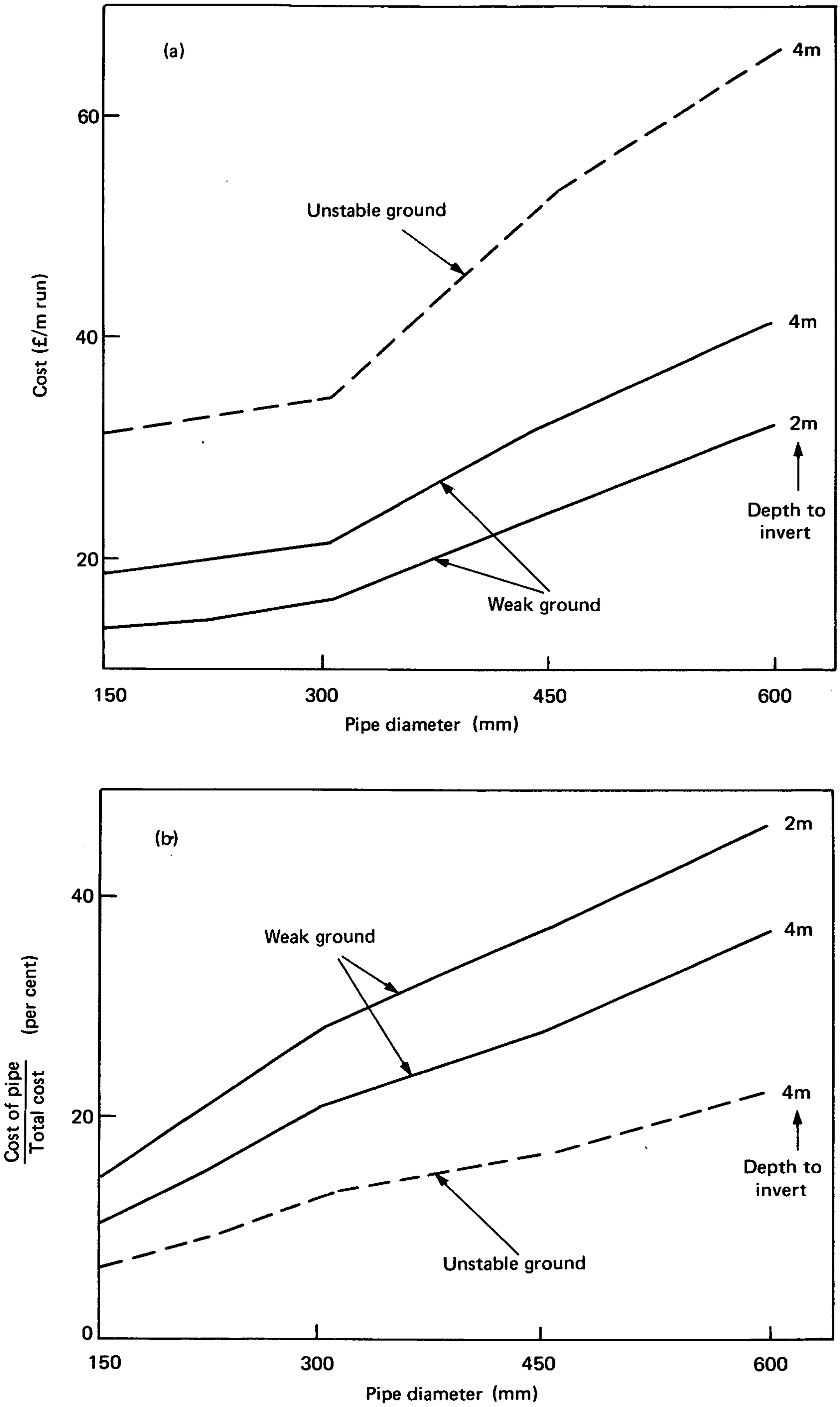

Fig. 6 CALCULATED COSTS OF SEWER PIPELINES, FOR TWO DEPTHS AND TWO TYPES OF GROUND

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ABSTRACT

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ABSTRACT

A PROCEDURE FOR CALCULATING THE COST OF LAYING RIGID SEWER PIPES: *D M Farrar:* Department of the Environment Department of Transport TRRL Supplementary Report 333: Crowthorne, 1977 (Transport and Road Research Laboratory). The Transport and Road Research Laboratory is engaged on research into the design and construction of underground pipelines. In order to assess the economic consequences of any changes in present practice which may be recommended, it is essential to have a detailed knowledge of the materials and operations involved and their costs.

This Report describes a procedure for calculating these costs, for rigid sewer pipes not exceeding 600 mm internal diameter, which is based upon site observations of the operations involved and published cost data. Costs obtained by this procedure are in reasonable agreement with costs in a limited number of tenders, and with other estimates. Its scope is at present limited by lack of data on some construction operations and by its simplified approach to site management problems.

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