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COST-ESTIMATION MANUAL FOR SEA DEFENCES

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Cost-estimation manual for sea defences

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EXECUTIVE SUMMARY

This manual is intended for use by NRA planners when developing strategic plans. It provides a quick, consistent assessment of sea defence costs and a ready source of national data. It also gives a consistent basis for the preparation of construction cost estimates and appraising work.

Data were acquired from successful tenders for sea defence contracts covering all the NRA Regions executing such Works. Cost functions were produced for the following catgeories of defence:

Earth embankments; Revetments; Rock armour; Seabees; Rock breakwaters and groynes; Concrete walls (including extensions to their height); Steel sheet piling. Cost information relating to timber groynes and beach recharge are also presented, however further data will be required before suitable cost formulae can be produced.

All the cost data have been adjusted to a common date basis, namely Quarter 3 for the year 1989. By relating costs to the scale of work undertaken in each category, cost-estimating formulae have been derived for national application.

The basic data were rather sparse in several instances and this is reflected in the confidence limits presented for some cost functions.

The recommendations include making progressive improvements to the preliminary cost-estimating models, by gathering further cost data systematically. The model-building techniques described here could also be used to produce cost functions for fluvial defences, as well as for other coastal and estuarine structures not addressed in the present report.

KEY WORDS

Sea defences, Cost-estimation, Embankment, Rock armour, Revetment, Piling, Concrete wall

1. INTRODUCTION

The aim of the study was originally set out in the Overall Project Objectives as "to provide unit cost values for the Works associated with adapting and extending sea defences to accommodate the effects of progressive rise in sea level". This aim was to include Works for strengthening existing defences to meet an increased incidence of wave attack, and allowed for a possible raising of existing defences. It became clear that these objectives were rather finely drawn, so by agreement with the NRA it was decided to produce this first edition of a Cost Estimating Manual for Sea Defences, which could be refined as necessary later. The Manual is intended to assist NRA planners and engineers to obtain preliminary cost estimates for various types of sea defence at the initial stages of project assessment.

Under the provisions of the 1989 Water Act and the 1976 Land Drainage Act, the NRA exercises a general supervision over all matters relating to flood defence and the authority has a substantial programme of work to protect coastal lowland areas in England and Wales against flooding from the sea. Under the 1949 Coast Protection Act, local authorities carry out coast protection works aimed at reducing or containing coastal erosion. In appropriate cases, grant-aid may be available from the Ministry of Agriculture, Fisheries and Food. There are some borderline cases where schemes may be classified partly as sea defences and partly as coastal protection works.

Prior to this study there were no nationally-held construction cost data specifically for sea defences. Section 2 of this Manual describes the data acquisition phase, which depended on NRA staff retrieving Specifications and Bills of Quantities of accepted sea defence tenders from their records and those of their predecessors. A few examples have also been drawn from coast protection schemes where their construction methods were comparable.

Section 2 also shows how Cost Functions can be developed, enabling the construction costs of a variety of sea defence structures to be estimated. All the cost data were adjusted for inflation to a common time basis, chosen as the third quarter of 1989. A statistical analysis is given for each model to enable users to assess the various degrees of confidence in the Cost Functions.

Correct use of the models is explained next, in Section 3. Using the cost functions, accounting for inflation, adding on indirect costs to the estimates and using confidence limits are all described here, making this a very important section. A worked example is presented for the case of constructing an earth embankment with a reveted seaward face.

Section 4 presents descriptions and Cost Functions for several types of sea defence works. These include earth embankments, revetments, rock armour, concrete Seabees, rock groynes, piling and concrete cantilever walls.

Appendices A-H at the end of the report cover statistical methods, cost indices, data sources and data tables.

There is a wide range of factors (such as design, site access, availability of materials and tidal range) which affect the costs of defences. Given the data available to the present study it was not possible to assess the importance of every parameter which was originally thought to have significance. The Cost Functions which have been generated so far rely on simple descriptors. Where data exist on other potentially-important parameters, these are also presented, even though at present they are not included in the Cost Functions. This will help to define the limitations on their use.

2. DATA COLLECTION AND MODEL BUILDING

2.1 Sources of data

The bulk of the data used was obtained through contacts at eight of the NRA regions.

The data were extracted from the accepted tender documents of contracts which had been let, after competitive tender, either by the NRA or by their predecessor Water Authorities. Tender documents were used since there are generally the required breakdowns in prices between various bill items in the Bills of Quantities (BoQs). This aided the allocation of costs to particular structures in contracts where more than one item was being built. Furthermore there was a single date (that of accepting the tender) from which prices could be adjusted to for each contract. In addition to BoQs, contract drawings and any other available documents were studied to obtain descriptions of the Works. The use of tender documents also meant that contracts for Works that were under construction at the time of data collection could be used.

During the initial stages of data collection it became apparent that there would be insufficient data to build useful models for certain structures if the NRA were the only source of data. Further data from other sources could also be used to improve existing cost functions. Some structures, although built for coast protection, have similar characteristics to those built as sea defences. For example groynes, revetments and beach nourishment may be used for both of the above purposes. Therefore certain local authorities and consultants who had recently been involved in sea defence and/or coast protection Works were approached as sources of data to increase the samples in certain model categories.

The local authorities were selected so as to increase the data from NRA regions from which little data had previously been collected and thus increase the geographical balance of the report. It was however noted that many of the sea walls built for coast protection generally had considerable design differences from those built as sea defences and such cases were excluded.

A large proportion of the data supplied came from the Anglian Region of the NRA as a result of the large amount of work carried out in the past ten years on their particularly vulnerable coastline. A significant number of contract documents were also supplied by Wessex and Southern Regions. The number of sets of contract documents is shown in Appendix H which also gives the regional distribution of the data points used to build the cost functions.

The amount of work carried out by in-house resources also varied throughout the country. Where schemes were not carried out under a competitive form of civil engineering contract their data were not used in this study.

2.2 Classifications

Models were developed for the following types of sea defences:

Earth embankments
Rock armour
Concrete 'Seabee' units
Steel-sheet piling for toe protection
Piling costs for steel-sheet piled walls
Rock breakwaters
Capping existing concrete walls
Concrete cantilever walls
Revetments

In addition data relating to timber groynes and beach recharge are presented.

2.3 Data analysis

The data were analysed using similar techniques to those developed for the production of the cost models in TR 61 (Water Research Centre 1977) (see Appendices A, B and F).

Typically, the contracts examined had been produced under the Civil Engineering Standard Method of Measurement (CESMM) format. The general structure of the BoQs was therefore similar, making analysis of costs consistent. Appendix D lists the data that were acquired in readiness for the cost modelling.

It was necessary to relate the dimensions of particular sea defence structures to their costs. In cases where only one item was being constructed this was a simple process, but where the BoQs referred to a number of items of interest it was necessary to separate the costs for each individual structural item. In certain cases it was not possible to extract all the relevant cost information on items such as piles or revetment blocks which had been supplied by the employer free of charge. The data therefore could not be used in such cases unless the purchase price of the supplied items was known.

Certain costs are non-specific to any single Bill item. These relate to contractual requirements, specified requirements and method-related charges. Unless otherwise stated in the relevant model description, such costs were separated from those costs directly attributable to a structure. Similarly the costs of dayworks and general provisional contingency sums were separated from direct costs. The cost functions produced therefore do not allow for these indirect costs.

However, the proportion of the cost of each structure which resulted from indirect costs was calculated. The mean value of percentage indirect cost is given for each of the data sets used to produce models. In addition frequency diagrams are presented for each model which illustrate the breakdowns in the percentage indirect costs. They are calculated as percentages of the costs of work directly attributable to the structures:

$$IDC = \frac{\text{indirect cost}}{\text{direct cost}} \times 100$$

the mean value of IDC (or another value calculated using the engineer's experience) may be used as described in Section 3 to compensate for indirect costs.

There were certain exceptions to the above method of dealing with indirect charges. The method-related charges section of the bills normally deals with items which are general to the works. These includes the setting-up, maintaining and removing of accommodation and buildings, temporary works and supervision. As described above these costs were removed during the model building phase of the analysis. However in some instances the method-related charges were solely or mainly due to specific bill items and were thus added to the construction cost of these items; an example of this is the rock breakwater model. This is stated in the model description where applicable. In such instances the indirect cost multiplier would be expected to be small.

The same is true for the provisional sums section of the BoQs. Again where a provisional sum was given which related to a particular bill item the cost of that provisional sum was added to the relevant bill item. The cost of the remainder of the provisional sum items was treated as a 'conditions of contract' cost and contributed to the frequency diagrams of percentage indirect costs.

It should also be noted that costs of planning, design, land purchase, management and supervision by the client have not been included in this analysis. Other techniques must be used to account for these costs.

2.4 Adjusting for inflation

The contracts examined for this study were let over an eleven year period from 1979 to 1990. Variations in costs due to inflation over this time have been accounted for using an inflation index. Initially there was a period of high inflation then prices were comparatively stable up to the latter part of the 1980s with costs again rising relatively fast over the last two or three years. For a variety of reasons the bulk of the data used comes from the latter part of the 1980s. Information was more easily obtained from contracts let after the restructuring of the water industry (i.e. NRA-let contracts) and it appears that relatively more contracts were let since the change in the allocation for funding sea defences since the formation of the NRA. Recently more work has gone out to tender than would have been the case six or seven years ago, hence increasing the data available for the present study.

Construction costs were adjusted to a common base date prior to developing cost functions. During the data collection phase discussions were held with several of the regional contacts to establish what indices were currently used to account for inflation. It was found that various indices were used with the Public Works Non Roads (PWNR) index being the most common since this was recommended by MAFF.

The choice of index was based upon the following considerations:

- The model developed using the preferred index should not have a substantially larger prediction error than those built using other indices.

- The prediction errors should not show a systematic pattern when plotted through time.

- The index should be appropriate to the subject.

During the development of cost functions several indices thought to be appropriate to the present study were tested (see Appendix C). Partly since the data samples were small it was frequently found that many of the indices examined produced models of similar significance. It would therefore be difficult to justify using different indices for different models. For consistency the Public Works index is used throughout this manual. This index closely corresponds with the PWNR index and has the merit of fewer 'provisional' entries (see Appendix C). Other indices such as the Public Sector Building Tender Price or the All New Construction Price Output Index could have been used instead to produce models of comparable statistical merit.

All tender costs were deflated from their tender dates using the third quarter of 1989 as a base.

2.5 Model building

The construction costs of the various data types listed in Appendix D had to be related to one or more design parameters. Lists of factors which were thought to be important were drawn up for each data area. For each model the costs of the structures were adjusted for inflation as described in the previous section. A statistical relationship was then sought between cost and the explanatory factors using multiple linear regression on the logged data. Such regressions were used since they produce confidence limits of an acceptable form (see Appendix A (iii) and (xi)), i.e. the variance about the regression line increases with project size. In many instances they also generate models which indicate economies of scale.

From the logged data, multiplicative power models were produced of the form

$$\text{adjusted cost} = a(\text{factor } 1)^{b}(\text{factor } 2)^{c}\ldots$$

The derived models thus appear as curvilinear regressions. Their confidence limits are also plotted; in this report these are shown at the 80% confidence level.

The validity of each model was established by a number of statistical tests (described in Appendix B(d)). Some of the data samples were only just large enough for such tests.

With the data currently available it was in most instances found that the cost of a structure could be related to only one factor (or descriptor) with a high degree of statistical significance.

A model should not be used to estimate the cost of a defence which has dimensions outside the range of the data used to construct the model. For example if a model was generated using data from structures which had been raised on average by 0.5 m and a maximum of 1.5 m then it would be inappropriate to use this model to cost a length of defence being raised by 1.75 m.

3. USE OF COST FUNCTIONS

The models presented in this report may be used to give estimates for the direct costs of sea defences at Quarter 3, 1989 prices. The cost functions may be employed after an initial appraisal of a proposed sea defence structure has been made and approximate sizes of the defence are known.

3.1 Earth embankment example

Cost functions

For example the cost function for a 200m long earth embankment requiring 2550 m^3 of imported clay fill is

Direct cost (£'000 Q3'89) = $26.6 * VOL^{0.605}$

VOL is the volume of fill material in '000 m^3.

Therefore an estimate of the direct cost of the above embankment is given by

Direct cost (£'000 Q3'89) = $26.6 \times 2.55^{0.605}$
= 46.9

Since the models are statistically based they offer objectively determined values which the planner can adjust using his experience to assess the individual peculiarities of a proposed scheme. There are many factors (such as state of the market, peculiarities of site, regional effects and types of structure), which can cause deviations from the values recommended by the cost functions. If the model description, data tables and other information presented on a defence in this report are significantly at variance with a defence under planning or there are unusual site specific conditions then it will be **necessary** to adjust the cost given by the cost function using engineering experience.

Accounting for indirect costs

The percentage indirect costs (IDC) for each item of data used are indicated in the data tables (Appendix D). Average values of percentage indirect costs are presented in the text for each model and may be used to account for expenses such as insurance of the works, setting up charges, dayworks and general provisional contingency sums. However, it may be more appropriate for the planner to use his own judgement and knowledge of a given site to estimate a different value for IDC than that given in the text.

Total cost = Direct cost * (1 + IDC/100)

For our earth embankment example at 1989 Q3 this is

Total cost (£'000 Q3'89) = 46.9 * (1 + 0.315)
= 61.7

Adjusting for inflation

The direct cost in say, 1990, Quarter 2 prices can be obtained using the PWNR index (or estimate) for 1990 Q2 (see Appendix C).

$$\text{COST (Q2'90)} = \text{COST (Q3'89)} * \frac{\text{PWNR index at 1990 Q2}}{\text{PWNR index at 1989 Q3}}$$

For our earth embankment example we obtain

$$\text{Total cost (£'000 Q2'90)} = 61.7 \times \frac{155.1}{150.7} = 63.5$$

Confidence limits

A measure of the uncertainty in a value predicted by a model is given by the confidence interval multipliers; these are discussed in Appendix A (ii) and (xi). The total cost estimated for the above scheme is £63 500 and the 80%

confidence limit multipliers for the model are given as 0.57 and 1.75. This means that there is an 80% chance that the actual total cost of such an embankment will lie between £36 200 (0.57 x £63 500) and £111 100 (1.75 x £63 500), (or that four out of five such schemes will lie within the above limits). This is a very large range. However, if there is no suitable local source so material has to be imported then it is likely that the actual cost will lie towards the top of the stated range. Conversely if it is known that all of the material can be taken from a local source or supplied by the NRA to the contractor then there is a high probability that the cost of the scheme will lie closer to the lower limit.

3.2 Combining estimates from two models

Suppose that it was proposed to armour 1000 m^2 of the above embankment with articulated precast concrete blocks placed on a layer of geotextile material. The relevant cost function for revetments given in Section 4.2 is

Direct cost (£'000 Q3'89) = $0.15 * AREA^{0.817}$

Which in our case gives

Direct cost (£'000 Q3'89) = 42.4

Using the average value of IDC given as 43.3% we obtain

Total cost (£'000 Q3'89) = 60.8

Adjusting for inflation

Total cost (£'000 Q2'90) = 62.6

The upper and lower 80% confidence limits are given by

Upper 80% confidence limit = £62 600 x 1.69 = £105 800

Lower 80% confidence limit = £62 600 x 0.59 = £36 900

An estimate of The total cost (at Q2'90 prices) of a 200 m long earth embankment requiring 2550 m^3 of imported clay fill having 1000 m^2 of its seaward face armoured with articulated precast concrete blocks is simply the sum of the above two estimates:

Total cost of scheme (Q2'90) = £63 500 + £62 600
= £126,100

The 80% confidence limits cannot be combined so easily. This is a consequence of the multiplicative structure which it was necessary to assume for each individual model; indeed under these circumstances no exact statistical solution can be found. There is, however an **approximate procedure** that can be used. This procedure is outlined in Appendix F, from which we need to use equations (F-iii) and (F-iv).

$$M = C_1(14.2)^{\sigma_1^2} + C_2(14.2)^{\sigma_2^2} \qquad \ldots\text{(F-iii)}$$

$$S = \sqrt{\{ C_1^2(200.7)^{\sigma_1^2}\{(200.7)^{\sigma_1^2} -1\} + C_2^2(200.7)^{\sigma_2^2}\{(200.7)^{\sigma_2^2} -1\}\}} \ldots \text{(F-iv)}$$

The definitions of M and S are given in Appendix F.

Using 0.183 as an estimate of $\sigma 1$ (from the information presented on the embankment model) and 0.157 as an estimate of $\sigma 2$ (from the information presented on the revetment model) we obtain (using costs at Q2'90 in £'000)

$$M = 63.5 \times 14.2^{0.183^2} + 62.6 \times 14.2^{0.157^2}$$
$$= 136$$

and

$$S = \sqrt{\{63.5^2 \times (200.7)^{0.183^2} \times \{(200.7)^{0.183^2} - 1\} + 62.6^2 \times (200.7)^{0.157^2} \times \{(200.7)^{0.157^2} - 1\}\}}$$

$$= \sqrt{\{936 + 623\}}$$
$$= 39.5$$

Approximate 80% confidence limits are given by M ± 1.3S

i.e. £85 000 to £187 000

which can be expressed relative to the estimate of total cost to give 80% confidence limit multipliers of 0.67 and 1.48.

Although the above limits are fairly wide, they are narrower than the 80% limits of (0.57, 1.75) and (0.59 and 1.69) for the two component models. This is a customary feature of multiplicative confidence limits when combining estimates.

3.3 Revision of cost function use

The 5 main steps involved in using the models are outlined below.

1. The cost functions are used to produce estimates for the direct costs of constructing defences.

2. The planner may wish to adjust the given estimate using his experience given knowledge of a particular scheme and site conditions.

3. Indirect costs are accounted for using the mean values of IDC given for each model (or other values thought to be more appropriate by the planner).

4. Inflation is accounted for using the relevant PWNR index value.

5. Confidence limits may be used to assess the uncertainty in an estimated value at any of the above steps.

4. DISCUSSION OF MODELS

4.1 Earth embankments

Sub-surface works may be required to improve the bearing capacity of the ground where the bank is to be built, or to control the seepage under the bank at times of high water level. A drainage ditch or french drain may be provided clear of the landward toe of the embankment, and new culverts may be required where watercourses cross the line of the bank. Organic topsoil will normally be removed from the area where the bank is to be built (or raised); the soil being stacked, and ultimately returned to areas which are to be reseeded or turfed on completion of construction.

The fill material may be obtained from local "borrow pits" or may be imported from a more distant source if supplies of suitable material are economically available from, say, a colliery spoil heap. Borrow pits may be on the foreshore or inland of the bank, and temporary haul roads may be required.

The fill material has to be excavated from the borrow pit or stock-pile, transported to the site of the bank, spread, compacted and finally shaped to the required profile. If the source of material is on the foreshore, excavation and haulage operations may be restricted to inter-tidal periods.

Access ramps will normally be provided over the bank at appropriate points, as will steps for pedestrians, and an access road along the length of the bank may be left in place to facilitate future maintenance.

Replacement of topsoil, seeding or turfing is included in the embankment model, but heavier surface protection such as stone revetment or flexible armouring systems are modelled separately. Costs associated with providing access ramps and access roads along the length of the embankment were included in the model, however, costs associated with haul roads were not. Figure 4.1 illustrates a typical cross section of a scheme used in this model.

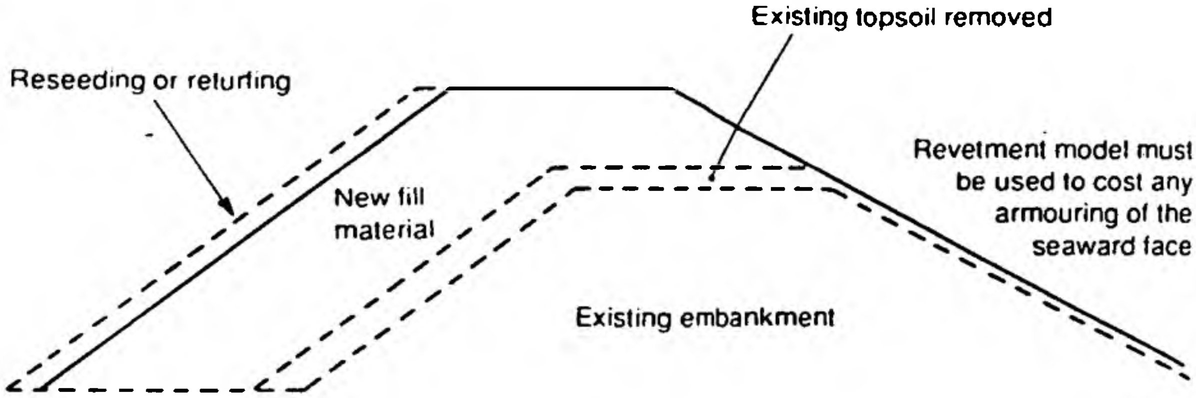


Figure 4.1 **Earth Embankment**

The data relating to earth embankments was mainly obtained from schemes designed to improve the standard of flood defence by modifying an existing embankment, however in a few cases a new length of embankment was constructed. Figure 4.2 illustrates the distribution of costs in the data used.

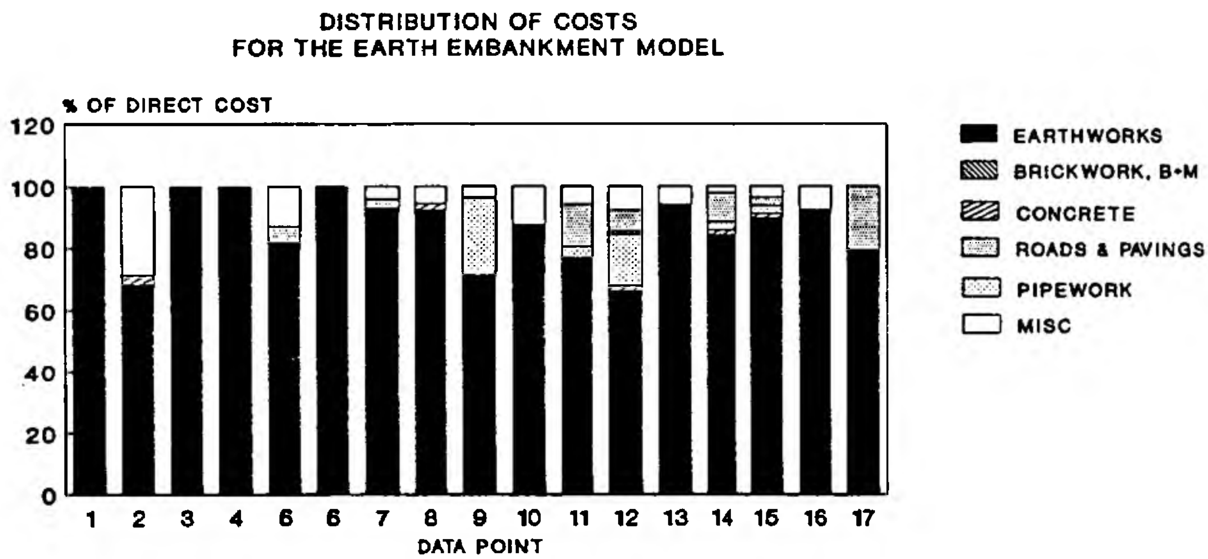


Figure 4.2

The lengths and heights that embankments were raised by were tested as model descriptors. It was found that these were unsuitable due to the varying profiles of earth embankments. Volume of fill material was found to be a suitable descriptor and produced the model illustrated in Figure 4.3. The model shows two outliers below the lower 80% confidence limit. For both of

EARTH EMBANKMENT MODEL

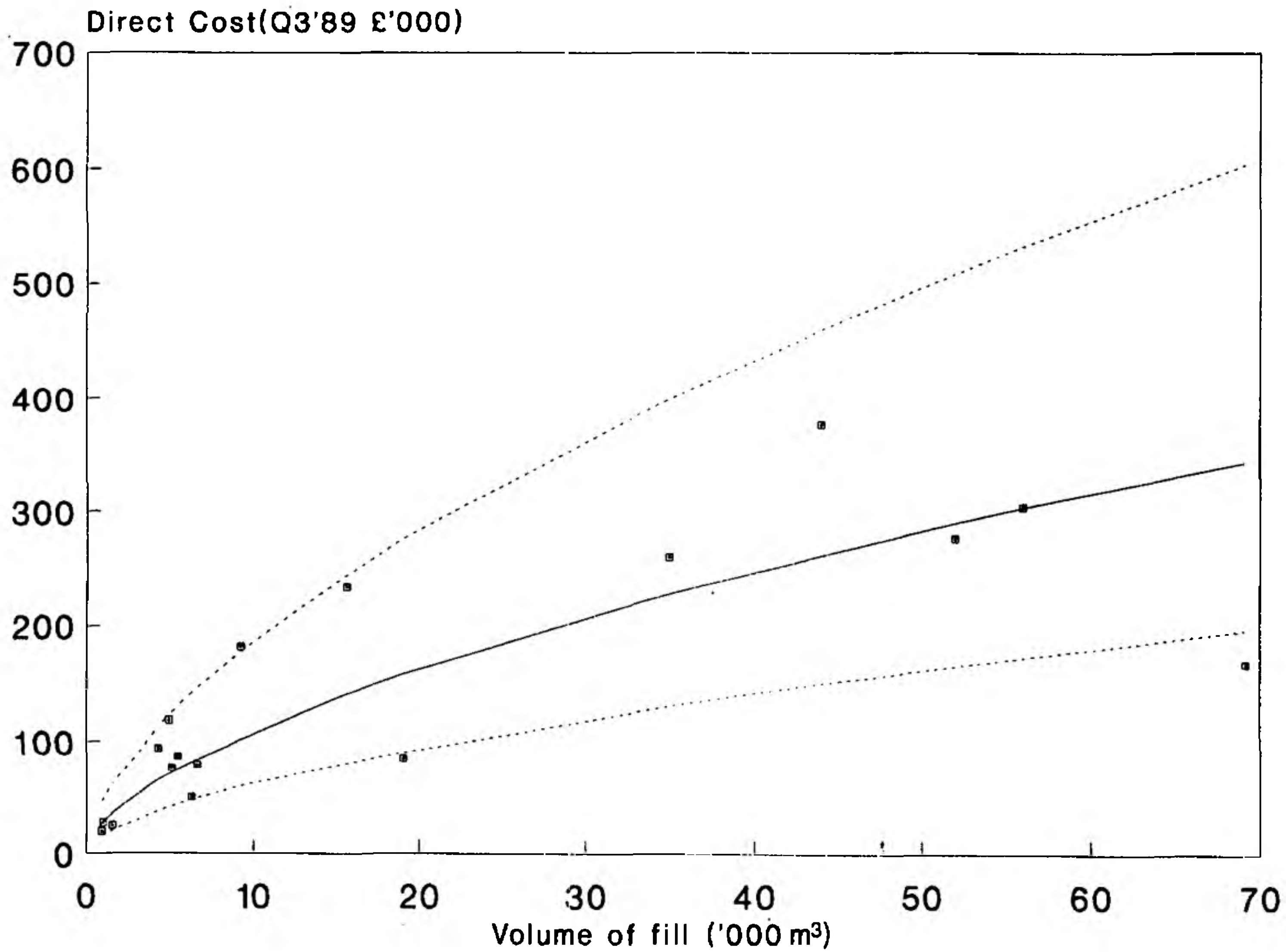


Figure 4.3

these cases fill material was available locally or supplied from a stockpile, little or no material being imported to the site. For the rest of the schemes material was not available locally and had to be imported.

An alternative way of presenting this model is given in Figure 4.4. This illustrates how the cost per m^3 decreases with the size of the Works.

UNIT COSTS DERIVED FROM
THE EARTH EMBANKMENT MODEL

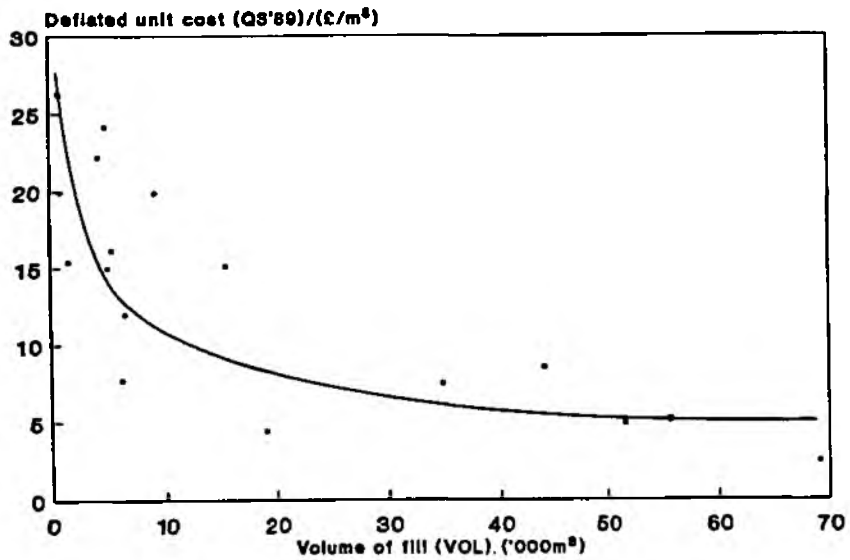


Figure 4.4

Number of Observations	17	
Explanatory variable	VOL	Volume of fill material in '000 m^3
Max VOL	69 120 m^3	
Min VOL	906 m^3	
Mean VOL	19 717 m^3	
T value VOL	8.01	
Significance level VOL	<0.1%	
Standard error of residuals (in $\log_{10}$ model)	0.183	

Approximate multipliers for confidence levels about a prediction:

	Upper	Lower
80% Confidence level	1.75	0.57

Equation, corresponding to the solid curve in Figure 4.3:

Direct cost (£'000 Q3'89) = 26.6 * $VOL^{0.605}$ 4.1

A frequency diagram of percentage indirect costs is given in Figure 4.5, the average value of IDC in the data sample used was 31.5%. Such costs must be added as shown in Section 3.

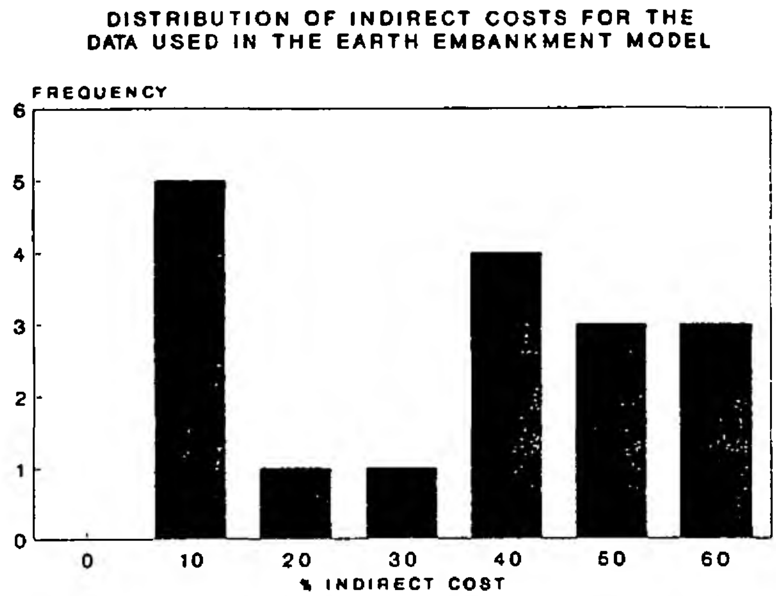


Figure 4.5

4.2 Revetments

Data from four different types of revetment were included in this model. The model estimates the cost of preparatory work on the existing slope, the nature of which will depend on the type and condition of the existing slope protection, followed by the placing of the revetment material or units on a geotextile layer as illustrated in Figure 4.6. The costs of raising or building an earth embankment are not accounted for by this model.

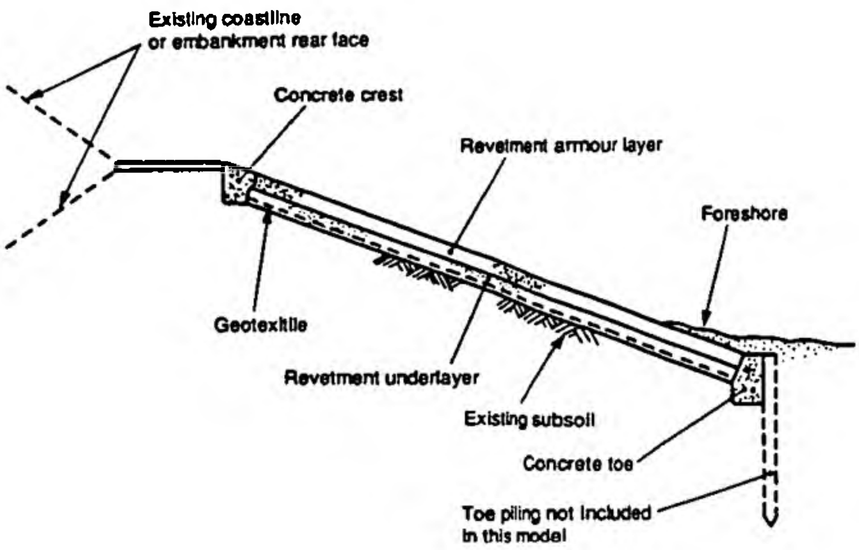


Figure 4.6 Revetment

The breakdown in costs for the data used in the model is illustrated by the stacked-bar chart in Figure 4.7. The three points concerned with the laying of articulated precast concrete blocks (depth approximately 85 mm) are easily distinguished as points 1, 2 and 5. Points 3 and 6 come from bitumen grouted blockstone revetments (about 300 mm deep), points 4 and 7 from rip rap (about 1 m deep) and point 8 from 300 mm deep maccaferri reno mattress cages.

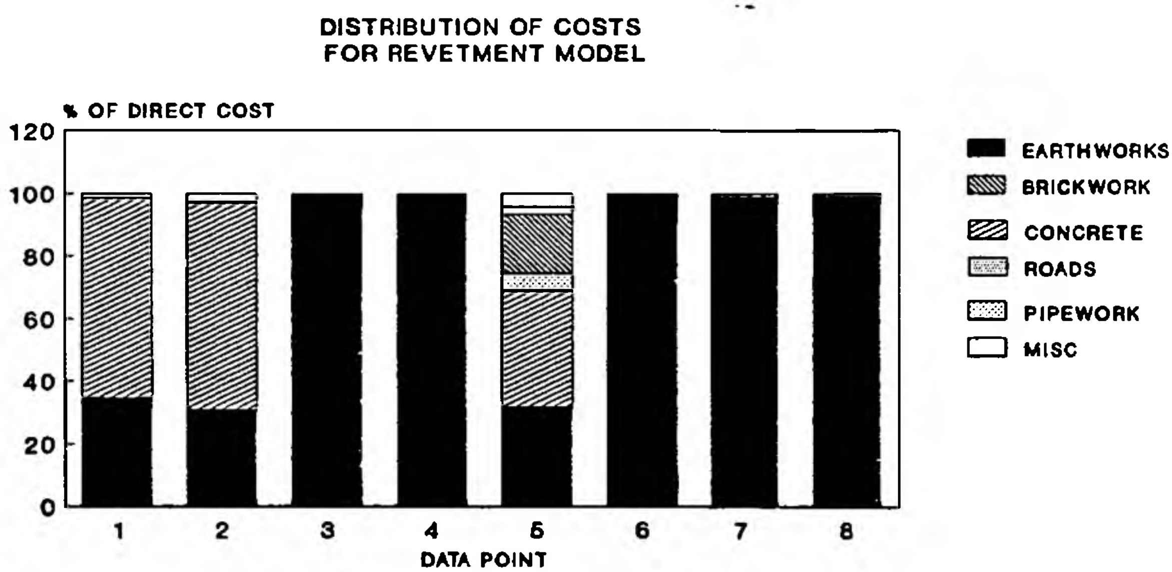


Figure 4.7

The area of revetment was found to be a suitable model descriptor.

REVETMENT MODEL

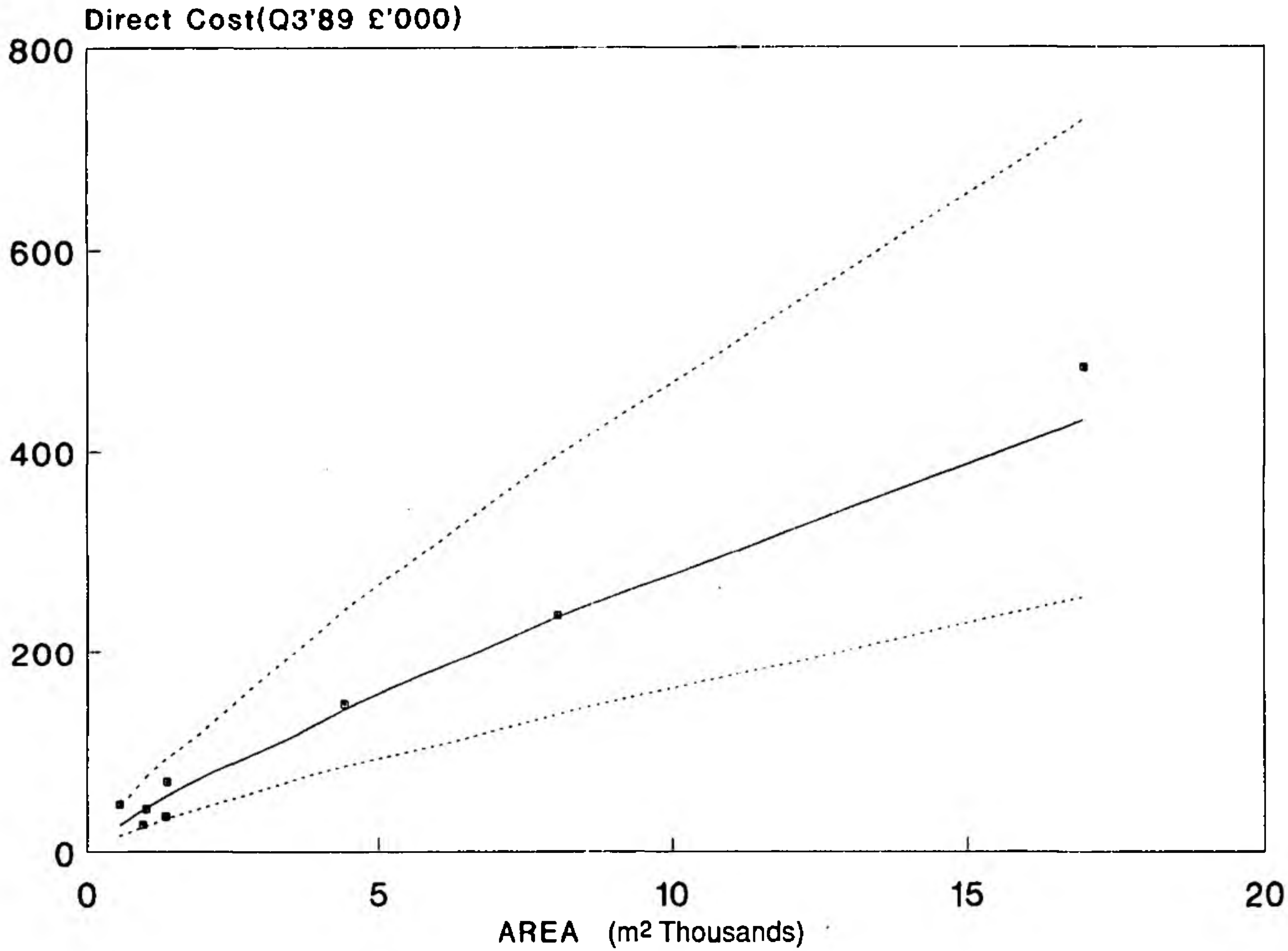


Figure 4.8

As in most categories, costs will be affected by the ease or difficulty of access to the site, tidal interruptions to the work etc..

Number of Observations	8	
Explanatory variable	AREA	Area of revetment in m^2
Max AREA	16 955 m^2	
Min AREA	540 m^2	
Mean AREA	4 323 m^2	
T value AREA	7.18	
Significance level AREA	<0.1%	
Standard error of residuals (in $\log_{10}$ model)	0.157	

Approximate multipliers for confidence levels about a prediction:

	Upper	Lower
80% Confidence level	1.69	0.59

Equation, corresponding to the solid curve in Figure 4.8:

Direct cost (£'000 Q3'89) = 0.15 * $AREA^{0.817}$ 4.2

A frequency diagram of percentage indirect costs is given in Figure 4.9, the average value of IDC in the data sample used was 43.3%. Such costs must be added as shown in Section 3.

DISTRIBUTION OF INDIRECT COSTS FOR THE DATA USED IN THE REVETMENT MODEL

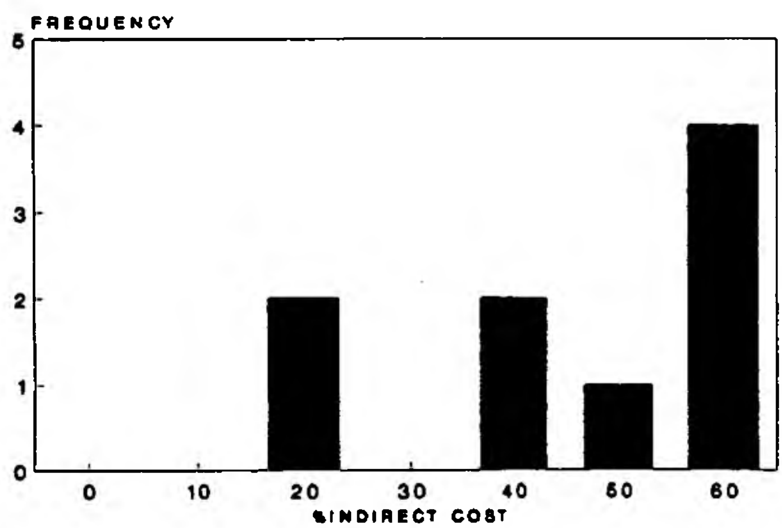


Figure 4.9

4.3 Rock armour

Large size stone may be placed at the seaward toe and on the seaward face of an embankment or sea wall to increase stability, reduce erosion and, particularly, to absorb much of the energy of incident waves. Sources of suitable stone may be many miles from the site and transport costs are significant. Stone may be delivered by land or sea, Scandinavian stone having been used for a number of schemes on the south-east cost of England.

A geotextile membrane, with suitable tensile, permeability and filtering properties, will usually be incorporated, sometimes with a filter layer of small stone below the main rock fill; see Figure 4.10. The quantity of rock supplied may be measured by weight, or by volume measured from cross-sections showing the required profile.

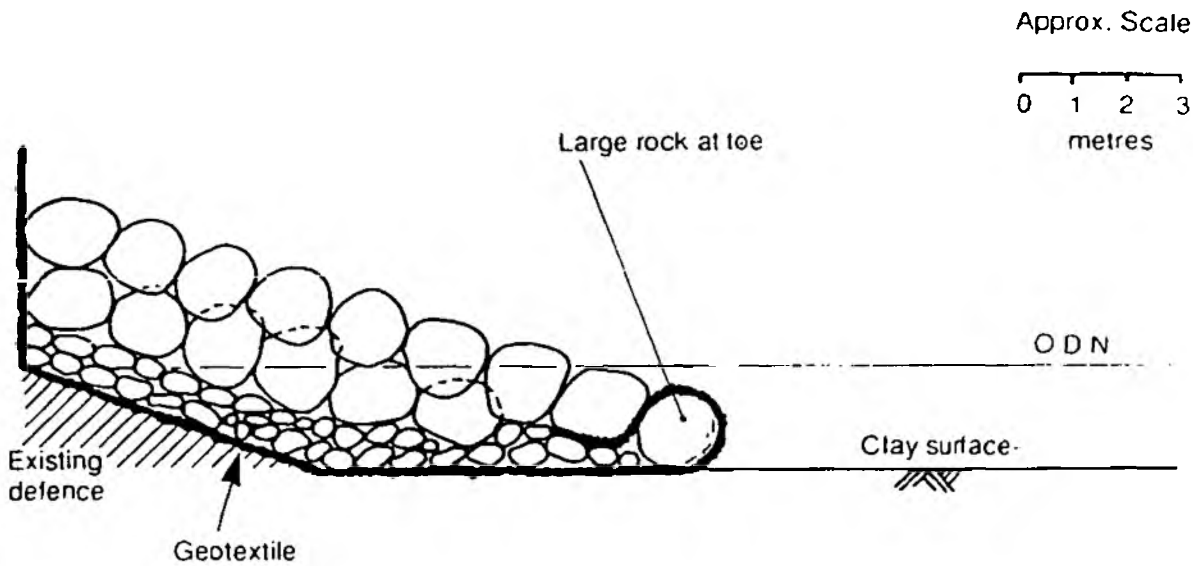


Figure 4.10 Rock Armour

An estimate of the volume of material required is likely to be known at initial planning stages. Total rock volume (i.e. of filter, core and armour layers) is therefore used in preference to mass of rock as the model descriptor. The model is illustrated in Figure 4.11.

ROCK ARMOUR MODEL

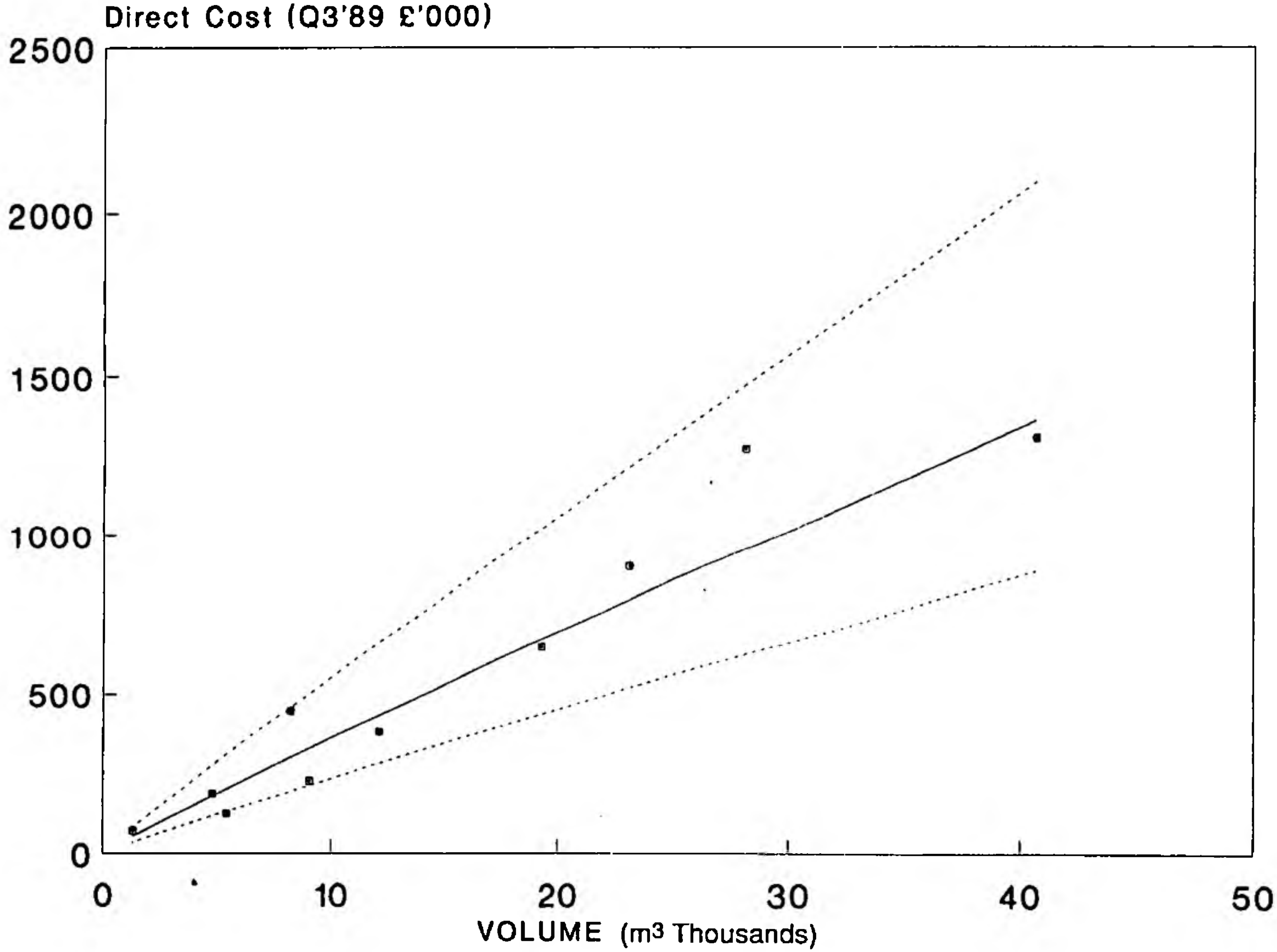


Figure 4.11

This model accounts for the provision and placing of a geotextile, rock filter and rock armour layers. It does not include the cost of any future topping-up of rock fill which may be required.

Number of Observations	10	
Explanatory variable	VOL	Volume of filter, core & armour rock in '000 m^3
Max VOL	40 700 m^3	
Min VOL	1 296 m^3	
Mean VOL	15 202 m^3	
T value VOL	9.57	
Significance level VOL	<0.1%	
Standard error of residuals (in $\log_{10}$ model)	0.132	

Approximate multipliers for confidence levels about a prediction:

	Upper	Lower
80% Confidence level	1.53	0.65

Equation, corresponding to the solid curve in Figure 4.11:

Direct cost (£'000 Q3'89) = 40.4 * VOL$^{0.95}$ 4.3

A frequency diagram of percentage indirect costs is given in Figure 4.12, the average value of IDC in the data sample used was 37.7%. Such costs must be added as shown in Section 3.

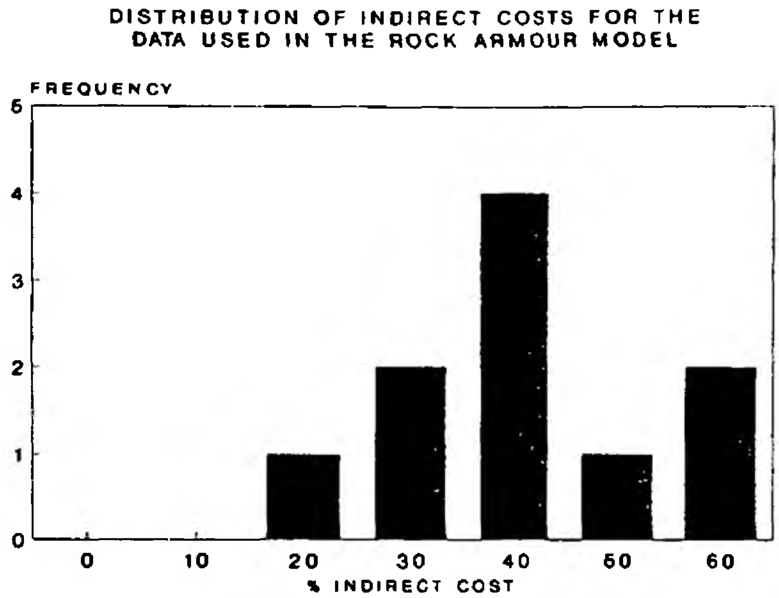


Figure 4.12

4.4 Concrete Seabee model

Parts of the Lincolnshire coast have recently been protected using precast concrete 'Seabee' armour units. These are used in a similar way to rock armour, i.e. they reduce erosion and absorb much of the energy of incident waves. However the total volume of material used for 'Seabees' is far less than that used for rock armour.

The data used referred to 700 mm deep 'Seabee' units. These were placed on a layer of approximately 600 mm deep 300-400 stone above a 400 mm thick layer of 20-100 stone laid on a geotextile as shown in Figure 4.13. The model accounts for the provision and placing of the above. However there will generally be additional costs from steel sheet piling at the toe, (use relevant model), plus any additional mass concrete used to cap the piles or on the crest. If applicable these costs (for piling and capping beam) must be added to that given by this model.

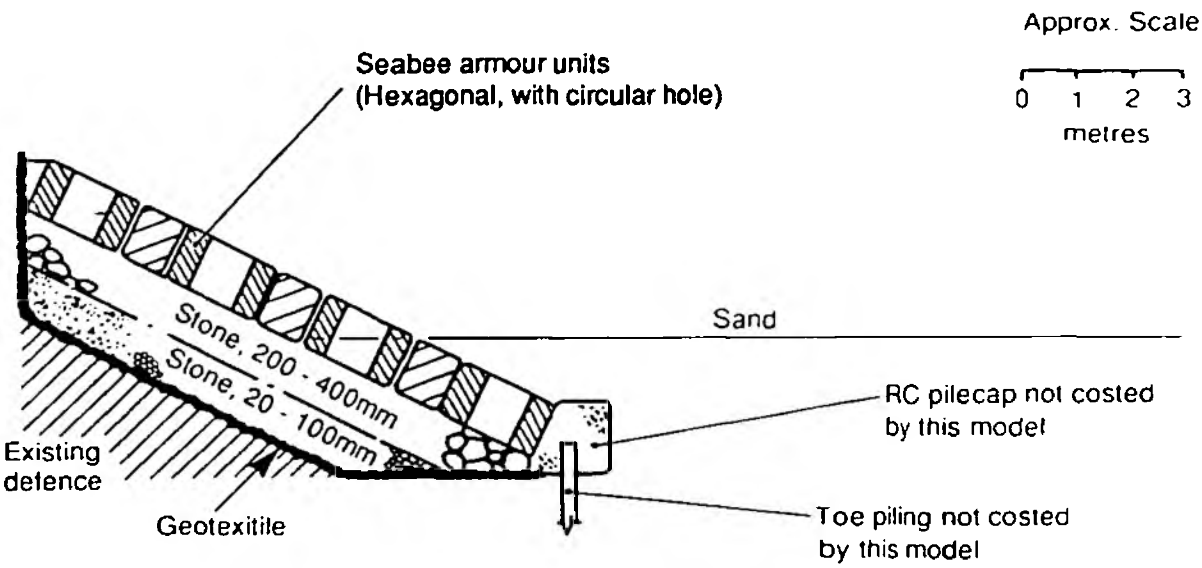


Figure 4.13 Concrete Seabee Armour Units

Number of Observations	5	
Explanatory variable	AREA	Area of revetment in m^2
Max AREA	3522 m^2	
Min AREA	385 m^2	
Mean AREA	1645 m^2	
T value AREA	12.3	
Significance level AREA	<1.0%	
Standard error of residuals (in $\log_{10}$ model)	0.058	

Approximate multipliers for confidence levels about a prediction:

	Upper	Lower
80% Confidence level	1.24	0.81

Equation, corresponding to the solid curve in Figure 4.14:

Direct cost (£'000 Q3'89) = 0.45 * AREA$^{0.84}$ 4.4

A frequency diagram of percentage indirect costs is given in Figure 4.15, the average value of IDC in the data sample used was 39.0%. Such costs must be added as shown in Section 3.

CONCRETE SEABEE MODEL

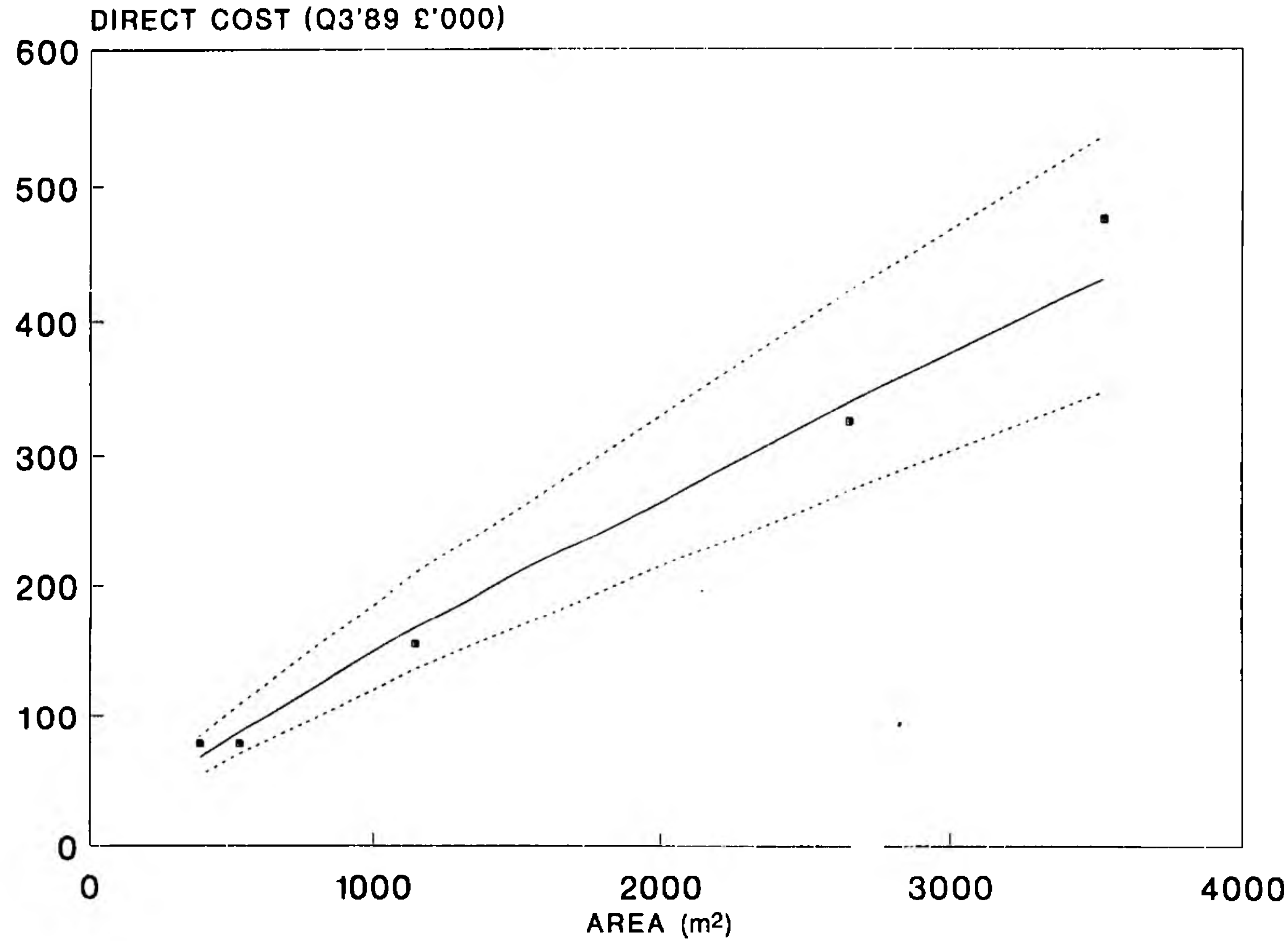


Figure 4.14

DISTRIBUTION OF INDIRECT COSTS IN THE DATA USED FOR THE SEABEE MODEL

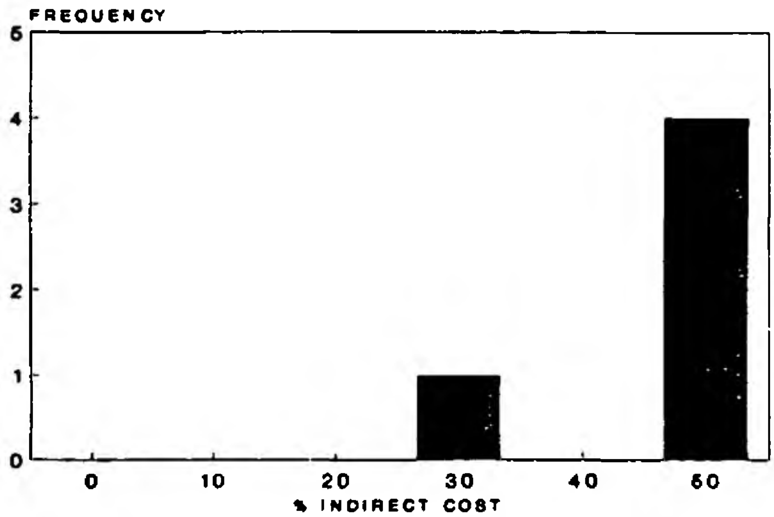


Figure 4.15

4.5 Rock breakwaters and groynes

The objective of these structures is to reduce the movement of beach material and to control wave energy. The rock used is similar to that used for rock armouring but smaller stone may be used for the body of the structure. The armour stone lies at an angle to the foreshore and may be joined by a landlink arm of smaller stone, as instanced by the example from Jaywick, Essex in Figure 4.16.

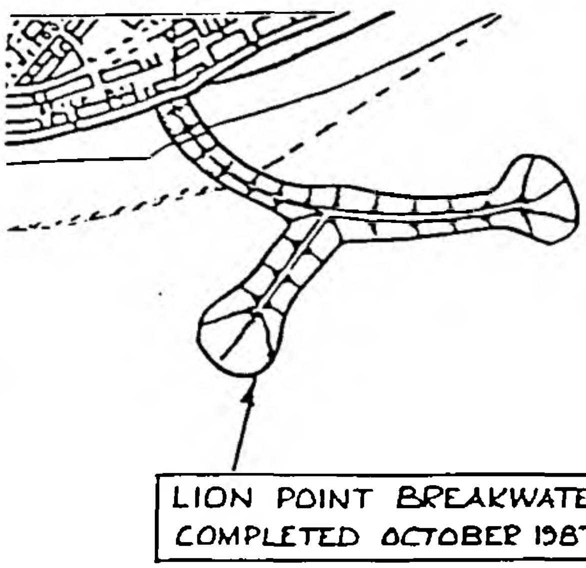


Figure 4.16

A bedstone layer of 0.6 m minimum thickness is normally laid directly on the foreshore with armour rock laid on top (usually about 3 m thick). The data for the model were all supplied by Anglian Region. A statistically good model has been produced despite there only being six points (taken from four contracts) in this classification. The armour rock was transported by barge from Norway in all cases. Some work was also carried out below MHWS.

The model accounts for the method related charges associated with the transportation and unloading of material in addition to the costs of supplying and placing material.

Number of Observations	6	
Explanatory variable	VOL	Volume of bedstone & armour rock in '000 m^3
Max VOL	79 500 m^3	
Min VOL	3 093 m^3	
Mean VOL	30 470 m^3	
T value VOL	12.7	
Significance level VOL	<0.1%	
Standard error of residuals (in $\log_{10}$ model)	0.090	

Approximate multipliers for confidence levels about a prediction:

	Upper	Lower
80% Confidence level	1.37	0.73

Equation, corresponding to the solid curve in Figure 4.17:

Direct cost (£'000 Q3'89) = 82.0 * $VOL^{0.82}$ 4.5

A frequency diagram of percentage indirect costs is given in Figure 4.18, the average value of IDC in the data sample used was 8.4%. Such costs must be added as shown in Section 3. The values of IDC are low here since the method related charge section of the BoQs which directly relate to rock breakwaters are included in the cost function.

ROCK GROYNE/BREAKWATER MODEL

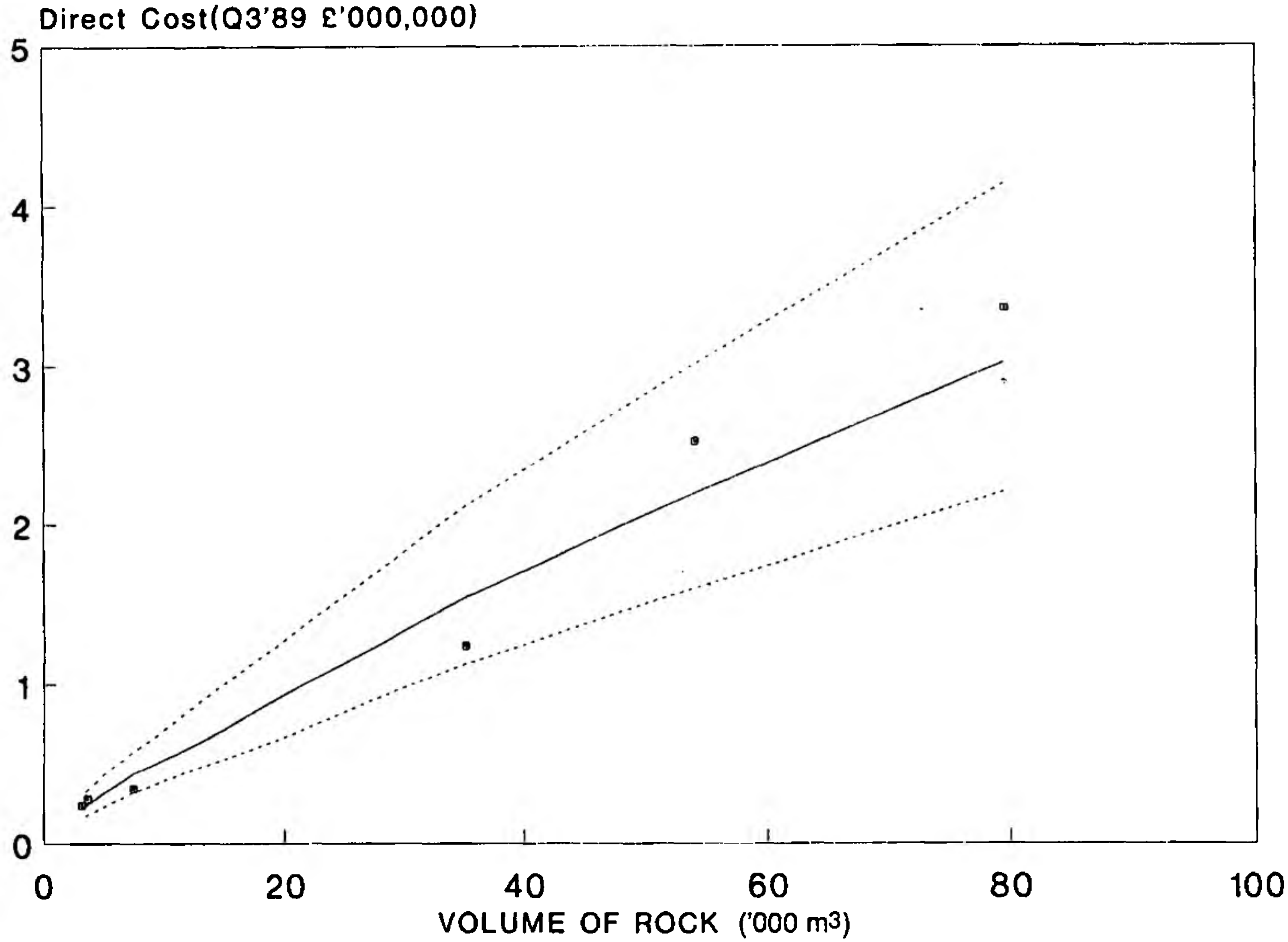


Figure 4.17

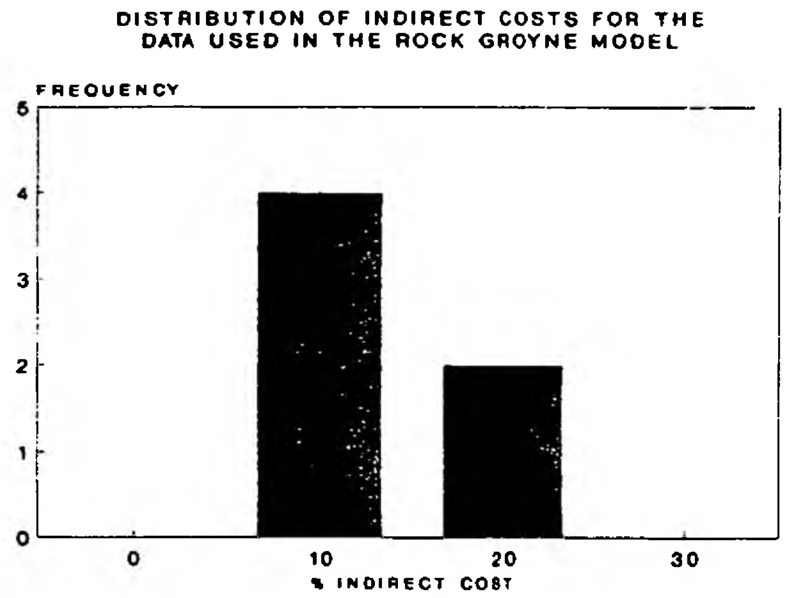


Figure 4.18

4.6 Concrete walls

This category refers to cantilever walls as illustrated in Figure 4.19. Data have been included from walls cast *in situ* and from those constructed from pre-cast units placed on the crest of an embankment or the top of a wall. Most of the data for this model came from Southern Region with Anglian Region being the only other contributor. WVOL was used as a descriptor, this is the total amount of concrete used for the structure, (i.e. the cross-sectional area of the wall multiplied by wall length). The largest cross-sectional area in the sample was 2.0 m^2, with the minimum and mean values being 0.7 m^2 and 1.1 m^2 respectively.

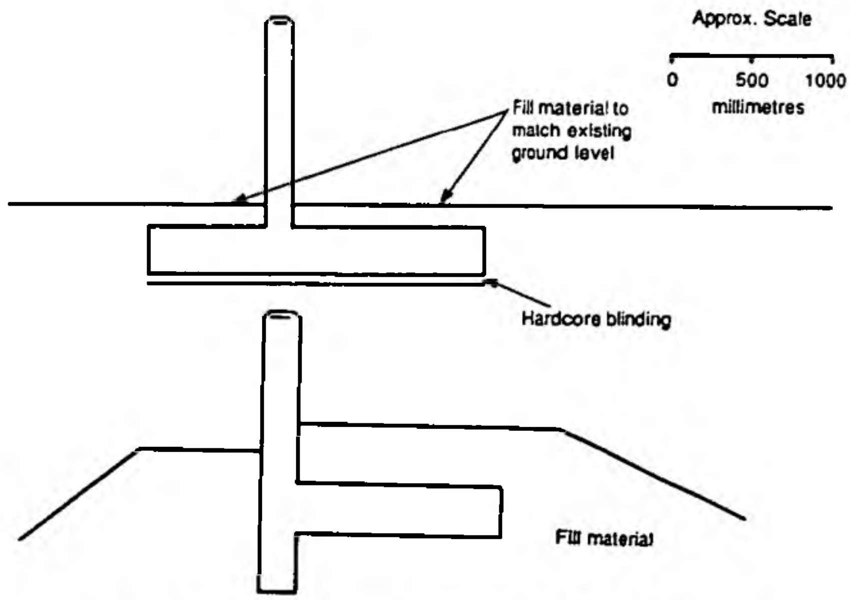


Figure 4.19 Examples of Concrete Wall Construction

A stacked-bar chart is given which illustrates the breakdowns in costs for the data used in the model. From that (Figure 4.20) it can be seen that concrete costs dominate, as would be expected. These costs account for supplying and placing of *in situ* concrete with reinforcement and associated shuttering, or supplying and installing precast units, suitably anchored to the existing structure. Some of the breaking out costs were included in the earthworks section along with backfilling, however it is evident from Figure 4.20 that these were not major items in the bills considered. Minor paving work was also carried out under some of the contracts.

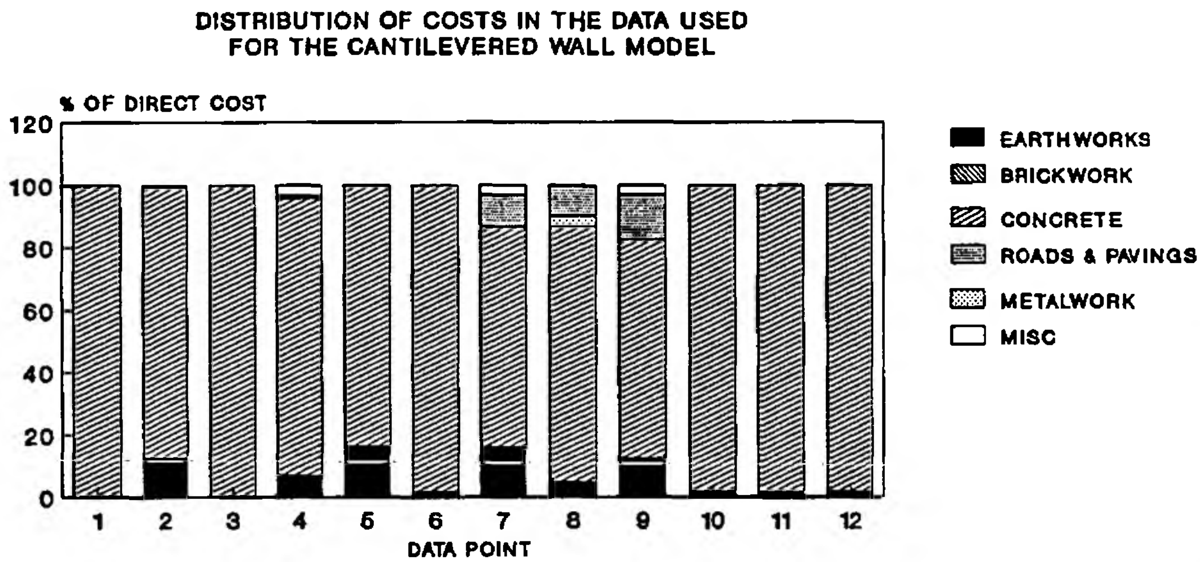


Figure 4.20

Number of Observations	12	
Explanatory variable	WVOL	(X-sectional area of wall x wall length) in m^3
Max WVOL	577.5 m^3	
Min WVOL	8.4 m^3	
Mean WVOL	211.5 m^3	
T value WVOL	32.38	
Significance level WVOL	<0.1%	
Standard error of residuals (in $\log_{10}$ model)	0.066	

CANTILEVER WALL MODEL

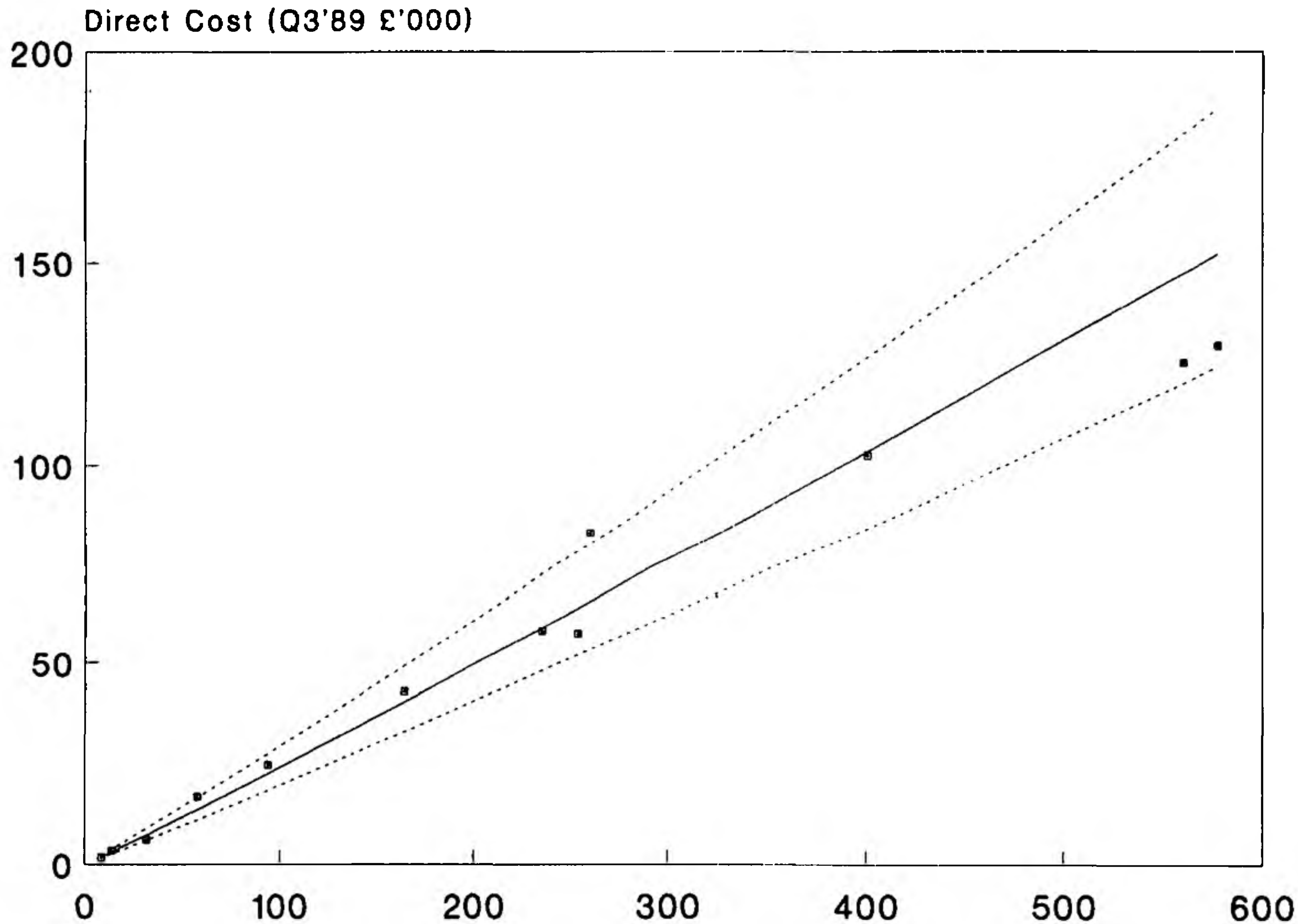


Figure 4.21

Approximate multipliers for confidence levels about a prediction:

	Upper	Lower
80% Confidence level	1.23	0.81

Equation, corresponding to the solid line in Figure 4.21:

Direct cost (£'000 Q3'89) = 0.19 * $WVOL^{1.05}$ 4.6

It is perhaps surprising that the exponent of the above equation exceeds unity. This indicates that a further descriptor is required to refine the model. However the exponent exceeds unity by only by a small amount and is not too significant when the confidence limits are taken into account, see Figure 4.21.

A frequency diagram of percentage indirect costs is given in Figure 4.22, the average value of IDC in the data sample used was 37.3%. Such costs must be added as shown in Section 3.

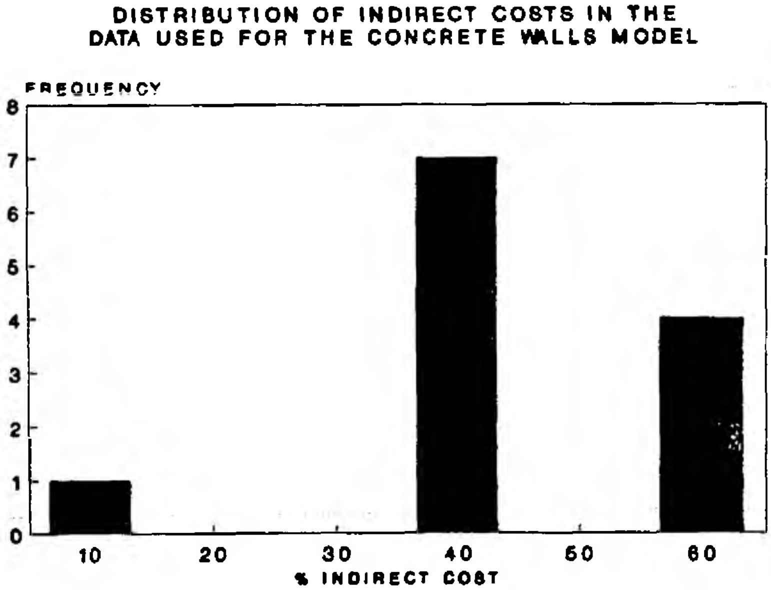


Figure 4.22

4.7 Extending the height of existing concrete walls

Several instances were found where existing walls did not provide sufficient protection and were improved. These improvements usually consisted of widening the existing wall using brickwork, blockwork or mass concrete and extending the height of the wall using pre-cast concrete units or mass concrete; an example is shown in Figure 4.23. In one case (data point 7) a concrete wave return wall was cast *in situ* where there was no significant existing wall.

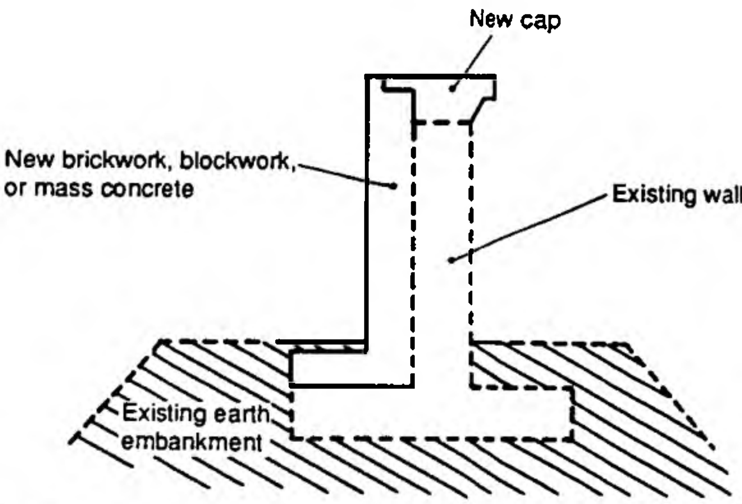


Figure 4.23 Extending the Height of Existing concrete Wall

The model uses the volume of material of the new Works as a descriptor. This can be estimated by calculating the cross-sectional area of the improved wall minus the cross-sectional area of the original wall and multiplying the resultant number by the wall length. The maximum cross-sectional area in the data was 1.25 m^2 with the minimum and mean values being 0.06 m^2 and 0.47 m^2 respectively.

The costs in the data include drilling the existing wall, fixing steel dowels/reinforcement, supplying and placing *in situ* concrete with associated shuttering or supplying and fixing pre-cast blocks, to form the crest of the wall. Any cladding may be of natural or reconstituted stone blocks or brickwork as appropriate to the environment in which the wall is located. If a significant amount of stone facing is required then the cost of the Works will increase to above that estimated using this model.

The breakdowns in costs for the data used in the model is illustrated by the stacked-bar chart in Figure 4.24. A limited amount of earthworks was required for all the points due to improvements to the wall foundations.

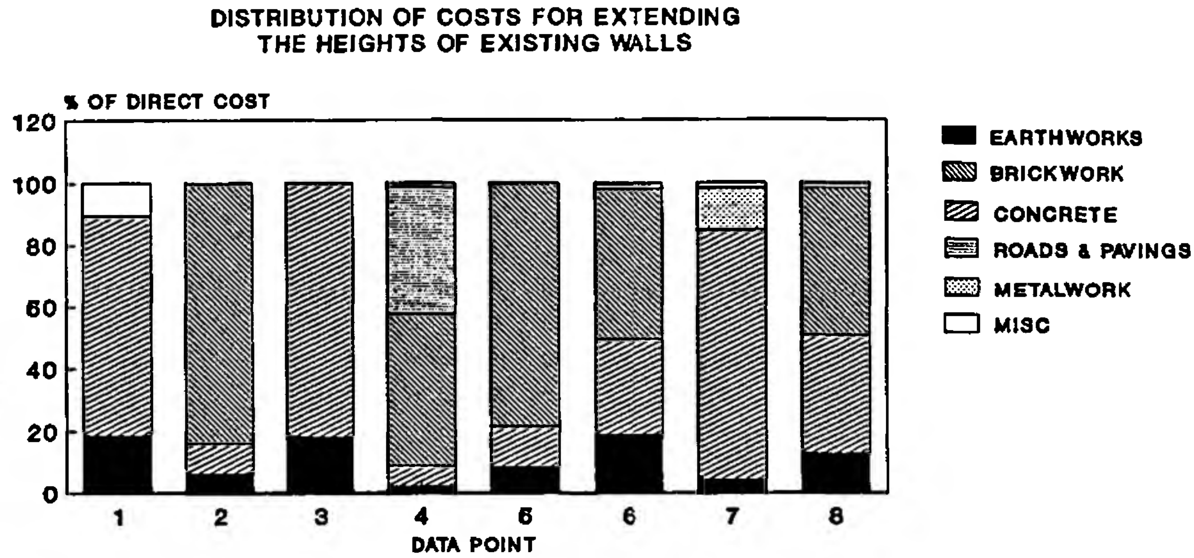


Figure 4.24

Number of Observations	8	
Explanatory variable	WVOL	(X-sectional area of new work on wall x wall length) in m^3
Max WVOL	113.75 m^3	
Min WVOL	0.654 m^3	
Mean WVOL	40.21 m^3	
T value WVOL	6.04	
Significance level WVOL	<0.1%	
Standard error of residuals (in $\log_{10}$ model)	0.234	

Approximate multipliers for confidence levels about a prediction:

	Upper	Lower
80% Confidence level	2.17	0.46

Equation, corresponding to the solid curve in Figure 4.25:

Direct cost (£'000 Q3'89) = 1.77 * $WVOL^{0.66}$ 4.7

MODEL FOR EXTENDING THE HEIGHTS OF EXISTING WALLS

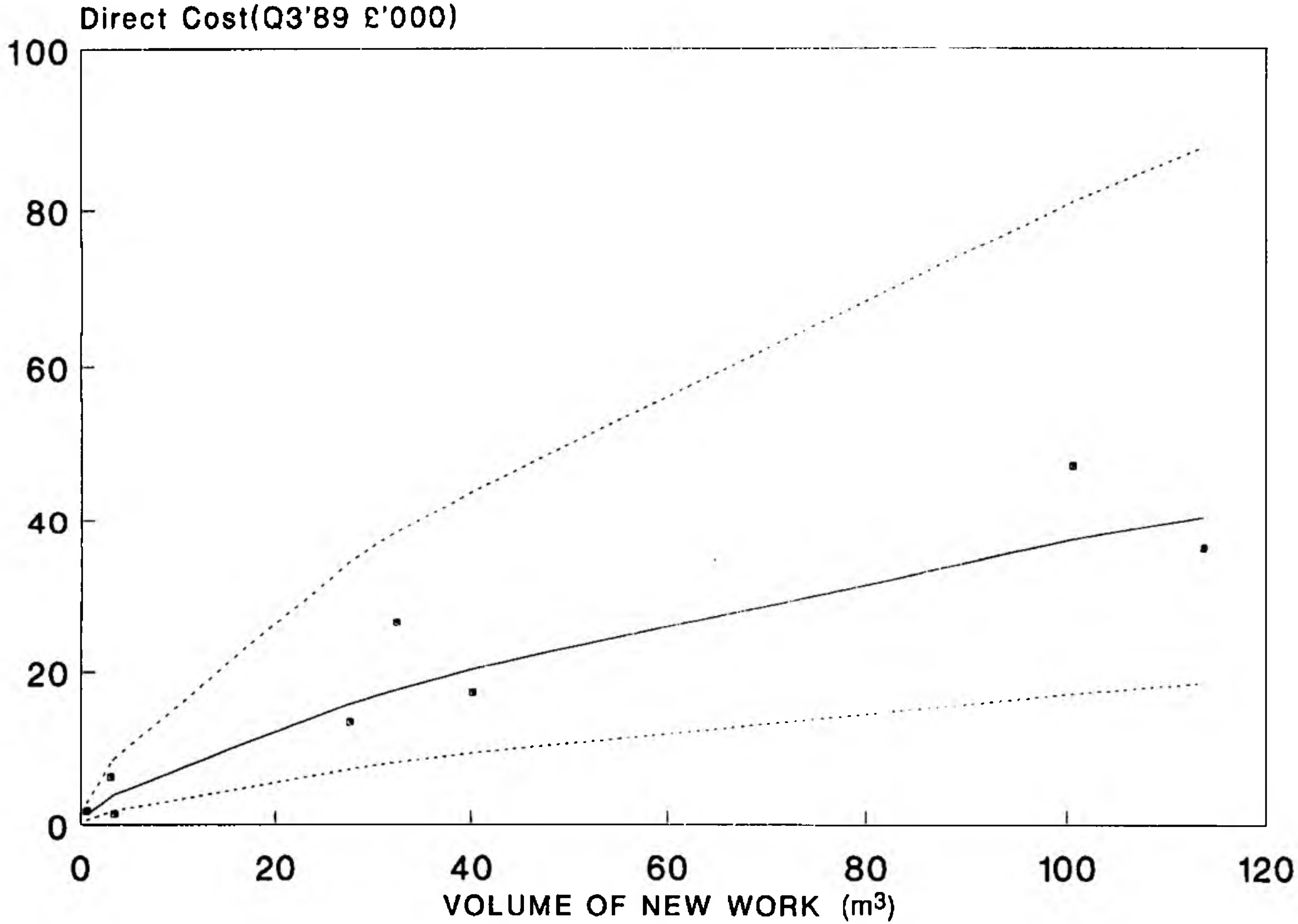


Figure 4.25

A frequency diagram of percentage indirect costs is given in Figure 4.26, the average value of IDC in the data sample used was 46.8%. Such costs must be added as shown in Section 3.

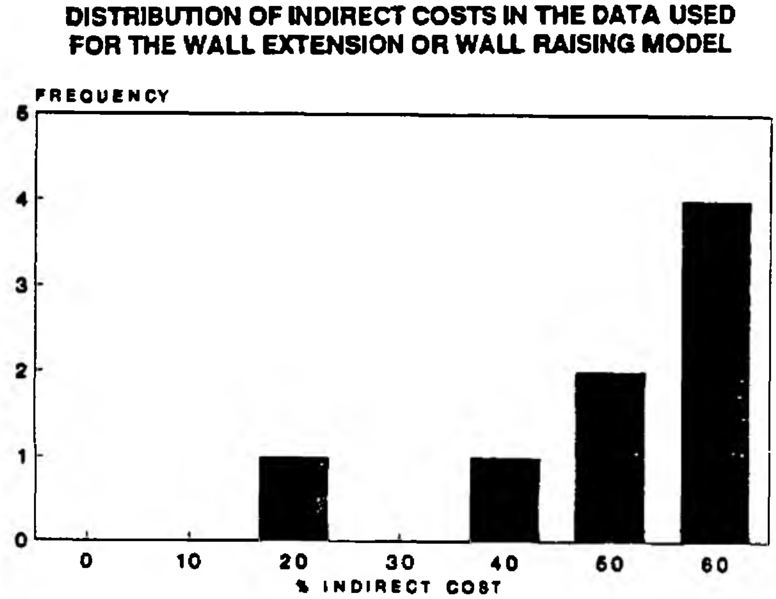


Figure 4.26

4.8 Steel sheet piling

Steel sheet piling is often used at the seaward toe of a sea defence structure, (see Figure 4.27) for two main purposes - to form a cut-off, reducing seepage under the structure, and to prevent erosion undermining the structure if the beach level falls. Such piling may also be used along a crest of an embankment, as illustrated in Figure 4.28, to increase the effective height of a defence, or as a retaining wall at the landward toe to reduce the overall width of an embankment.

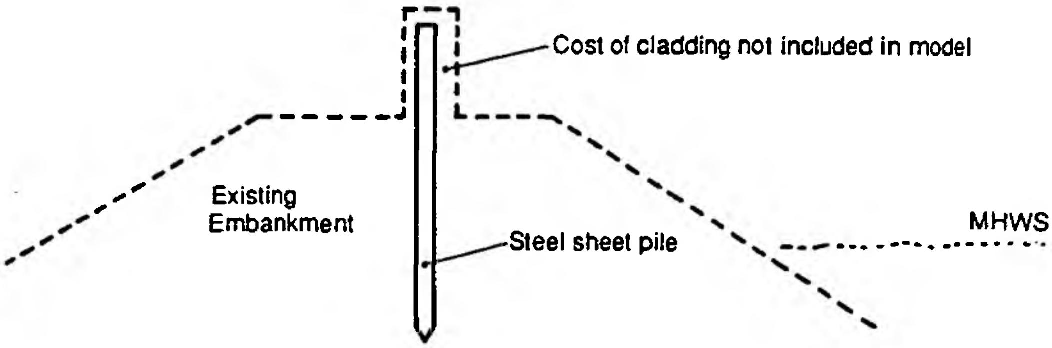


Figure 4.27 Example of Steel Sheet Piling for Walls

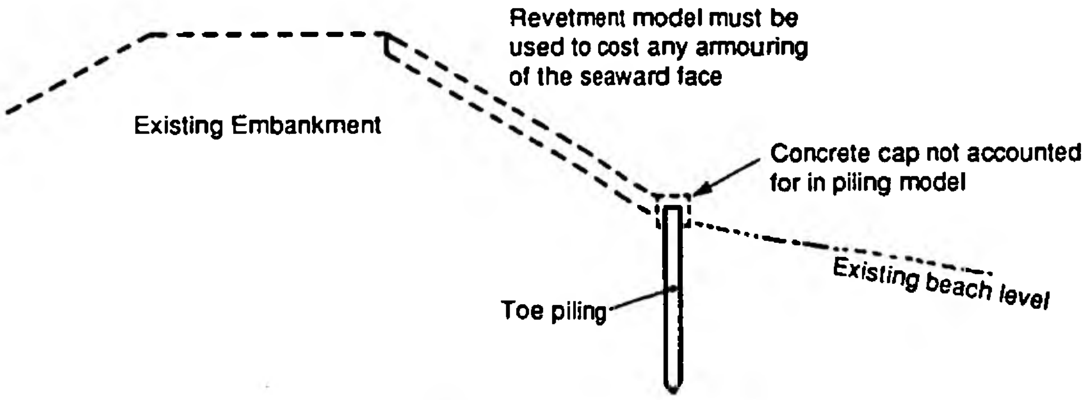


Figure 4.28 Steel Sheet Piling at Toe

There is a wide range of piling sections weighing from less than 100 to over 200 kg/m^2 and the choice of section is likely to influence costs.

Main costs are related to the provision of the piling on site, handling, pitching and driving the piles. In some cases the piling may be tied back to anchorages via walings and tie rods. Anchorages may be concrete blocks or panels of piling, and sometimes thrust-boring techniques are used to install the tie rods. It is usual to burn off the tops of the piles at the required level and to provide a reinforced concrete capping beam. There may be additional relatively minor costs associated with protective coatings, cathodic protection etc.

The data used for the models included costs for the provision of the piles on site, handling, pitching and driving. In addition the costs of burning off the tops of piles and other ancillary work was included, i.e. the data generally came from CESMM classification sections P8, Q6, Q7 and Q8. Work such as tying back to anchorages and providing concrete capping is not accounted for in the models. Provision of drainage for the fill behind piling is sometimes necessary, the costs of which will also be additional to that calculated by the models.

Since there are two distinct regions where steel sheet piling is used it was decided to produce two separate models.

Steel Sheet Piling to Toe

On the basis of data received, piling carried out at the seaward toe of a defence generally used 5 m deep piles driven to over 90% depth in conditions below MHWS. The piles were generally Frodingham 1N, however Larssen piles were also frequently used (details are given in Appendix D data set 8)

Number of Observations	11	
Explanatory variable	AREA	Area of piling in m^2
Max AREA	2492 m^2	
Min AREA	275 m^2	
Mean AREA	1095 m^2	
T value AREA	13.13	
Significance level AREA	<0.1%	
Standard error of residuals (in $\log_{10}$ model)	0.089	

Approximate multipliers for confidence levels about a prediction:

	Upper	Lower
80% Confidence level	1.33	0.75

Equation, corresponding to the solid line in Figure 4.29:

Direct cost (£'000 Q3'89) = 0.055 * AREA$^{1.01}$ 4.8

The above relationship shows a very near linear relationship between piling area and cost. The exponent exceeds unity by a very small amount but this is not significant when the confidence limits are taken into account, see Figure 4.29. Note that Equation 4.8 strictly applies only to piles of ~5 m length, as usually employed for toe piling.

MODEL FOR SHEET PILING AT TOE
GENERALLY WITH 5m LONG PILES

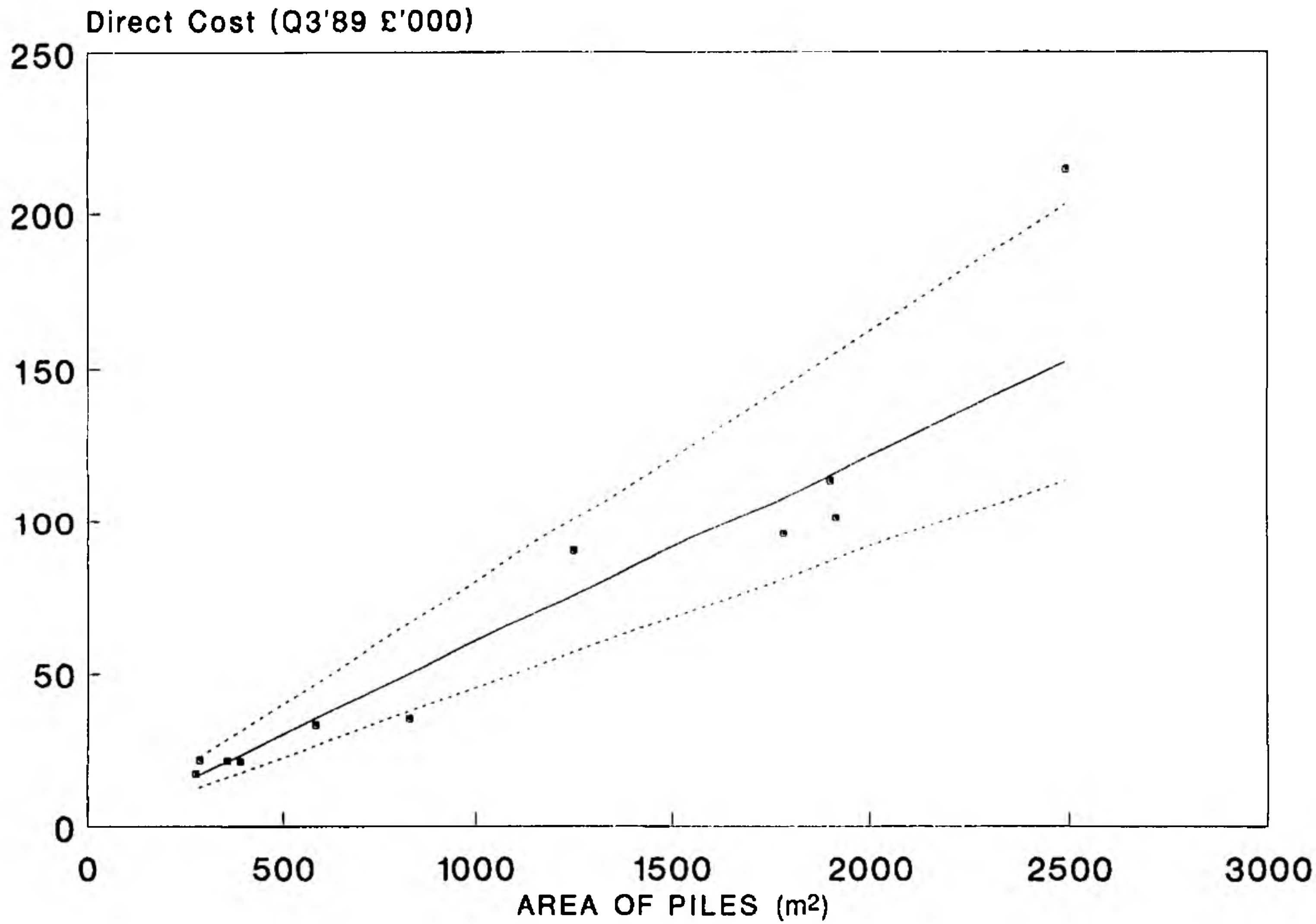


Figure 4.29

A frequency diagram of percentage indirect costs is given in Figure 4.30, the average value of IDC in the data sample used was 30.2%. Such costs must be added as shown in Section 3.

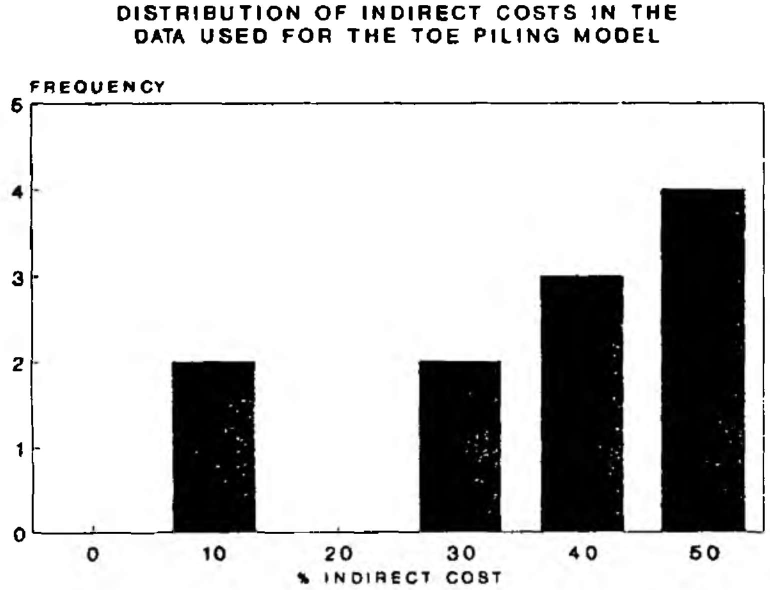


Figure 4.30

Steel Sheet Piling for Walls

The depth of the piles used along the crest of an embankment can vary considerably and they are not driven proportionally so deep (normally to 2/3 pile depth) as those used for toe protection. In addition the work is generally carried out under less hostile conditions.

Number of Observations	13	
Explanatory variable	LEN	Length of wall in m
Max LEN	2210 m	
Min LEN	22 m	
Mean LEN	538 m	
Explanatory variable	PLEN	Total depth of pile in m
Max PLEN	12.35 m	
Min PLEN	2.5 m	
Mean PLEN	7.08 m	
T value LEN	10.93	
T value PLEN	6.32	
Significance level LEN	<0.1%	

MODEL FOR PILING COSTS FOR WALLS

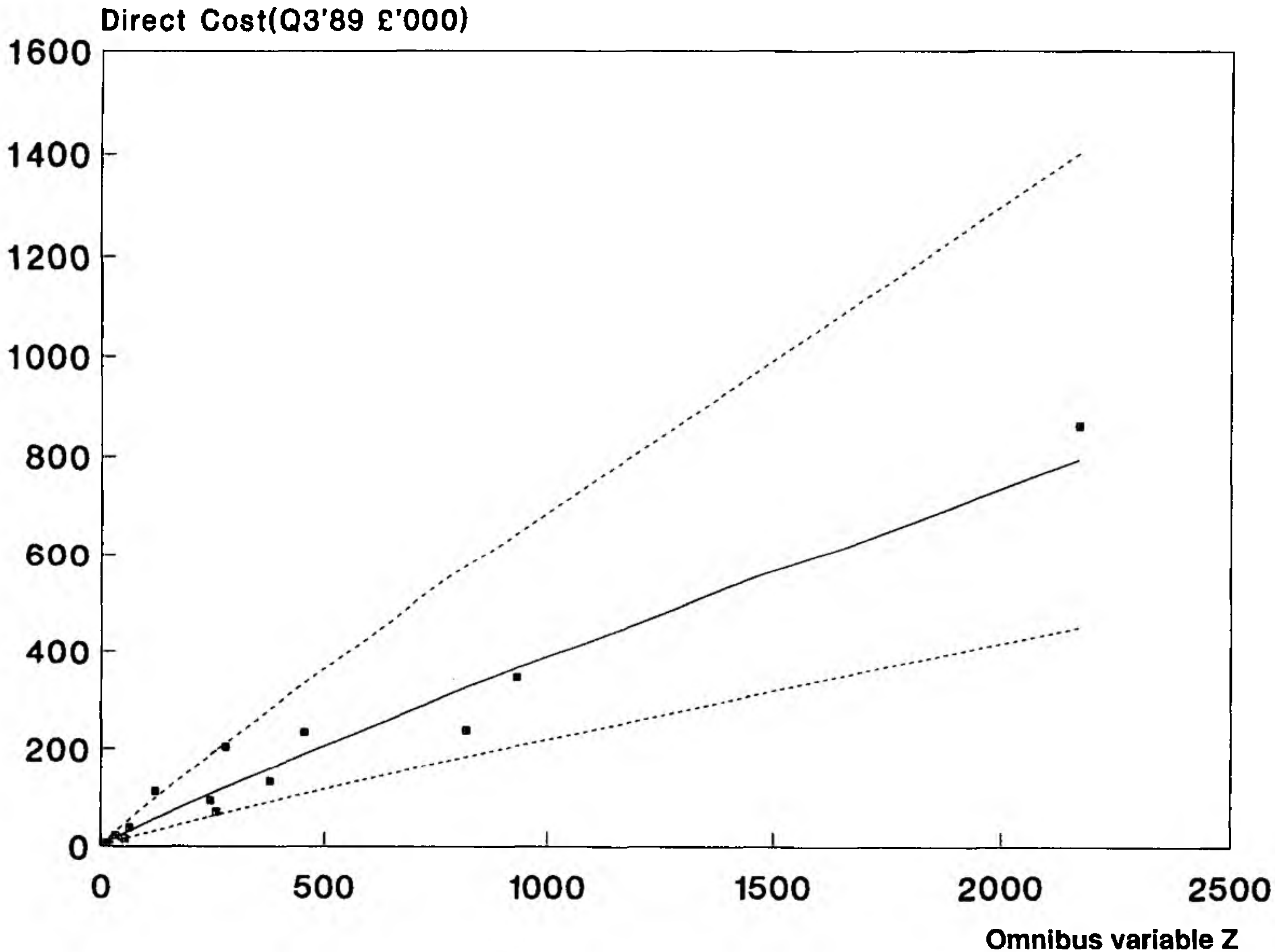


Figure 4.31

Significance level PLEN	<0.1%	
Standard error of residuals		
(in $\log_{10}$ model)	0.180	

Approximate multipliers for confidence levels about a prediction:

	Upper	Lower
80% Confidence level	1.77	0.57

Equation, corresponding to the solid curve in Figure 4.31:

$$\textbf{Direct cost (£'000 Q3'89)} = 0.0434 * LEN^{0.92} * PLEN^{1.40} \qquad 4.9$$

The omnibus variable Z described in Appendix A (xiii) is

$$Z = (LEN * PLEN^{1.52})/19.6 \qquad 4.10$$

A frequency diagram of percentage indirect costs is given in Figure 4.32, the average value of IDC in the data sample used was 31.5%. Such costs must be added as shown in Section 3.

DISTRIBUTION OF INDIRECT COSTS IN THE DATA USED FOR THE WALL PILING MODEL

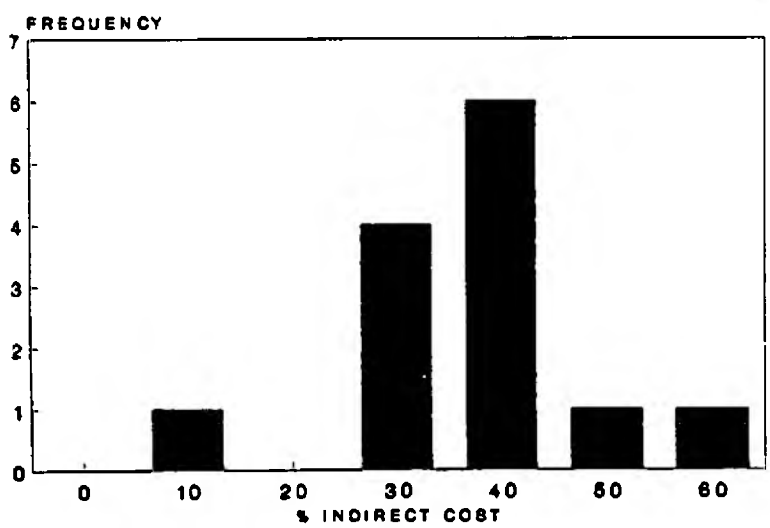


Figure 4.32

4.9 <u>Timber groynes</u>

May be of hardwood or softwood construction based on vertical king piles driven into the foreshore. Generally, the groynes from the contracts examined were constructed by driving timber sheeters (generally 225 x 75 mm) between the king piles and connecting them together via walings. This type of constructions shown in Figure 4.33. Timber stringers may added to increase the heights of the groynes as the beach level rises. Costs will be related to the type and amount of timber used, access and tidal influences.

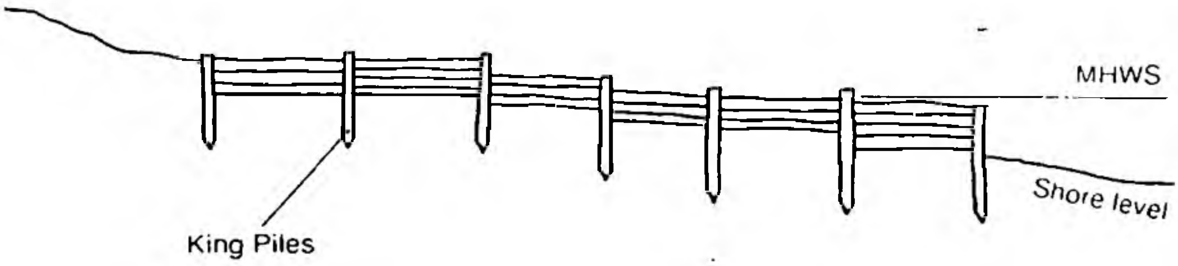


Figure 4.33 Timber Groynes

All of the data used was supplied by Anglian Region, however not enough information was gathered to produce a cost function.

A total of 31 groynes were built at Aldeburgh. The bill of quantities gives breakdowns for five sections of coastline. From this the following was deduced

Groyne type : Greenheart piles and sheeters.

King piles (250 x 250 mm) length from 6.0 m to 8.5 m (average 7.2 m)

Maximum groyne length	40.71 m
Minimum groyne length	37.50 m
Average groyne length	39.40 m

Average area of sheeters per groyne	68.4 m^2
Average direct cost per groyne (Q3'89)	£31 606

A further four contracts covering 19 groynes built on the Lincolnshire coast gave the following information

Groyne type : Douglas Fir pressure impregnated with creosote.

King piles (250 x 250 mm) length generally 9.5 m
Sheeters (225 x 75 mm) length generally 2.4 m

Maximum groyne length	48.60 m
Minimum groyne length	39.60 m
Average groyne length	43.83 m
Average area of sheeters per groyne	111 m^2
Average direct cost per groyne (Q3'89)	£16 761

More detailed information can be found in data set 10 of Appendix D.

4.10 Beach recharge

This may be mainly a one-off operation to provide the required beach level between features which will control the littoral movement of material, Figure 4.34. In this case only occasional replenishment may be required. In other cases the recharge may be a regular operation recycling material from the downdrift end of the beach so as to maintain beach levels along a frontage. Recharge is commonly associated with a series of groynes to reduce beach movement.

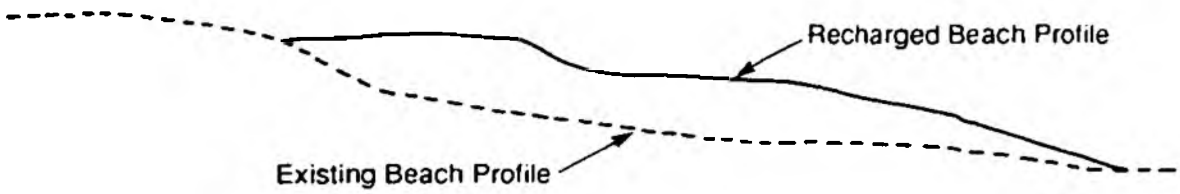
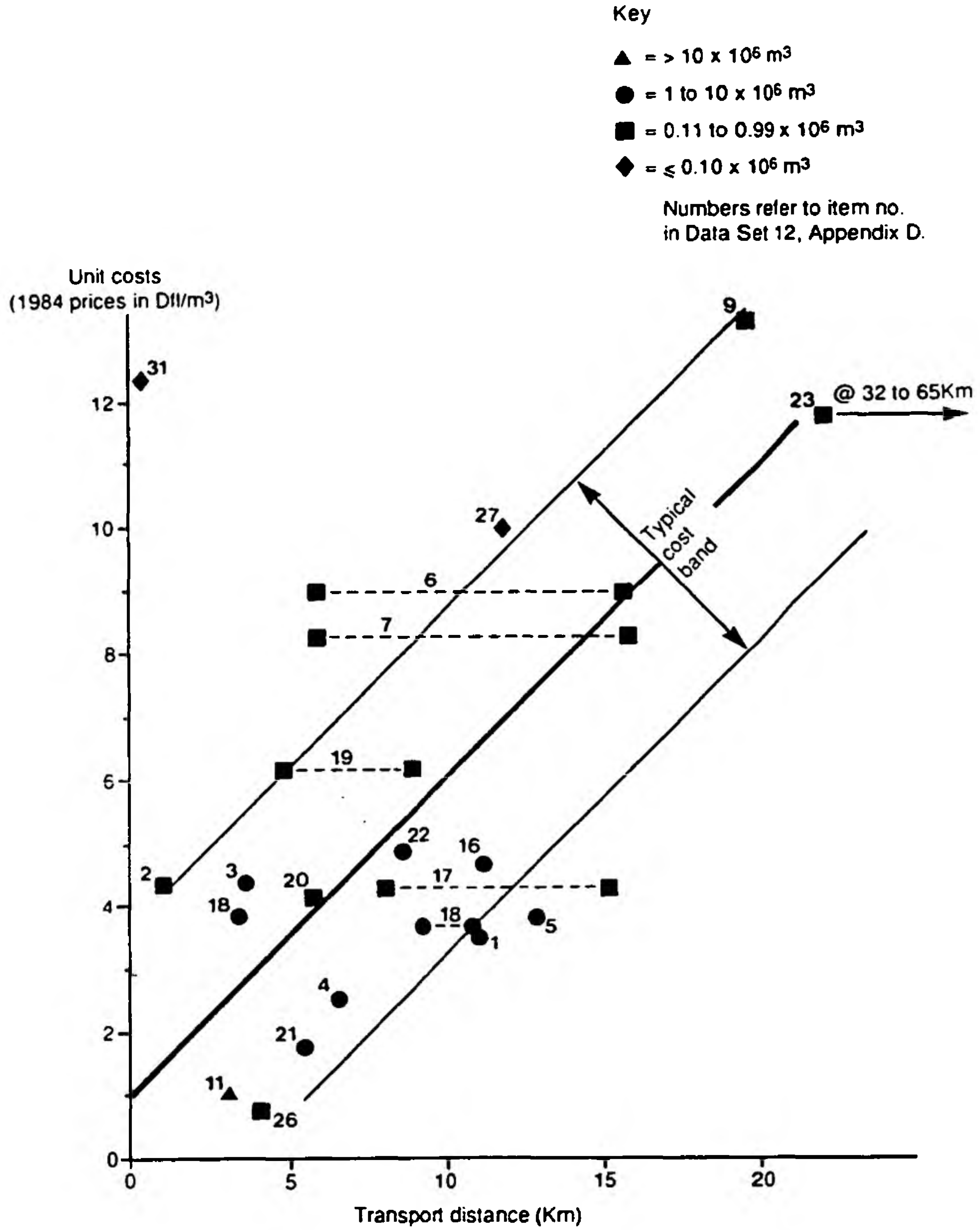


Figure 4.34 Beach Recharge

Material may be dredged from a suitable area off-shore and pumped to the beach. Recycling may be by conventional transport methods. In either case the unit cost of the material deposited on the beach may be significantly influenced by the distance the material has to be transported, and there will probably be a substantial mobilisation cost for dredging/pumping equipment where this is used.

British data on the costs of beach recharge are scarce; see Data Set 11 Appendix D. Accordingly no cost model has been fitted to those data. It is, however, useful to present some data from Dutch sources, as published the report 'Handboek Zandsuppleties' (Rijkswaterstaat 1988). The table on pp34-5 of that report incorporates cost data for 32 beach recharge and dune-strengthening schemes, mostly adjusted to 1984 prices. Costs are expressed per volume of sand delivered and include the costs of shaping beach or dune frontage. The total quantity of sand delivered and the transport distance are given in most instances; Data Set 12 at the end of Appendix D summarises the Dutch data for the 19 cases where unit costs, quantity and distance transported are all known. Using this information, Figure 4.35 shows the relation between unit costs and transport distance, with the expected positive correlation, even though the scatter is considerable.



Dutch cost data on beach nourishment

(from the Rijkswaterstaat "Handboek zandsuppleties")

Figure 4.35

The mid-line of the cost band shown in Figure 4.35 corresponds to:

$D = 1.05 + 0.48X$ where D = Dutch unit cost in Dfl/m^3 at 1984 prices
and X = transport distance in km

Converting by (150.7/106.0) to obtain 1989 Q3 prices and by £0.30/Dfl results in the expression:

$$S = 0.45 + 0.12X \quad (4.11)$$

where S = sterling equivalent unit cost in £/m^3 at 1989 Q3 prices.

5. CONCLUSIONS

Comparisons of construction costs for selected types of sea defence works have been presented in this report. Based on the limited data available nine preliminary cost estimating models have been developed. A wide range of factors affect the costs of defences so this manual is not intended to replace site specific studies, but it may be used in conjunction with them.

This manual is intended for use by NRA planners when developing strategic plans. It provides a quick, consistent assessment of costs and a ready source of national data. Importantly, it also gives a consistent basis for the preparation of construction cost estimates and appraising work.

6. RECOMMENDATIONS

1. The collection of further data relating to sea defences would improve existing cost functions and should enable the production of statistically acceptable cost functions for timber groynes and beach recharge.

2. Data from accepted tenders need to be available before an update of this manual is made. Therefore it is recommended that NRA engineers notify a central contact when a tender has been accepted. When it is judged that a suitable number of BoQs is available then a revision may begin. This knowledge of location and number of tender documents should also aid the data collection phase. To assist this process a pro-forma has been produced and can be found in Appendix G. Basic information is requested on this form the completion of which will minimise time spent on searching for new data.

3. The techniques used for the production of these models could be applied to estuarine and fluvial structures, further enhancing the range of models available and maintaining a consistent structure in estimates of future capital expenditure. Further data collected from estuarine and fluvial works involving some structures, earth embankments and revetments for example, may be suitable for enhancing existing models.

ACKNOWLEDGEMENTS

This investigation has depended considerably on flood defence staff, as cited in Appendix E, who have supplied tender documents, bills of quantities and engineering specifications from their regional records. The generous provision of data and reports by Ir H J Verhagen of the Road and Hydraulic Engineering Division, Rijkswaterstaat, Delft is also gratefully acknowledged.

The final draft of this report was reviewed by Mr G M West and Mr R Runcie of NRA Southern and Anglian Regions respectively. Helpful comments were also received from consulting and contracting civil engineering firms as follows:

Babtie, Shaw and Morton
W A Dawson Ltd
Haiste Ltd
Edmund Nuttal Ltd
Posford Duvivier
Sir William Halcrow and Partners
Shore Line Management Partnership

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APPENDIX A

DESCRIPTION OF STATISTICAL TERMS

i) **Coefficient of determination:** the square of the **correlation coefficient**. R^2 lies between 0 and 1 and measures the proportion of the original **variance** which is 'explained' by the regression model.

ii) **Coefficient of variation:** the **standard deviation** divided by the **mean**. It is a proportional measure of spread, usually expressed as a percentage.

iii) **Confidence:** The confidence interval is a statistical device which gives information on how far the **mean** calculated from available data might conceivably be from the true mean. In this report 80% confidence levels are used, the widths (or confidence limits) of which are dependent on **multipliers**. It has been assumed that the data are **Normally** distributed.

iv) **Correlation coefficient:** a quantity, usually denoted by R, which indicates the overall goodness of fit of a regression model. It lies between -1 and +1. A value of +1 (or -1) represents a perfect fit between two columns of data which are directly (or indirectly) proportional to each other. A value close to zero indicates a low correlation.

v) **Data, Sample:** the collected values of all **variables** under consideration; the starting point of a statistical study.

vi) **F-statistic:** is used to indicate the **significance** of a **variable** in a regression model. The larger its value the greater the significance of the variable.

vii) **Function, Model:** terms used interchangeably in this report to mean a statistically derived relationship relating one **variable** (usually cost) to other explanatory **variables**.

viii) **Histogram:** a discretely-segmented diagram showing the way a sample of data (such as cost) is distributed with respect to some variable (for instance, revetment area or pile length).

ix) **Mean:** the sum of the values of a **variable** divided by the number of values. It locates the 'centre', in one sense, of a data sample.

x) **Multiple regression:** an extension of simple regression to deal with more than one explanatory variable.

xi) **Multipliers:** a term used in this report to denote the quantities by which an estimate must be multiplied to obtain a specified **confidence** interval. They are calculated from the **standard error** of the residuals, s, and the relevant T-value, t, by the equations:

lower multiplier = 10^{-ts}
upper multiplier = 10^{+ts}

The values of t depend upon both the number of points in a given model and the number of descriptors it uses. For models using more than 15 data points approximate values for t are 1.3 for 80% limits and 2.1 for 95%.

xii) **Normal distribution:** a symmetrical bell-shaped distribution of great importance in statistical theory and practice. The validity of the **confidence limits** quoted in this report rests on the assumption that the **residuals** from the various regression models are **Normally** distributed.

xiii) **Omnibus variable:** a single variable Z which combines all the explanatory **variables** in a regression model so that the model is compressed into two dimensions and can be demonstrated graphically. For instance, if the cost of an item depends on two variables, Var1 and Var2, such that

$$\text{Cost} = \alpha * (\text{Var1})^{\beta} * (\text{Var2})^{\gamma}$$

and in addition the mean value of Var2 is MV2, then the 'omnibus' variable is defined as

$$Z = Var1 * \left[\frac{Var2}{MV2}\right]^{\gamma/\beta}$$

This allows the model to be written as

$$Cost = C' * Z^{\beta}$$

where $C' = \alpha * MV2^{\gamma}$

If Z is calculated for each item of data, both the model and the data can be displayed on a diagram of cost against Z. This indicates how much 'unexplained' scatter there is about the model.

xiv) **Outlier:** an extreme data value suspiciously far away from other members of the sample.

xv) **Parameters:** numerical values relating to an underlying population. For the whole **population** the true relationship between cost and a **variable**, Var, might be

$$Log(Cost) = \alpha + \beta * Log(Var)$$

α and β are population parameters.

xvi) **Population:** the entire set of possible values of a **variable.**

xvii) **Regression coefficient:** calculated numerical values in a regression equation. In the regression model on logged data

$$Log(Cost) = \alpha' + \beta' * Log(Var)$$

the regression coefficients are α' and β'. They are related to the **population parameters** by the relationships

$\alpha' = \alpha + \text{error}$

$\beta' = \beta + \text{error}$

xviii) **Residual:** the difference between an actual value and its estimate from a regression model. Whether or not a model may be taken to be satisfactory depends largely upon a study of the residuals. Here the residuals are defined as

log(actual cost) - log(estimated cost),

since the regressions are done on logged data.

xix) **Significance:** the essence of statistics is to use the information in a sample to make inferences about the underlying **population**. No theory can be proved by statistics, it can only be rejected as being unlikely. The more unlikely a theory is estimated to be then the greater the statistical significance of the rejection. The statement that a term in a regression equation is significant at the 1% level means that the improvement brought about by its inclusion could not have occurred by chance on more than one occasion in a hundred in the long term. The theory, or hypothesis, that the variable has no real effect is thus rejected at the 1% level.

xx) **Simple regression:** a statistical technique for deriving a model relating a **variable** (such as cost) to just one explanatory variable.

xxi) **Standard deviation:** the most commonly used measure of 'spread'. For a **Normally** distributed **variable** roughly 95% of the values in a sample will lie within two standard deviations of the **mean**. The sample standard deviation is defined as

$$\sqrt{\frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n - 1}}$$

Where n is the number of points in the sample and x the values of the variable.

xxii) **Standard error:** a term preferred to **standard deviation** though meaning exactly the same when referring to uncertainties in an estimate of a **population** parameter.

xxiii) **Statistic:** any summary measure calculated from a data sample, (e.g. sample **mean** or **standard deviation**).

xxiv) **Variable:** a measurable factor of interest, (e.g. cost of a scheme, date of construction, volume of concrete, height of wall).

xxv) **Variance:** the square of the **standard deviation**.

APPENDIX B

REGRESSION MODELS

a) Simple linear regression

The method of 'least squares' has been used in this report as the criterion for finding the best straight line through two sets of data plotted on a scatter diagram. This method minimises the square of the residual values.

Figure B1 shows a scatter diagram of Var1 against Var2 and a line AA' drawn through the data points. The vertical deviation of a point P from the line is d. For some points this will be positive and for others it will be negative. The square of this deviation is calculated for all data points and summed to give the total squared deviation about the line. If a different line were drawn, such as BB' in Figure B1, it is unlikely that the total squared deviation about this line would be the same as that about AA'. If it were less then BB' would intuitively be a better fit to the data than AA'. The method of least squares provides the straight line which minimises the sum of squared deviations about the line, and so is in that sense the 'best' straight line through the data.

The regression line has the form

$$Var1 = \alpha + \beta * Var2$$

where α is the intercept and β is the slope of the line. The regression line has the useful property that it passes through the mean of the data, i.e. the point where both Var1 and Var2 take their mean values. A further consequence of this procedure is that the mean of the deviations, d, over all the data is zero.

The closer the points lie to the regression line then the better the model will be. The standard error of the residuals measures their degree of spread about the line, and therefore provides a useful measure of the

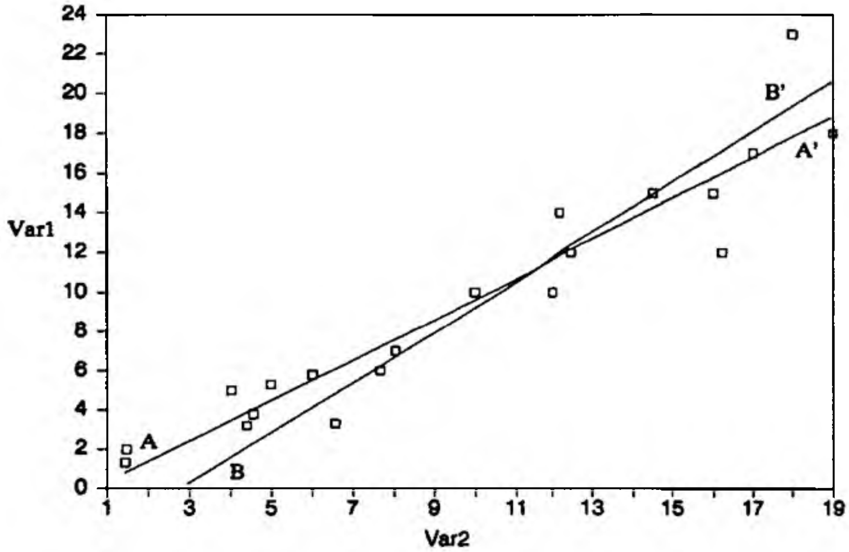

Figure B.1 Scatter diagram of Var1 against Var2

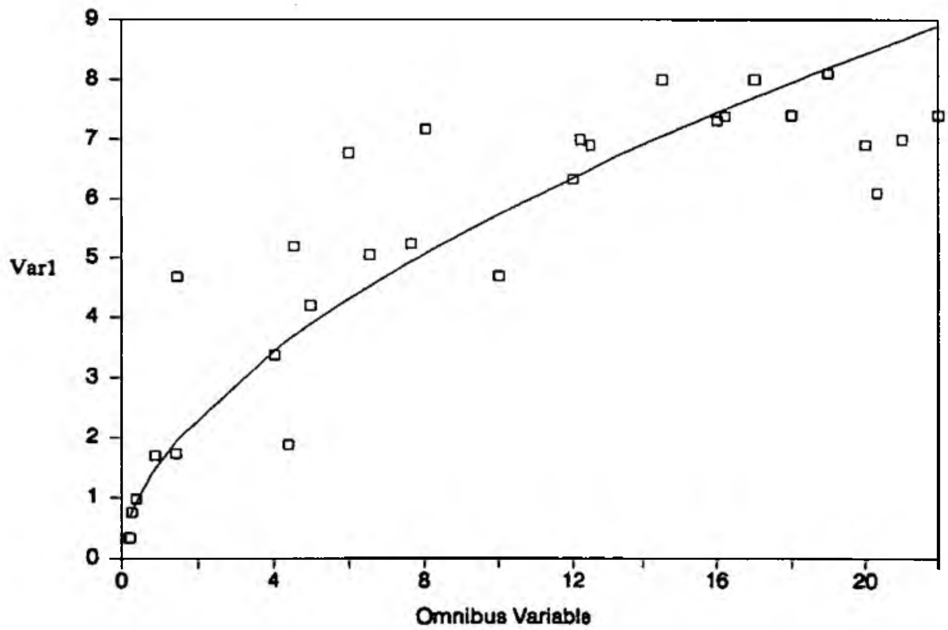

Figure B.2 Example non-linear model

uncertainty associated with the regression model. This standard error is also used for calculating confidence limits of predictions by the model.

b) Multiple linear regression

In the case of steel sheet piling there was justification in including two variables in the model. The civil construction costs (Var1) was thought to be related to both the lengths of defence and depth of pile (Var2 and Var3 respectively). For such a case multiple regression can be used to produce equations of the form

$$Var1 = \alpha' + \beta' * Var2 + \gamma * Var3$$

The least squares principle would again be used to determine the three regression coefficients α', β' and γ. The total squared deviation of a multiple regression model will be no larger than that of a simple regression model since if Var3 was not in any way related to Var1 then γ would be zero and the equation would revert to its simpler form. Since including additional variables generally reduces the total squared deviation a decision has to be made on the significance of including additional variables in models. To determine this the T-value associated with each variable was examined. If the T-value was below a set threshold then the variable was rejected as making no worthwhile contribution to the model. Since the objective was to construct purely empirical models which were statistically valid this rejection due to low T-values occurred even for cases where it was thought, on grounds of experience for example, that a given variable would affect cost.

If Var2 and Var3 are only slightly correlated, the new coefficient, β', of Var2 will not be very different from its earlier value, β. If, however, Var2 and Var3 are highly correlated then Var3 is unable to contribute much fresh information not already residing in Var2, so it is usually best to discard either Var2 or Var3.

Further explanatory variables may be included in the regression. Again significance tests would need to be performed to assess whether the observed reduction in total squared deviation was more than could be attributed reasonably to chance.

c) Non-linear models

It was found that a better fit to the data was generally achieved by using non-linear relationships, as opposed to those produced by simple linear regression. This frequently reflected economies of scale. A further consequence of this form of model is that the variance about the regression line increases with Var1 (or construction cost) as would be expected. A multiplicative model structure approach was adopted in keeping with that of TR 61. Such models are of the form below and represented in Figure B2.

$$Var1 = \alpha * Var2^{\beta} * Var3^{\gamma}$$

If logarithms are taken then the above relationship may be written as

$$\log(Var1) = \log(\alpha) + \beta \log(Var2) + \gamma \log(Var3)$$

Therefore a multiple regression of log(Var1) against the explanatory variables log(Var2) and log(Var3) will produce values for $\log(\alpha)$, β and γ, allowing a multiplicative model to be established.

In this report Var1 is generally the deflated civil construction cost. Regressions were therefore carried out on log(deflated cost) against the logarithms of one or more explanatory variable. Once a cost function was generated it was necessary to check its statistical validity and to assess the uncertainty in the prediction. The mechanisms for doing these are outlined below.

d) Testing the validity of a model

Assumptions are made about the residuals in regression theory. It is therefore necessary to examine the residuals after building a model to check whether or not they meet these assumptions. If the assumptions are not met then the coefficients in the model could be seriously biased and any confidence limits will probably be misleading. For the simple case of a linear regression of Var1 on Var2 these assumptions are:

i) In the long term average of the residuals is zero

This is automatically fulfilled by the least squares method.

ii) The residuals have a constant standard deviation which is independent of Var2; i.e. the spread of data about the line is no wider or narrower at different parts of the line. This can be examined by plotting the residuals against each explanatory variable in the model as illustrated in Figures B3 and B4.

iii) The residuals are uncorrelated with one another.

That is to say if the nth data value lies above the regression line then it has no influence on whether the (n+1)th value lies above or below the line. This can be checked by examining both the scatter diagram of the model and a plot of the residuals against time. This latter plot should indicate if the index used for deflation accurately reflects the way in which costs change. That is there should be no pattern in this plot of residuals against time.

iv) The residuals are Normally distributed.

This is examined by constructing a histogram of the residuals.

Outliers can be identified from this histogram or from the graph which illustrates the model equation. These outliers may distort the coefficients, make the correlation coefficient spuriously high or unrealistically widen the model's apparent range of applicability. These outliers were therefore examined in detail and discarded if any clear physical justification could be made. However they were not rejected on a purely statistical basis.

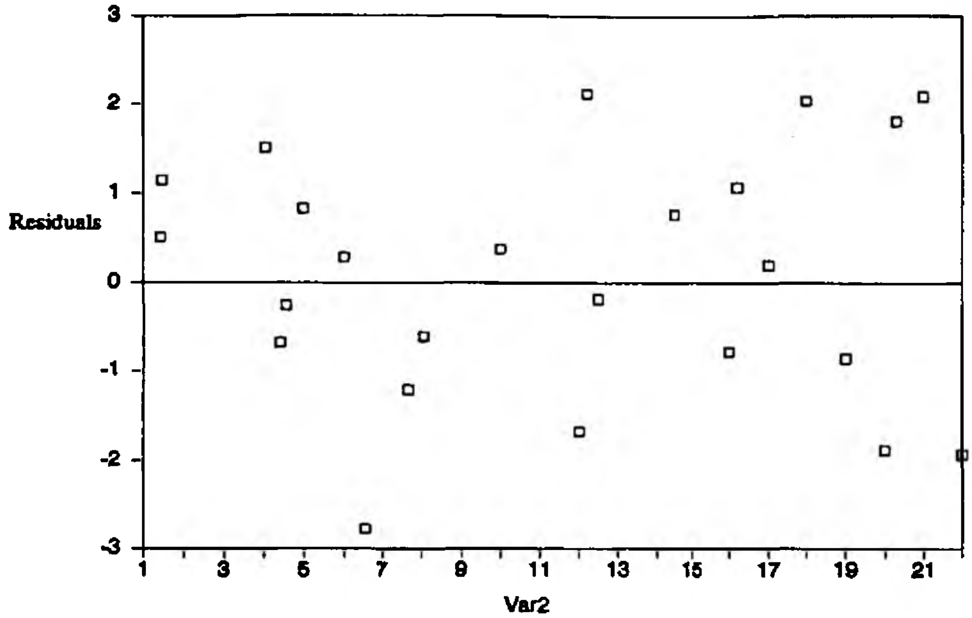

Figure B.3 Constant variance

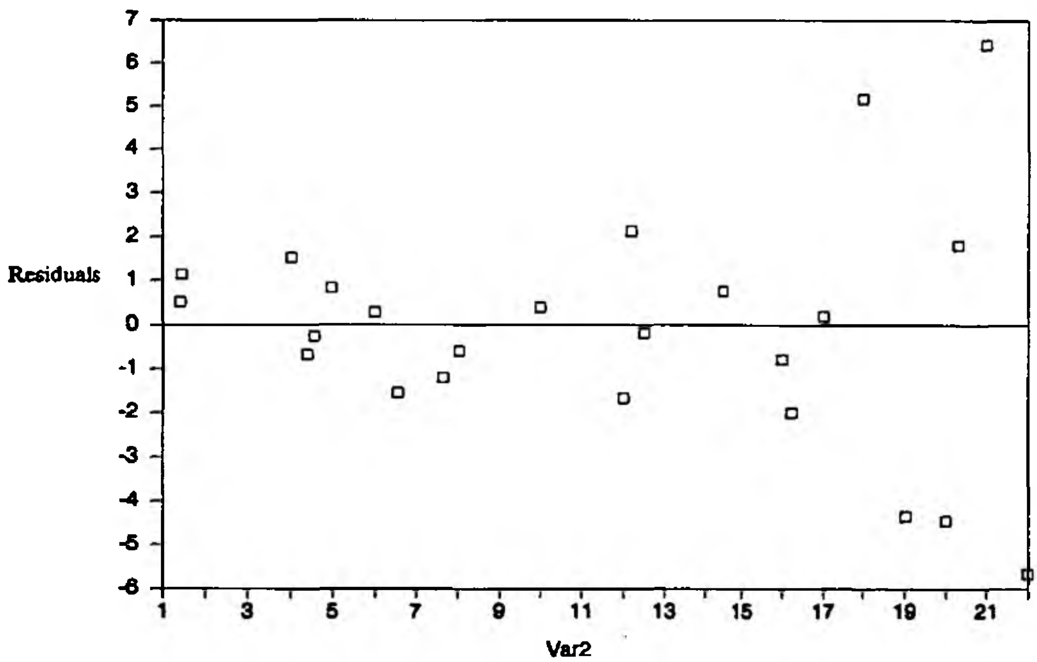

Figure B.4 Variance increasing with Var2

APPENDIX C

TABLE OF COST INDEX VALUES (1980=100)

These figures are in accord with WRc's latest information @ June 1991

	PUBLIC WKS	PWNR	METAL GDS	PUBLIC BLD	CONSTR MAT	G RETAIL P
80Q1	91.0	91.5	96.5	97.7	94.8	94.3
80Q2	97.0	96.6	99.0	104.0	99.8	99.8
80Q3	105.0	105.0	101.5	99.6	102.2	102.0
80Q4	107.0	106.9	103.0	98.7	103.3	103.9
81Q1	107.0	106.4	104.7	93.0	104.2	106.3
81Q2	106.0	105.2	106.4	96.0	107.6	111.5
81Q3	106.0	104.8	108.0	92.0	109.5	113.4
81Q4	105.0	104.3	109.8	95.0	111.4	116.2
82Q1	105.0	104.2	111.9	100.0	114.2	118.1
82Q2	104.0	103.7	113.5	93.0	116.8	121.9
82Q3	104.0	103.6	114.5	96.0	118.4	122.5
82Q4	103.0	102.7	115.4	92.0	119.5	123.4
83Q1	102.0	101.4	116.9	97.0	121.1	124.0
83Q2	103.0	102.2	119.0	97.0	124.4	126.5
83Q3	104.0	103.0	120.2	96.0	126.0	128.2
83Q4	103.0	102.6	121.7	95.0	128.2	129.6
84Q1	103.0	102.3	123.9	98.0	130.0	130.4
84Q2	104.0	103.1	125.4	102.0	133.0	133.0
84Q3	106.0	103.1	126.7	104.0	134.4	134.2
84Q4	106.0	105.6	128.2	100.0	136.6	135.9
85Q1	107.0	106.4	130.8	107.0	139.4	137.6
85Q2	108.0	108.1	133.2	109.0	141.9	142.3
85Q3	111.0	110.8	134.8	113.0	142.8	142.7
85Q4	112.0	112.0	136.1	113.0	143.1	143.4
86Q1	112.0	113.0	137.9	113.0	143.9	144.4
86Q2	112.0	113.7	139.5	111.0	145.9	146.3
86Q3	113.0	114.7	140.8	110.0	147.1	146.4
86Q4	114.0	114.8	142.0	115.0	148.6	148.3

	PUBLIC WKS	PWNR	METAL GDS	PUBLIC BLD	CONSTR MAT	G RETAIL P
87Q1	115.0	116.1	144.2	120.0	151.3	150.1
87Q2	116.0	117.9	145.7	118.0	153.7	152.4
87Q3	119.0	120.2	147.1	120.0	155.6	152.7
87Q4	121.0	122.3	148.4	118.0	157.5	154.4
88Q1	124.3	125.2	149.3	135.4	160.0	155.1
88Q2	127.6	130.0	151.2	138.8	162.1	158.9
88Q3	132.0	134.5	153.0	152.1	164.7	161.1
88Q4	137.5	138.6	154.7	148.7	167.9	164.5
89Q1	144.1	142.5	157.5	153.2	171.6	167.1
89Q2	147.4	147.0	159.5	184.3	174.5	171.9
89Q3	150.7	152.0P	161.3	160.9	176.1	173.5
89Q4	152.9	157.0P	163.6	157.6	177.8	176.9
90Q1	154.0	161.5P	166.7	154.3	180.2	180.1
90Q2	155.1 P	0.0	169.6	170.9 P	183.8	188.5
90Q3	0.0	0.0	171.8	0.0	185.2	191.6

0.0 = value NOT AVAILABLE   P = PROVISIONAL value

Short name	Full name/Notes
PWNR	PUBLIC WORKS NON-ROADS INDEX
PUBLIC WKS	PUBLIC WORKS OUTPUT PRICE Replaces Cost of New Construction Index for civil engineering work carried out by Public Sector.
METAL GDS	METAL GOODS ENGINEERING & VEHICLE INDUSTRIES OUTPUT PRICE Replaces Engineering & Allied Industries Output Price Index from 1981. Index for general engineering.
PUBLIC BLD	PUBLIC SECTOR BUILDING TENDER PRICE (ALL-IN INDEX) Produced by Directorate of Quantity Surveying Services. Replaces old DQSS index from 1976.
CONSTR MAT	CONSTRUCTION MATERIALS WHOLESALE PURCHASE PRICE Relates to materials purchased by the Construction Industry
G RETAIL P	GENERAL RETAIL PRICE (ALL ITEMS) Relates to goods and services purchased by domestic consumers.

APPENDIX D

DATA LISTINGS

DATA SET 1 - EARTH EMBANKMENTS

Data Point	Length m	Volume of fill '000m³	Direct cost '000	IDC %	Local material	Date
1	60	0.906	12.66	57.4	no	4.81
2	86	0.964	17.54	47.7	?	4.82
3	210	1.500	15.88	39.2	no	9.83
4	100	4.205	50.00	12.7	no	8.79
5	280	4.870	62.95	31.3	?	9.79
6	150	4.998	59.94	8.6	no	11.87
7	355	5.328	68.84	8.6	no	11.87
8	410	6.188	33.45	56.8	no	4.81
9	430	6.520	54.69	57.4	no	4.81
10	250	9.165	125.25	47.7	?	4.82
11	1043	15.500	164.16	9.4	partly	5.81
12	280	19.000	80.87	49.3	yes	4.89
13	2525	34.921	244.97	4.2	?	3.89
14	280	44.000	264.38	9.4	no	5.81
15	1400	52.000	287.88	36.4	partly	5.90
16	3080	56.000	250.50	22.4	?	3.88
17	?	69.120	177.45	37.2	yes	6.90

DATA SET 2 - REVETMENTS

Data Point	AREA m²	TYPE	IDC %	DIRECT COST £'000	DATE
1	540	1	12.74	24.412	8.79
2	940	1	52.96	24.419	1.89
3	1000	2	89.80	40.97	8.89
4	1332	3	51.26	34.619	12.89
5	1360	1	40.48	47.858	2.85
6	4400	2	51.43	147.66	8.89
7	8060	3	17.76	213.02	10.88
8	16955	4	30.24	336.22	2.82

TYPE
1 CON BLOCK
2 BLOCKSTONE
3 RIP RAP
4 RENO MATRESS

DATA SET 3 - ROCK ARMOUR

Data Point	ROCK VOLUME m^3	AREA m^2	ORIGIN OF ROCK	IDC %	DIRECT COST £'000	DATE
1	1296	469	SCANDINAVIA	33.54	64.491	4.89
2	4800	1480	UNKNOWN	36.65	187.24	12.89
3	5415	3500	UNKNOWN	51.26	122.6	12.89
4	8208	4320	SCANDINAVIA	33.54	427.358	4.89
5	9030	7848	UNKNOWN	51.13	226.042	8.89
6	12096	5000	SCANDINAVIA	41.55	413.945	8.90
7	19250	6663	UNKNOWN	38.28	621.727	4.89
8	23100	8580	UNKNOWN	19.49	927.563	2.90
9	28129	8800	IMPORTED	22.12	1355.033	5.90
10	40700	13400	UNKNOWN	29.74	1332.177	11.89

DATA SET 4 - CONCRETE SEABEES

Data Point	AREA m^2	IDC %	DIR COST £'000	DEPTH OF ARMOUR m	DATE
1	385	42.27	82.346	0.70	5.90
2	525	42.27	82.457	0.70	5.90
3	1144	46.51	163.059	0.70	4.90
4	2651	21.75	295.905	0.70	11.88
5	3522	42.27	503.442	0.70	5.90

DATA SET 5 - ROCK GROYNE OR BREAKWATER

Data Point	LENGTH OF ARMS (ARMOURED) m	LENGTH OF LAND LINK m	VOLUME OF ROCK m^3	IDC %	DIRECT COST £'000	DATE
1	120	60	3093	12.31	174.061	12.86
2	130	80	3607	12.31	203.072	12.86
3	134	70	7400	7.79	271.661	2.88
4	293	112	35200	7.79	1018.733	2.88
5	410	180	54020	5.69	1871.189	4.86
6	435	180	79500	4.81	2533.565	12.86

DATA SET 6 - CANTILEVERED WALLS

Data Point	LENGTH m	X-SECTIONAL AREA m^2	VOLUME OF CONCRETE m^3	IDC %	DIRECT COST £'000	DATE
1	12	0.7	8.4	32.83	0.999	4.80
2	9	1.54	13.86	32.80	1.994	4.80
3	16	2	32	6.71	3.75	4.80
4	49	1.18	57.82	32.81	16.507	7.89
5	134	0.7	93.8	53.63	15.638	4.80
6	205	0.8	164	32.81	29.707	10.81
7	155	1.52	235.6	42.27	31.124	9.79
8	308	0.825	254.1	32.81	36.861	4.80
9	210	1.24	260.4	31.15	44.675	9.79
10	520	0.77	400.4	53.63	71.125	10.81
11	700	0.8	560	53.63	86.942	10.81
12	770	0.75	577.5	53.63	89.935	10.81

DATA SET 7 - RAISING EXISTING WALLS

Data Point	LENGTH m	HEIGHT RAISED m	X-SECTIONAL AREA m^2	VOLUME OF NEW MATERIAL m^3	IDC %	DIRECT COST £'000	DATE
1	10.9	0.3	0.06	0.654	47.56	1.743	6.89
2	16.8	0.3	0.18	3.024	58.90	6.007	6.89
3	21.5	0.3	0.16	3.44	58.91	1.363	6.89
4	60	0.8	0.46	27.6	32.80	8.631	4.80
5	98.3	?	0.33	32.439	58.90	25.478	6.89
6	44.1	0.3	0.91	40.131	47.57	16.632	6.89
7	250	0.42	0.4025	100.625	11.05	37.891	11.87
8	91	0.3	1.25	113.75	58.90	34.699	6.89

DATA SET 8 - PILING AT THE TOE

Data Point	LENGTH OF WALL m	AREA OF PILES m	PILE TYPE	PILING COST £'000	IDC %	DATE
1	52.0	275	F-1N	17.769	42.3	5.90
2	57.0	285	F-1N	22.353	42.3	5.90
3	71.0	355	F-1N	22.239	42.3	5.90
4	82.5	388	L-3	21.319	32.0	10.89
5	135.0	582	L-3	33.173	32.0	10.89
6	205.0	828	L-3	35.235	32.0	10.89
7	200.0	1250	L-6W	93.409	46.5	4.90
8	350.0	1780	F-1N	78.498	25.2	1.88
9	380.0	1900	F-1N	86.903	8.9	1.87
10	375.0	1914	F-1N	92.222	21.7	11.88
11	280.0	2492	L10B20	144.143	7.2	2.83

DATA SET 9 - PILING COSTS FOR WALLS

Data Point	LENGTH OF WALL m	LENGTH OF PILES m	PILING COST £'000	IDC %	DATE
1	38	3.325	5.680	26.0	10.89
2	22	9.0	20.976	6.7	7.89
3	28	12.0	35.075	47.6	6.89
4	88	5.0	14.027	26.0	10.89
5	440	3.0	76.161	33.5	8.83
6	145.5	10.8	194.779	58.9	6.89
7	200	8.35	47.897	31.2	7.80
8	402	5.10	92.814	26.0	10.89
9	1200	3.30	92.537	26.6	1.81
10	2210	2.50	160.734	33.5	8.83
11	655	8.20	165.422	31.2	7.80
12	634	9.11	239.375	31.2	7.80
13	930	12.35	598.212	31.2	7.80

DATA SET 10 - TIMBER GROYNES

Data Point	GROYNE LENGTH m	TYPE	TOTAL AREA OF SHEETERS m^2	NUMBER OF GROYNES	DIRECT COST £'000	DATE
1	37.5	1	172	5	116.889	5.90
2	37.6	1	100	2	48.824	5.90
3	37.6	1	290	4	127.369	5.90
4	39.86	1	492	7	198.042	5.90
5	40.71	1	1066	13	536.121	5.90
6	45.93	2	867	7	130.502	2.90
7	48.6	2	467	4	85.882	4.90
8	39.6	2	577	6	86.89	4.89
9	39.6	2	192	2	19.787	12.89
10	38.4	3	?	1	10.642	3.89

1 Greenheart piles and sheeters
2 Douglas Fir pressure impregnated with creosote
3 EKKI boarding (type of piling unknown)

DATA SET 11 - BEACH RECHARGE

Data Point	VOLUME m^3	SOURCE OF MATERIAL	IDC %	DIRECT COST £'000	DATE
1	7376	Store	26.83	7.924	2.81
2	17900	Store	25.03	54.889	4.88
3	30000	?	41.55	50.586	8.90
4	50000	Dredged	0.79	584.74	8.87
5	58500	LOCAL	7.06	504.25	12.86
6	81000	?	4.93	726.2	6.86
7	98586	LOCAL	7.29	505.171	5.90
8	132000	?	17.66	1025.9	12.86
9	250000	LOCAL	5.36	694.65	6.83
10	278503	?	8.35	3881.67	6.90
11	1450000	Dredged	1.13	6486.7	10.86

DATA SET 12 - DUTCH DATA ON BEACH RECHARGE

Item *	RECHARGE LOCALITY	YEAR	SAND QUANTITY (10^6 m^3)	SEA TRANSPORT DISTANCE (km)	UNIT PRICE AT 1984 LEVELS (DFL m^{-3})	FEATURES OF SCHEME
1.	Ameland	1980	2.20	8 to 14	3.51	Dune protection
2.	Ameland	1979	0.31	08. to 1.5	4.35	Dune protection and recreational beach
3.	Texel Eierland	1979	3.05	2.5 to <>.0	4.35	Protection of hinterland
4.	Texel Eierland	1985	2.85	4 to 9	2.50	Erosion control
5.	Texel, De Koog	1984	3.02	10 to 16	3.80	Protection of dune area with recreational interest
6.	Callanstoog	1976/77	0.35	6 to 15	8.97	
7.	Callanstoog	1979/80	0.47	6 to 15	8.25	
9.	Scheveningen	1975	0.70	20	13.30	Additional 1 to 3.5 km distance for transport and compaction overland; recreational beach
11.	Hoek van Holland	1971/72	18.94	2 to 4	0.99	Protection of hinterland
16.	Voorne	1977	1.10	10 to 12.5	4.64	Strengthening dunes; protection of hinterland
18.	Voorne	1984/85	3.40	9 to 12	3.80	
19.	Goeree	1969/70	0.40	5 to 9	6.17	
20.	Goeree	1971	0.61	5 to 6.5	4.07	
21.	Goeree	1973/74	3.64	4. to 7	1.74	
22.	Goeree	1977	1.27	7.5 to 4.80	4.80	
23.	Goeree	1985	0.33	32 to 65	11.70	
26.	Noord Beveland	1973	0.21	4	0.69	Erosion control
27.	Walcheren	1984	0.20	11 to 13	10.00	Erosion control
31.	Vlissingen	1975	0.045	0.5	12.14	Extending beach for recreation

* Numbering corresponds to Table 3.1, pp34-5 of Rijkswaterstaat 'Handboek zandsuppleties' (1988)

APPENDIX E

PROJECT CONTACTS

REGION	PROJECT CONTACT	
ANGLIAN	Robert Runcie	0733 371811
	Fax	0733 231840
NORTHUMBRIAN	Tony Clarke	091 2130266
NORTH WEST	Paul Stainer	0925 53999
SOUTHERN	Graham Fisher	0903 820692
SOUTH WEST	David Woodcock	0392 444000
WELSH	Mike Davies	0248 370970
WESSEX	Bill Clarke	0278 457333
YORKSHIRE	Kevin Jeynes	0532 440191

Note : Severn Trent and Thames Regions did not contribute data due to their lack of seaboard.

APPENDIX F

COMBINATION OF ESTIMATES

Each model will give an estimated cost and associated confidence limits, in order to obtain the total cost it is necessary to combine the estimates and calculate confidence limits for the total.

The total of estimates is simply the sum of the individual estimates. However, it is not possible to combine the corresponding individual confidence intervals in the same way to obtain a confidence interval about the overall estimate. This is a consequence of the multiplicative structure which it was necessary to assume for each individual model; indeed under these circumstances no exact statistical solution can be found, there is, however an **approximate procedure** that can be used.

For simplicity suppose that just two cost functions, C_1 and C_2, are being combined to provide a total cost estimate for a particular schemes (the argument can be generalised to more than two functions without difficulty). Associated with each cost function is a multiplicative error: suppose these are denoted by m_1 and m_2.

Then estimated total cost = $C_1 + C_2$ ... (F-i)

and actual total cost = $C_1m_1 + C_2m_2$ ... (F-ii)

It is important to appreciate that the scheme in question will at this stage only be in the planning stage, and not actually have been built. Its cost is **estimated** by equation (F-i), but the **actual** cost is unknown and can be thought of as lying somewhere in the distribution obtained by varying the errors m_1 and m_2 in equation (F-ii). The quantities m_1 and m_2 are in fact log-Normally distributed: this follows from the assumption discussed in Section 2 and upheld by thorough checks during the development of the models, that the errors about the log-log models are Normally distributed. Thus 'actual' cost as defined by equation (F-ii) is the sum of two log-Normal variables. Unfortunately this does not produce a recognisable distribution which can be handled by analytical statistical methods (in the same way that, for example, the sum of two Normally distributed variables is itself Normal). There is therefore no exact method of obtaining confidence limits about the quantity $C_1 + C_2$.

It is, however, possible to calculate the mean and standard deviation of $C_1m_1 + C_2m_2$ knowing the distributions of m_1 and m_2, and these form the basis of an approximate confidence interval, as follows.

Suppose that $\log_{10}m_1$ is Normally distributed with mean 0 and standard deviation $\sigma1$ and that similarly $\log_{10}m_2$ has standard deviation $\sigma2$.

Making the assumption that m_1 and m_2 are statistically independent, the variable $C_1m_1 + C_2m_2$ has a mean

$$M = C_1(14.2)^{\sigma1^2} + C_2(14.2)^{\sigma2^2} \qquad \ldots \text{(F-iii)}$$

and standard deviation

$$S = \sqrt{\{ C_1^2(200.7)^{\sigma1^2}\{(200.7)^{\sigma1^2} -1\} + C_2^2(200.7)^{\sigma2^2}\{(200.7)^{\sigma2^2} -1\}\}} \ldots \text{(F-iv)}$$

(The numbers 14.2 and 200.7 arise as various combinations of 10 and the mathematical quantity e).

Although the exact distributions of $C_1m_1 + C_2m_2$ cannot be determined, there is some statistical justification (the Central Limit Theorem) for supposing that it is at least approximately Normal. Under this assumption, confidence limits for $C_1m_1 + C_2m_2$ can be formed in the usual way, namely $M \pm 1.3S$ (80%) and $M \pm 2.0S$ (95%).

It is convenient to turn these additive limits into multiplicative limits by expressing them relative to the estimated cost, $C_1 + C_2$. Thus the 80% multipliers, for example, would be

$$\frac{M - 1.3S}{C_1 + C_2} \quad \text{and} \quad \frac{M + 1.3S}{C_1 + C_2} \qquad \ldots \text{(F-v)}$$

If the total cost estimate is formed by summing more component estimates, equations (F-iii) and (F-iv) are simply extended by similar terms involving C_3, $\sigma 3$, C_4 and $\sigma 4$ and so on as necessary.

APPENDIX G

PRO-FORMA CALLING FOR FURTHER DATA

In order to maintain an update of this manual, it would be helpful if engineers awarding sea defence construction contracts would provide the following brief particulars:

NOTIFICATION OF CONTRACT AWARDED FOR SEA DEFENCE WORKS

NRA Region ....

NRA contact (name and tel. no.) ....
....

Contract name ....
and description ....
....

Project Reference No. ....

Tender price and date £.............. __ /___/199_

Extent of works ....(km)
(include NGRs of each end) ....
....

Categories of work included
(tick boxes)

Embankments < >
Revetment < >
Steel sheet piling < >
Precast concrete < >
Poured concrete < >
Groynes < >
Beach recharge < >
Rock armour < >
Access roads < >

Please send completed forms to:

R Runcie
NRA Anglian Region
Kingfisher House
Goldhay Way
Orton Goldhay
Peterborough
PE2 0ZR

APPENDIX H

DISTRIBUTION OF DATA POINTS BY REGION

CLASSIFICATION / REGION	Revetments	Rock Armour	Timber Groynes	Rock Groynes	Beach Nourishment	Concrete Walls	Concrete Caps	Earth Embankments	Sea-bees	SS Piling Walls	SS Piling Toe	TOTAL
(35) ANGLIAN	1	4	10	6	5	3	6	7	5	11	10	68
(9)* NORTHUMBRIAN	1	1	-	-	1	-	-	-	-	-	1	4
(2) NORTH WEST	-	-	-	-	-	-	-	2	-	-	-	2
(8) SOUTHERN	1	-	-	-	2	9	1	6	-	-	-	19
(2) SOUTH WEST	-	-	-	-	-	-	-	-	-	-	-	-
(3) WELSH	-	-	-	-	-	-	1	1	-	2	-	4
(7) WESSEX	4	2	-	-	2	-	-	1	-	-	-	9
(4)** YORKSHIRE	1	3	-	-	-	-	-	-	-	-	-	4
NO OF POINTS IN MODELS	8	10	10	6	10	12	8	17	5	13	11	110

NOTE : The numbers in parenthesis above the names of the Regions indicate the number of sets of tender documents supplied. In some cases information was incomplete and could not be used, in other cases a set of tender documents supplied two or more data points.

* Northumbrian tenders provided by Wansbeck D.C. (3), Blyth Valley (3), Hartlepool B.C. (2) and Berwick-upon-Tweed B.C. (1).

** Two of the Yorkshire tenders were supplied by HOLDERNESS B.C.