EVALUATION AND DEVELOPMENT

OF

DRAINAGE AND PIPELINE CONSTRUCTION PROCESSES

VOLUME 1

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A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

THE UNIVERSITY OF ASTON

OCTOBER 1981

S U M M A R Y

In 1974 Dr D M Bramwell published his research work at The University of Aston, a part of which was the establishment of an elemental work study data base covering drainage construction. The Transport and Road Research Laboratory decided to extend that work as part of their continuing research programme into the design and construction of buried pipelines by placing a research contract with Bryant Construction.

This research may be considered under two broad categories. In the first, site studies were undertaken to validate and extend the data base. The studies showed good agreement with the existing data with the exception of the excavation, trench shoring and pipelaying data which was amended to incorporate new construction plant and methods. An inter-active on-line computer system for drainage estimating was developed. This system stores the elemental data, synthesizes the standard time of each drainage operation and is used to determine the required resources and construction method of the total drainage activity.

The remainder of the research was into the general topic of construction efficiency. An on-line command driven computer system was produced. This system uses a stochastic simulation technique, based on distributions of site efficiency measurements, to evaluate the effects of varying performance levels. The analysis of this performance data quantifies the variability inherent in construction and demonstrates how some of this variability can be reconciled by considering the characteristics of a contract. A long term trend of decreasing efficiency with contract duration was also identified.

The results obtained from the simulation suite were compared to site records collected from current contracts. This showed that this approach will give comparable answers, but these are greatly affected by the site performance parameters.

Keywords: Drainage, Work Study, Estimating, Simulation.

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Submitted for The Degree of Doctor of Philosophy

1981

ACKNOWLEDGEMENTS

The Author wishes to express his thanks to the following people for their assistance and guidance throughout the research period;

DR D M BRAMWELL	-	Alwood Limited
DR T R E CHIDLEY	-	The University of Aston Department of Civil Engineering
MR D M FARRAR	-	The Transport and Road Research Laboratory
MR J McGREGOR	-	The University of Aston Management Centre
MR M C G SMITH	-	Bryant Construction Limited
DR D J vanREST	-	The University of Aston Interdisciplinary Higher Degrees Scheme

The Author would also like to express his thanks for the encouragement and assistance of all his family, colleagues and friends in the production of this work.

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NOTATION

Section 3.3 Simulation Theory

n = Theoretical gang size

na = Actual gang size

Z = Number of hours per day

Pm = Total productive measured hours (man hours)

Pu = Total productive unmeasured hours (man hours)

Wt = Waste time - Wat, Waiting, Non-productive (man hours)

ta = Total attendance time (man hours)

Su = Standard man hours per unit of production

Sh = Total standard hours based on measured work

q = Quantity produced in unit time period

Q = Total activity quantity

T = Simulated construction duration (gang hours)

Ts = Standard activity duration (gang hours)

$\hat{Pu}$ = Pu expressed as a percentage of ta

Section 3.4.3 Network Analysis

Tsi = Standard duration of operation i

Ci = Total cost of operation i

Pij = Number of items of plant type j required in operation i

Lij = Number of labour type j required in operation i

Mij = The quantity of material type j required in operation i

cpj = Unit cost of plant type j

clj = Unit cost of labour type j

cmj = Unit cost of material type j

CHAPTER 1.

INTRODUCTION.

1.1 COLLABORATING ORGANISATIONS.

This research resulted from a tripartite agreement between three different types of organisation. The work was instigated by the Transport and Road Research Laboratory, a government research establishment and carried out at Bryant Construction Limited, building and civil engineering contractors. The project was undertaken by a graduate student of the University of Aston's Interdisciplinary Higher Degrees and Total Technology schemes and the department of Civil Engineering.

1.1.1. Bryant Construction.

The company is a wholly owned subsidiary of Bryant Holdings Limited of Solihull, West Midlands. The parent company was founded in the late 1880's and became a "limited liability" company in 1927. The Bryant Holdings Group operate in all aspects of construction work; property development, local authority and private housing,structural design, civil engineering and general construction. In the early 1960's the Civil Engineering division was formed to undertake 'pure'civil engineering,including roads,structures,and main drainage sewage schemes and tunnelling. During its early years that divisions work was mainly within the Birmingham conurbation although later its working area was expanded to cover all the Midlands, Yorkshire,Wiltshire and Oxfordshire.
In 1979 due to restructuring within the Group the general contracting division and the Civil Engineering division were amalgamated into one company, Bryant Construction. At the present time this company has 30 contracts under construction with an annual turnover of approximately £30M.

1.1.2 The Interdisciplinary Higher Degrees Scheme.

The main aim of the IHD scheme is to broaden a graduates experience by means of interdisciplinary research training (see van Rest in Braun 1977). Not only in the narrow sence of breaking into neighbouring fields such as extending civil, into mechanical engineering but also to cover the full range of industrial activity both commercial and technical as is required in practical problem solving in real situations. Chang (1973) quotes the Joint Science Research Council and the Social Science Research Council Committee of taking the view that :

> "...research in breadth is as challenging and demanding as specialist research, is in no way superficial or shallow, requires able people to persue its aims and is a proper activity for a university to undertake"...

This approach is based on a three year period of research which is intended to solve an industry based 'problem'. The student is guided through the research by a committee which is made up of academic supervisors from the relative disciplines within the university,industrial supervisors from the sponsoring organisations and an IHD tutor to coordinate the research as a whole. Each student spends the majority of his time working in the sponsoring organisation on the project or closely related topics, the remainder being at the university. In addition to this the Total Technology scheme provides formal courswork on unrelated topics and also opportunities to participate in business games, design exercises, visits etc..(see Mongomerie 1977) to augment the project work and to further realise the objectives of the scheme.

1.1.3 The Transport and Road Research Laboratory.

The Laboratory was first formed in 1933 as the Road Research Laboratory to tackle a limied range of highway problems, Since that time its scope has increased and from 1960 onwards the engineering work has expanded to include research on bridges and tunnels and also work began on transport operations and systems. In 1972 it was renamed the Transport and Road Research Laboratory to reflect its wider activities and interests.

1.1.3.1. The laboratory provides technical and scientific advice and information to help in formulating,developing and implementing government policies relating to roads and transport, including their interaction with urban and regional planning. This is achieved by carrying out research and related activities in highway engineering,traffic engineering and safety, and in more general transport.

1.2 BACKGROUND TO THE RESEARCH

The research was conceived following the work of Dr. D.M.Bramwell who had successfully completed a period of research under IHD at Bryant's in 1974. Bramwell's brief was to analyse the company's existing management information systems and to indicate where the introduction of computer facilities would be beneficial. He found that such systems were 'data hungry' and consequently one aspect of his work was to complile a work measurement data base covering main drainage construction. This data primarily for estimating both pipeline and manhole construction costs is stored on computor and provides "raw" data for construction estimators and planners. To extend this standard time data into anticipated construction durations Bramwell developed a stochastic simulation suite of computer programmes to model site construction. The suite uses distribution of actual site efficiency measurements available from Bryants to investigate the effects of the numerous factors which affect site productivity. In essence Bramwell's system can be summarised as follows :

(a) Determine the resources required, and standard duration of each operation to be performed using the work measurement data, and

(b) Investigate the effects of and make allowances for site productivity using the sumulation suite.

1.3 TRRL INVOLVEMENT.

At about the time that Bramwell's research was published the Earthworks and Underground Pipes division of TRRL were also investigating drainage construction costs. This forms part of their programme of research into the design and construction of underground pipelines. They appreciated that the draw backs to their own cost model (Farrar, 1976) were the limited amount of data on some construction operations and also its simplified approach to site management problems. Consequently they decided that it would be advantageous to continue Bramwell's work to overcome these shortcomings. This was achieved by awarding an external research contract to Bryant, who in turn, placed a postgraduate student in the IHD scheme at Aston University.

1.4. THE BRIEF

The research brief can be considered in two stages :

(a) To verify the existing work measurement data base and to extend this to cover new and changed construction methods and materials.

(b) To verify the simulation suite using site production data and to then use this model to investigate pipeline construction methods and materials.

1.5. RESEARCH PRESENTATION.

The thesis is presented in two volumes, the first of which contains the main text. The second volume contains detailed data records, computer listings and users handbooks etc.. The main test is in five chapters of which chapters one and five are the introduction and conclusion respectively. To expand on the research brief the remaining chapters are summarised below.

1.5.1. The first problem was the validation of the work measurement data base. This was approached by performing work studies on site to obtain global time measurements which were then compared to the computer synthesis. Where anomalies were found then further, more detailed studies were carried out to correct these discrepancies. This work is described in the first part of chapter two. The remainder of that chapter presents the new computer software for on-line data storage and retrieval.

1.5.2. Bramwell's system utilises the site performance measurements which are recorded at Bryant's. Additional data was available and this, together with the various investigations into the nature of these measurements are presented in the first part of chapter three. The latter part of that chapter presents the new computer software for on-line, command driven project analysis and simulation.

1.5.3. The objective of the computer simulation programmes is to evaluate the effects on construction duration, of varying levels of site performance. In order to verify this simulation it is necessary to have something to "measure" it against. Chapter four presents the data which was collected and the subsequent comparisons which were made between that data and the results from the simulation programmes.

1.6. HISTORICAL REVIEW.

1.6.1. Work Study.

The first recorded example of work study was in 1760 by Perronet, using the "scientific" method to study pin manufacture, this approach was continued by Babbage in 1832 with further studies of the same operation. Modern work study techniques were pioneered by Taylor and Gilbreth in the USA during the late 19th and early 20th centuries, and the first major applications of these techniques was in the study of munitions manufacture during the 1914-18 war. In the 1930's and 40's Imperial Chemical Industries practised time and motion studies and some of the experience of that organisation were published by Currie (1947).

The construction industry was slow to realise the full potential of work study (Geary, 1969) which seems surprising as Gilbreth was a civil engineering contractor in the USA. Many contractors have work study functions to maintain work measurement data bases. These data are closely guarded but an example is quoted by Laing (1976), and the way they are used in a total project system is described by Kelsall (1972). Work study has been applied to construction to obtain data for specific analyses. The Building Research Establishment has used activity sampling in a study of critical path methods.(Roderick,1977) and the Transport and Road Research Laboratory have used various work measurement techniques for highway bridge construction (Hall,1976) and for efficiency studies of earthmoving plant (Parsons,1977). Work Study departments have been slow to accept computers (Mapes,1975), although various authors have described the way in which they can be used (Steel,1974,Bonney, 1975). There are three main areas in which computers can be used to process work measurement data :

(a) In the analysis of large amounts of data,as in the study of the clerical activities of the United States unemployment Insurance service (Kenyon,1975).
(b) For the generation of standard times based on different combinations of the same ground of elements in situations where a file of elemental standard data can be maintained on the computer. (Murphy,1979, Johnson,1973, Lippowitz,1972).
(c) To convert the results of motion analysis into standard data as in the 4M data system (Martin,1974).

1.6.2. Planning.

Modern network planning techniques were developed in the USA during the 1950's. PERT, the programme evaluation and review technique was used by the bureau of naval weapons for the Polaris project and Critical path methods (CPM) were developed in 1957 and 1958 by the Dupont Company and Remmington Rand Univac.

A survey of the construction industry in 1968 (Wade) showed that these techniques described by Baker (1969) were widely used by both contractors and consultants. At that time the smaller networks, under around 200 activities could be analysed manually with the larger and more complex being processed by computer.

A disadvantage of this was the large amount of computer output produced, Martin (1969) rationalised the use of PERT based on the 'Principle of Minimum Information' (Broome 1967).

The increasing availability and use of computers (Townsend 1969) had a great effect on the use of network planning techniques and specific programmes were developed for generating and drawing networks (Smith, 1972-Hayes 1969, Gramlich, 1972) and for construction cash flow forecasting (Reinscmidt 1976). During the 1970's there has been a change in the use of computers from batch to on-line processing, one of the earliest applications was "MINIPERT" (Hansen, 1969) a command driven critical path programme. From a survey in 1974 (Reilly) the desirable features of inter active planning programmes were identified. Project control is an allied function to planning and the relationships between planning and control are described by Naaman (1974) and Paulson (1976), Croissant (1974) describes an on-line computer programme for project control.

1.6.3. Simulation

The process of simulation involves the use of random sampling from known distributions of empirical data. The present day use of these stochastic processes is extensive although the technique is now new.

The first recorded incidence of sampling was in 1908 by W.S. Gosset (student) when developing students "t" statistic, cited by Teicharew (1956). Randomness in sampling was first used by L.H.C. Tippett in 1925. Stochastic simulation is a tedius and time consuming business when performed manually and with the increasing availability and use of computers in the early 1970's it was realised that here was a way to investigate the uncertainties inherent in the construction industry (Tavistock Institute 1965). The most commonly used method that of "Monte-Carlo" simulation and its application to construction is described by Berman, (1965).

One of the main drawbacks in the use of network planning techniques is the estimation of activity times (Wade). This is partially overcome by PERT's use of three times for each activity (Robillard, 1976) and one of the first applications of simulation was to investigate the effect of introducing randomness into networks. This had been done deterministically by Pore (1969) who calculated the mean and standard deviation of each activity duration and was further analysed stochastically by Gray (1969), Halpin (1972) and Dessousky (1972). Gray developed a "criticallity index" showing how often each activity was on the critical path in successive simulations of the same network. Fine (1970) developed a management game based on the construction of twenty repetative office blocks, to investigate the effect of different construction strategies and again in 1976 discussed the effects of randomness in construction.

The first application of simulation to a specific operation was by Gaarsley (1969) who used a stochastic model to estimate the productivity of materials handling equipment. This model with some modification was used in conjunction with general queuing theory to estimate earthmoving costs (Willenbrock, 1972). The effects of the weather on construction has been the subject of research by various authors, Benjamin 1973, Harris 1975 and Shepard 1977, these last two authors used distributions of actual weather statistics collected by the Meterological office. A tunnelling cost model was developed by Moavenzedah (1976) using probabilistic distribution of geological conditions and construction operations.

1.6.4. Estimating

There are two main methods of construction cost estimating namely unit costs and operational pricing. Unit costing is the traditional widely used method although operational pricing is becoming more popular (Erickson 1976). Both of these methods use some form of historic data, depending on the system being used, as a starting point from which a "new" estimate is derived. For an example of unit cost data see Geddes (1971) while for operational pricing data is required on resource usage (see work study section). These requirements pose problems of data collection and interpretation, Nordby (1970) describes a system for collecting unit cost data. The estimator must then amend these historic data to conform to the specific conditions under consideration this is usually done from a subjective assessment by the estimator although various statistical techniques are available to analyse unit costs, weighted and moving averages etc, described by Kawal (1971).

The basis of estimating is the Bill of Quantities (B of Q) which sets out the quantities of the work to be performed. Stark (1971) using Fine's management game showed how the B of Q distorts project planning. In 1971 a major revision to the Standard Method of Measurement of Civil Engineering Quantities was instigated. One of the objectives of this revision was

> "to take account of new techniques in Civil Engineering construction and management, their influence on the work itself and on the administration of the contract".

In this way the Civil Engineering Standard Method of Measurement (CESMM, 1976) changed the bias from "quantity" to "operational" B of Q's which in turn laid more emphasis on operational pricing.

This new B of Q structure also facilitated data manipulation by computer by using standardised work classifications.

Construction variability is as prevalent in estimating as it is in planning and various authors have investigated probablistic estimating, Gates (1971) categorised the various contingencies into four groups, mistakes, subjective uncertainty, objective uncertainty and chance variation. A mathematical model was developed by Spooner (1974) by assuming that all estimates are random variables, and showed that the risk and uncertainty of an estimate can be quantified based on subjective three value estimates for primary quantities as well as judgements about the correlation between different activities. The accuracy of an estimate is also dependant on the level of detail considered Vergara (1974) presents a method whereby the optimum level of detail can be determined based on the increase of accuracy against the value of this increased reliability of estimate.

With the increase in the use of computers various computerised estimating systems have been developed. Boyer (1972) describes an on-line interactive estimating system which uses an eight stage process in estimate build up, from accessing historical data to producing the final estimated figure. There has also been an increase in the use of cost models, one of the earliest of which is described by Barnes (1972) who in subsequent papers discusses their use in planning and cost control (1977) and for evaluating different design and construction strategies (1976). Farrar (1977) produced a model for hand calculation of the costs of laying rigid sewer pipes, and the Transport and Road Research Laboratory have developed a computer based design/cost model for highway construction (Bailey 1978).

CHAPTER 2

PIPELINE ESTIMATING SYSTEM

SUMMARY

This chapter describes the additions to, and revisions of, the work measurement data base of pipeline construction operations. Subsequently an estimating system which uses this data is introduced, together with an inter-active on-line pipeline estimating computer suite.

2.1 INTRODUCTION.

The primary source of data for the time analysis section of the estimating system described in section 2.4 is the work measurement data base. The data is in elemental form so that it can be used for the synthetic evaluation of any drainage configuration. This is achieved by combining the basic elements of work which comprise each pipeline construction operation. The objectives of the research undertaken in connection with thedata base are as follows:-

(a) By applying work measurement techniques to on-site construction obtain operation standard times to compare to those arrived at by synthesizing the same operation, and

(b) Where disparities are observed in these two measurements to perform more detailed studies to rectify the discrepancies.

(c) To obtain data on 'new' construction operations which have been developed since Bramwell's original work.

2.2 DATA BASE.

2.2.1. Construction Operations.

Pipeline construction consists of, at most, six construction operations, these are:-

Road Breakout - This applies mainly to urban construction where the metalled road surface is removed prior to trench excavation.

Trench Excavation- The trench which will recieve the pipe is excavated, usually by hydraulic excavator, although in certain circumstances hand excavation may be necessary.

Shoring --The trench support structure is erected within the trench. This structure may be of the traditional "plank and strut" kind or one of the proprietory trench support systems.

Pipe Bedding - The permanent pipe support structure is constructed. This structure may be of concrete, gravel or selected excavated material or a collection of one or more of these materials.

Pipe-laying. -The pipe is then lowered into the trench, jointed with those already laid and is checked for alignment.

Backfill. -The trench is then backfilled, usually up to the original ground level.

2.2.2. Work Elements.

Each construction operation is comprised of a number of work elements, the number of elements which are observed for a particular operation will vary but may be as many as seventeen in the case of pipelaying. The individual elements are discussed in more detail in the relevant parts of section 2.3.

2.2.3. Data Collection.

To obtain data with which to check the accuracy of the existing synthesis studies were made of site construction. Two different work measurement techniques were used, depending on the type of data required.

2.2.3.1. Activity Sampling.

This is a work measurement technique in which a large number of instantaneous observations are made of a group of workers. At each observation the particular item of work each operative is employed on is recorded. The individual times are then the percentage of the total study period occupied by each operation. For site studies systematic activity sampling (Flowerdew, 1963) was used. This method is applicable for studies of operations where the sampling interval is less than the shortest element. In these studies only the various construction operations were observed with no attempt being made to split operations into smaller work elements.

Table 2.1 WORK STUDY, RELAXATION AND CONTINGENCY ALLOWANCES.

Operation Element	A	B	C	D	E	F	Total (%)	Work Cont.%	Delay Cont.%
Excavation	8	2	4	2	0	1	17	1	2
Excavation Support	8	2	0	4	4	0	18	1	2
Pipe Laying	8	2	5	4	4	0	23	1	2
Pipe Bedding	8	2	0	4	4	0	18	1	2
Backfill	8	2	0	4	2	0	16	1	2
Road Breakout	8	2	0	4	4	0	18	1	2
Base Blinding	8	2	4	4	4	0	22	1	2
Channel Construction	8	2	4	2	1	0	17	1	2
Manhole Structure	8	2	4	4	4	0	22	1	2
Concrete Surround	8	2	0	4	4	0	18	1	2
Concrete Slabs	8	2	0	4	4	0	18	1	2
Benching	8	2	5	2	1	0	18	1	2
Fitting	8	2	0	4	1	1	16	1	2
Miscellaneous	8	2	0	4	4	0	18	1	2

2.2.3.2. Stop Watch Studies.

Where data on "new" construction activities was required, and where the activity sampling had showed a wide divergence from the existing sysnthesis, then more detailed stop watch studies (see I.L.O. 1977) were performed. These studies considered the individual work elements which comprise each operation.

2.2.3.3. Relaxation Allowances.

With both types of study the results are expressed in basic minutes. To determine the standard times various relaxation and contingency allowances must be made depending on the type of work being observed. The relaxation and contingency allowances are shown in Table 2.1.

2.3. DATA REVISIONS.

The revisions to the data base which were made as a result of the above studies are discussed below.

2.3.1. Excavation.

The existing excavation model used both physical and operational data covering ten hydraulic excavators.

2.3.1.1. Physical data.

Details of the excavators considered by Bramwell are shown in table 2.2. Since that time the machine manufacturers have rationalised their product range and this has meant a revised machine list of nine excavators. In addition to this there has also been a standardisation of bucket sizes and capacities. This revised data is shown in tables 2.3 and 2.4.

Table 2.2 Excavator Physical Data, Bramwell (1974).

Machine Type	Digging Depth (mm)			Horizontal Reach (mm)			Loading Height (mm)		
	Normal	Short arm	Long arm	Normal	Short arm	Long arm	Normal	Short arm	Long arm
JCB 3	3700			5410			3450		
JCB 3C	4190			5570			3380		
JCB 3D	4180			5570			3290		
JCB 5C		5760			9020			6270	
JCB 6C		5610	6350		8740	9200		5330	6050
JCB 6D		5610	6350		8740	9200		5330	6050
JCB 7B		6100			9300			5540	
JCB 7C		5660	6730		8690	9730		5640	6100
Hy-Mac 580		2819	6425		7469	9093		5358	3073
RH 6		4500	6700		8400	10500		3000	3000

Table 2.3 Latest Excavator Physical Data.

JCB 3	3 721			5309			3416		
JCB 3C	4120			5490			3350		
JCB 3D	4690			6170			4240		
JCB 805		5020	5810		8380	9020		5530	5740
JCB 806B		5200	5810		8570	9090		5500	5720
JCB 807B		5200	6360		8570	9750		5500	6110
JCB 808		5760	6800		9170	10180		5730	6180
Hymac 580		4420	6430		7470	9070		5360	3050
RH 6		5100	6700		8250	9900		4000	4000

Table 2.4 Bucket sizes and theoretical capacities.

Machine Type	Min. Bucket Width (mm)	Capacity (m^3)	Max.Bucket width (mm)	Capacity (m^3)
JCB 3	350	.070	950	.300
JCB 3C	350	.070	950	.300
JCB 3D	350	.070	950	.300
JCB 805	508	.20	914	.60
JCB 806	508	.20	914	.60
JCB 807	508	.20	914	.60
JCB 808	610	.40	1120	1.00
Hymac 580	405	.20	910	.57
RH 6	700	.40	1200	.90

Table 2.5 Measured vs. Synthetic Excavation Rates.

m/c	Depth m	Synthetic output m^3/hr.	Measured output m^3/hr.	Revised synthetic m^3/hr.
Hy-mac 580	4.4	24.0	51.0	52.0
JCB 807	4.6	15.0	36.0	37.4
JCB 808	5.5	27.0	47.0	42.6

Table 2.6 Measured vs Synthetic Cycle Times.

m/c	Depth m	Original synthetic cycle time mins.	Measured cycle time mins.	Revised synthetic cycle time mins.
JCB 808	4.0	.520	.470	.490
Hymac 590	4.4	.440	.390	.370
JCB 807	4.8	.580	.521	.505

2.3.1.2. Operational data.

The comparison of observed to synthetic standard outputs, see table 2.5 showed a wide divergence. Bramwell's excavation model, see Appendex A considers the excavation operation in two parts:-

(a) The excavation cycle time, and

(b) The amount of material contained in a bucket.

To investigate the divergence of output rates stop watch studies were performed to check the synthetic cycle times, see table 2.6. The small differences in cycle time can be reconciled by comparing excavator specifications, in particular slewing speed. This comparison showed that modern excavators are slightly quicker see table 2.7. By applying the factors for U_T and E_T shown in table 2.7 the difference in cycle times is reduced.

2.3.1.2.1. Bucket Capacities.

From the above analysis the main disparities were considered to be in the amount of excavated material which is contained in each bucket. The data published by Meadows (1978), and the manufacturers technical literature was tested in the excavation model and gave satisfactory results when compared to the observed excavation rates, (table 2.5).

2.3.2. Trench Support Structure.

2.3.2.1. Traditional Shoring.

The basis of Bramwell's data had been a shoring configuration shown in fig. 2.1(a), comprising trench sheets, backed by structural steel walings and timber struts. However, the most commonly observed system uses trench sheets, with timber walings and 'accrow' type trench struts,

Table 2.7 Comparison of Excavator Specifications.

360 degree excavators

cf. JCB 805 to JCB 5C	805	5C	Ratio
Hydraulic pressure kg/cm^2	176	176	1.0
Slew speed rpm	6.6	6.0	1.10
Travel speed kph	2.12	1.84	1.15
Breakout force kgf	7173	6545	1.09
cf. JCB 806 to JCB 6D/6C	**806**	**6D/6C**	**Ratio**
Hydraulic pressure kg/cm^2	120	140	.85
Slew speed rpm	7.2	6.5	1.11
Travel speed kph	1.84	1.80	1.02
Breakout force kgf	6073	4900	1.24
O & K RH6	**C1978**	**C1974**	**Ratio**
Hyrraulic pressure kg/cm^2	3550	3550	1.00
Slew speed rpm	10.50	10.00	1.05
Travel speed kph	1.6	1.43	1.18
Breakout force kgf	12000	11600	1.03
Hy-mac 580	**C1978**	**C1974**	**Ratio**
Slew speed rpm	10.8	9.8	1.10

1. Unload time, U_t based on slewing speed

   Mean ratio 1 1.09

   Therefore multiply U_t by 1/1.09

2. Excavate time, E_t based on breakout force

   Mean ratio 1 1.12

   Therefore multiply E_t by 1/1.12

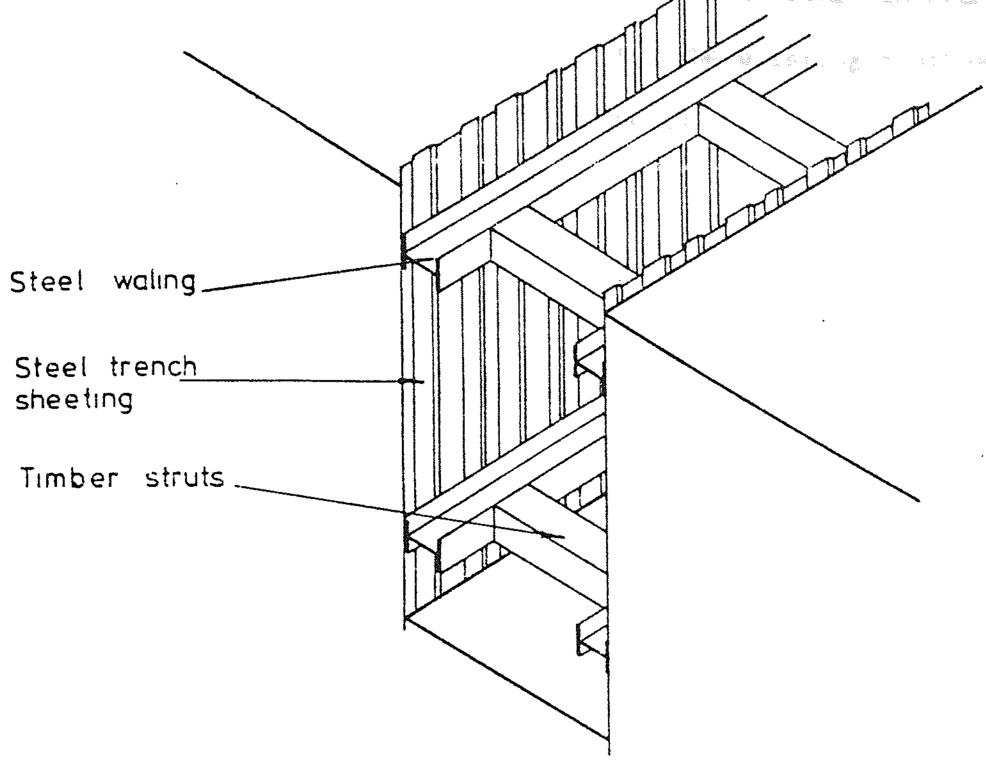


Fig. 2.1 (a) TRENCH SUPPORT SYSTEM (Bramwell, 1974)

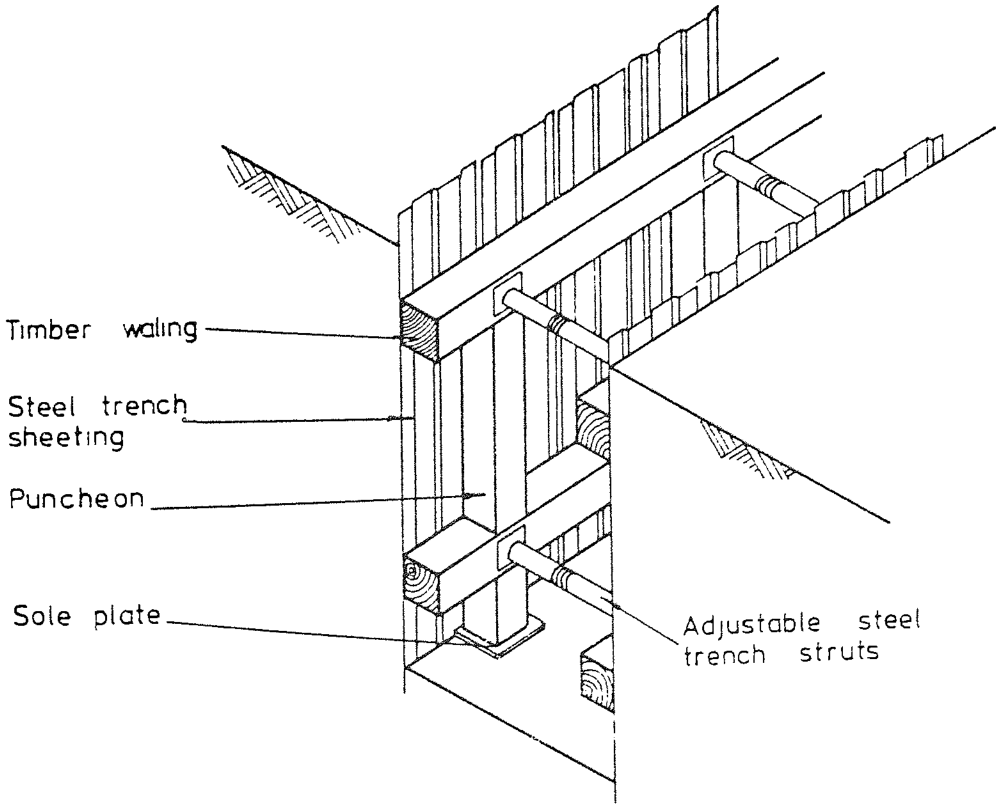


Fig. 2.1 (b) CLOSE SHEETED TRENCH SUPPORT SYSTEM

Fig. 2.1(b). To remedy this situation additional data was collected on the work elements which do not occur in Bramwells Model, viz, the erection of trench struts. The existing systhesis was used for the analysis of both trench sheets and timber walings.

2.3.2.2. Proprietory Trench Shoring

One of the recent innovations in pipeline construction has been the change from traditional to mechanical forms of trench shoring. A recent CIRIA survey (Mackay, 1979), showed that although traditional methods are the most frequently used, there is a significant use of these mechanical systems.

2.3.2.2.1. Escon Boxes

The mechanical shoring system on which it was possible to collect data is the "Escon box", manufactured by Shorco Trenching Systems Ltd., see fig. 2.2. These units are handled by crane or excavator and provide continuous support to the trench sides. The method of use and the elemental work measurement data for this system is detailed in Vol 2.

2.3.3. Pipe Laying

The results of the activity sampling comparison showed a divergency between measured and synthetic pipe laying times, see Table 2.8. However after revisions were made to the model, and the basis of comparison these discrepancies were reduced.

2.3.3.1 Method of Comparison

The observed site methods of laying pipes are sometimes different the 'correct' methods (see National Building Studies 1964). Consequently some of the pipelaying elements listed in table 2.9 are not always observed in a work study. The most frequent departure from the 'correct' method is in the use of a jack for jointing the pipes.

Consequently it was not possible to check Bramwell's times for these elements and therefore they have been omitted from the comparison. The revisions which were made to the model are described below.

Table 2.8 Measured vs Synthetic Pipe Laying Times.

Pipe dia (mm)	Depth (m)	Measured Output (m/hr)	Synthetic Output (m/hr)	Measured Output * (m/hr)	Revised Synthetic + Output (m/hr)
600	3.7	11.4	4.0	12.0	13.3
600	5.5	10.5	3.7	10.6	10.9
600	6.1	10.4	3.7	11.2	10.3
1275	3.7	8.3	2.4	9.0	8.0
1275	6.1	7.8	2.3	8.6	5.8

* Excluding pipe jointing times
\+ Excluding pipe jointing times, plus amendments to model.

2.3.3.2 Amendments of the Pipelaying model

2.3.3.2.1 Element Combination

For the analysis of a particular pipe all the elements listed in table 2.9 are not required. The individual elements are determined from the setting out method and both the pipe and bedding materials.

2.3.3.2.2. Laser Setting Out

There has been an increase in the use of lasers for the control of pipe line and level. This method is quicker than the traditional use of profile boards and traveller, or "boning rod". This construction innovation is incorporated into the pipe laying data by the addition of an element (no 17) for laser checking of alignment. Thus where lasers are being used this element will replace the three levelling elements.

2.3.3.2.3 Effect of Pipe type

In the pipe handling section a lubricated socket is only required with certain pipe types. Where pipes are jointed using rolling rubber ring seals, concrete and asbestos cement, this element is omitted.

2.3.3.2.4 Effect of bedding type

In the preparation section the need to use blocks is governed by the

Table 2.9 Pipelaying Elements.

Section	No.	Description.
Preparation	1	Prepare blocks
	2	Lower blocks
	3	Place and level blocks.
Pipe handling	4	Place sling on pipe
	5	Lower and position pipe
	6	Place gasket
	7	Lubricate socket.
Jointing	8	Set jack
	9	jack
	10	Release jack
Levelling	11	Lower travellor
	12	Bone
	13	Lift traveller
Finishing	14	Adjust pipe
	15	Remove sling
	16	Check level (Spirit).
Lasers	17	Check level (lasers).

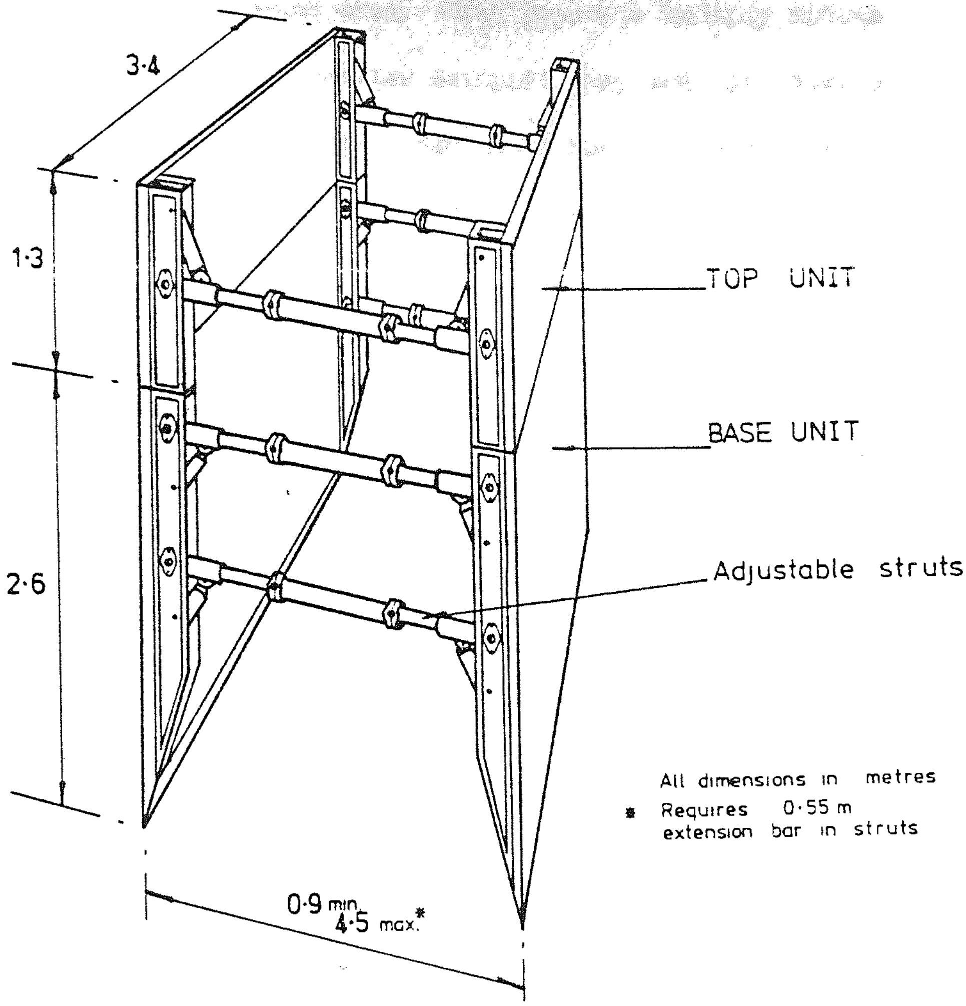


Fig. 2.2 'Shorco' Boxes Trench Support System

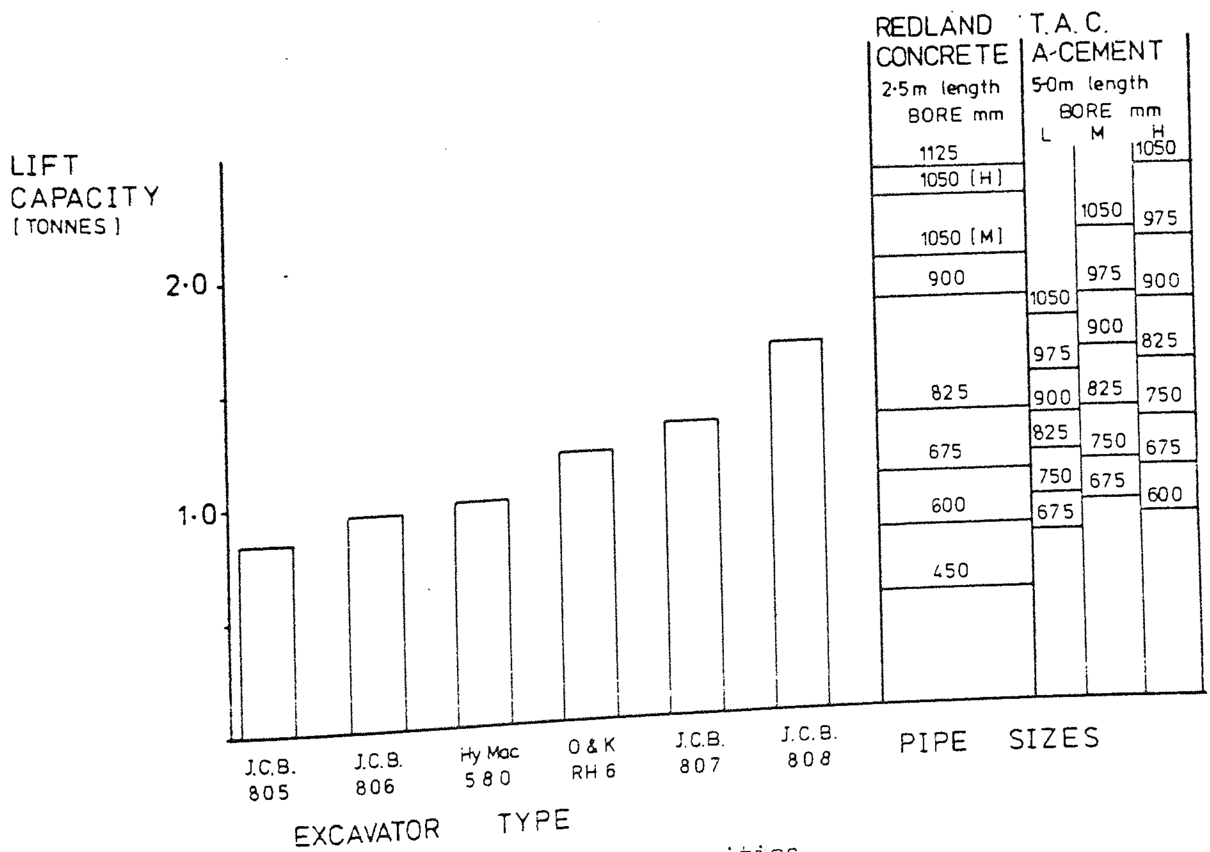


Fig. 2.3 Excavator lifting capacities.

type of bedding material being used. With concrete bedding blocks are required, however, with granular material they are not usually employed and any blocks which were used would have to be removed upon completion (National Building Studies, 1964).

2.3.3.3. Pipelaying Resources

The labour requirements for pipelaying used by Bramwell agreed with those observed, the gang usually consisting of one ganger and two labourers. The selection of plant however, was based on the pipe diameter and depth, the change from excavator to crane handling being at 450mm dia. and 5 m depth. However, the suitability of excavators for pipe laying is based on the total weight of the pipe, and the particular excavators lifting capacity when temporarily being used as a crane. The statutory requirements for site lifting are set out in the construction (lifting operations) regulations 1961. For pipe-laying certain of these regulations are relaxed in favour of exemption certificate number 2 (see appendix B for details of these regulations). Using these statutory requirements and manufacturers literature, the lifting capacities of the excavators used in the model is shown in fig. 2.3.

2.4 Pipeline Estimating

This section describes the operational prƂcing estimating system on which the computer suite (section 2.5) was modelled. The estimating process consists of combining and analysing the various sources of information which together form the raw date for the estimate. This process is shown graphically in fig 2.4.

2.4.1. Contract Specification

The first requirement is to form an overall outline of the contract, this involves abstracting the relevant data from the following documents.

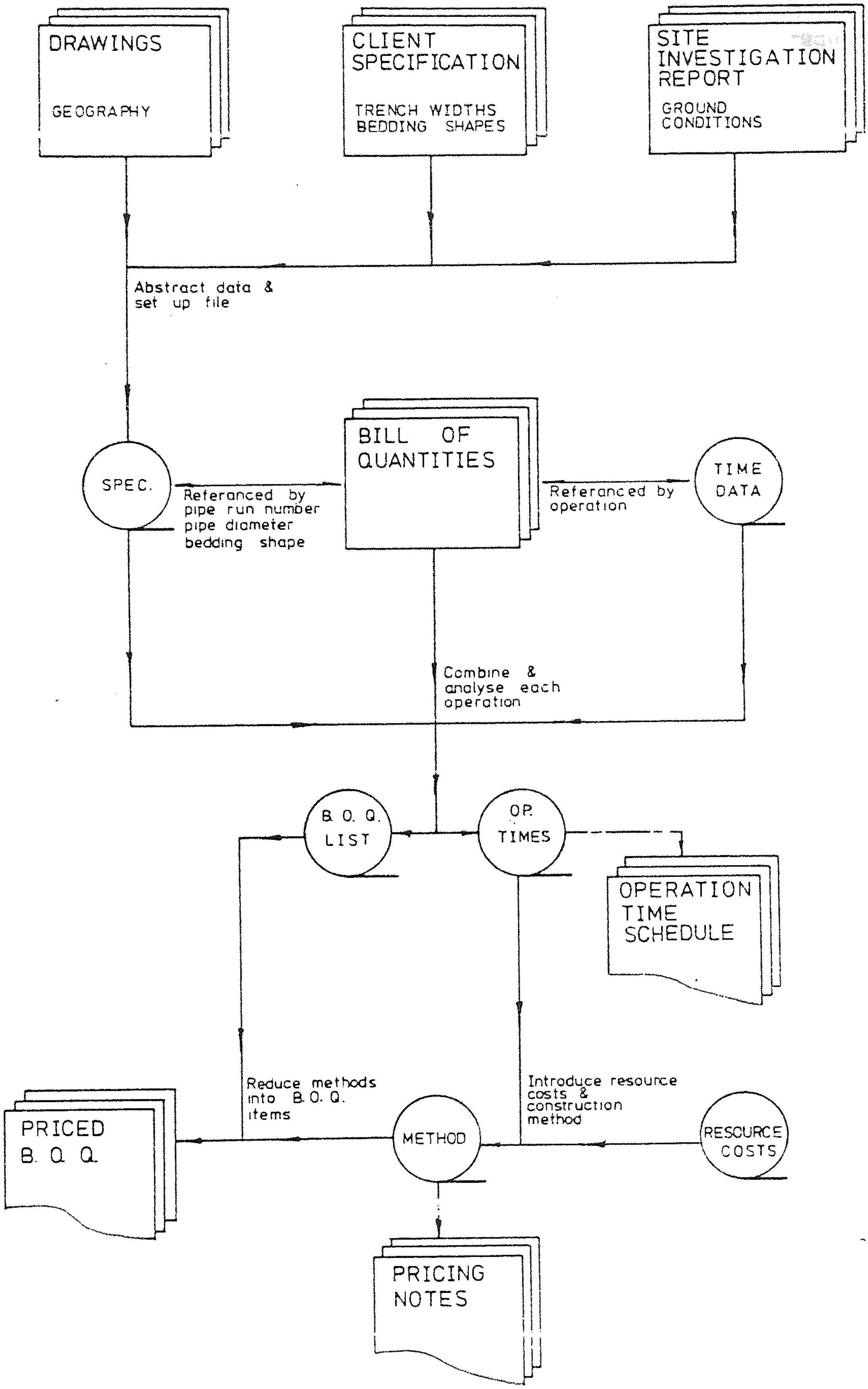


Fig. 2.4 Pipeline Estimating System

2.4.1.1. Contract Drawings.

The drawings contain the geography of the contract. The information required from this source is a list of all the pipe runs. This will form the 'skeleton' of the contract from which the remaining information will be cross-referenced.

2.4.1.2. Client specification.

The clients specification covers the required physical dimensions of construction i.e. Trench width, bedding types and dimensions, and backfill layer thickness. A comparison of specifications from various local authorities and consultants revealed variations in specified dimensions. To provide a basis for the input to the system the Scottish Development Department Specification (1976) was used. This was selected not for any reasons of engineering design but rather as a readily available reference document.

2.4.1.3. Site Investigation Report.

This document contains details of the various ground conditions expected along the pipe length. Information on each ground type is abstracted and is added to the geography 'skeleton' by specifying which pipe runs fall within each ground type.

2.4.2. Time Analysis.

Having set up the contract specification the next stage is to analyse the Bill of Quantities (B.o.Q) to determine the resources required and durations of each construction operation. This time analysis brings together the specification data, referenced by run number and pipe diameter, and the work measurement data which is accessed according to the construction operations which are included in each B.o.Q item.

2.4.2.1. Bill of Quantities

The B.O.Q. is the basic reference document for the time analysis. This document lists the work content of the contract. However, B.O.Q's can be in one of two general forms.

a) A 'quantity' based B.O.Q is the traditional method of presenting a B.O.Q. This type of document is a listing of the quantities in each work category.

b) A method based B.O.Q. is one which allows for the contractors proposed method of construction when building up the estimate (CESMM, 1976).

2.4.2.2. At the present time there are approximately equal numbers of each type of B.O.Q. With a CESMM document the individual item code numbers are beneficial for retrieving work measurement data, as the operations which are to be included in that item are implicitly defined. With 'quantity' based bills this is not the case and there may be several items, each of which relates to a specific operation for a single pipe run.

2.4.3. Cost Analysis

At this stage the method of working and resource costs are considered to determine the economic construction method. This process consists of combining the various B.O.Q. items which relate to a specific pipe run and examine the effects of changes in method and/or resources. The final task is to break down the method and resource configuration to give the price of each B.O.Q. item.

2.5 Computer Estimating System.

2.5.1. Introduction.

The structure of the pipeline estimating suite is shown in fig. 2.5. This is an on-line interactive system comprising thirteen individual programmes designed to be mounted on small, micro computers. With on-line processing the user has immediate access to data and this overcomes one of the drawbacks in Bramwell's system that of batch processing. The suite is a complete system for pipeline estimating and all the programmes are interlinked, with the exception of the Standard Unit Cost data programme, SUCD. In addition the time analysis programmes and the price sub-system are free standing and can be used in isolation from the complete system. The following section describes each of the programmes in the logical sequence of execution of the system. Reference should be made to the users manual, Vol. 2 for operating details, and to Appendix C for descriptions of the symbols used in the programme flowcharts.

2.5.2. Master Programme - PLEP

The PipeLine Estimating Programme, PLEP is the master programme for the system, see fig. 2.6. This programme fulfills three main functions:-

(a) Contract Identification and File generation.

(b) Run Control.

(c) Time Analysis control segment.

2.5.2.1. Contract Identification and File generation.

Information on several contracts can be stored by PLEP at one time, to ensure that the correct data files are being accessed each contract must be identified. This is achieved by assigning to each contract a unique alphanumeric code, termed the estimate reference. Thus when running PLEP the users first input is the estimate reference. These codes are stored on the master file and from its position on that file, file names are generated according to the following convention.

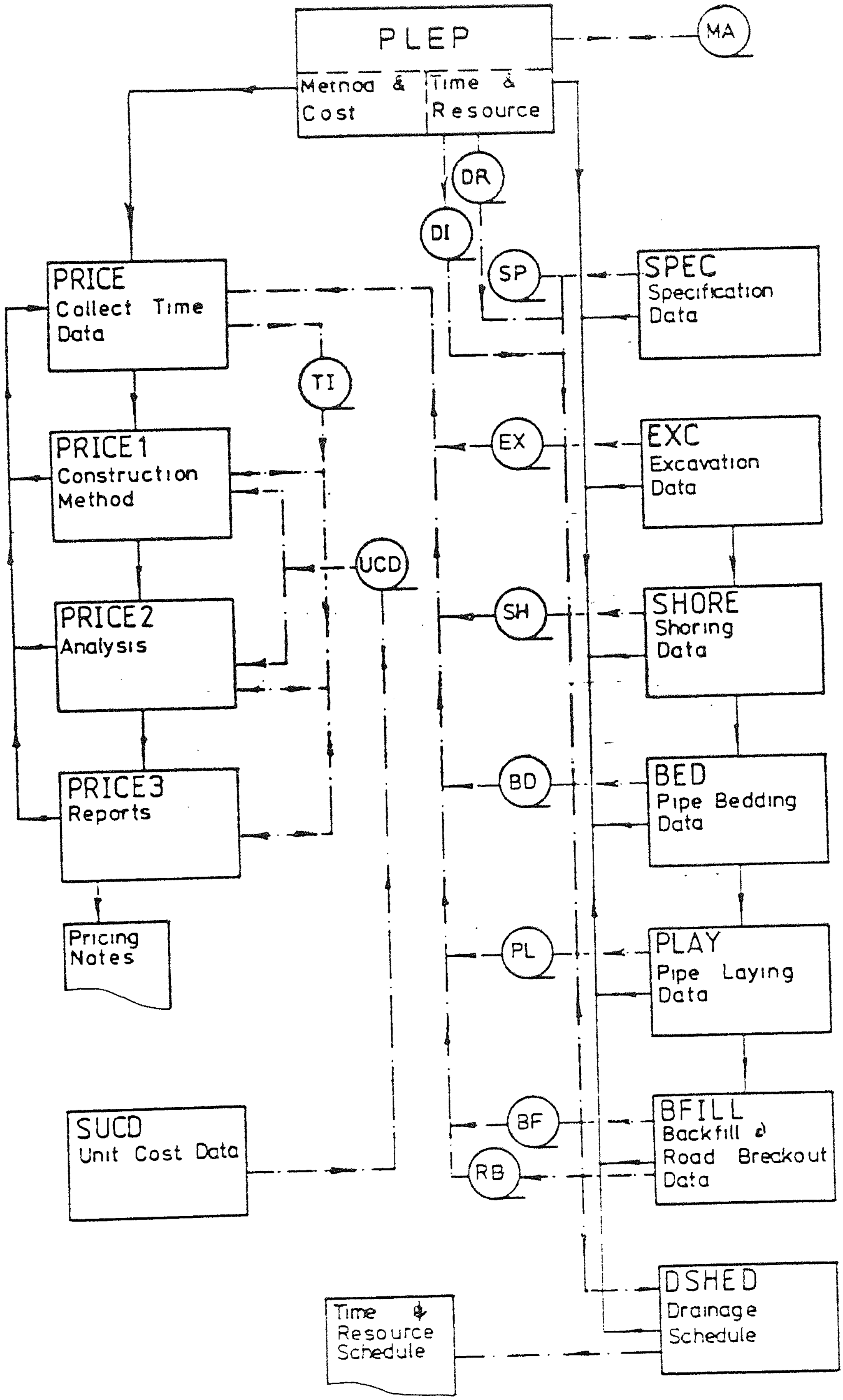


Fig 2.5 Pipeline Estimating Programmes - PLEP

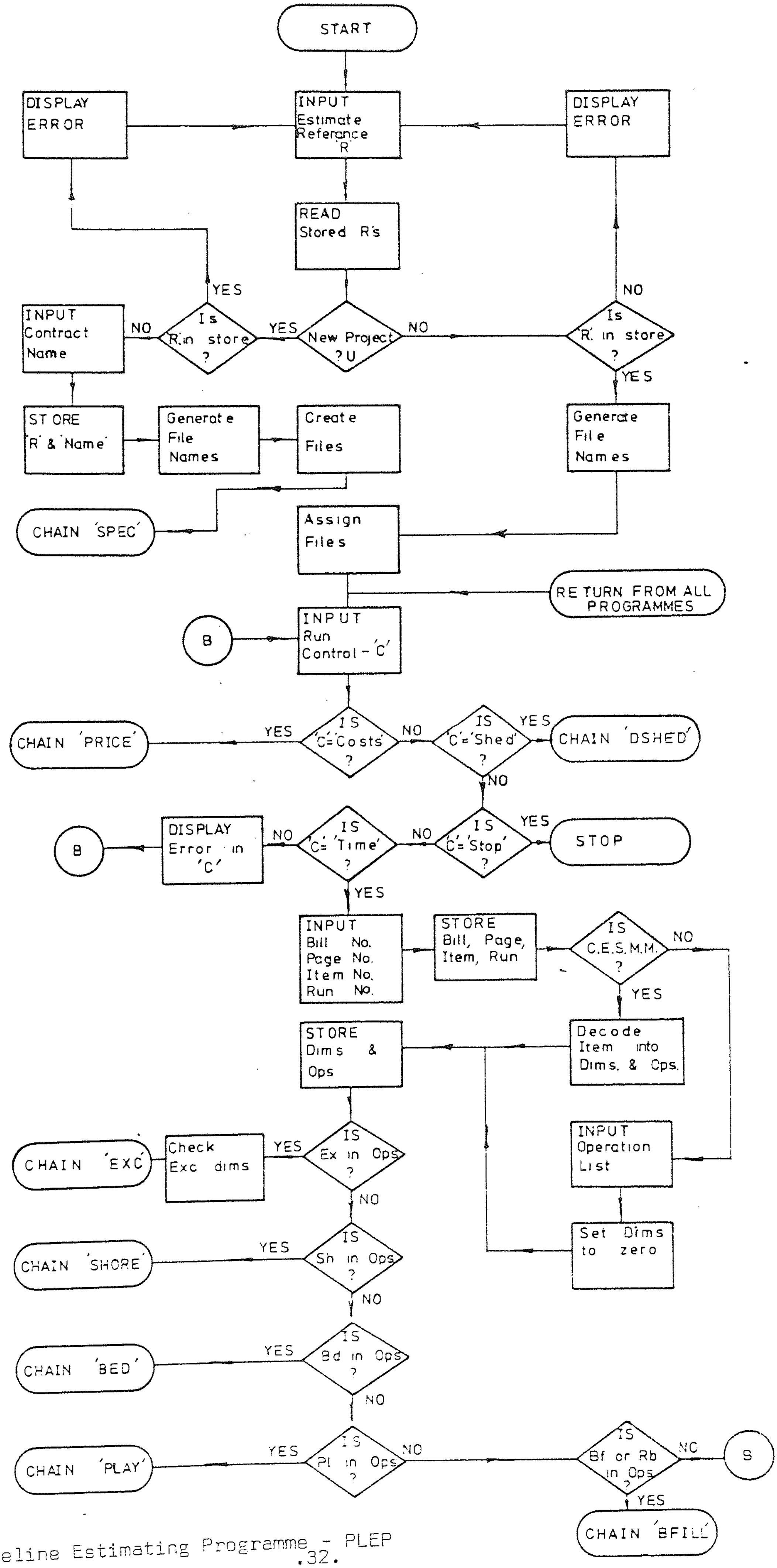


Fig. 2.6 Pipeline Estimating Programme - PLEP

2.5.2.1.1. File Names

Each file used by PLEP has a three character name, the first two characters define the data type, DI for dimensions, EX for excavation, etc., The third character in each file name is a digit corresponding to the position in the master file of the particular estimate reference. Thus if the reference "AB/1" is third in the master list, then the generated files would be DI3, EX3, etc., When starting a new contract all the data files required by PLEP are created automatically.

2.5.2.2. Run Control.

During the running of PLEP the user is prompted for a run-control character which instructs PLEP which sub-system is to be executed next.

The suite comprises the following sub-systems.

(a) Specification Input - SPEC,

(b) Time Analysis - EXC,SHORE, BED, PLAY, BFILL

(c) Drainage Time Schedule - DSHED

(d) Cost Analysis - PRICE, PRICE 1, PRICE 2, PRICE 3.

The user can instigate the execution of the last three sub-systems by inputting the relevant run-control character.

2.5.2.3. Time Analysis.

The remainder of PLEP consists of the time Analysis control segment, and this portion of PLEP is described in section 2.5.4.

2.5.3. Specification Sub-system

The specification sub-system comprises of the single programme, spec. (see fig. 2.7). This programme is chained automatically from PLEP when the analysis of a new project is started. The object of this programme is to set up the contract specification file, SP containing the required information from the contract documents.

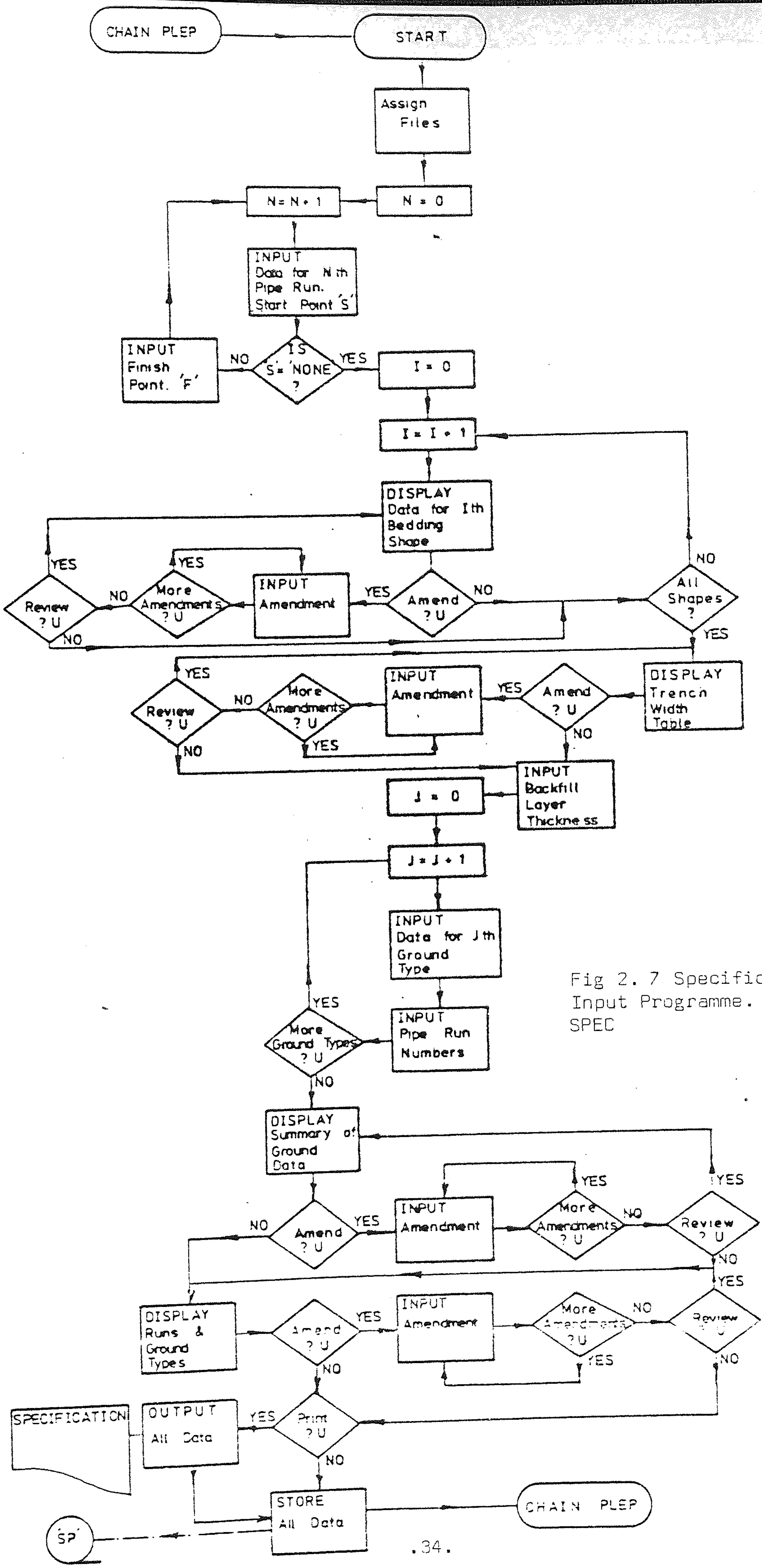


Fig 2. 7 Specification Input Programme. SPEC

2.5.3.1. Geography Input.

The first requirement is for a listing of the individual pipe runs. For identification purposes each run is assigned a start and end point, e.g. manhole numbers, chainages etc., each of which can be up to eight alphanumeric characters.

2.5.3.2. Client Specification.

SPEC requires three sets of data from the clients specification, these are:-

(a) Trench widths (table 2.10)

(b) Bedding dimensions (fig. 2.8)

(c) Backfill layer thickness.

SPEC stores 'standard' data from the Scottish Development Department specification (1976), (see section 2.4.1.2) and this is displayed to the user for him to make any ammendments which are necessary. This revised data is then stored in the file 'SP'.

2.5.3.2.1. Trench Widths.

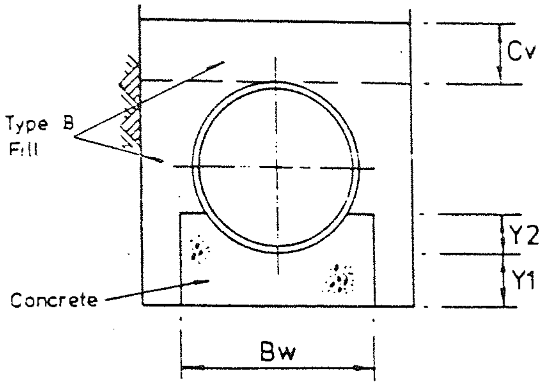
Single pipe trench widths are referenced from the pipe diameter. This allows the width to be determined automatically when required, thereby reducing the amount of input required from the user. Dual pipe trenches cannot be handled in this way as dual trench width tables are too complex to be easily amended by the user. Consequently in the analysis of dual trenches the user is prompted for the particular dimensions.

2.5.3.2.2. Bedding Dimensions.

Four standard bedding types and shapes are stored within the programme. The deminsions are stored in equation form and consequently the volume of each bedding material is calculated from the particular trench conditions.

STANDARD SHAPES	DIMENSIONS

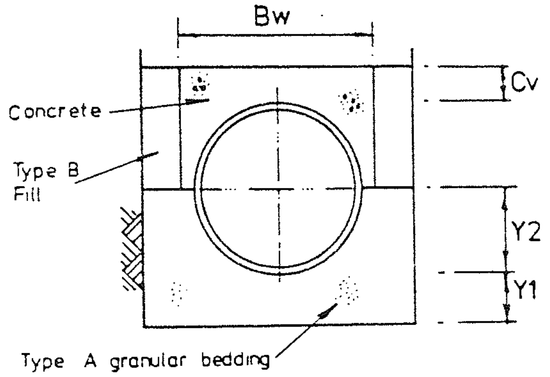
CLASS 1 - CONCRETE CRADLE



NOTE Bc = Pipe Outside Diameter
D = Pipe Bore
All Dimensions in metres

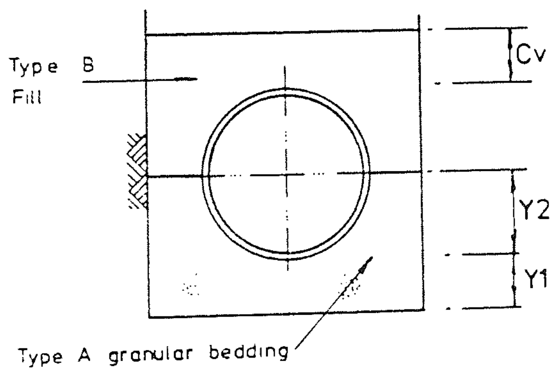
Bw = 1·25 Bc – Bc + 0·2 min.
Y1 = 0·25 D – 0·1 min.
Y2 = 0·25 Bc
Cv = 0·3 min.

CLASS 2 – CONCRETE ARCH



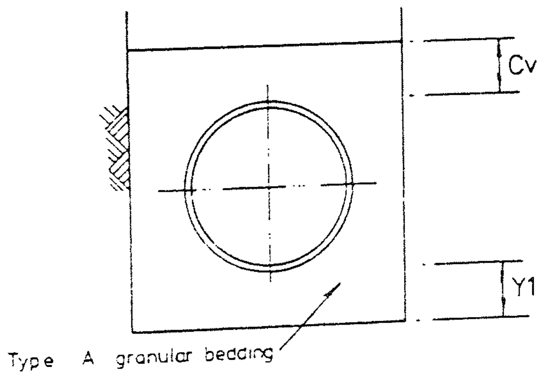
Bw = 1·25 Bc – Bc + 0·2 min.
Y1 = 0·25 D – 0·2 min. MIXED SOILS
Y1 = 0·16 D – 0·1 min. UNIFORM SOILS
Y2 = 0·5 Bc
Cv = 0·25 D – 0·1 min.

CLASS 3 – GRANULAR BED



Y1 = 0·25 D – 0·2 min MIXED SOILS
Y1 = 0·16 D – 0·1 min UNIFORM SOILS
Y2 = 0·5 Bc
Cv = 0·3

CLASS 4 – GRANULAR SURROUND



Y1 = 1·0 D - 0·15 max.
Cv = 1·0 D - 0·15 max.

Fig. 2.8 Standard bedding shapes

diameter m	Minimum Trench width m	Maximum Trench width m
0.100	0.430	0.630
0.150	0.490	0.690
0.225	0.580	0.780
0.300	0.680	0.880
0.375	0.950	1.150
0.450	1.030	1.230
0.525	1.120	1.320
0.600	1.240	1.440
0.675	1.330	1.530
0.750	1.400	1.600
0.825	1.490	1.690
0.900	1.920	2.120
1.050	2.100	2.300
1.200	2.290	2.490
Above 1.2	Bc + 0.80	Bc + 1.00

Bc = pipe outside diameter.

Table 2.10 Trench Widths (Scottish Development Department, 1973).

TABLE 2.11 STRATA GRADINGS

Grading	Description *		Casagrande Group Symbol
1	ROCK	Strata and boulders exceeding 0.2m^3 in size requiring blasting or phuematic tools	
2	MEDIUM ROCK	As 1 but 0.008-0.2m^3 in size	
3	SOFT ROCK	As 2 but not exceeding 0.008m^3 in size or possessing bedding planes to allow breakage	
4	WEAK ROCK	As 3 but weak (slate, soft sandstone, shale)	
5	COHESIVE SOIL	Low Plasticity	ML. CL. OL.
6	COHESIVE SOIL	Medium Plasticity	MI. CI. OI.
7	COHESIVE SOIL	High Plasticity	MH. CH. OH.
8	COARSE GRAINED	Sands and gravels	GW. GC. GV
9	COARSE GRAINED	Well graded	GP. GF. SW. SG.
10	COARSE GRAINED	Uniformly graded.	SU. SP. SF.

* Geological Society Engineering Group Working Party (1977)

* British Standard Code of Practice CP 2001 (1957).

TABLE 2.12 OBSTRUCTION GRADINGS *

Grading	Description
1	Metalled road surfaces or similar obstructions on top of frequently occurring services.
2	Frequently occurring major services and house connections.
3	a) Infrequent major services and frequent house connections, or ... b) Infrequent major and minor services, or ... c) Infrequent minor services, and or, tree roots etc.
4	Minor obstructions only e.g. tree roots, small quantities of hardcore.
5	No obstruction other than those which are an integral part of the strata.

* Bramwell (1974)

2.5.3.2.3. Backfill layer thickness.

The last item required from the clients specification is the backfill layer thickness used in the time analysis of the backfill operation.

2.5.3.3. Ground Conditions.

Working from the site investigation report various ground types are specified. For each type the required input parameters are:-

(a) Strata Grading (table 2.11).

(b) Obstruction Grading (table 2.12).

(c) Cohesion KN/m^2

(d) Angle of internal friction, phi, degrees.

(e) Density Kg/m^3.

If any of these last three parameters are unknown then during analysis typical values will be selected from table 2.13. To complete the ground condition input the pipe run numbers which fall within this ground type must be specified.

2.5.4. Time Analysis Sub-system.

The time analysis sub-system is controlled directly from PLEP, and consists of the following programmes:-

EXC, SHORE, BED, PLAY, BFILL.

Each of these programmes is free standing so that as well as being used for the analysis of a complete Bo.Q. item they can be used separately to analyse a particular operation. The programmes store the work measurement data (section 2.2) and sorts this data based on the particular dimension's and circumstances of each operation.

2.5.4.1. Operation coverage and Dimensions.

For each item which is analysed PLEP requires which operations are to be included in that item. For CESMM B.o.Q. the operation list is defined from the item code number, in addition certain dimensions are also defined. For non-CESMM bills the operation coverage is specified by the user. The dimensions relating to each item are stored on file 'DI'. In the analysis of an operation this file is accessed and if any required information has not been specified then the user is prompted for that dimension. In this way the minimum amount of data is input by the user, and dimensions which are input in one programme are available in the analysis of a subsequent operation.

2.5.4.2. Excavation Programme - EXC

The excavation programme, see fig. 2.9, stores data on nine hydraulic excavators, detailed in section 2.4.1. The programme has two main functions:-

(a) Machine Selection.

(b) Excavation Rate Computation.

2.5.4.2.1. Machine Selection.

The programme compares the maximum operating dimensions of each excavator against the required trench dimensions. Any machines which are unable to meet the requirements are excluded from the list. In addition to this internal checking the user has the option of excluding any machines which he does not want to consider.

2.5.4.2.2. Excavation Rate Computation.

The excavation rate for each included excavator is calculated using the procedure described in appendix A. These rates are then displayed to the user for his information and revision. By this procedure the user can

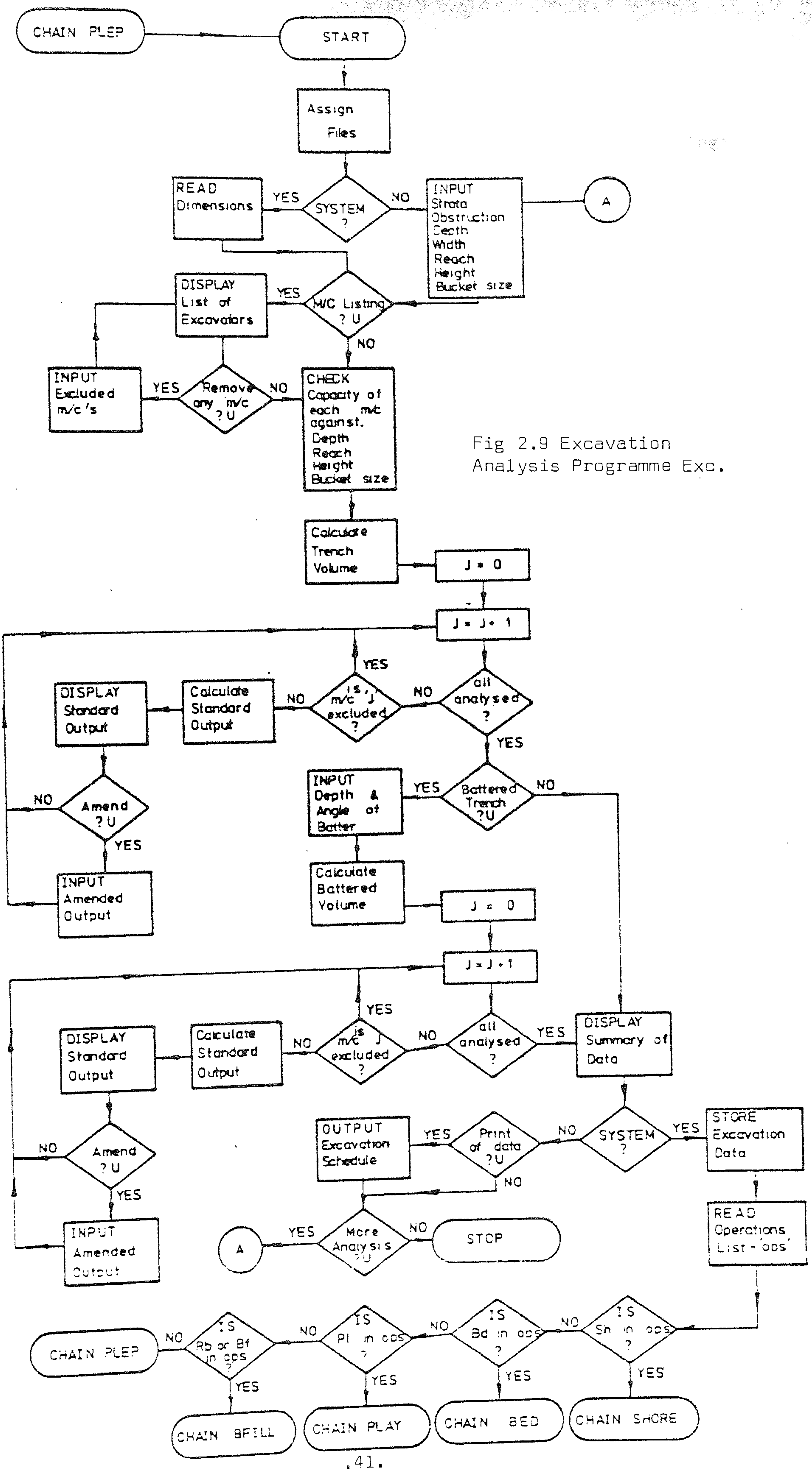


Fig 2.9 Excavation Analysis Programme Exc.

exercise his experience and judgement and make allowances for such things as working space, disposal of spoil etc., The user also has the option of specifying a battered trench cross-section, in which case the excavation rates are re-calculated.

Table 2.13 Typical Ground Parameters (after Tomlinson 1973).

Strata Grading	Cohesion (KN/M^2)	Angle of Internal Friction (Degrees)	Density (kg/M^3)
5	50.0	7	2200
6	20.0	5	2000
7	7.5	3	1800
8	0.0	30	1800
9	0.0	40	2000
10	0.0	30	1800

2.5.4.3. Shoring Programme - SHORE,

The trench support analysis programme, fig. 2.10, analyses the shoring requirements of the trench. Five shoring types are considered, of the type shown in fig. 2.1 (b).

(a) Close Sheeting - Continuous support (fig. 2.11 a).

(b) Medium Sheeting - Alternate sheets omitted (fig. 2.11 b)

(c) Open sheeting - Two in three sheets omitted (fig. 2.11 c)

(d) Pinchers - Isolated pairs of sheets (fig. 2.11 d)

(e) Shorco boxes - Proprietary continuous support (fig. 2.2)

2.5.4.3.1. Shoring design.

For trench depth less than 6m the detailed structural design of shoring is considered unnecessary (Tomlinson, 1969). For trenches up to this depth the required waling and strut size and spacing is selected from table 2.14 (code of federal regulations, 1976). The system does not cater for the support of trenches which are over 6m deep.

2.5.4.3.2. Time Analysis.

The programme then uses the size and spacing data to calculate the material requirements for each shoring configuration, and determines the standard duration and resource requirements using the stored work measurement data (volume 2.). This data is then displayed to the user for inspection and revision.

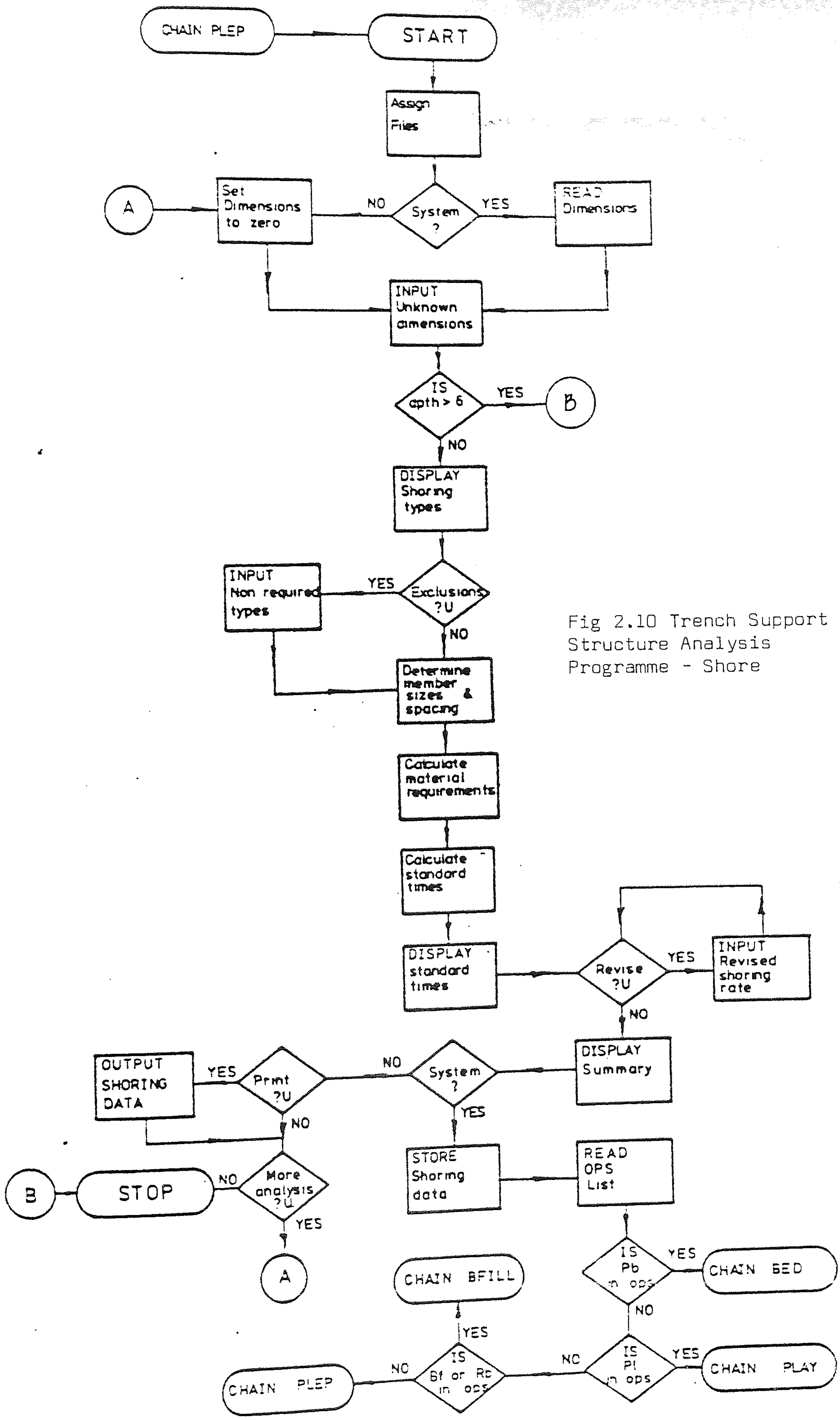
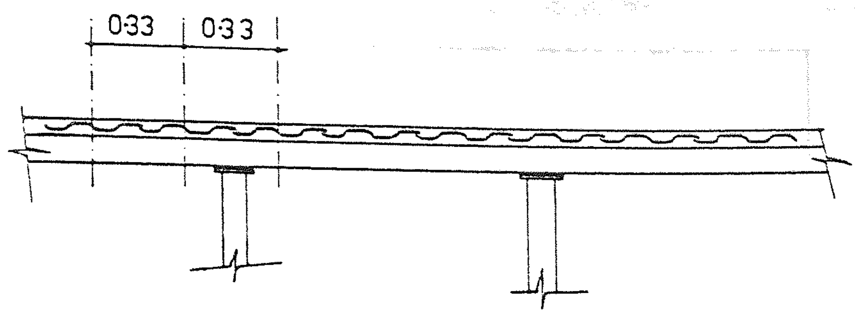
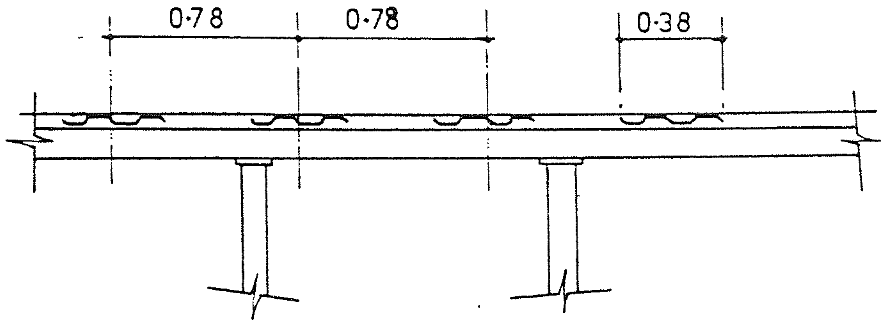


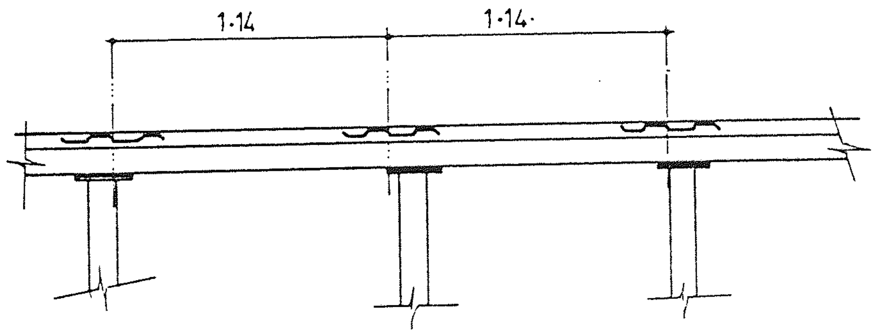
Fig 2.10 Trench Support Structure Analysis Programme - Shore



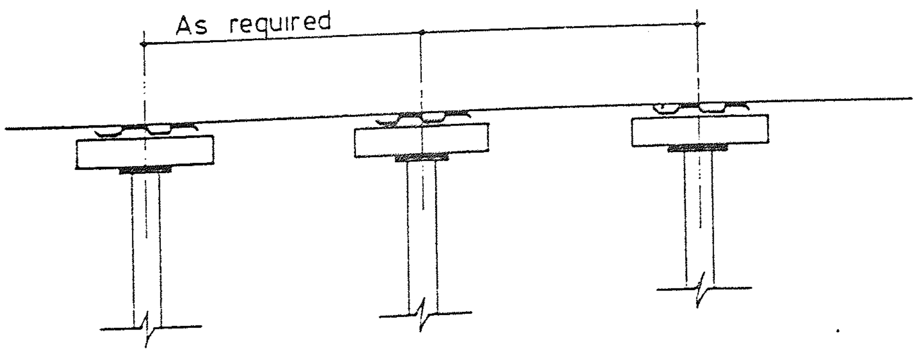
(a) CLOSE SHEETING



(b) MEDIUM SHEETING



(c) OPEN SHEETING



(d) PINCHERS

Fig. 2.11 Trench Support types.

Depth (m)	Ground condition	Trench Sheets max. spacing m	Walings		STRUTS Maximum Spacing m.	
			min. dimensions (mm)	max. spacing m	Vertical	Horizontal
1.5 - 3.0	Hard, compact	1.8			1.2	1.8
	likely to crack	1.0	100 x 150	1.2	1.2	1.8
	Soft, sandy or filled	close	100 x 150	1.2	1.2	1.8
	Hydrostatic pressure	close	150 x 200	1.2	1.2	1.8
3.0 - 4.5	Hard	1.8	100 x 150	1.2	1.2	1.8
	likely to crack	0.6	100 x 150	1.2	1.2	1.8
	Soft, sandy, filled	close	100 x 150	1.2	1.2	1.8
	Hydrostatic pressure	close	200 x 300	1.2	1.2	1.8
4.5 - 6.0	All types	close	100 x 300	1.2	1.2	1.8
over 6.0	All types	close	150 x 200	1.2	1.2	1.8

Table 2.14 - Trench Shoring - minimum requirements (Code of Federal Regulations 1979)

2.5.4.4. Pipe Support Structure programme - BED

The bedding analysis programme, fig. 2.13, considers the bedding dimensions for the four standard shapes (fig. 2.8) in equation form. This data is as already input using 'SPEC' (see 2.5.3) or is defined by the user, depending on the way the programme is being executed. In addition the user has the option of analysing a non-standard shape (fig. 2.12) by inputting the actual bedding dimensions. The programme calculates the volumes of each bedding material and the standard duration of construction using the work measurement data (volume 2).

2.5.4.4.1. Bedding Materials.

The programme calculates the construction duration for three commonly used materials, concrete, granular or selected fill. The material types are defined implicity from the bedding shape code, with a non-standard shape the user spectifies which material is to be analysed.

2.5.4.4.2. Pipe Material.

The pipe outside diameter, Bc used in the calculation of bedding material volumes is dependent on pipe bore and also on pipe material.
See Volume 2.

(a) Clay
(b) Concrete
(c) Iron.
(d) Steel
(e) Plastics
(f) Asbestos Cement
(g) Pitch fibre.

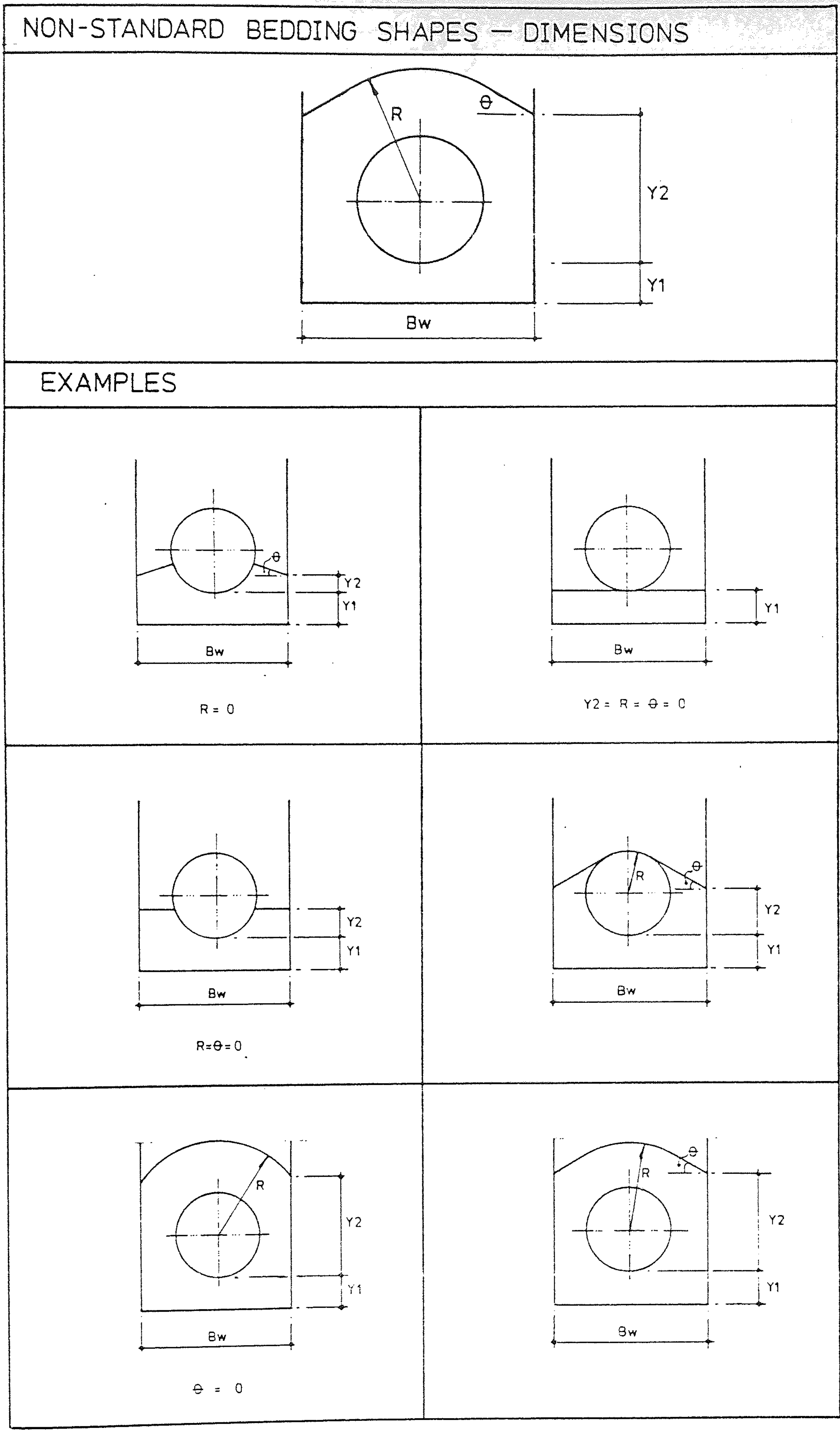


Fig. 2.12 Non-Standard Bedding dimensions.

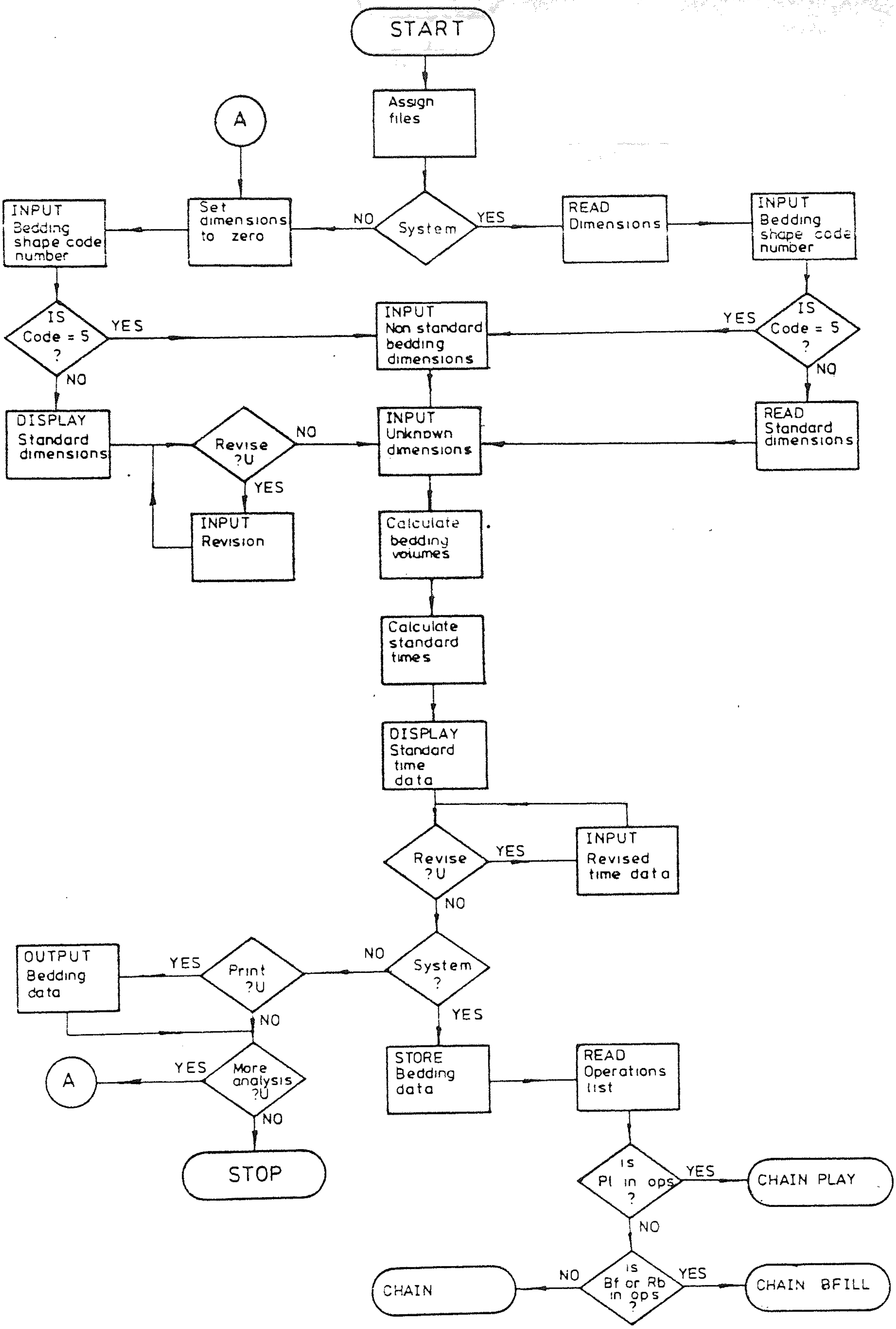


Fig. 2.13 Pipe Support Structure Analysis Rrogramme - BED

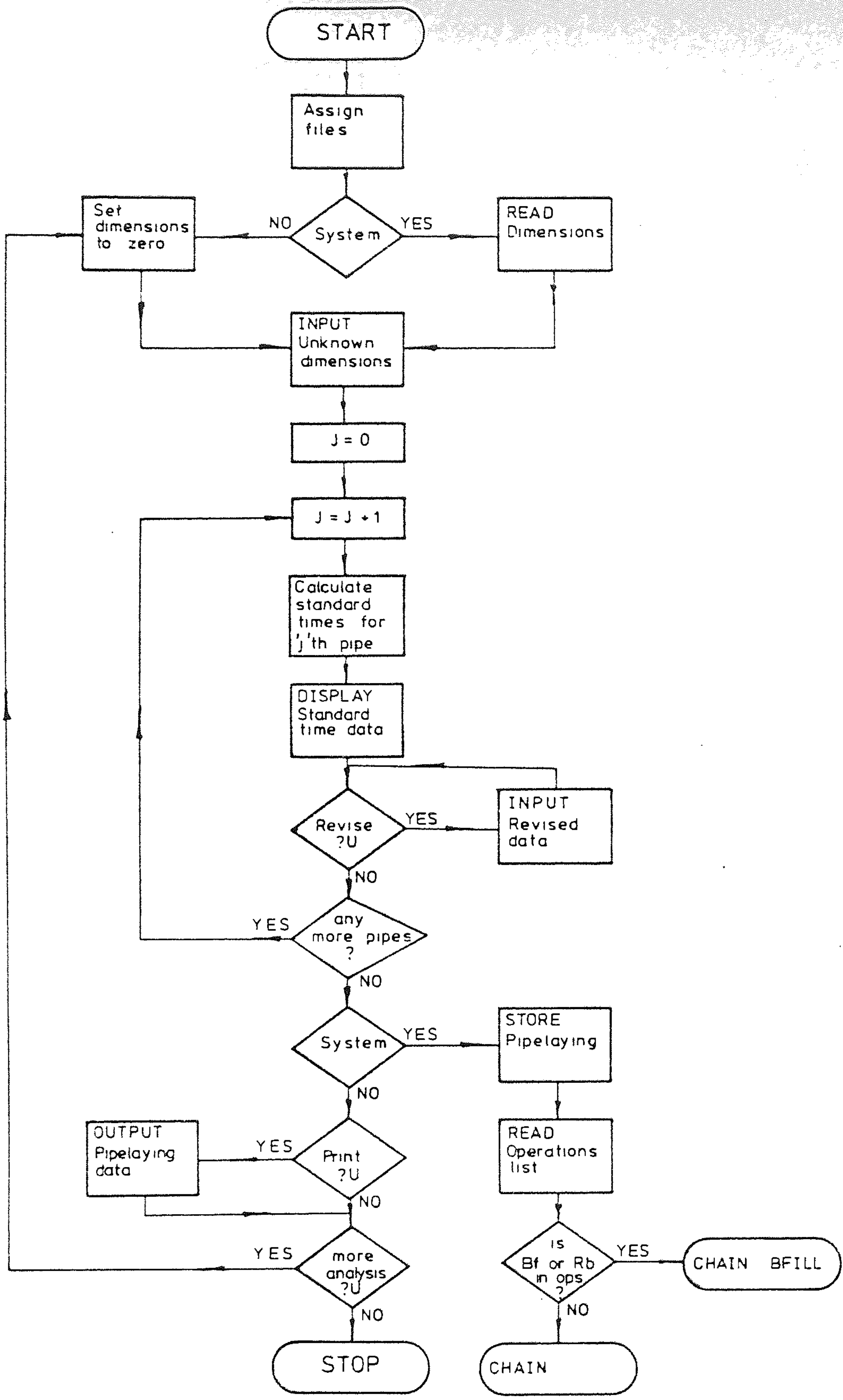


Fig. 2.14 Pipelaying Analysis programme - PLAY

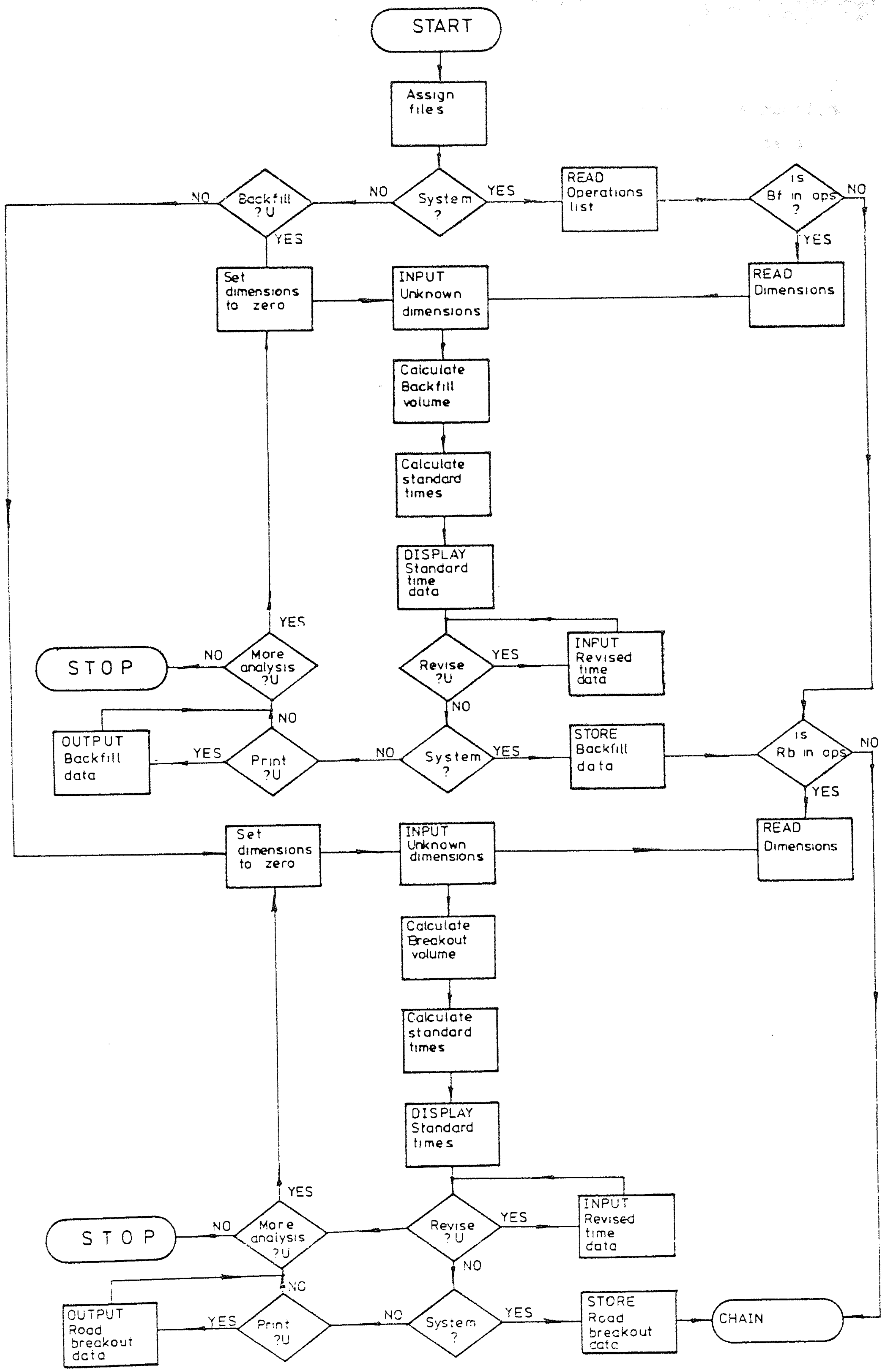


Fig. 2.15 Backfill and Road Breakout Analysis Programme - BFILL

2.5.4.5. Pipelaying Analysis programme - PLAY

The pipelaying programme, fig. 2.14 produces the standard construction duration based on the work elements shown in table 2.3. This data is sorted based on the dimensions, materials and setting out method, as described in section 2.3.3.

2.5.4.6. Backfill and Road Breakout programme - BFILL

This programme analyses both the backfill and road breakout operations, see fig. 2.15.

2.5.4.6.1. Backfill Analysis

The backfill standard duration is determined for four different resource levels, fig 2.16. The volume of backfill is either calculated directly or is obtained from the results of the excavation and bedding analyses. The standard outputs for this operation are dependent on the compaction layer thickness which is either input by the User, or retrieved from the specification data file.

2.5.4.6.2. Road Breakout Analysis

This sub-programme calculates the standard duration of breakout for roads of either concrete or flexible construction. Two different resource levels are considered, a manual operation using medium breakers, and a machine assisted operation. The standard outputs are again displayed to the User for his inspection and revision.

2.5.4.7. Operation Time Schedule Programme - DSHED

The results from each of the operation analysis programmes are stored on separate disc files. This programme which is called from the users run control character (2.5.2.2.) produces the operation time schedule for each Bill of Quantity item. An example of this schedule is shown in fig. 2.16.

2.5.5. Cost Analysis sub-system.

This sub-system, See fig. 2.17 comprises the following programmes:- PRICE, PRICE1, PRICE2, PRICE 3.

It is free standing, so that it can be used within the overall PLEP system or solitarily to analyse a particular pipeline construction activity. The object of these programmes is to assist the user in selecting the optimum resource configuration and construction method using the operation time data. Having determined this the relevant costs are calculated for each Bill of Quantiy item.

2.5.5.1. Input Data.

In the analysis of a B.o.Q more than one item may refer to a pipe run between manholes. PRICE accesses the individual operation analysis files and brings forward all the data relating to a specified pipe run. This data is then averaged to give representative volumes and production rates for each operation for use in the method analysis.

2.5.5.1.1. Resource Costs.

The labour and plant unit costs are retrieved from the file UCD (see 2.5.5.). Materials costs can vary greatly from contract to contract and therefore, this data is input as required for each activity analysis.

2.5.5.2. Method Definition.

The user is then required to define the first trial method. This consists of

BILL ITEM TIME ANALYSIS
****

DATE 11: 3:80

ESTIMATE REFERENCE NB/3
CONTRACT BURTON-ON-TRENT IN TOWN DRAINAGE

[ITEM COUNT 1]
BILL NUMBER 1
PAGE NUMBER 1
ITEM NUMBER 1
RUN NUMBER 1 = MH 19 - MH 20

EXCAVATION	VOLUMES [M3/M]	RESOURCE	STD OUTPUT [M3/HR]	REV OUTPUT [M3/HR]	DURATION [HR/M]
STRATA 9	VERTICAL 5.6	JCB 3D	14.25	14.25	0.39
OBSTRUCTION 1		JCB 805	24.63	24.63	0.23
DEPTH 2.25		JCB 806	26.00	26.00	0.22
WIDTH 2.5		JCB 807	27.37	27.37	0.21
		HY-MAC 580	30.81	30.81	0.18
		O & K RH6	30.41	30.41	0.18
		JCB 808	33.01	33.01	0.15

SHORING	TYPE	MATERIALS	RESOURCES	STD OUTPUT M/HR	REV OUTPUT M/HR	DURATION HR/M
DEPTH 2.25	CLOSE	SHEETS 30 NO WALERS 0.10 * 0.15 - 4 NO STRUTS 8 NO	3 MEN	2.88	2.88	0.35
	MEDIUM	SHEETS 14 NO WALERS 0.10 * 0.15 - 4 NO STRUTS 8 NO	3 MEN	4.41	4.41	0.23
	OPEN	SHEETS 10 NO WALERS 0.10 * 0.15 - 4 NO STRUTS 8 NO	3 MEN	5.43	5.43	0.18
	PINCHERS	SHEETS 8 NO WALERS 0.08 * 0.08 - 16 NO STRUTS 8 NO	3 MEN	6.24	6.24	0.16
	SHORCO	1 NO 2.6 * 3.4	3 MEN JCB 807	10.53	10.53	0.09

BEDDING	PIPE NO	VOLUMES [M3/M]		DISPLACED [M3/M]	RESOURCES	STD OUTPUT [M3/HR]	REV OUTPUT [M3/HR]	DURATION [HR/M]
SHAPE 5	1	CONCRETE	0.85	1.90	1 GNGR 2 LAB	7.33	7.33	0.12
	1	GRANULAR	0.00			0.00	0.00	
SHAPE 5	2	CONCRETE	0.55	0.65	1 GNGR 2 LAB	3.33	3.33	0.16
	2	GRANULAR	0.00			0.00	0.00	
				0.00				0.28

PIPELAYING	DEPTH [M]	DIA [M]	MATERIAL	RESOURCES	STD OUTPUT [M/HR]	REV OUTPUT [M/HR]	DURATION [HR/M]
1	2.25	1.050	A/CEMENT	3 LAB + O&K RH6	5.52	5.52	0.18
2	2.25	0.300	CLAY	3 LAB + ANY M/C	8.69	8.69	0.12

BACKFILL LAYERS = 0.30 M	VOLUME [M3/M]	RESOURCES	STD OUTPUT [M3/HR]	REV OUTPUT [M3/HR]	DURATION
VERTICAL	3.50	2 LAB	5.59	5.59	0.63
		2 LAB + DUMPER	16.00	16.00	0.27
		2 LAB + JCB #3C	20.00	20.00	0.18

Fig. 2.16 TYPICAL TIME AND RESOURCE SCHEDULE

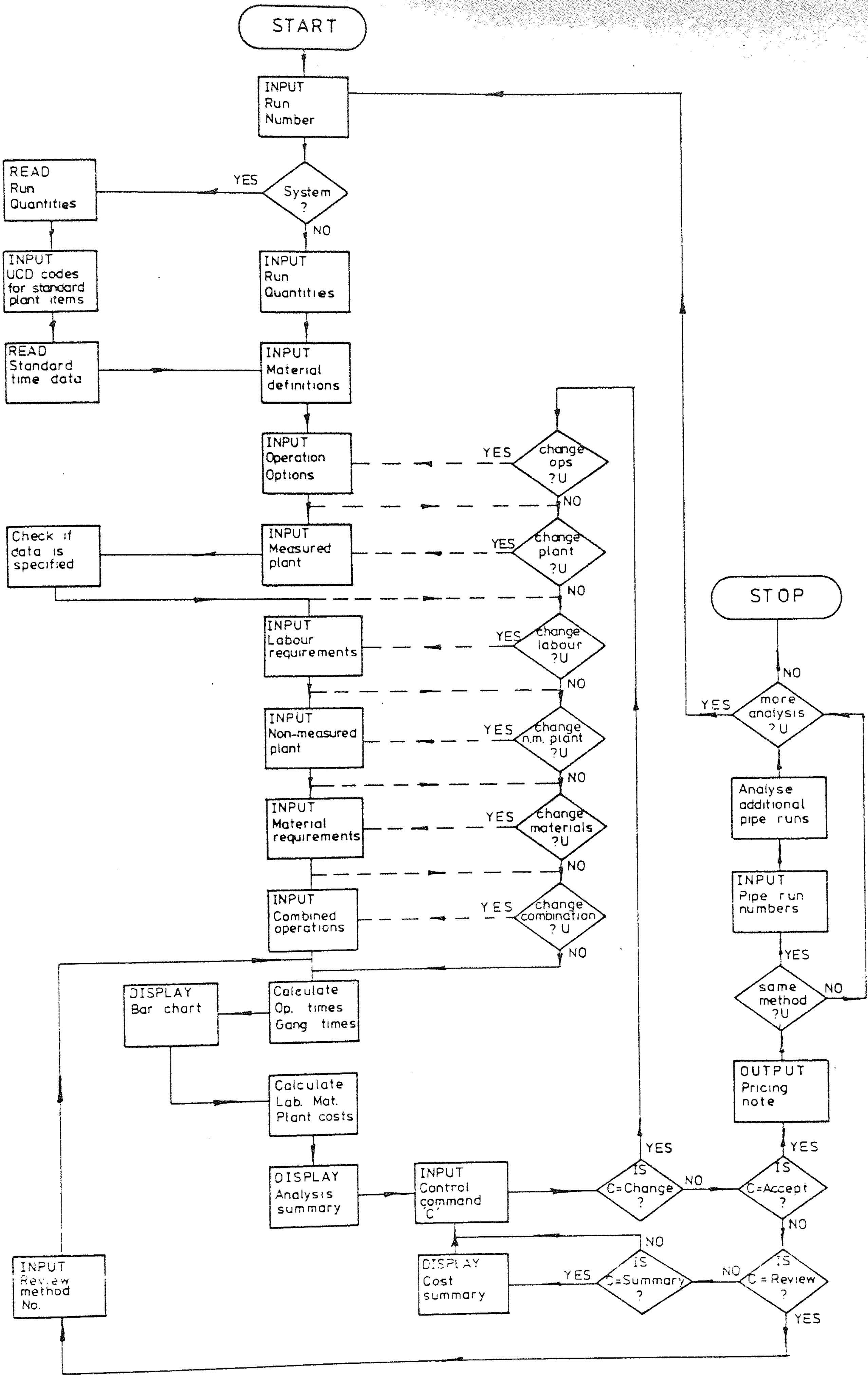


Fig. 2.17 PRICE Sub-System.

specifying the following information.

2.5.5.2.1. Operation Options.

The trench cross section, either vertically sided or battered, and the shoring type are defined.

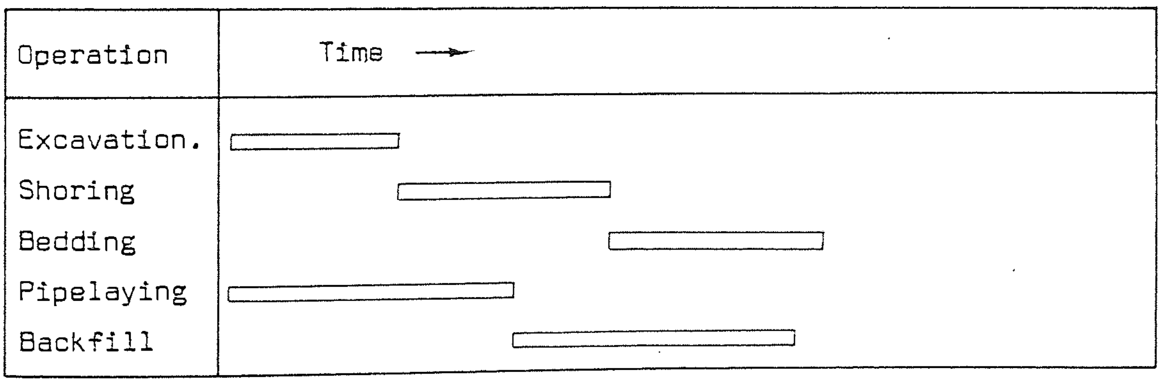
2.5.5.2.2. Resource definitions.

The labour, materials and plant for each operation are input. PRICE then checks the production rate data to ensure that an output is known for each operation with the specified resource. If the data is not known then the user is prompted for that data item.

2.5.5.2.3. Combined Operations.

The construction sequence is defined by specifying the combined operations. These are the operations which are performed consecutively, an example is shown in fig. 2.18 below.

Fig. 2.18 Combined Operations - Example Bar Chart.



The combined operations for this sequence would be:-

(a) Excavation, Shoring, Bedding.

(b) Pipelaying, Backfill

2.5.5.3. Analysis.

2.5.5.3.1. Operation & Gang Times.

The individual operation times are calculated from quantities and production rates for the specified resources. The gang times are found by summing the times for each of the consecutive operations and the total duration is then the maximum of these gang times.

2.5.5.3.2. Total Resource Requirements.

The total resource requirements are determined by finding the maximum resource level in each consecutive operation list for each different resource type, and then summing these individual gang totals.

2.5.5.3.3. Costs.

The cost of construction, divided into labour, materials and plant is then calculated using the total activity duration, and the total resource requirements. A summary of this data is displayed to the user.

2.5.5.4. Control Commands.

At the completion of the analysis of a trial method the user has four options for the next sequence of operations.

2.5.5.4.1. Change.

The change command instructs PRICE to prepare a new trial method for analysis. The user is prompted for revisions to each category of method definition input. If any categories are not revised then these data in the old method are carried forward into the new, which is then analysed.

2.5.5.4.2. Accept.

Having found a method which is acceptable to the user, PRICE then generates the pricing note and calculates the labour, materials and plant costs for each B.o.Q. item which relates to that pipe run. The user is then prompted for any more pipe runs which are to be priced using this resource configuration. The data for these are abstracted from the PLEP files and each is priced according to the actual production rates for the specified resource for each operation.

2.5.5.4.3. Review.

This command produces a detailed review of a specified already analysed method.

2.5.5.4.4. Summary.

A labour, materials, plant and total cost summary of the methods analysed for that pipe run is displayed to the user.

2.5.5.5. Resource Cost Programme - SUCD

This programme See fig. 2.19 is independant of the PLEP system and is used to set up and periodically revise the unit cost data file UCD.

2.5.5.5.1. Plant Costs.

The programme can store data on twenty different classes of plant, each of which can contain twenty individual plant items. Each plant item is identified by a two digit alphanumeric code, e.g. E1. The first digit identifies the plant class, e.g. Excavators, the second, identifies the particular plant item within that class. Costs are assigned with two components, the basic hire rate and the fuel cost addition.

2.5.5.5.2. Labour Costs.

The labour costs are stored under class L. Individual labour categories being identified in the same way as plant.. The data required is the all in cost of each labour category.

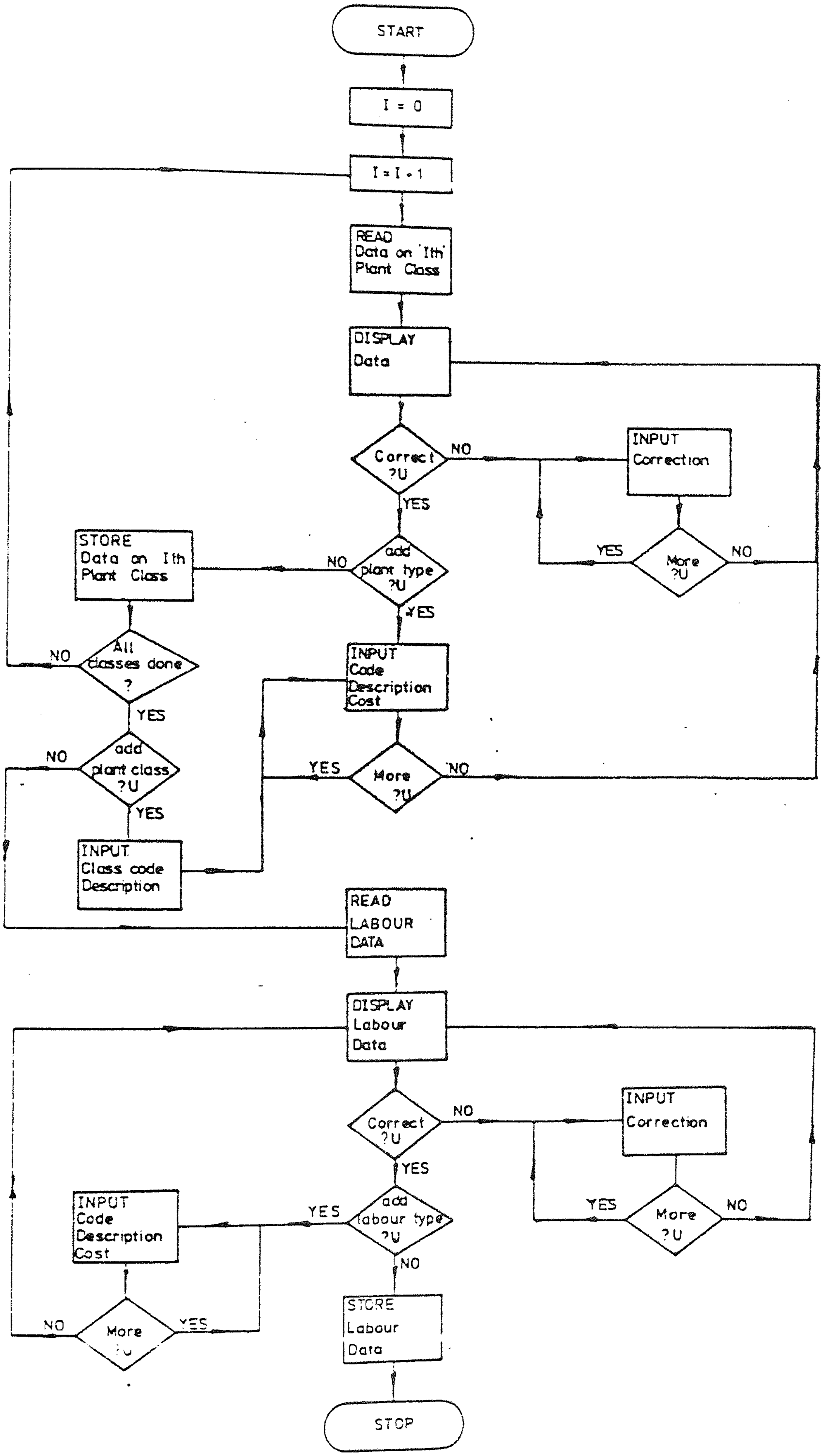


Fig 2.19 Resource Cost Programme - UCD

2.6 Precast Concrete Manholes

The standard time data produced by Bramwell was used on the basis for new computer programmes for the analysis of pre-cast concrete manholes. This analysis is considered in two stages.

2.6 Materials Quantities

The first requirement is to determine the materials quantities of each of the structural components:-

Insitu bases

Chamber Rings

Shaft Rings

Tapers

Reducing Slabs

Insitu Surround

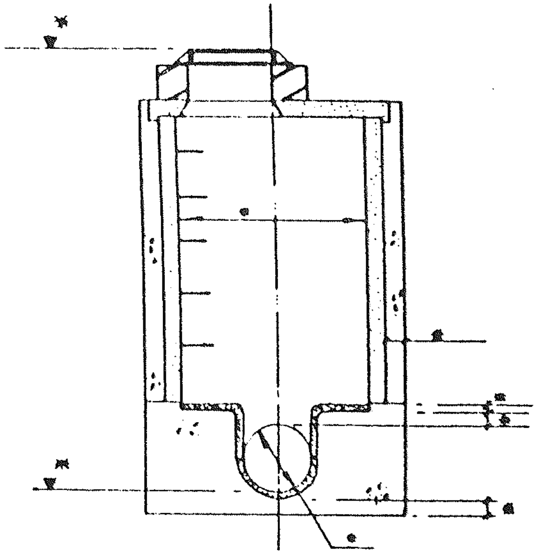
Cover Slabs

Covers & Frames

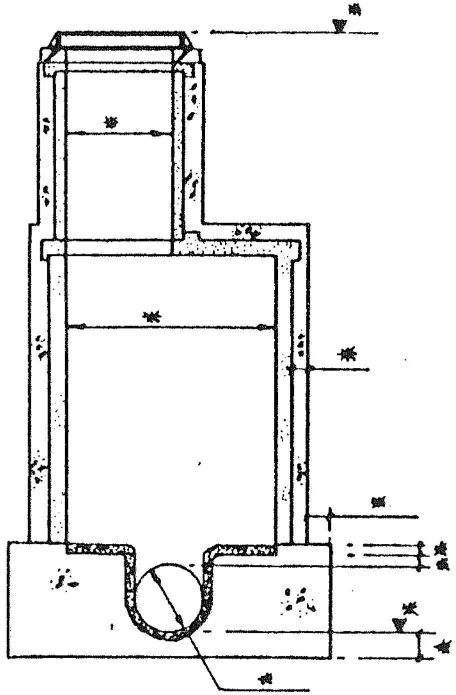
Three types of manhole are covered by the programme see fig 2.20. The standard dimensions of each type are input by the user on commencement of the analysis and the various materials quantities are then calculated following the user's input of the manhole type and the total depth, from cover to invert.

2.6.2. Standard Times

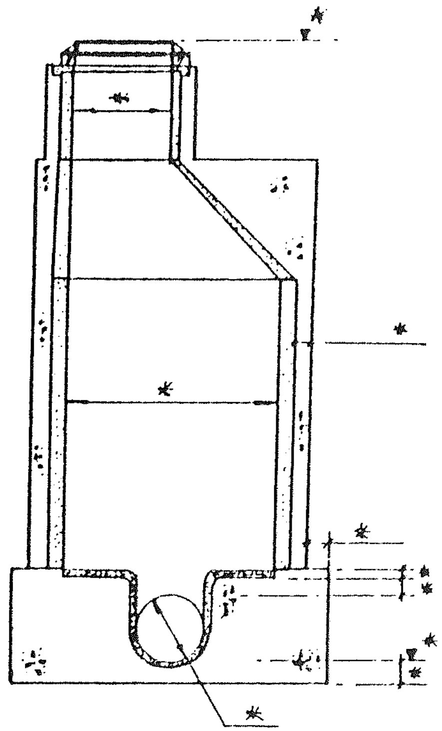
The standard time for the construction of each structural component is then calculated from the quantities produced and the stored work measurement data. A manhole schedule is then produced detailing the results of the analysis see fig 2.21



Type 1
Chamber only



Type 2
Chamber and Reducing
Slab and Shaft



Type 3
Chamber and Taper
and Shaft

* Indicates dimensions supplied by the User.

Fig 2.20 Manhole Types.

MANHOLE SCHEDULE
****

CONTRACT example

MANHOLE TYPES
****

1 type a
2 type b1
3 types f

COVERS & FRAMES
****

1 42c
2

MH	COV LVL	INV LVL	DEPTH M	TYPE	PIPE DIA M	BASE M3	MANHOLE DIA M	RINGS LGTH M3	SURR	R/D	COV SLAB M	BWK	COV FRAME
s1	50.000	47.000	3.000	1	0.600	5.79	1.800	1.800	0.77	NIL	LD	0.017	1
s2	50.000	45.000	5.000	2	0.600	5.79	1.800	1.984	2.47	SLAB	LD	0.163	1
							0.675	3.355					
3	50.000	45.000	5.000	3	0.675	6.40	1.800	1.984	2.80	TAP	LD	0.079	1
							0.675	0.615					

MANHOLE TIME ANALYSIS
****

CONTRACT example
******** ******************************

STANDARD DURATIONS EXPRESSED IN GANG HOURS
GANG SIZES [1] - 2 LABOURERS PLUS 1 EXCAVATOR
[2] - 2 LABOURERS

GANG	1	1	1	1	1	1	1	2	
MH	BASE	CHAMBER	SHAFT	TAPER	R/D SLAB	SURRD.	COV SLAB	COV & FRM	TOTAL
s1	17.43	2.10	0.00	0.00	0.00	4.50	0.23	0.50	29.75
s2	17.43	2.10	1.61	0.00	0.64	5.48	0.23	0.50	35.08
3	18.92	2.10	0.30	0.69	0.00	5.82	0.23	0.50	36.13

Fig 2.21 Typical Manhole Schedules

CHAPTER 3 PROJECT SIMULATION

SUMMARY

The theoretical background to the stochastic construction model is presented, together with a command driven suite of computer programmes for project analysis and simulation.

3.1 Introduction

The preceding chapter described the way in which the standard duration of pipeline construction is determined. The standard time for an operation is defined as 'The total time in which a task should be completed at .... the rate of output which qualified workers can achieve without over exertion as an average over the working day or shift provided they adhere to the specified method and provided they are motivated to apply themselves to their work.' (British Standards Institution 1979). However, the time taken on site to perform that task will rarely, if ever, be the same as the standard time. This is due to various time wastage factors which include operative absenteeism and productivity, materials shortages, management efficiency etc.... (for examples see Tavistock Institute, 1966). Consequently in any model of construction work the effect of these wastage factors must be evaluated to determine the actual construction duration and resource usage. The results of this analysis are used in pre-contract appraisal to determine anticipated costs and the degree of risk associated with a particular duration/cost figure, and in post-contract monitoring to provide assessments of likely outcome during the progress of a contract.

3.1.1. This chapter presents a stochastic model of site construction starting with the historic data base of site efficiency measurements, termed "performance data". A simulation method is then presented which uses distributions of these data to determine the anticipated duration of an operation based on the standard time for that operation. This is a lengthy manual procedure, and consequently a command driven suite of computer programmes was developed which are described in section 4.

3.2 Performance Data

The simulation method described in section 3.3 uses distributions of site efficiency measurements, the 'performance data'. These data are global measurements as the individual time wastage factors are too numerous to quantify individually. The data is calculated by comparing the actual construction duration to the allowed standard time for a particular operation.

3.2.1. Definitions

The performance data used in this chapter comprises the following:-

Operatives Performance Index (OPI)
The ratio of the standard time allowed for an operation to the actual productive time required to complete that operation. It is expressed as a multiple of 100.

Site Performance Index (SPI)
The ratio of the standard time allowed for an operation to the total time spent on that operation. It is expressed as a multiple of 100.

Productive unmeasured time (Pu)
This is the amount of time spent on work which is either too complex or insignificant to measure. It is expressed as a percentage of the total attendance time of the operative or gang.

3.2.2. Data Collection

The primary source of this data are the site gangers and foremen who are required daily to complete allocation sheets showing on which jobs their gang was employed and the time spent on each task. The site production surveying staff collect these sheets and measure the work produced by each gang. The standard hours for the operations are then assigned based on the time standards contained in the company's production data manual. The above indeces are then calculated and entered on weekly production summary sheets (fig. 3.1) and sent to head office for analysis.

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WEEKLY PRODUCTION SUMMARY

CONTRACT
CONTRACT Nº
WEEK ENDING

GANG	GANG SIZE	TRADE	OPERATIVE PERFORMANCE INDEX: STANDARD HOURS	OPERATIVE PERFORMANCE INDEX: PRODUCTIVE HOURS	O.P.I	PRODUCTIVE BONUS £	ADJUST-MENTS £	BONUS PAID £	SITE PERFORMANCE INDEX: STANDARD HOURS	SITE PERFORMANCE INDEX: TOTAL HOURS	S.P.I	REMARKS
Carash	4	Lab.	93.14	164.5	56				93.14	176.25	53	Concrete.
Cloutman	4	Lab.	192.9	203.5	95				192.9	205.0	94.	Concrete and formwork.
White.	7	Lab.	237.8	283.0	84				237.8	283.0	84	Drainage.
Hollister	5	Lab.	105.9	180.2	58				105.9	201.2	52	Place type 2.
Bachs	4	Lab.	122.0	175.0	69				122.0	175.0	69.	Gen. labourer.
TOTAL DIRECT	24		751.86	1006.25	74.7				751.86	1040.5	72.2	
PRELIM' LABOUR										258.7		
GRAND TOTAL												

HOURS SUMMARY	MAN-HOURS	PERCENTAGE
PRODUCTIVE MEASURED	675.25	65
PRODUCTIVE UNMEASURED	331.25	32
NON-PRODUCTIVE	31.00	3
WAITING TIME	3.00	-
WET TIME		
TOTAL	1040.5	100
PRELIMINARIES	258.7	
GRAND TOTAL	1299.25	

Fig. 3.1 Weekly Production Summary

3.2.2.1. The data from eleven recent contracts was abstracted from these summaries and this, together with the data collected by Bramwell made a total of twenty nine samples available for analysis. The new data is shown in tables 3.1, 3.2, 3.3 and 3.4, and Bramwell's data is included in Appendix D.

3.2.3 Data Analysis

The analyses performed on the performance data can be divided into two groups:-

(a) Between sample tests

(b) Within sample tests

3.2.3.1. Between sample tests

The objectives of this series of tests were twofold:-

(a) To determine if a significant difference exists between data sets, or can they all be considered to be independent samples drawn from the same parent population.

(b) To consider the site factors which may affect mean performance figures to enable a future sites efficiency level to be predicted.

3.2.3.1.1. Sample Differences

The differences between the sites was investigated by considering the standard error of the sample means. This analysis showed that all the samples cannot be considered as being drawn from the same parent population. Generally if the mean S.P.I. from two sites differ by more than 10 then the samples are significantly different. Thus over the total range of mean S.P.I's observed (58-119), there are significant differences between the contracts and we must further consider the factors which may affect the productivity of a particular site.

CONTRACT	No. of readings	O.P.I.				S.P.I.			
		MIN	MAX	MEAN	S.D.	MIN	MAX	MEAN	S.D.
Roundhill	1186	17	232	107	23	12	232	82	29
B'ham MRR	1068	14	242	94	22	9	178	65	23
Rushmore	166	37	162	111	24	32	179	88	32
Wakefield	32	83	134	103	13	67	128	94	16
W'hampton IRR	300	51	154	100	14	38	154	92	19
Cricklade	192	8	150	74	29	4	150	57	29
Gravelly Park	212	45	248	104	23	25	240	90	28
Horninglow	285	43	150	97	23	6	150	75	28
Shawbirch	108	29	131	89	24	5	131	72	31
Upton Way	145	28	189	76	33	2	172	59	32
Telford N.E.P.R.	1038	20	166	96	25	8	160	76	26
Stratton	292	53	264	98	18	15	155	71	23
MEAN				94.3	12.6			74.16	13.17
Standard dev.				13.3	5.4			11.57	3.90

TABLE 3.1 Performance Data - All Site

CONTRACT	No. of readings	O.P.I.				S.P.I.			
		MIN	MAX	MEAN	S.D.	MIN	MAX	MEAN	S.D
Roundhill	588	17	232	110	28	12	232	86	32
B'ham MRR	532	20	229	95	26	17	178	72	23
Rushmore	130	52	162	112	26	32	179	92	33
Wakefield	17	84	134	107	15	72	128	98	17
W'hampton IRR	122	51	154	99	18	38	154	93	23
Cricklade	95	19	150	80	31	4	150	64	32
Gravelly Park	107	45	150	107	21	35	155	93	23
Horninglow	85	45	132	91	24	19	123	67	27
Shawbirch	25	31	131	77	26	5	131	54	34
Upton Way	44	35	158	84	36	25	148	74	33
Telford N.E.P.R.	340	20	166	91	31	8	150	74	28
Stratton	21	53	135	96	24	48	135	90	26
Mean				95.8	25.5			79.70	27.5
s.d.				11.7	5.8			14.07	5.4

TABLE 3.2 Tradesmen O.P.I. & S.P.I

CONTRACT	No. of Readings	O.P.I.				S.P.I.			
		MIN	MAX	MEAN	S.D.	MIN	MAX	MEAN	S.D
Roundhill	597	47	163	104	18	21	168	77	25
B'ham MRR	536	14	242	93	18	9	140	59	21
Rushmore	36	75	128	106	15	37	103	72	17
Wakefield	15	83	114	98	7	67	102	88	12
W'hampton IRR	186	68	125	100	11	38	121	91	15
Cricklade	96	8	137	68	26	4	99	50	24
Gravelly Park	105	45	248	102	25	25	240	88	32
Hornignlow	200	43	150	99	22	6	150	79	28
Shawbirch	83	39	125	92	23	29	125	78	28
Upton Way	101	28	189	72	31	2	172	53	29
Telford N.E.P.R.	698	38	160	98	24	9	160	77	24
Stratton	271	57	264	99	19	15	155	70	22
Mean				94.2	19.8				
s d				12.0	6.7				

TABLE 3.3 Labourers O.P.I & S.P.I

CONTRACT	No. of Readings	PRODUCTIVE UNMEASURED TIME %				WET/WAITING TIME %			
		MIN	MAX	MEAN	S.D.	MIN	MAX	MEAN	S.D
Roundhill	74	0.00	28.00	5.84	4.38	0.00	44.00	7.73	8.44
B'ham M.R.R.	111	0.00	57.00	20.47	15.23	0.00	27.00	3.38	3.42
Rushmore	35	0.00	16.00	3.98	4.35	0.00	39.00	6.09	9.19
Wakefield	15	0.00	17.00	5.30	5.55	0.00	14.00	1.93	4.19
W'hampton I.R.R.	45	0.00	34.00	12.52	7.40	0.00	13.70	2.28	5.86
Cricklade	36	0.00	47.00	17.00	10.80	0.00	31.00	5.40	8.70
Gravelly Park	28	0.00	45.00	18.25	10.11	0.00	5.00	0.71	1.27
Horninglow	43	0.00	20.00	6.33	4.22	0.00	20.50	3.54	5.78
Shawbirch	13	0.00	18.00	2.92	5.40	0.00	34.00	3.53	9.75
Upton Way	44	0.00	45.00	15.20	9.60	0.00	35.50	1.52	5.70
Telford N.E.P.R.	83	0.00	59.00	15.76	11.86	0.00	20.00	4.05	6.13
Stratton	51	0.00	48.00	16.36	12.16	0.00	25.00	3.22	6.54
MEAN				11.66	8.42			3.61	6.22
STANDARD DEVIATION				6.32	3.70			2.00	.247

TABLE 3.4 Productive Unmeasured and Wet/Waiting Time

3.2.3.1.2. Performance Data Prediction

To consider the factors which affect the mean S.P.I and O.P.I values the total sample was sub-divided according to certain criteria:-

Location - Urban, Rural
Size - Large, Medium, Small.
Type - Roads, Sewage Works, Structures, Factory Estates, Tunnels.

The mean performance figures for each category, Table 3.5, are different between sub-divisions. However, analysis of variance tests, table 3.6 showed that these differences are not great enough for us to assume specific between sample effects. Thus the various sites cannot be classified according to any one of these various criterea.

Table 3.5 Performance data sub-divisions

Category	Sample Size	Factor	S.P.I. Mean	S.P.I. S.D	O.P.I. Mean	O.P.I S.D
Location						
Rural	15	1	74.2	9.7	90.8	10.5
Urban	14	2	77.9	11.7	96.1	9.0
Size						
Large	15	1	72.5	9.5	91.1	89.0
Medium	7	2	76.5	11.5	94.2	10.9
Small	7	3	82.8	10.1	97.5	11.2
Type						
Roads	19	1	73.1	10.5	90.9	9.7
Sewage	6	2	76.0	5.7	94.5	9.7
Structures	2	3	86.1	10.7	100.6	3.3
Factory	1	4	90.3	0.0	104.5	0.0
Tunnel	1	5	95.0	0.0	108.6	0.0

Table 3.6 Analysis of Variance

Test	Source of Variance	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Fc
1	within samples between smaples	2663.6 536.5	26 2	102.4 268.2	2.61	3.40
2	within samples between samples	3100.5 99.6	27 1	114.8 99.6	1.15	63.3
3	within samples between samples	2500.7 186.1	24 2	104.1 174.8	1.67	2.78
4	within samples between samples	2601.9 186.1	26 2	100.0 93.0	1.07	19.5
5	within samples between samples	2589.1 198.9	27 1	95.9 198.9	2.01	2.79
6	within samples between samples	2159.1 628.9	24 4	89.9 157.2	1.74	2.78

Tests.

1. S.P.I. - Size
2. S.P.I. - Location
3. S.P.I. - Type
4. O.P.I. - Size
5. O.P.I. - Location
6. O.P.I. - Type

The observed values of the variance ratio, F are less than the critical value, Fc and therefore we cannot reject the null hypothesis, thus in each case there is no specific between sample effect.

3.2.3.1.2.1. Regression analyses were performed in order to relate the mean production figures to the site factors. In addition the contract value, reduced to a base date of 1970, (Water Research Centre, 1977) was included as an independent variable. The correlation matrix, table 3.7, shows the results of this analysis. Mean OPI and SPI are highly correlated, but the contract value has no relationship to any of the performance figures. In some instances the contract factors showed significant correlations to the production figures. These factors were combined into a single factor F;-

$$F = Lf \times Sf \times Tf$$

Where Lf = Location factor

Sf = Size factor

Tf = Type factor

The correlation coefficient between F and mean S.P.I. is 0.54 and this shows that by considering the physical parameters of a site we can only account for approximately 29% of the total variability of the sample. Thus the unquantifiable site parameters, e.g. management efficiency are very significant when assessing site productivity.

Table 3.7 Correlation between contract factors & physical parameters

	SPI mean	SPI s.d	OPI mean	OPI s.d	Value	Location	Site	Type
SPI mean	1.00							
SPI s.d	0.02	1.00						
OPI mean	0.80	-0.04	1.00					
OPI s.d	-0.10	0.52	-0.24	1.00				
Value	-0.09	-0.03	0.05	-0.08	1.00			
Location	0.17	-0.36	0.27	0.02	0.44	1.00		
Size	0.40	-0.03	0.27	0.01	-0.32	0.01	1.00	
Type	0.52	-0.26	0.46	-0.06	0.05	0.26	0.57	1.00
F	0.54	-0.33	0.46	0.02	-0.04	0.41	0.65	0.94

3.2.3.1.2.2. From the foregoing analysis the prediction of mean S.P.I. is best made from a subjective assessment of all the factors affecting a particular site. The regression equations shown in table 3.8 can be used as a guide to the mean figure but these are open to interpretation. With a mean S.P.I. figure the value of mean O.P.I. can then be calculated. For simulation purposes we also wish to know the standard deviation of the performance data distribution for a proposed site, this is determined by considering the coefficient of variation Cv ($\sigma/\bar{x}$). This statistic was calculated for each sample and found to be relatively constant see table 3.9. Thus the standard deviation of each performance data distribution can be found from the mean value and Cv.

Table 3.8 Regression Equations.

Dependant Variable	Independant Variable	Regression Equation	Standard error of estimate
S.P.I. (S)	Contract factor (F)	S = .84(F) + 71.6	9.0
O.P.I. (O)	S.P.I. (S)	O = .75(S) + 36.7	6.0
S.P.I. (S)	O.P.I. (O)	S = .86(O) - 4.14	6.4

Note - The estimated value will be within 2 standard error of the actual value in 95% of the cases.

Table 3.9 Coefficient of Variability, Cv

Performance Index	Mean Cv	Cv. Standard Deviation
S.P.I.	0.37	0.08
O.P.I.	0.30	0.08

3.2.3.2. Within Sample Tests

This series of tests was undertaken with the following objectives.

(a) To investigate the changes in performance data with time, in respect to both long term trend and seasonal effect.

(b) To determine the shape of each sample distribution.

3.2.3.2.1. Time Analyses

The values of the mean monthly figures for each sample were transformed using the equation:-

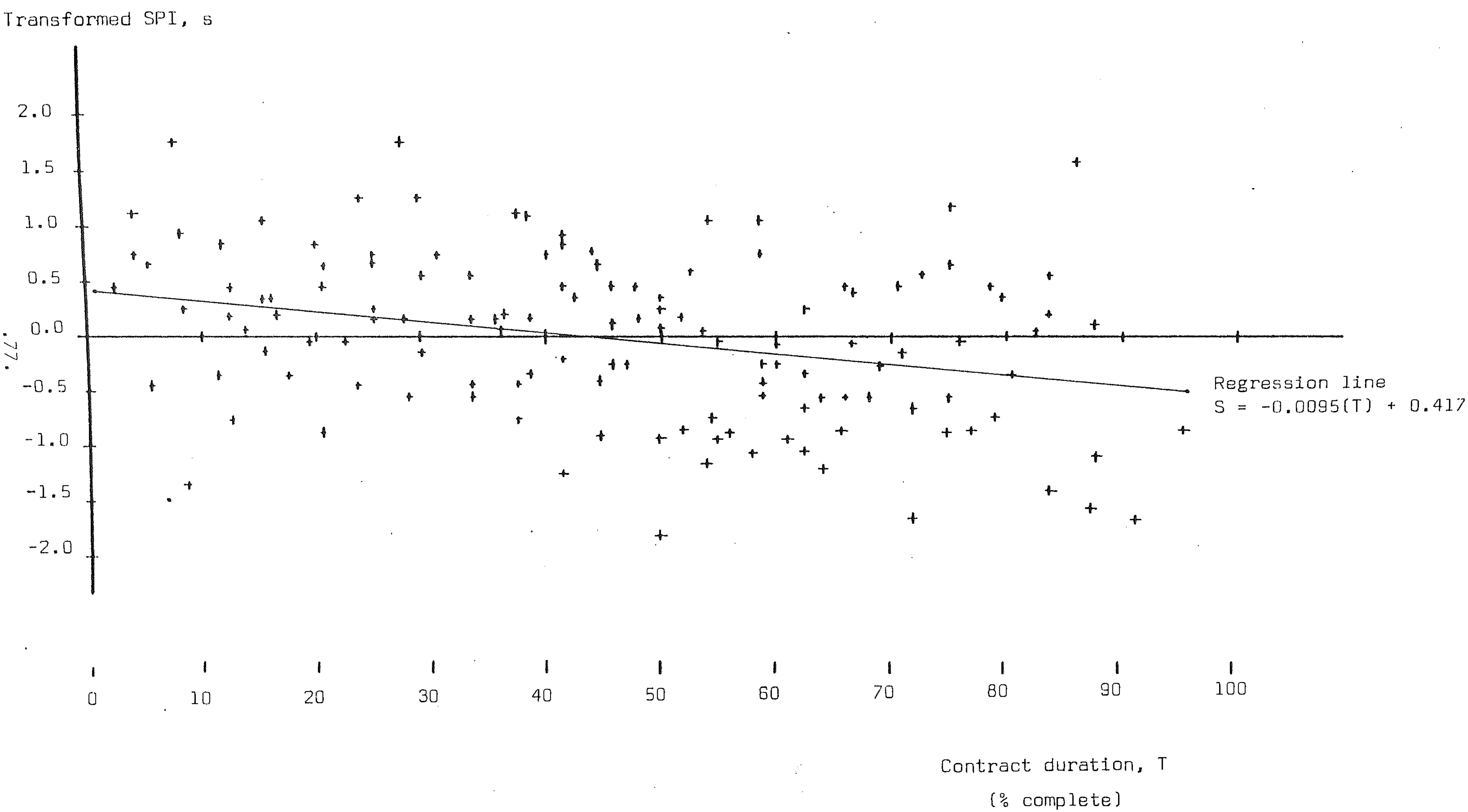
$$t = (x - \bar{x}) / \sigma$$

where $\bar{x}$ and σ are the sample mean and standard deviation respectively. By using this transformation the fluctuations about the sample mean could be considered, and also the samples can be pooled to investigate global effects.

3.2.3.2.1.1. Long Term Trend

The transformed variable plotted against time is shown in figure 3.2. It will be seen that there is a large scatter of points, but a regression analysis showed a small but significant negative correlation between transformed SPI and time, see table 3.10. The best fit line shows that on average after approximately 45% of the contract duration has elapsed the SPI will fall below the site average. However, in certain individual samples the trend was opposite to this showing a rise in SPI with time.

Fig. 3.2 Transformed SPI vs Contract Duration



3.2.3.2.1.2. Seasonal Effect

The plot of transformed SPI vs month, fig. 3.3 shows a general trend for values to be higher in the summer than the winter. In order to test this by regression the values for each month were coded as follows:-

$$Mi = \cos \left\{ \frac{(x-1)\pi}{11} \right\}$$

where x = month number, Jan = 1, Feb = 2 etc..

By this transformation the coded value for Jan = -1, and July = 0.96.

The correlation coefficients shown in table 3.10 show that no relationship exists between the month and the transformed SPI and OPI figures and consequently no seasonal effect is evident.

3.2.3.2.2. Sample Distributions

The samples were tested against the Null hypothesis that there was no significant difference between the observed distribution and a normal distribution with the same mean and standard deviation. The results of this series of tests are shown in Table 3.11. These results agree with Bramwell's findings, table D.4 and D.5 that not all samples can be considered to be normally distributed. In addition no pattern is evident from which to predict the normally distributed performance data distributions.

Table 3.10 Correlation Matrix. Time Analysis

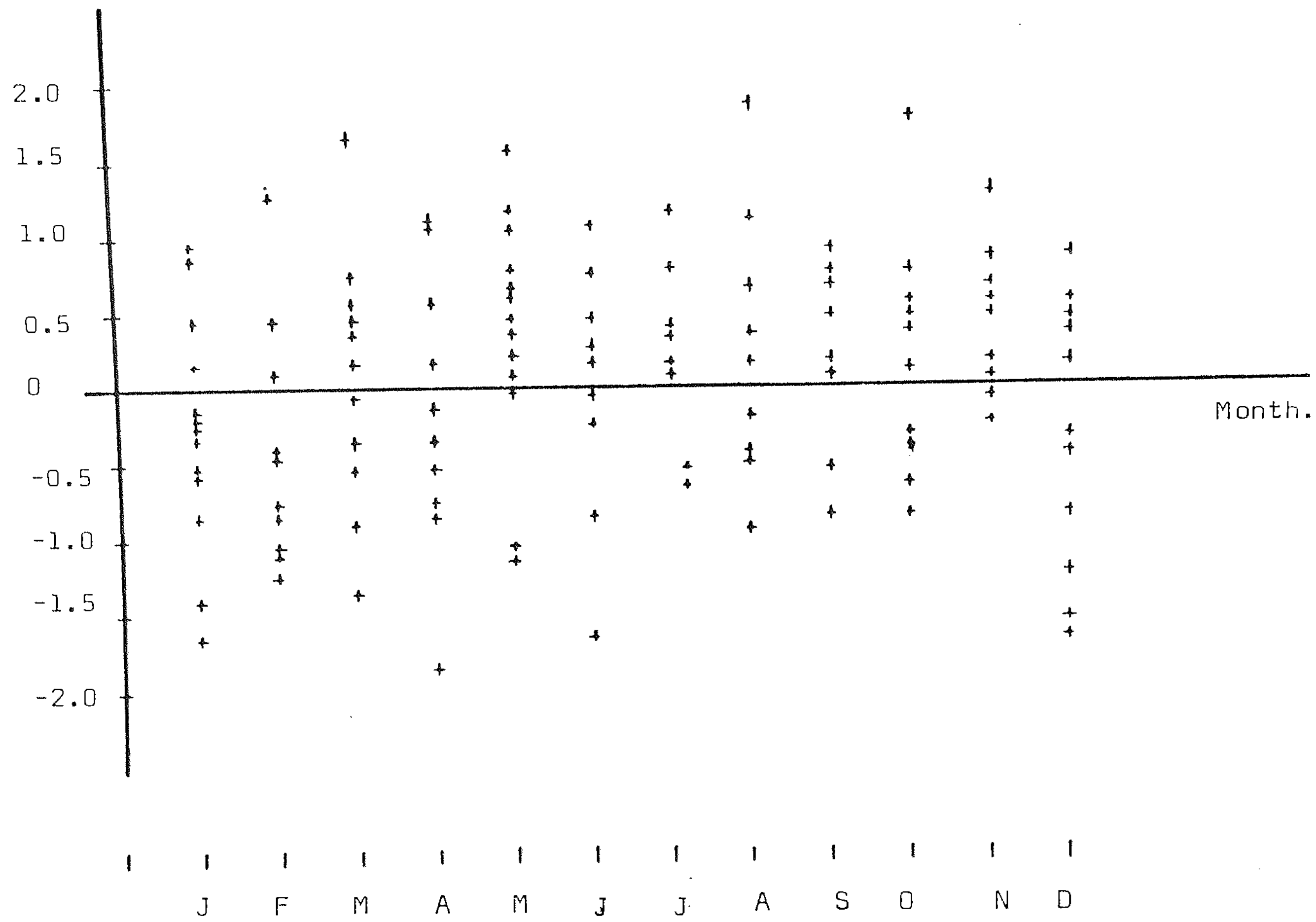
	Month	% duration	SPI	OPI
Month	1.00			
% duration	-0.09	1.00		
SPI	0.18	-0.30	1.00	
OPI	-0.03	-0.03	0.55	1.00

Sample Size 155

Critical Values Rc = 0.25 @ 1% Significance level

Rc = 0.20 @ 5% significance level

Fig. 3.3 Transformed SPI VS Month.



CONTRACT	LABOUR O.P.I.	LABOUR S.P.I.	TRADESMEN O.P.I.	TRADESMEN S.P.I.	ALL SITE O.P.I.	ALL SITE S.P.I.
Roundhill	R	R	A	A	R	A
B'ham M.R.R.	A	A	R	A	R	R
Rushmore	A	A	R	A	R	A
Wakefield	A	A	A	A	R	A
W'hampton IRR	R	A	A	R	A	R
Cricklade	A	A	A	R	A	A
Gravelly Park	R	R	A	A	R	A
Horninglow	R	R	A	A	R	A
Shawbirch	A	A	A	R	R	A
Upton Way	A	A	R	R	R	A
Telford NEPR	A	R	R	R	R	A
Stratton	A	A	A	R	A	R
Null hypothesis	Ho : No difference between sample distributions and a normal distribution with the same mean and standard deviation. R = Reject Ho A = Accept Ho					

Table 3.11 Distributions of Site Performance Indices.

3.3. Stochastic Simulation

The preceding section described the performance data collected by the company. This data is calculated knowing the actual site duration of an operation. This section describes the reverse procedure whereby with known performance figures the construction duration can be determined. This is achieved by calculating the quantity of work produced in unit time periods q. The simulated construction duration, T is then equal to the number of time periods which have elapsed when the total operation quantity has been produced.

i.e. $T = J$, when $Q - \sum_{i=1}^{j} q_i = 0$ see fig. 3.4.

3.3.1. Calculation of q.

The value of q for each time period is calculated from values of SPI, OPI and Pu. The values which are used in the calculation are selected from distributions of these data using various sampling techniques which are described in section 3.3.2. The theoretical determination of q is presented in appendix E and summarised below.

(a) Determine actual gang size, na.

(b) Calculate total attendance time, ta = na.Ƶ

(c) Sample productive unmeasured time distribution P*

(d) Calculate productive unmeasured time Pu = P (na.Ƶ)

(e) Sample SPI distribution, S

(f) Sample OPI distribution, Ø

(g) Calculate waste time, Wt from equation (3.6)

$$Wt = \frac{(na.Ƶ)\ (Ø - s)}{Ø}$$

(h) Calculate productive measured time, Pm, from eqn (3.7)

$$Pm = (na.Ƶ) - Pu - Wt$$

(i) Calculate the standard hours from eqn (3.8) - Sh = Ø. Pm

(j) Calculate q from equation (3.9)

$$q = Sh/Su$$

* P is expressed as a percentage of the total attendance time

3.3.1.1. Adjusting for Overrun

The above calculations are repeated until the quantity left to construct becomes zero. This will occur very rarely after a number of integer steps, i.e. the remaining quantity being positive after j and negative after j+1 increments. The production rate is assumed constant within each time period and therefore the over-run δt is determined from a pro-rata analysis of the j+1 th increment.

3.3.2. Distribution Sampling

The method of sampling the performance data for use in the foregoing calculation depends on whether the data are independant of each other or are in some way related.

3.3.2.1. Relationship Between Performance Data

The correlation coefficient, r between the various performance data are shown in table 3.14. Table 3.14(a) shows the values obtained between weekly SPI, OPI and Productive Unmeasured time. In only three cases was this correlation significant and consequently it is assumed that Pu is independant of both OPI and SPI. The correlation between the weekly gang figures of OPI and SPI is shown in table 3.14(b) and in every case there is a significant correlation. Thus Pu can be sampled as an independant variable using a monte-carlo sampling technique, whereas OPI and SPI must be treated as multivariates.

3.3.2.2. Monte-carlo distribution sampling

The sampling of productive unmeasured time is illustrated by the following example. A typical probability distribution of a variable, x is shown in fig. 3.5(a). For sampling purposes this distribution is transposed into a

Correlation Coefficients

Table 3.14(a) Weekly Figures

Contract	Sample Size	Critical Value	r (Pu.SPI)	r Pu.OPI
Upton Way	44	.30	.071	.171
Shawbirch	13	.55	-.229	-.460
Telford N.E.P.R.	83	.22	-.235	-.380
Cricklade	36	.33	.208	-.114
Horninglow	43	.30	-.100	-.142
Stratton	51	.28	-.375	..124
Gravelly Park	28	.37	.148	-.010
Wakefield	15	.52	.125	.315
Rushmore	35	.33	.176	.119
BMRR	105	.19	-.100	-.117
Roundhill	74	.23	.159	-.178

Table 3.14 (b) Weekly Gang Figures

Contract	Sample Size	Critical Value	r SPI - OPI
Upton Way	145	.166	.801
Shawbirch	108	.192	.755
Telford N.R.P.R.	1038	.062	.595
Cricklade	191	.144	.797
Horninglow	285	.118	.793
Stratton	292	.117	.397
Gravelly Park	212	.137	.829
Wakefield	32	.350	.786
Rushmore	166	.155	.774
BMRR	1068	.061	.553
Roundhill	1186	.058	.681
		Mean	.704
		Standard Deviation	.136

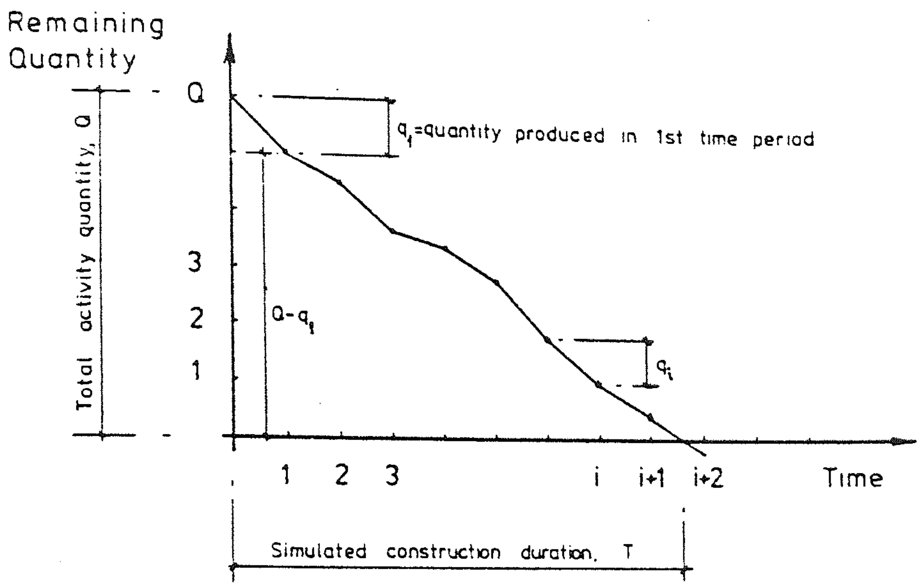


Fig. 3.4 Simulation of Construction Duration.

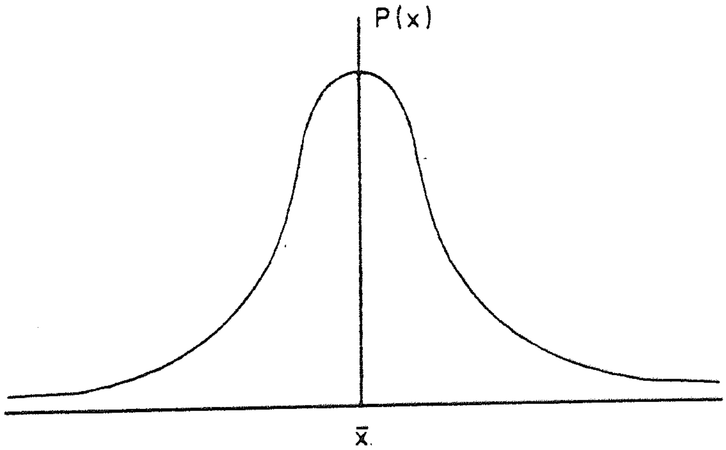


Fig. 3.5 (a) Typical Probability Distribution of variable (x)

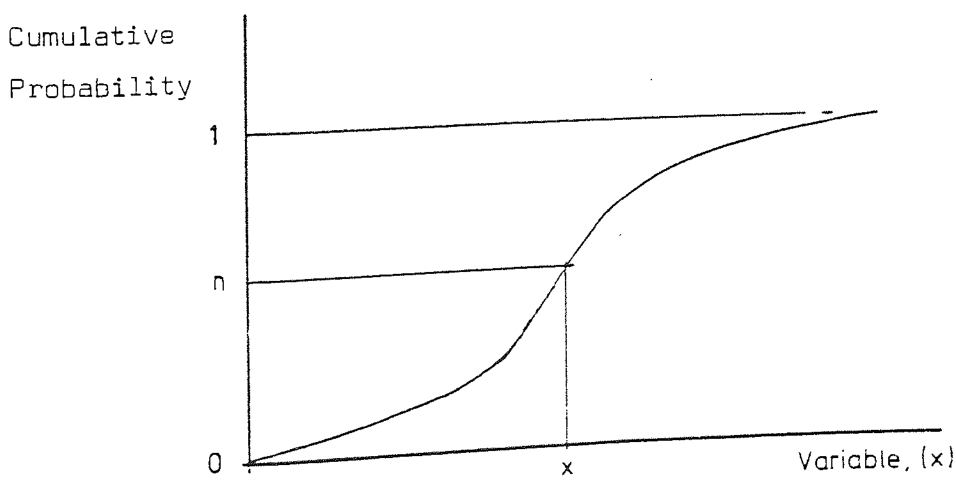


Fig. 3.5 (b) Cumulative probabiltiy curve

cumulative distribution of the type shown in fig. 3.5(b). To select a value of x a random number n, in the range 0 to 1 is required, the sampled value of x is then read directly from the cumulative distribution.

3.3.2.3. Sampling of OPI and SPI

The values of SPI and OPI have been shown to be correlated therefore in the sampling process the values obtained must also be correlated to the same extent. This is achieved using the following equations:-

$$to = r.\eta_1 + (1-r)^{\frac{1}{2}} \qquad (3.17)$$

$$ts = \eta_2 \qquad (3.18)$$

Where, $to = \dfrac{OPI - \overline{OPI}}{\sigma_{OPI}}$

$ts = \dfrac{SPI - \overline{SPI}}{\sigma_{SPI}}$

r = the correlation coefficient between SPI and OPI

and are randam numbers with zero mean and unit variance.

The derivation of equations 3.17 and 3.18 is shown in appendix F. The values of η_1 and η_2 are generated from random numbers C and D, in the range 0 to 1 using the Box-Muller transformation:-

$$\eta_1 = (-2\,LnA)^{\frac{1}{2}} \cdot COS\,(2.\pi.D)$$

$$\eta_2 = (-2\,LnA)^{\frac{1}{2}} \cdot Sin\,(2.\pi.D)$$

Equations 3.17 and 3.18 were tested by selecting typical values for the mean and standard deviation of OPI and SPI and for the correlation coefficient. The equations were solved using 100 pairs of random numbers, C, and D. and the means and standard deviations of the results computed. The input and computed values showed good agreement, table 3.15.

Table 3.15 Results of Testing of Equations 3.17 and 3.18.

	Input	Computed
Mean SPI	75.0	74.7
Std dev. SPI	20.0	19.7
Mean OPI	100.0	98.6
Std dev. OPI	20.0	19.6
Correlation coefficient	0.8	0.8

3.4 Computer System

The computer system - 'SIM' - is a general purpose suite for project analysis and simulation. SIM is not designed specifically for pipeline construction but can be used for the analysis of any type of construction work. The system is interactive and command driven, that is the user controls execution of SIM by entering commands, a series of english type words and mnemonics which instruct SIM to perform certain tasks. The advantage of this approach is in the alternatives open to the user to perform various analyses as and when they are required and not to be restricted by pre-determined input/output requirements.

3.4.1. Structure

The suite consists of ten individual programmes, see fig. 3.6. This number was required so that the size of each programme could be accommodated on the development hardware (see Vol. 2). All data which is entered into, or generated by SIM is stored on data files, see Volume 2. Each programme has a particular file associated with it, the name of which consists of a standard three character code suffixed with a generation number. The file names and the files themselves are generated automatically by the master programme in the same way that files are handled in the 'PLEP' system (see chapter 2).

3.4.1.1. Commands

To control execution of SIM the user enters command words into the computer. A full SIM instruction consists of a main command, to specify the general type of instruction, a sub-command which gives the detailed type of input data or required analysis and various parameters which are commonly the users input data. A listing of SIM commands and parameters is shown in Table 3.12 and a full description of command input and usage is contained in the users handbook, (Vol. 2).

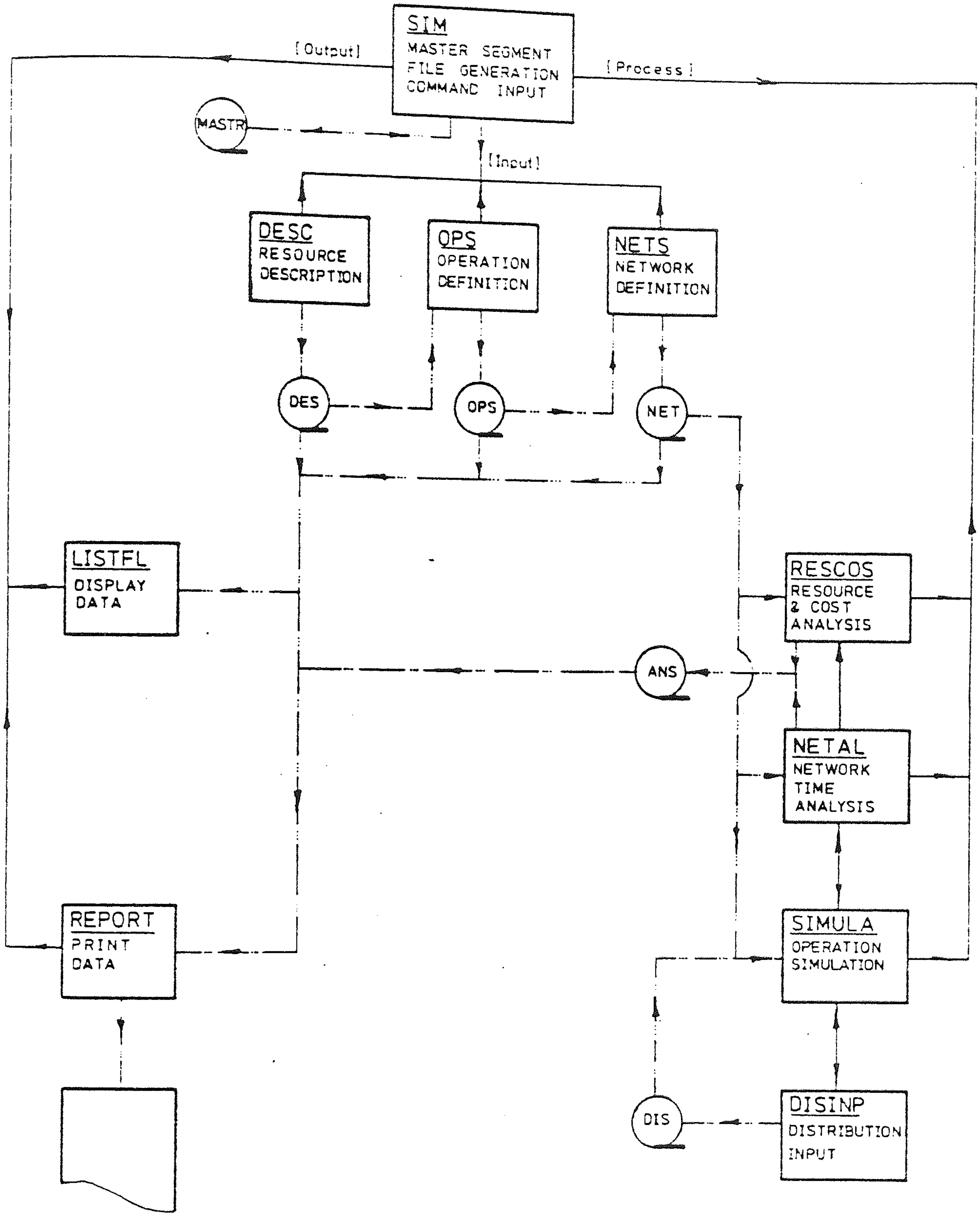


Fig 3.6 PROJECT SIMULATION SUITE

Table 3.12 Simulation Suite Commands

	RESOURCE DESCRIPTIONS			OPERATION DEFINITIONS				NETWORK DEFINITION		NETWORK ANALYSIS			NETWORK SIMULATION	
MAIN COMMAND	DES			OPS				NETS		ANA			SIM	
SUB COMMAND	LAB	MAT	PL	DEF	LAB	MAT	PL	DEF	EDIT	SNET/ MNET			SNET/MNET	
PARAMETER [1]	Labour Code	Material Code	Plant Code	Operation Code	Operation Code	Operation Code	Operation Code	Snet or Mnet	Snet or Mnet	Network Code			Network Code	
[2]	Description	Description	Description	Description	Labour Code	Material Code	Plant Code	Network Code	Network Code	Time	Resource	Cost		
[3]	Cost	Cost	Cost	Standard Duration	Number Required	Quantity	Number Required	Description						
[4]	Units	Units	Units	Units		Units								

3.4.2. Input Data

The first task for the user is to enter the basic data which will form a representation of the complete project. This input data is in three parts, (see Fig. 3.7):-

a) Resource description.
b) Operation definition.
c) Network definition.

3.4.2.1. Resource Descriptions

The basic data for the project model are the resource descriptions, it is necessary for the user to specify the various types of labour, materials and plant which will be used during the project. This is accomplished by issuing the DES command with the required sub-commands and parameters, this calls the programme DESC (see Fig. 3.8) which accepts this data and stores it on the file DESf.. The input data consists of a resource code - a two digit alphanumeric code which will be used to identify that resource throughout the running of SIM - , and a fuller description for use in reports. The final data items are the cost and unit of cost for that resource, e.g. £/m, £/hr etc...

3.4.2.2. Operation definition

The next stage is to consider the construction operations which are to be performed. All SIM instructions relating to operations are grouped under the main command OPS, which calls the programme of the same name (see Fig. 3.9). The first task is to define the operation, using the DEF sub-command. This requires as input data an operation code and a fuller description, as for resources together with the total quantity to be produced and the standard duration of that operation. The last two data items are used in the analysis and simulation of construction networks.

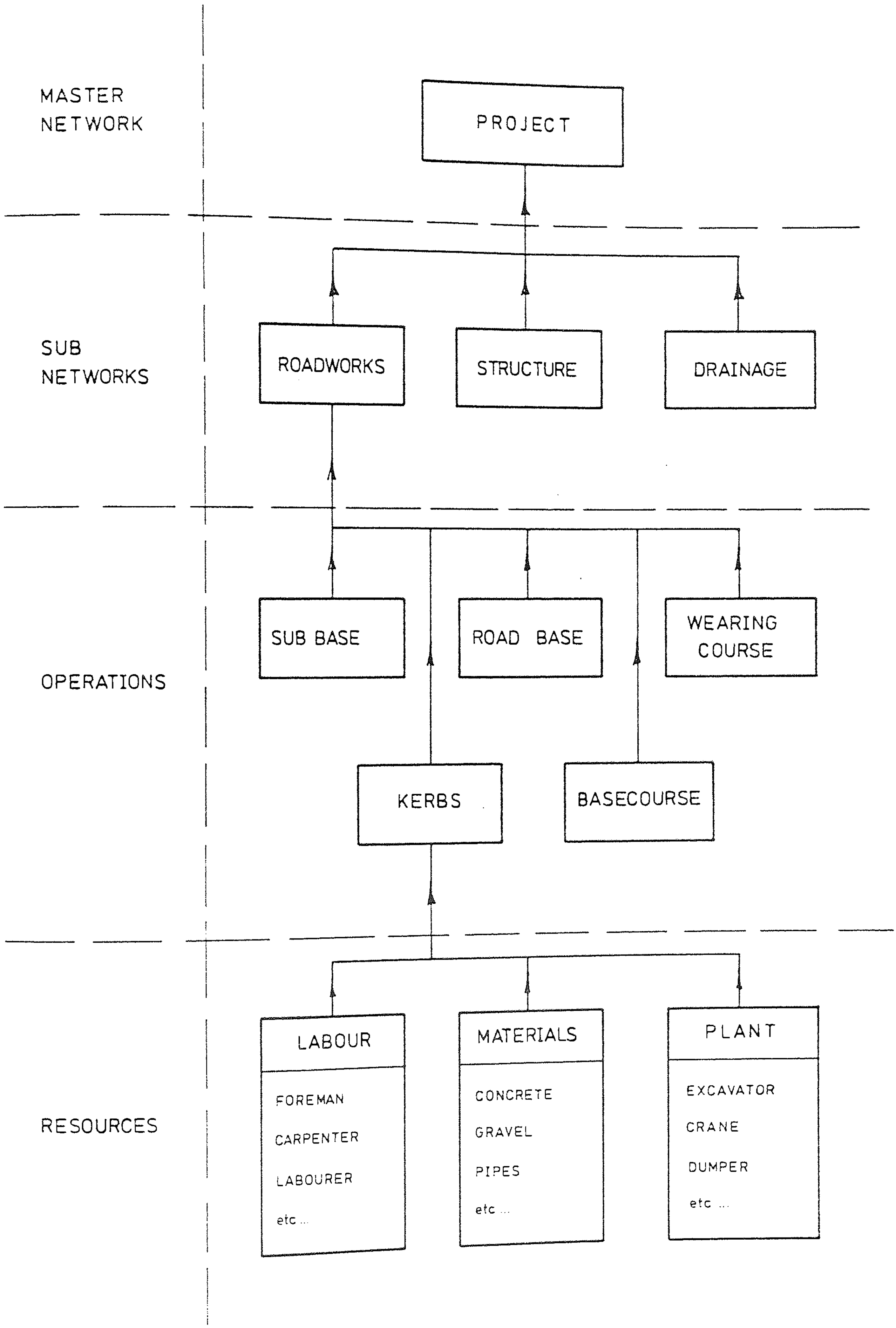


Fig. 3.7 Project Breakdown

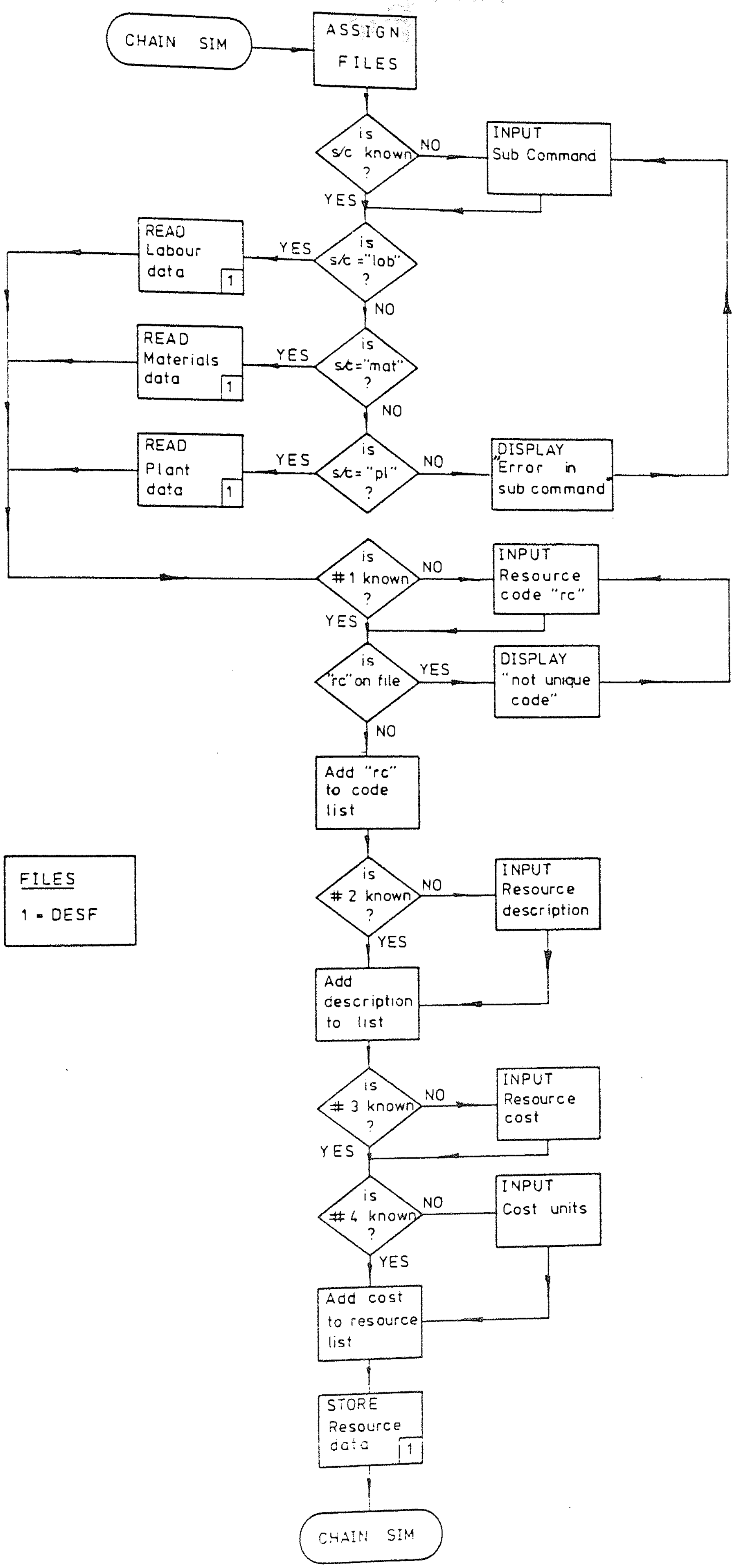


Fig. 3.8 Resource description programme - DESC

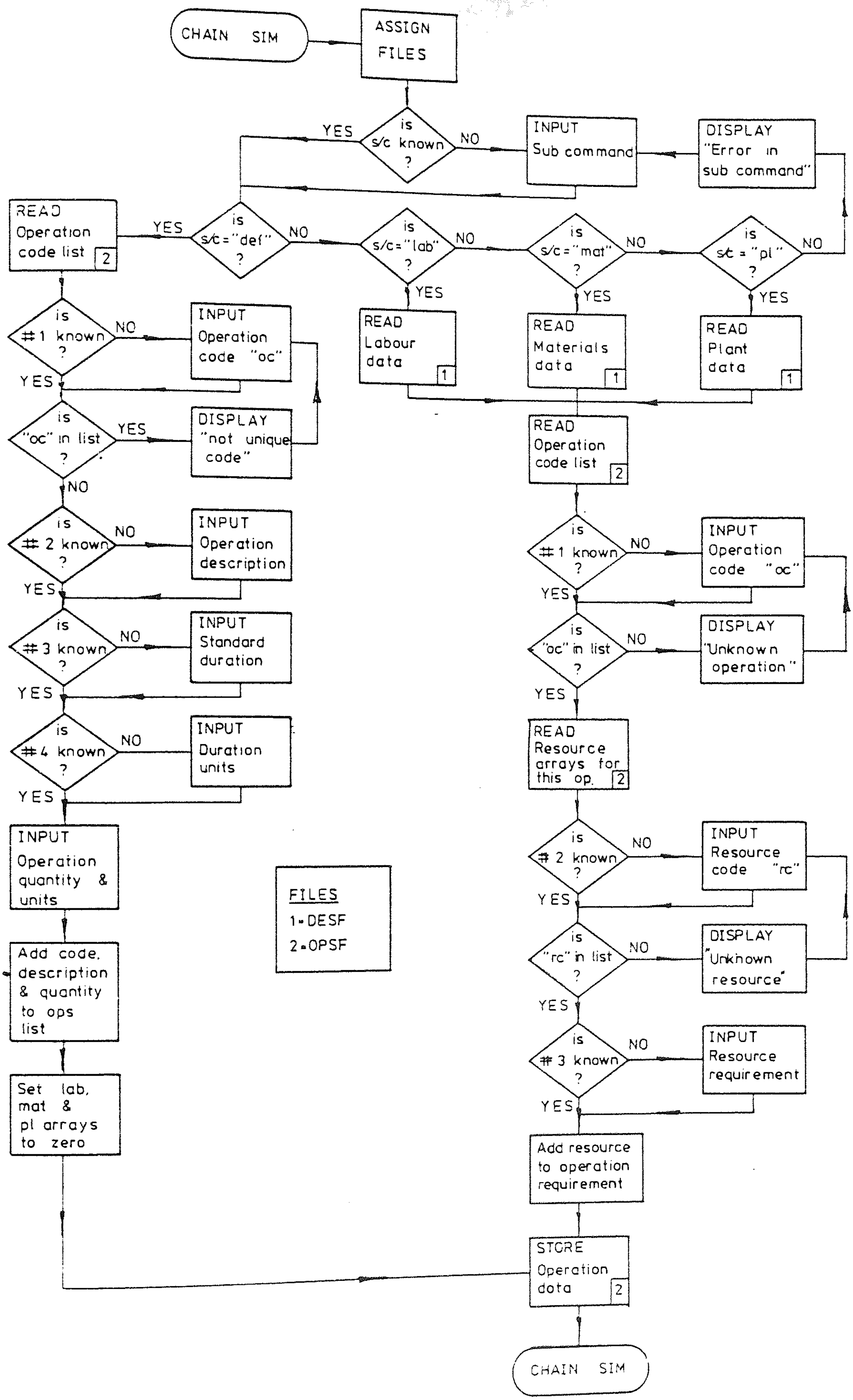


Fig. 3.9 Operations Definition Programme - OPS

3.4.2.3. Construction Networks

The final stage in building up the project model is to consider networks of construction operations. Owing to limitations imposed by the computer hardware the size of each network had to be limited to thirty operations. To overcome this restriction two types of network are considered:-

a) Sub-networks - To gather together in logical sequence all the operations which comprise a particular section of a project.

b) Master-network- One network which combines all the sub-networks to form the complete project model.

All SIM commands relating to networks are grouped under the main command NET, with two sub-commands for definition and editing. This command calls the programme NETS, see fig. 3.10

3.4.2.3.1. Network Definition

The system works with activity on the node precedence networks. This type was selected in preference to activity or the arrow networks because of the ease of input and analysis and also because dummy activities are not required. To define a network the user needs to specify each operation together with its immediate predecessors. Upon completion of network definition SIM sorts the operations into chronological order and checks for the presence of loops. This is accomplished by considering each precedence relationship as an inequality and then numbering the operations so that all inequalities are satisfied. An example of network definition and sorting is shown in Appendix G .

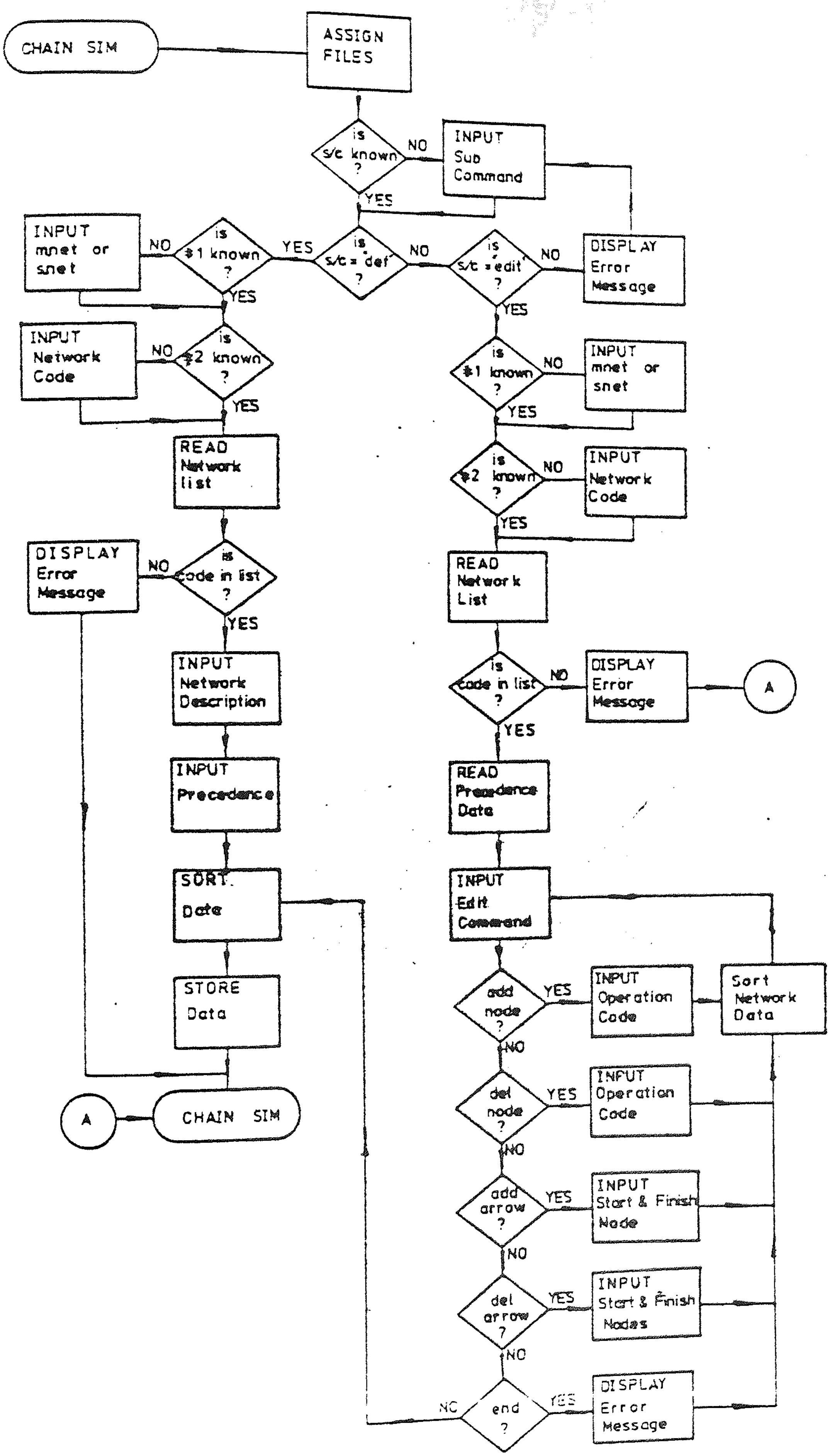


FIG 3.10 NETWORK DEFINITION AND EDITING PROGRAMME - NETS

3.4.2.3.2. Network Editing

The provision within SIM of a network editing facility was considered necessary for the following reasons:-

(a) To remove loops from a network
(b) To allow the user to modify a network for re-analysis to investigate the effects of changes in construction method and network logic.

The network editor has four functions which allows the user to add into, or delete from a network either a node or arrow. This facility is shown in fig. 3.11.

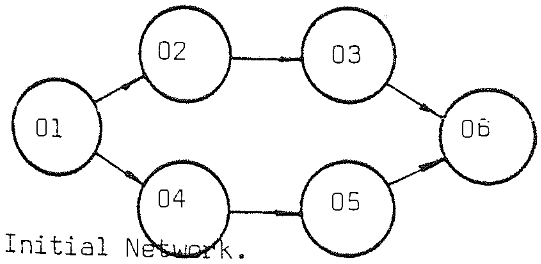
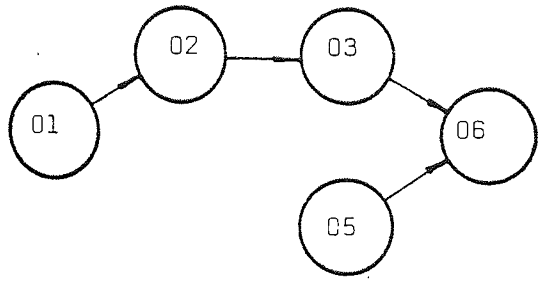
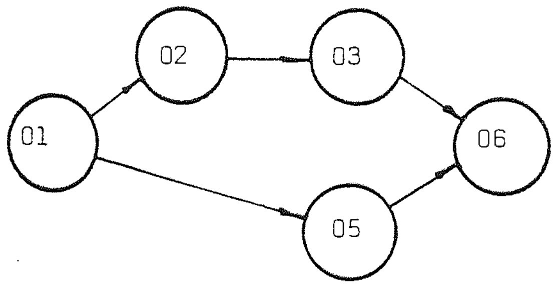
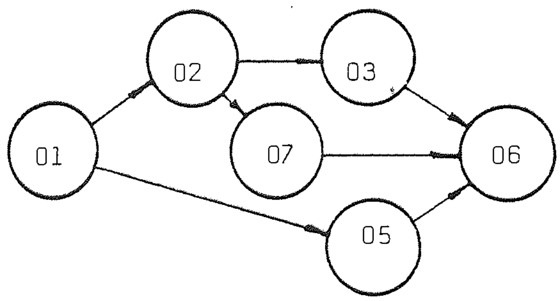
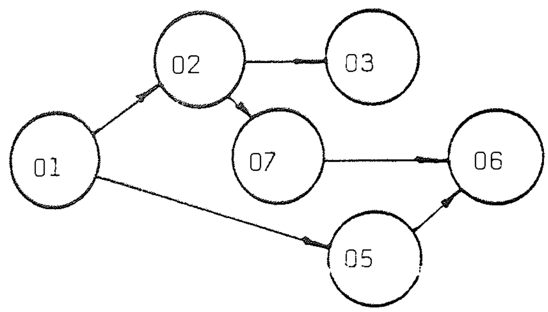
3.4.3. Network Analysis

A network can be analysed in three ways, with respect to time, costs or resources. These analyses are instigated by the main command ANA, which calls the programmes NETAL (fig. 3.12), and RESCOS (fig. 3.13). Under this command the analyses are performed using the operation standard durations as specified by the user. This facility, together with the network editing commands enable the "optimum" network logic to be found before proceding onto project simulation.

3.4.3.1. Time Analysis

The network time analysis calculates for each operation the early and late start and finish times, the total float time and also the critical path through the network. This is done by a forward pass through the network to determine early start and finish times, and a backward pass for late start and finish times. Finally the total float is calculated together with the critical path which joins all the operations having a float time of Zero. An example of this analysis is shown in fig. 3.14.

Fig. 3.11 Network Editing

SIM INTERACTION	EFFECT ON NETWORK
> NETS. Sub-Command (Def/Edit) ? Edit. Editor is ready. Need Help ? No.	 Initial Network.
* DEL.NODE. Operation Code ? 04 Predecessors ? 01 Successor. ? 05	
* ADD,ARROW Start Node ? 01 Finish Node ? 05	
* ADD,NODE Operation Code ? 07 Predecessors ? 02 Successors. ? 06	
* DEL,ARROW Start Node ? 03 Finish Node ? 06 * END (Finish network edit). > (NEXT COMMAND)	

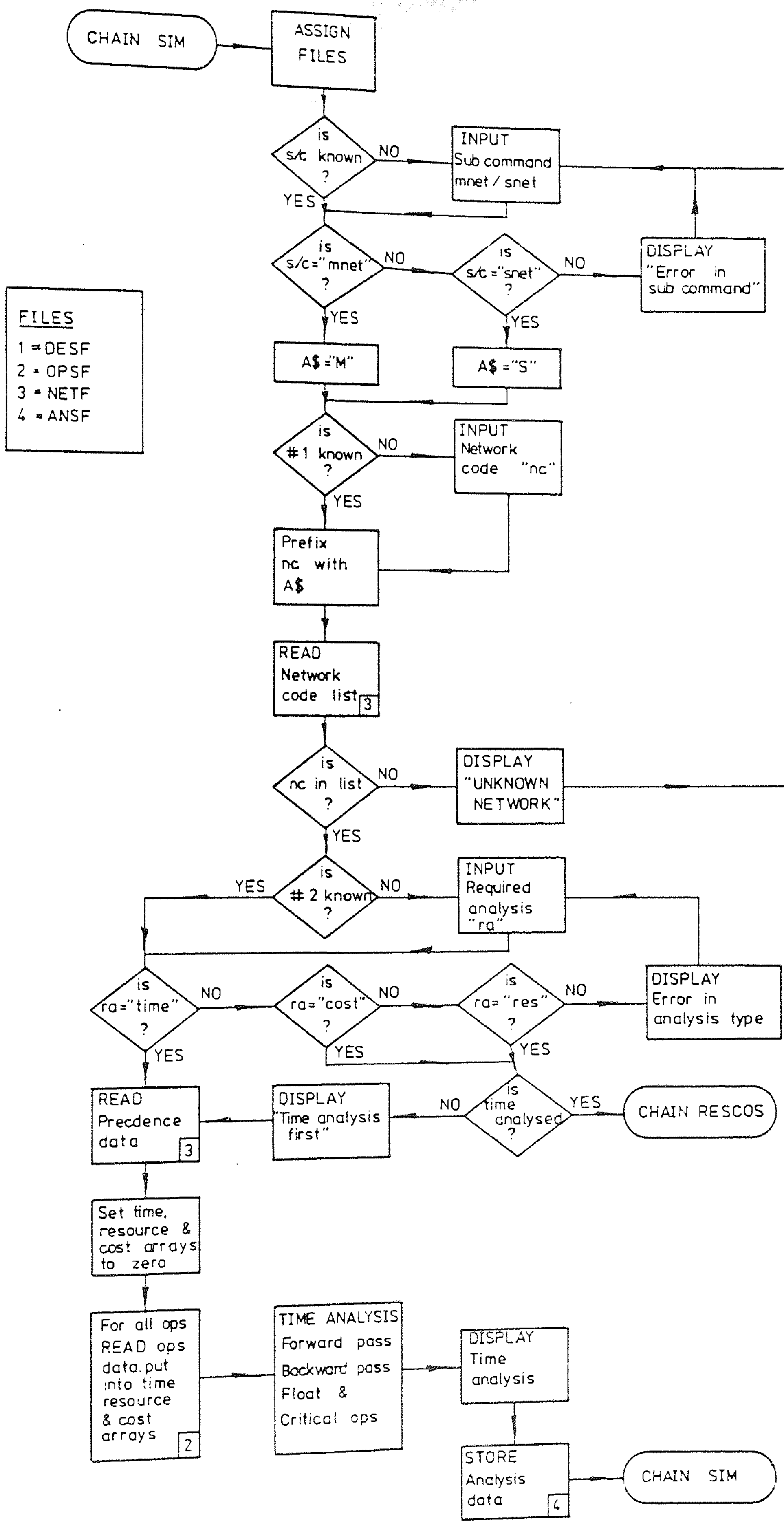


Fig. 3.12 Network Time Analysis Programme - NETAL

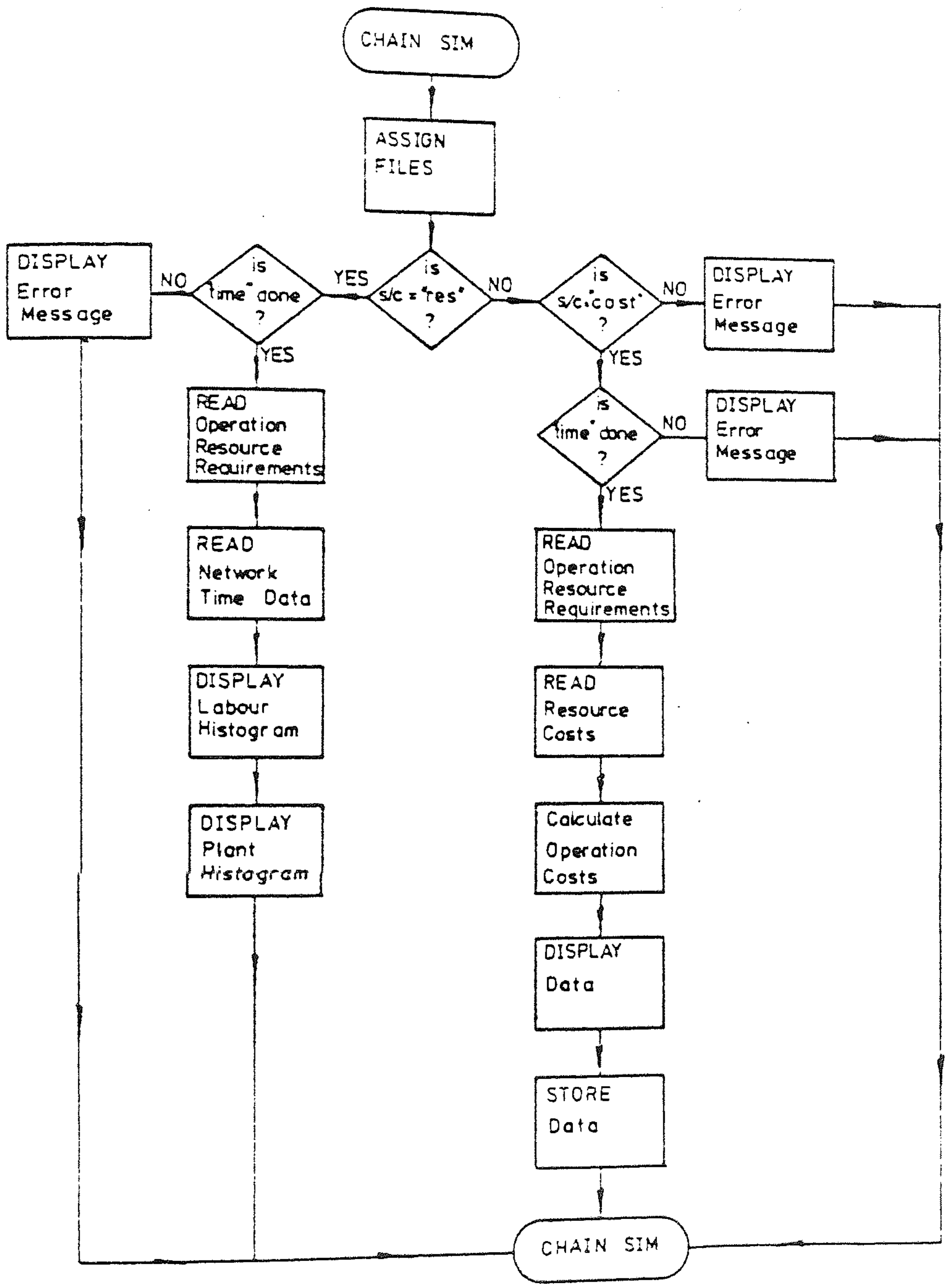


Fig. 3.13 Research and Cost Analysis - RESCOS

Fig. 3.14 Example Time Analysis

KEY

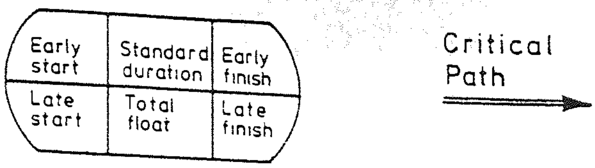


Fig. 3.14 (a) Initial Network

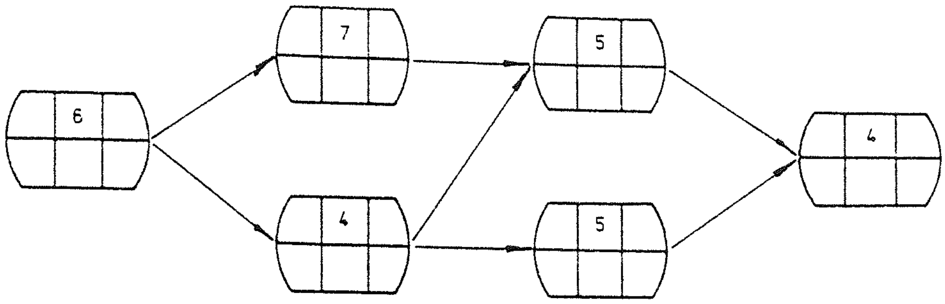


Fig. 3.14 (b) Forward pass - Early Start & Finish Times

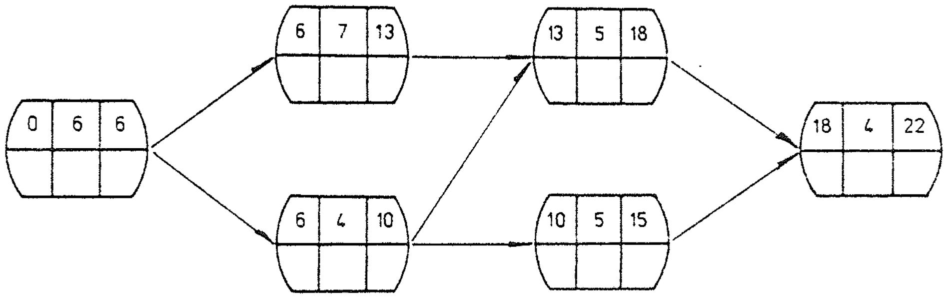


Fig. 3.14 (c) Backward pass - Late Start & Finish Times

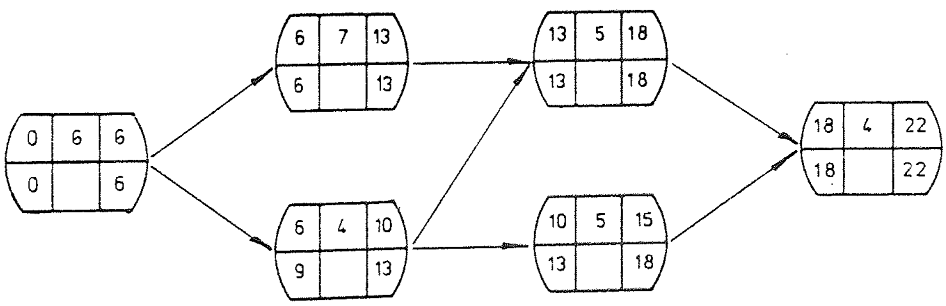
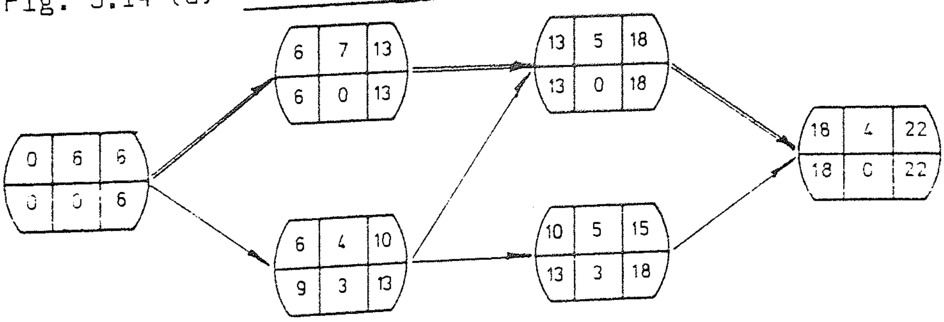


Fig. 3.14 (d) Total Float & Critical Path



3.4.3.2. Cost Analysis

The total cost of each operation is found by summing the individual resource costs thus:-

$$Ci = Tsi \times \sum (Pij \times cpj) + Tsi \times \sum (Lij \times clj) + \sum (Mij \times cmj)$$

These costs are reported to the user in two ways:-

(a) By operation, broken down into labour, materials and plant costs.

(b) Against time, showing the rate of expenditure over the duration of the network, assuming a constant rate of resource usage during each operation.

3.4.3.3. Resource Analysis

This analysis determines the total requirements of each type of resource throughout the duration of a network. This is done by considering time increments and then summing the individual resources from all the operations which are active within that time increment. This analysis is performed with respect to labour and plant with operations commencing at early and then late start times.

3.4.4. Stochastic Simulation

The simulation programme, SIMULA see fig. 3.15, is called by issuing the main command, SIM. The simulation of a construction network is in three stages:

a) Distribution input
b) Simulation of operation times
c) Simulation of network times.

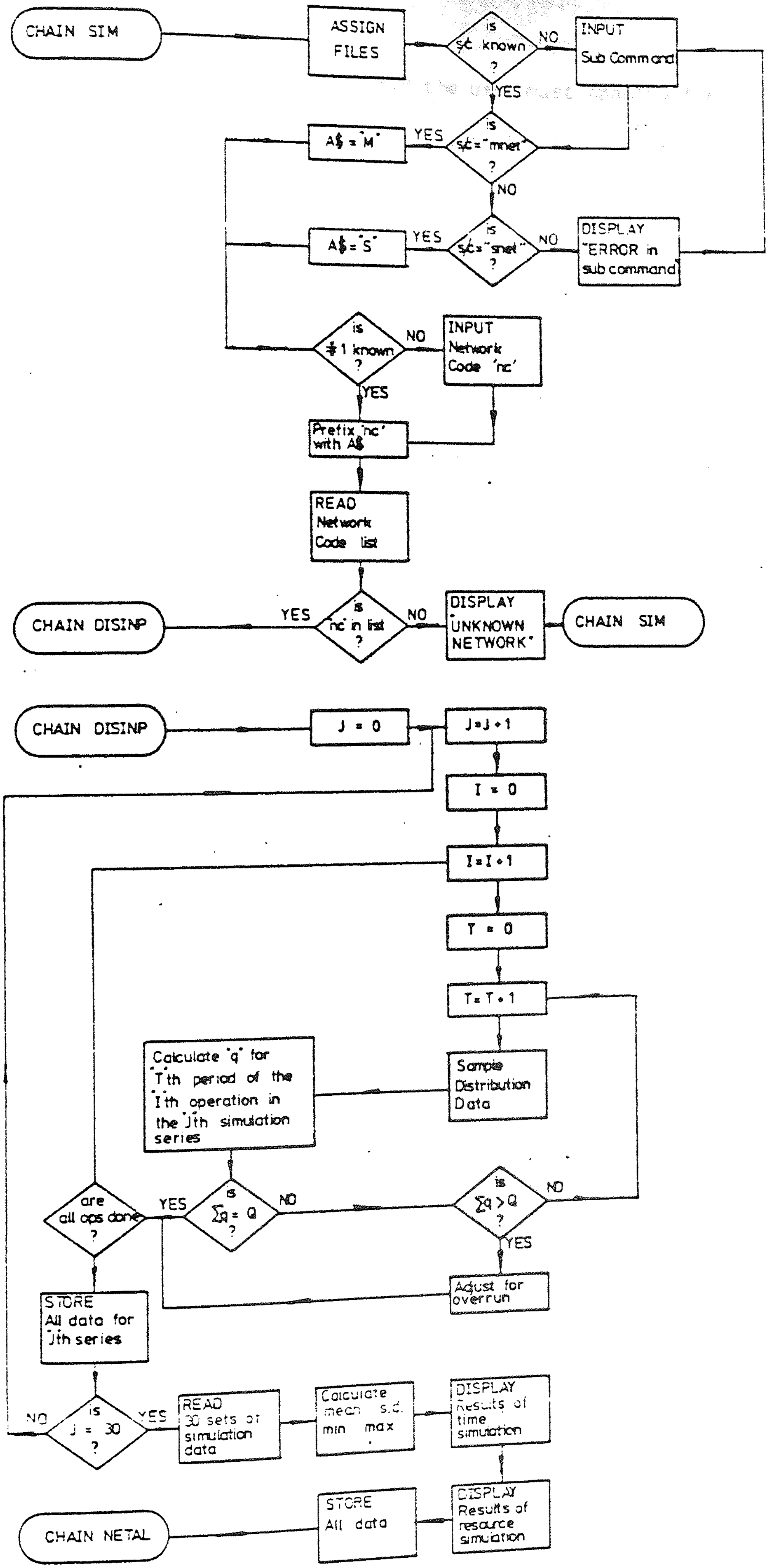


Fig 3.15 Operation Simulation Programme SIMULA

3.4.4.1. Distribution Input.

Before the simulation can be performed the user must specify the distributions of performance data from which samples are to be taken. These distributions can be in one of two forms.

3.4.4.1.1. Normal Distribution.

To use a normal distribution the user need only specify the mean and standard deviation. SIM will automatically generate the cumulative distribution from these parameters.

3.4.4.1.2. Non-Normal Distributions.

The user can specify non-normal distributions by inputting values of the performance data, together with the percentage occurrence of that value in the distribution. These user defined distributions are stored on the file DISf by the programme, DISINP fig . 3.16. The mean and standard deviation of the distribution is calculated and displayed to the user, for subsequent re-use the user must merely specify these parameters and the particular distribution will be selected from the file.

3.4.4.2. Operation Simulation.

For the second stage of the process each operation is considered in isolation. The simulated duration of that operation is then calculated using the method described in section 3.3. and is repeated thirty times to build up a matrix of possible operation durations. This is then repeated until all the operations in the network have been processed. For each operation the minimum, maximum and mean operation duration, together with the duration standard deviation are displayed to the user.

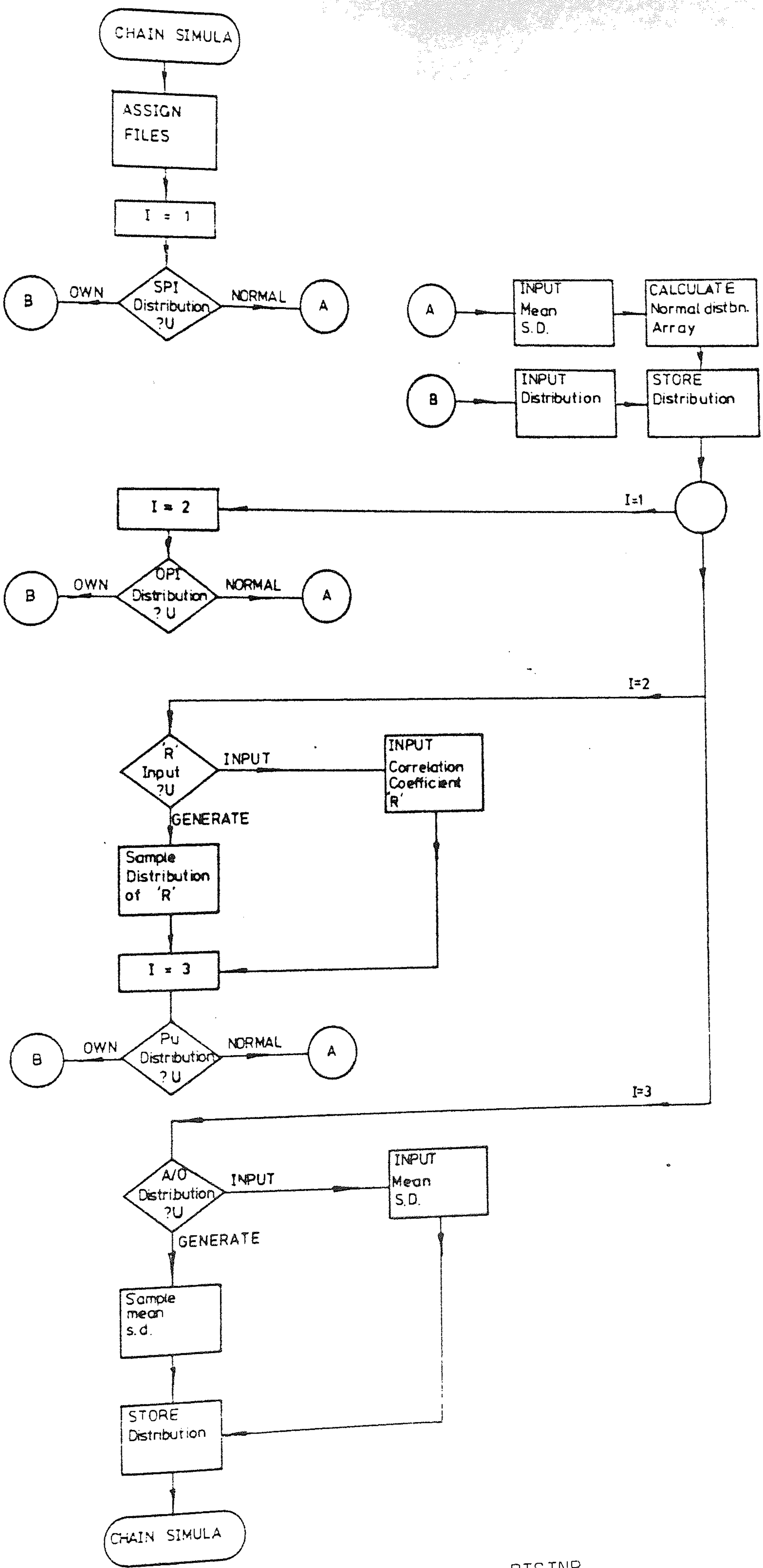


Fig 3.16 Distribution Input Programme - DISINP

3.4.4.3. Network Simulation

The next stage in the simulation process is to consider the effect on the construction network of these different operation times. This is achieved by analysing the network with each set of operation times. The results of this analysis are the minimum, maximum, mean and standard deviation of the network durations. In addition the criticality index of each operation is found from the number of times that operation lay on the critical path during this series of network analyses.

3.5. DISCUSSION.

This chapter has described a method of assessing the effects of changes in site productivity. This procedure is based on distributions of performance data which are quantitative measurements of site efficiency. The various analysis of this data were undertaken in order to provide the user of the computer system with more insight into the factors which affect site productivity.

3.5.1. The performance data are derived from the standard time of each construction operation. To avoid discrepancies it is important that the performance indices calculated on all the contracts are based on the same standard times. This is achieved at Bryant's, as all the production surveying staff use the company's own standard time manual.

3.5.2. In the analysis of this data the first requirement was to determine if the individual data sets could be considered to be random samples drawn from one parent population. If this was the case then only one global distribution would br required. This was not the case and we must assume that there are significant differences between the samples. However, the within sample variability is such that if the mean SPI from two sites differs by less than 10 then they can be considered to come from the same population.

3.5.3. Having shown that sites differ significantly, it was necessary to investigate the factors which may affect efficiency. The factors considered were contract location, physical size and type of construction (see table 3.5). The various sub-divisions did give different mean values but in no case was the difference great enough for us to be able to classify sites according to any one criteria. Thus it appears that a combination of factors may be of assistance in predicting mean performance indices.

3.5.4. Regression analyses were performed to test the correlation between these factors and mean performance figures. A significant correlation was found between mean OPI and SPI and the global factor, F, obtained by multiplying the individual factors together. Thus for predicting the mean value of SPI or OPI some guidance is given in the form of regression equations (table 3.8), but these must be interpreted with caution. This analysis showed that we can account for approximately 29% of the sample variability to predictable factors, and consequently the unquantifiable parapeters of site construction must be evaluated subjectively when interpreting the regression equations.

3.5.5. The final parameters required are the standard deviation and the form of the distribution. The standard deviation is determined from the coefficient of variability ($\sigma/\bar{x}$) see table 3.9 with known values of the mean. The form of the sample distributions was tested against the null hypothesis that there was no difference between the observed and a normal distribution with the same mean and standard deviation. The results of this series of tests, table 3.11, confirmed Bramwell's earlier findings that not all samples can be classified as normally distributed.

3.5.6. The final analysis of this data considered the effects of time, both long term trend and seasonal effect. One would expect site efficiency to be lower in the winter than the summer. From the analysis described in 3.2, this hypothesis is not proven and there is no seasonal effect present. The change in SPI with contract duration fig. 3.2. showed that on average after 45% of the contract has elapsed the observed monthly SPI figures will be below the site average. This finding has a use in a manual estimating system where a global average efficiency factor is usually incorporated. This global figure could be amended to allow less time for the early operations and more time for the later operations in a project.

3.5.7. The computer suite, SIM which was developed is designed to provide an easy and rapid means of modelling site construction. This is achieved by making the system inter-active, thus allowing immediate access to data and command driven, allowing the user flexibility of analysis. The system operates with activity on the node precedence networks, these were chosen in preference to activity on the arrow networks because of the ease of indentification of an operation and the data is in the correct form for computer processing. In addition these types of networks are easy to amend. (see fig. 3.11) and also dummy activities are not required. These and other reasons are discussed by Kelsall (1972).

3.5.8. From the analyses of the performance data it was evident that the system would have to be able to accept both normal and non-normal distributions with a range of means and standard deviations. For this reason no standard distributions were built into SIM, the user being required to identify and then input a specific distribution.

CHAPTER 4.

CONTRACT ANALYSIS.

SUMMARY:

Records of actual construction performance are presented. The comparisons of this data and the results obtained from the simulation programmes are also presented and discussed.

4.1 INTRODUCTION.

The preceding chapter describes the way in which standard time data is used as the basis of a stochastic simulation model which evaluates the various factors which affect site productivity. This model uses distributions of site efficiency measurements, the "performance data", to determine the simulated, or anticipated construction duration and cost. Before we can comment on the accuracy of this approach to modelling, or outline some of the uses of such a model it is first necessary to compare the simulation of a project with actual site performance. A pre-requisite for any comparisons of this kind is a knowledge of the resources which were used, and the length of time taken for the actual construction of projects. This chapter presents the records which were collected of construction performance and the subsequent comparison of those records with results obtained from the simulation model.

4.2 SITE RECORDS.

The term site records is used to cover the various types of information which together form a catalogue of the work undertaken and the resources used for construction. They are an inventory of the daily or weekly production and the resources employed, no attempt was made during collection to compare them with any pre-determined time standards for the work being undertaken, they merely record, as accurately as possible what actually happened.

4.2.1. SITES CONSIDERED.

These records were collected from a number of contracts which were being undertaken by Bryants during the research period. All the sites considered were either wholly drainage construction, or had a large pipeline content. These contracts covered a wide variety of conditions ranging from Cross-country, "greenfield" construction to urban work. A brief description of the contracts covered is given in Table 4.1.

4.2.2. SITE RECORDS COLLECTION.

The records of actual production and resource usage proved to be very difficult to collect. The main sources of this data were the site line management, section engineers etc. who showed great diligence in recording the daily site conditions and production. Various methods of data collection were tried, the first was by issuing pro-forma's to site, see Fig. 4.1, but these were found to be unworkable owing to the large variations between contracts. The method of collecting data was therefore different for each contract under consideration and was arrived at following discussion with, and persuasion of all the site personnel involved. The form of this raw data was very variable and consisted in one instance of a progress chart prepared specifically for that contract, and in others of site diaries of section engineers. On some contracts the site manager required that the engineers complete a daily record sheet and these formed the data collection method. To ensure continuity of data frequent site visits were made to ensure site personnel that the data they were recording was in fact going to be used,and not simply forgotten, which was a frequent criticism made by site staff of this type of feedback data.

4.2.3. DATA PRESENTATION.

From the various sources described above the relevant data was abstracted covering pipeline and manhole construction. The complete catalogue of site records is contained in Volume 2.

Table 4.1. DETAILS OF CONSTRUCTION SITES STUDIED.

Site No.	Type of Sewer.	Approx length. (KM).	Range of :-		Site.
			Diameters. (mm)	Depths. (M)	
1.	Foul.	5.0	450-525	2.0-6.0	Main sewer. Rural area with few road crossings.
2*	Surface water.	0.6	225-1050	2.3-3.8	Drainage for urban area, construction under roads.
3	Foul and surface water.	0.6	300-10000	2.1-6.0	Renewal of existing sewers. Garden and paved sections in urban area.
4*	Foul and surface water.	2.5	225-1350	1.3-4.2	Drainage works for roads and housing on a 'green field' site.
5	Surface water.	5.0	225-525	1.0-6.6	Urban and rural, both green field and under existing road.

* Sites previously used in analysis of performance data.

BRYANT

DRAINAGE FEEDBACK	CONTRACT & No.	DATE
LOCATION	WEATHER	REPORT PREPARED BY

SITE CONDITIONS	SOIL CLASSIFICATION	OBSTRUCTION GRADING
ROAD BREAKOUT TYPE THICKNESS	GROUND WATER DEPTH	WORKING SPACE

OTHER CONSTRAINTS (please specify)

RESOURCES	GANG REFERENCE	GANG SIZE

EXCAVATOR TYPE .... BUCKET SIZE ....

OTHER PLANT

CONSTRUCTION METHOD

PIPE DIAMETER	PIPE TYPE	PIPE LENGTH

TRENCH CROSS SECTION	SHORING USED

BACKFILL MATERIAL	BACKFILL LAYER THICKNESS	LENGTH CONSTRUCTED

BEDDING MATERIAL
TYPE
VOLUME

SURROUND MATERIAL
TYPE
VOLUME

	DIRECT LABOUR	SUB-CONTRACT
Productive hours		
Prod. unmeasured		
Non productive		
Waiting time		
Wet time		
TARGET	S.P.I.	OUTPUT

Fig. 4.1 Standard pro-forma for site records.

4.2.3.1. PIPELINE CONSTRUCTION RECORDS.

The pipeline construction records were the simplest to record due to the concentration of resources in a relatively small area. The site records for this activity are presented in the form of the resources utilised for the completion of a particular pipe run, see table 4.2. The length of each piperun was determined from the number of pipes laid, whilst the depths and bedding volumes were taken from the contract documents. The remainder of the information shown in Table 4.1 was obtained from the raw data.

4.2.3.2. MANHOLE CONSTRUCTION RECORDS.

The recording of manhole construction is a more difficult task owing to the fragmented nature of construction, with the manhole gang being spread over the site working in different locations on the same day. It was not possible to record manhole construction on all the contracts but those records which are available are contained in Volume 2.

Generally in rural construction the excavation and shoring for a manhole was performed by the pipe laying gang with the remainder of the operations being performed by a separate gang. In urban construction the whole of the manhole construction is performed as an integral part of the pipelaying gangs activities.

4.3. CONTRACT ANALYSIS.

The objective of this analysis was to compare the observed outcome of a contract with that arrived at synthetically. The site records formed one set of data for this comparison and the other was obtained from an analysis of each contract. These analyses are very time consuming and consequently it was only possible to analyse three of the five contracts,although all the records from all the contracts are contained in Volume 2.

Table 4.2 PIPELINE CONSTRUCTION RECORDS.

SANDRIDGE SEWER - ST. ALBANS

LOCATION	LENGTH (m)	PIPE DIA.	DEPTH (m)		BEDDING VOLUME (m3/m)	SHORING	TOTAL DURATION (days)	RESOURCE USAGE				REMARKS
								LABOUR		PLANT		
			MAX	MEAN				TYPE	Man DAYS	TYPE	m/c DAYS	
C116 - LL1	104.5	500 S.I.	3.50	2.50	0.37 granular 0.62 Sel.fill	CLOSE SHEETING	12	FOREMAN LABOURER	12 42.5	JCB 806 JCB 5c Cat 951 2" pump 2T dumper	12 12 12 12 12	Restricted access. Very bad ground conditions.
LL1 - LL2	148.5	500 S.I.	4.50	3.00	0.37 granular 0.62 Sel.fill.	CLOSE SHEETING	7	FOREMAN GANGER LABOURER	2 5 16	JCB 806 JCB 5c Cat 951 Hy-mac 590 Hy-mac 580 3T dumper 4" pump 2" pump	2 2 2 3 3 3 8 5	
LL2 - LL3	52.5	525 A/C	2.75	2.50	0.38 granular 0.63 Sel.fill	PINCHERS	1.5	GANGER LABOURER	1.5 5.5	Hy-mac 590 Hy-mac 580 3T dumper	1.5 1.5 1.5	

4.3.1. METHOD OF ANALYSIS.

Each contract was analysed using both the 'PLEP' and 'SIM' computer systems. The sequence of analysis is shown graphically in Fig.4.2 and described below.

4.3.1.1. STANDARD TIME GENERATION.

The first stage is to generate using 'PLEP' (see chapter 2) the standard time of each construction operation. The main source of input data is the site investigation report. The output from this analysis is a time and resource schedule showing the operation durations for various resources. (see Fig.4.3).

4.3.1.2. METHOD OF CONSTRUCTION.

The next stage in the analysis is to consider the sequence of construction and hence the overall standard duration. The operation standard times were those generated by 'PLEP' for the particular resources which were used on site and the overall standard duration was determined by the restraints imposed by the actual labour and plant employed.

4.3.1.3. SIMULATION.

Each pipeline activity from manhole to manhole formed the basic 'SIM' operation. The first stage of the simulation was to set up the resources and operation data files, using standard 'SIM' data sheets (see Fig.4.4 and 4.5). The second stage of the simulation was to input the distributions of performance data which were to be sampled. These distributions were decided upon based on the particular comparision being made, being either abstracted from the site records or estimated from the regression equations presented previously.

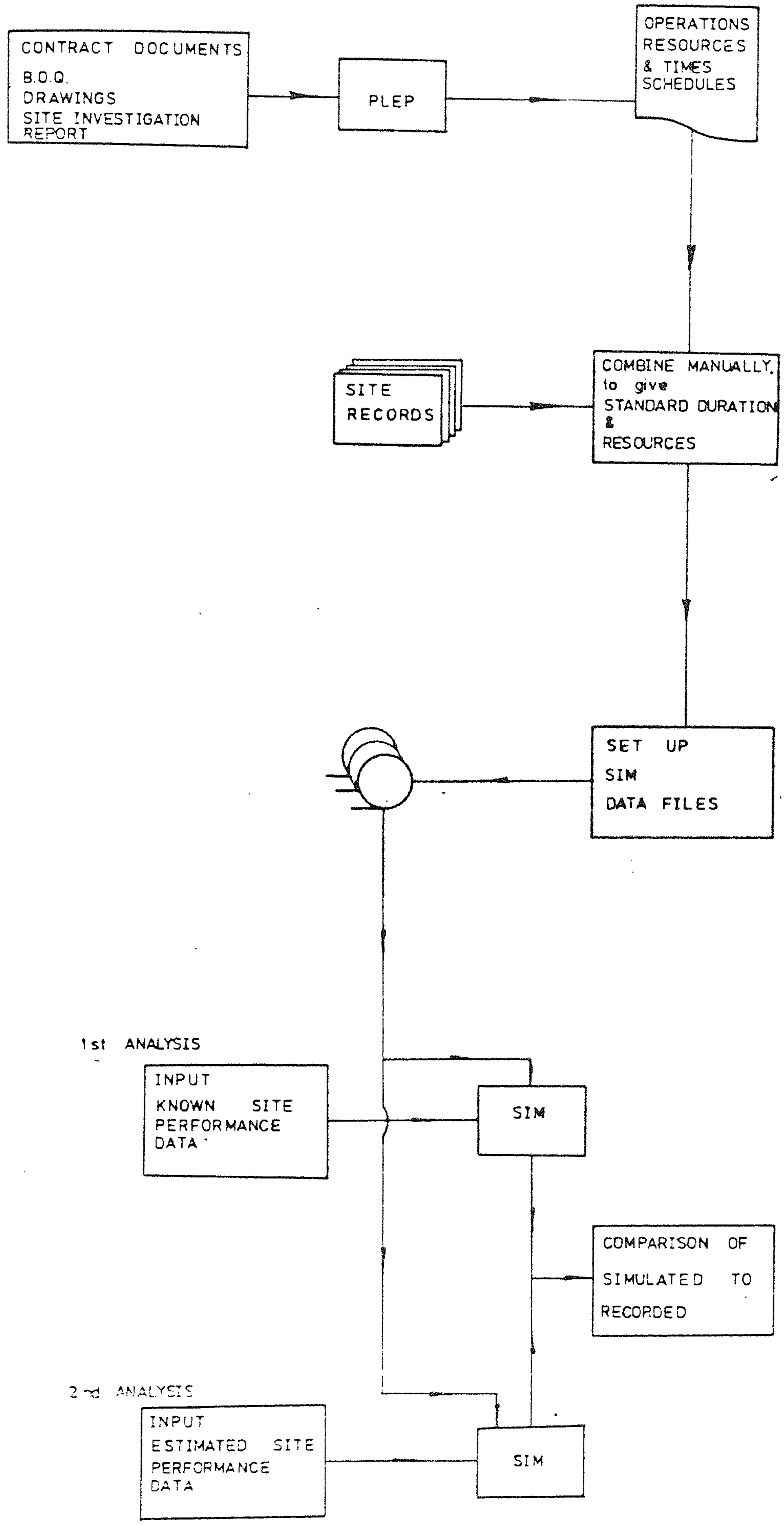


Fig 4.2 Method of Contract Analysis

BILL ITEM TIME ANALYSIS

DATE 11/3/80

ESTIMATE REFERENCE NB/3
CONTRACT BURTON-ON-TRENT IN TOWN DRAINAGE

ITEM COUNT	1			
BILL NUMBER	1			
PAGE NUMBER	1			
ITEM NUMBER	1			
RUN NUMBER	1	= MH 19	-	MH 20

EXCAVATION	VOLUMES [M3/M]	RESOURCE	STD OUTPUT [M3/HR]	REV OUTPUT [M3/HR]	DURATION [HR/M]
STRATA 9	VERTICAL 5.6	JCB 3D	14.25	14.25	0.39
OBSTRUCTION 1		JCB 805	24.63	24.63	0.23
DEPTH 2.25		JCB 806	26.00	26.00	0.22
WIDTH 2.5		JCB 807	27.37	27.37	0.21
		HY-MAC 580	30.81	30.81	0.18
		O & K RH6	30.41	30.41	0.18
		JCB 808	38.01	33.01	0.15

SHORING	TYPE	MATERIALS	RESOURCES	STD OUTPUT M/HR	REV OUTPUT M/HR	DURATION HR/M
DEPTH 2.25	CLOSE	SHEETS 30 NO WALERS 0.10 * 0.15 - 4 NO STRUTS 8 NO	3 MEN	2.88	2.88	0.35
	MEDIUM	SHEETS 14 NO WALERS 0.10 * 0.15 - 4 NO STRUTS 8 NO	3 MEN	4.41	4.41	0.23
	OPEN	SHEETS 10 NO WALERS 0.10 * 0.15 - 4 NO STRUTS 8 NO	3 MEN	5.43	5.43	0.18
	PINCHERS	SHEETS 8 NO WALERS 0.08 * 0.08 - 16 NO STRUTS 8 NO	3 MEN	6.24	6.24	0.16
	SHORCO	1 NO 2.6 * 3.4	3 MEN JCB 807	10.53	10.53	0.09

BEDDING	PIPE NO	VOLUMES [M3/M]		DISPLACED [M3/M]	RESOURCES	STD OUTPUT [M3/HR]	REV OUTPUT [M3/HR]	DURATION [HR/M]
SHAPE 5	1	CONCRETE	0.85	1.90	1 GNGR 2 LAB	7.33	7.33	0.12
	1	GRANULAR	0.00			0.00	0.00	
SHAPE 5	2	CONCRETE	0.53	0.65	1 GNGR 2 LAB	3.33	3.33	0.16
	2	GRANULAR	0.00			0.00	0.00	
				0.00				0.28

PIPELAYING	DEPTH [M]	DIA [M]	MATERIAL	RESOURCES	STD OUTPUT [M/HR]	REV OUTPUT [M/HR]	DURATION [HR/M]
1	2.25	1.050	A/CEMENT	3 LAB + O&K RH6	5.52	5.02	0.18
2	2.25	0.300	CLAY	3 LAB + ANY M/C	8.69	8.69	0.12

BACKFILL LAYERS = 0.30 M	VOLUME [M3/M]	RESOURCES	STD OUTPUT [M3/HR]	REV OUTPUT [M3/HR]	DURATION
VERTICAL	3.50	2 LAB	5.59	5.59	0.63
		2 LAB + DUMPER	16.00	16.00	0.22

FIG. 4.3 Typical time and resource schedule.

RESOURCES	Estimate Reference. NB/2 AUDNAN DRAINAGE - STOURBRIDGE.	SIM/1

COMMAND : DES

SUB-COMMANDS : Lab.Mat.Pl.

RESOURCE	CODE	DESCRIPTION	RATE	UNIT
LABOUR	L1	GANGER.	3.00	hr.
	L2	LABOURER.	2.65	hr.
MATERIALS	M1	GRANULAR BEDDING.	9.04	M3
	M2	CONCRETE BEDDING.	19.95	M3
	M3	600 dia. CONC.PIPE.	24.90	M
	M4	1200 dia.CONC.PIPE.	104.62	M
	M5	300 dia.CONC.PIPE.	8.78	M
	M6	600 dia. A/C PIPE.	30.50	M
PLANT.	P1	JCB 808	14.75	hr.
	P2	JCB 806	12.01	hr.
	P3	2T COMPRESSOR.	1.69	hr.
	P4	3" PUMP	0.98	hr.
	P5	22 RB	11.60	hr.
	P6	3T DUMPER	1.30	hr.
	P7	BOMAG ROLLER	0.94	hr.
	P8	LASER	0.25	hr.

Fig. 4.4 Typical 'SIM' data sheet - resources.

OPERATIONS	ESTIMATE REFERENCE NB/2	SIM/2
	SHEET 1 of 8	

COMMAND : OPS

SUB-COMMAND : DEF,LAB,MAT,PL

CODE	Ø 1		CODE	Ø 2	
DESCRIPTION	FMH2 - FMH3		DESCRIPTION	SMH2-SMH3	
STD DURATION.	1.484 WK.		STD DURATION.	1.508 WK.	
QUANTITY.	51.25M		QUANTITY.	40.0M	
RESOURCE.	CODE	REQUIRED	RESOURCE	CODE	REQUIRED.
LABOUR	L1	1 No.	LABOUR	L1	1 No.
	L2	2 No.		L2	2 No.
MATERIALS	M3	51.25M	MATERIALS.	MH	40.0M
	M2	53.81M3		M1	83.2M3
PLANT	P1	1 No.	PLANT	P1	1 No.
	P3	1 No.		P3	1 No.
	P4	1 No.		P4	1 No.
	P8	1 No.		P8	1 No.
	P6	1 No.		P6	1 No.

Fig. 4.5 Typical 'SIM' data sheet - Operations.

4.3.1.3.1. SIMULATION OF ACTUAL PERFORMANCE.

The first run of the simulation model was designed to test the accuracy of this approach to simulation. That is, by inputting all the known data of resources, standard times and performance figures would the model produce the actual duration ? Consequently the mean SPI for the simulation of each pipe run was calculated from the productive hours abstracted from the site records, and all the remaining parameters were estimated from this using the regression equations presented in Chapter 3.

4.3.1.3.2. SIMULATION OF PREDICTED PERFORMANCE.

The second run of 'SIM' was made in order to test its accuracy as a predictor. Consequently the mean SPI used was constant for all operations and was estimated from the "contract factor " (see Chaper 3). The remaining performance data parameters were estimated from regression equations as above.

4.4. RESULTS AND COMPARISONS.

4.4.1. GENERAL SIMULATION.

The first series of simulation runs were undertaken in order to test the accuracy of the model. Each manhole length was considered independantly with different input parameters. The results of this series of tests is shown in Table 4.3. which details the summation of recorded durations, together with thesummation of simulated durations for each analysed contract. This table shows a high degree of accuracy between the model predictions and the site records.

CONTRACT NO	*	RECORDED (Gang hours)	SIMULATED (Gang hours)
Sandridge	1	237.5	238.4
Audnam	3	109.5	106.2
Horninglow	2	75.8	75.9

Table 4.3. Summation of recorded hours 'actual' simulated durations.

CONTRACT NO	*	MEAN	S.D.	MIN	MAX
Sandridge	1	1.002	.047	.867	1.158
Audnam	3	1.001	.038	.929	1.068
Horninglow	2	0.996	.025	.959	1.037

Table 4.4 Divergence statistic for 'actual' simulation.

CONTRACT NO	*	RECORDED (Gang hours)	SIMULATED (Gang hours)
Sandridge	1	237.5	312.0
Audnam	3	109.5	98.93
Horninglow	2	75.8	75.6

Table 4.5 Summation of recorded hours 'predicted' simulation.

CONTRACT NO	*	MEAN	S.D	MIN	MAX
Sandridge	1	0.847	.967	.292	6.746
Audnam	3	1.226	.425	.646	2.413
Horninglow	2	1.050	.193	.844	.1455

Table 4.6 Divergence statistic for 'predicted' simulation.

* Refer to table 4.1

4.4.1.1. INDIVIDUAL PIPE RUNS.

Table 4.3. shows the overall comparison but does not indicate the accuracy of the individual duration estimates. A measure of the individual estimates is found by calculating the ratio of recorded to mean simulated duration, which if the model was completely accurate would always be unity. Table 4.4 shows the mean and standard deviation of this statistic. The means are very close to unity with small standard deviations.

4.4.2. PREDICTION.

To test the use of the model as a predictor the second set of simulation runs used one set of estimated performance figures for all pipe runs. The overall results of this series of runs is shown in Table 4.5. This shows that in two of the three cases observed the model showed good agreement with the site records.

4.4.2.1. INDIVIDUAL PIPE RUNS.

The ratio's of recorded to mean simulated duration is shown in Table 4.6. The mean values of this statistic are close to unity, but with a greater spread of individual results than was observed in the first series of tests.

4.5. DISCUSSION.

4.5.1. DATA COLLECTION.

The site records presented in this chapter were collected over the whole of the research period. The recording of site conditions, resources etc is very difficult owing to the great demands on the time of site staff in carrying out their own work without the added burden of compiling records. For this reason it is impossible to record all the individual things which affect productivity in both the positive and negative sense, for instance, it is as difficult to record the hours 'lost' due to a broken pump and flooded excavations as it is the hours ' gained' by good on-site preparation and planning of say materials deliveries. However, the site records contain, with good accuracy the overall time spent in constructing the works.

4.5.1.1. WORKMANSHIP.

In collecting the records no account was made of workmanship in the sense of acceptability of the finished article. The times quoted are those expended in the production of finished work, including any time spent on making good, repairs etc.. The most contentious issues of site workmanship are usually pipe joints, trench shoring,bedding and backfill. These must be assumed as being acceptable, i.e. the pipe joints are checked by pressure test and any faults rectified and the trench shoring was adequate for the conditions encountered. The pipe bedding volumes were calculated from the contract documents and will have varied on site. From the points raised above it is impossible to record the actual bedding and trench excavation volumes. The checking of backfill specifications is also difficult but again it must be assumed that the standard of backfilling was acceptable to the client's representative.

4.5.2. CONTRACT ANALYSIS.

This type of contract analysis is the working up of an estimate of construction duration and then to compare that to the actual record. This is a time consuming task, considering the amount of data which has to be assembled and analysed.

4.5.2.1. STANDARD TIME GENERATION.

This portion of the analysis was performed on the computer. The time taken to analyse one Bill of Quantity (B o Q) item is fairly small, the data required can be generated in typically 3 minutes. However, a large proportion of this analysis is repetitious and a possible feature to reduce the time taken to analyse a complet B of Q would be the introduction of a "copy" routine which would merely call up data from an already analysed item for use in the current item.

4.5.2.1.1. TYPES OF BILL OF QUANTITIES.

The system is designed to accommodate any type of B o Q compiled using any method of measurement. However, some B o Q's are more easily handled than others, the CESMM type of B o Q is more suited to operational pricing by allowing the estimator to consider the whole of the construction operation. There are other types of B o Q whereby the individual operations are listed out, each with a separate Bill item, these too can be readily analysed by 'PLEP' providing the location on site is known so that any different ground conditions etc can be considered. The third type of B o Q, produced in accordance with DOE method of measurement, collects together all the drainage in depth bands from all over the site and no attempt is made to identify each pipe run. These bills can also be handled by 'PLEP but the subsequent analysis is difficult without first trying to locate each separate pipe run.

4.5.2.2. METHOD ANALYSIS.

The 'PLEP' sub-system 'PRICE' is designed to assist the user in selecting the appropriate, most economic plant and labour and construction method. In the contract analyses described this analysis was performed manually. The reason for this being that in this case the labour and plant to be used was already known from the site records, and consequently the method analysis consisted of abstracting the appropriate standard times and combining them in the observed method, not to decide from scratch the most economic confirguration.

4.5.2.2.1. BILL OF QUANTITIES.

Again in the method analysis the structure of the BOQ has a large effect. For a CESMM BOQ each manhole length may be measured under two or three items, each of which includes all the construction operations. Other 'adhock' BOQ's have for each manhole length two or three items each of which measures a different construction operation. Thus for both types of BOQ some aggregation of Bill items is required in order to assess a manhole length, which will almost invariably be constructed using one set of resources. When this aggregation and analysis has been completed then the resulting duration and hence cost has to be broken down again in order to put a price againsteach Bill item. It is this process which the 'PRICE' sub-system is designed to accomplish.

4.5.3. SIMULATION.

The first series of simulation tests were undertaken in order to validate this approach to modelling. The results quoted in tables 4.3 to 4.6 show that the model is behaving correctly. Using all known data the model predicted the "correct"answer. In the second series of tests the basic resource data was again used but this time the performance data was estimated. In two of the three cases the overall results were "correct" but individual estimates showed greater divergence from the observed. The third contract St. Albans, showed a large difference from the observed. The reason for this descrepancy is probably due to the statistical basis of the regression equations used for performance data prediction.

4.5.3.1. PERFORMANCE DATA PREDICTION.

The regression equations presented in chaper three were derived from the analysis of past contracts. All equations of this kind are calculated "on the average" and consequently will not predict extremes at either end of the scale. The two sites at Horninglow and Audnam conformed to this statistical base in that their performance figures were very close to those predicted, St. Albans did not, it was manisfestly more productive than we might reasonably have expected it to be. This second series of tests showed that the accuracy of the estimate is therefore greatly dependant on the accuracy of the prediction of site performance. This is obviously a critical area and one where further work is required to investigate and consider some of the more intangible factors affecting site efficiency.

CHAPTER 5.

DISCUSSION AND CONCLUSIONS.

5.1 INTRODUCTION

This thesis presents details of investigations and studies of drainage construction. Two computer systems were produced which model the construction process, starting with the elemental standard time data and ending with a simulated estimate of the actual construction duration.

5.2 WORK MEASUREMENT DATA

The work measurement data base produced by Bramwell was amended and extended to cover new construction operations. An advantage of elemental data of this kind is that it can be used to synthesize a range of operations. The data available at present covers drainage construction but this approach could be readily extended into other activities, formwork, falsework, etc ...

5.2.1 Data Base Maintenance

As with any data base there will be a need for periodic revisions as improvements are made in construction plant and new methods and materials are introduced. For example excavation plant manufacturers will presumably continue to improve their product and consequently the data base will need to be checked periodically. Similarly new construction methods will have to be incorporated, although one use of this data for synthesizing the requirements of new products is discussed below.

5.2.2 Method of Working

Site studies showed that there is sometimes a difference between site practice and the accepted 'correct'methods of construction. These are not included in the data base. This disparity was most noticeable in pipelaying where, by jointing a pipe using 'brute' force, considerable time savings are made over conventional methods.

5.2.3 Rating.

In the work measurement techniques described the observer has to 'rate' the performance of the operatives. Thus the standard times may be affected by the work study practioners concept of 'standard rating'. From the studies undertaken the amendments made to the data were predominantly in machine operations or in the method of element combination. Consequently we must conclude that the ratings applied by the Author were comparable to those observed in previous studies.

5.3. ESTIMATING.

The pipeline estimating system PLEP stores and manipulates the elemental standard data. The system can also be used in determining the required resources and construction method.

5.3.1. Use of the System.

There are certain desirable features of computer systems which make them more easily accepted into a workplace. One such feature identified is the ease of use of the system. Thus by basing the pipeline estimating programmes on a micro-computer which can be situated on an office desk we are providing immediate access to the data. PLEP is an interactive on-line system and consequently the need for tedious "form filling" is removed. Another feature of PLEP is that it is not "all powerfull", the facility of amending output was provided so that the estimator can use his experience skill, judgement etc.. in compiling the estimate. PLEP also provides the user with a number of time standards, using different resources for each operation. This allows the user better access to more data, but causes problems of sorting the information. Consequently the PRICE sub-system of PLEP is designed to assist the user in determining the resource requirements and method of construction. The system has already been mounted on a TRRL computer.

5.3.2 Specifications

One of the basic inputs into the system is the contract specification. Comparisons of different drainage specifications showed that although they are all broadly the same there are detail differences. Consequently one standard specification could not be built into the system.

5.3.3 Bill of Quantities

The Bill of Quantities is the major reference document in producing an estimate. Problems were encountered in producing PLEP due to the structure of the various BoQ's which are used, and more specifically in the item coverage. In the collection of the site records it was observed that resources are seldom intentionally changed during construction, except at well defined break points, e.g. changes in pipe diameter, depth etc. Consequently the basic unit of operational pipeline pricing is the run of pipes from manhole to manhole, and the problem is to determine the gang size, plant requirements etc. However in all the Methods of Measurement used to compile BoQ's more than one item may relate to one manhole length. Thus some aggregation of items is required to obtain a representative activity for the analysis of construction method. Then the resulting resource costs have to be broken down again into the relative price of each BoQ item. Consequently the structure of the various BoQ has a great effect on the computerisation of estimating.

5.3.4 Uses of the System

The PLEP system is primarily aimed at a contractor's estimating function, however it will have applications in other, closely related areas. In the design stage of an estimating project the system will provide consistent data against which to evaluate alternative designs. In addition it can be used to identify the areas where improved plant, materials and methods will have the most impact, as in pipe jointing discussed above. It must be noted that any comparisons of this kind that are made are not confined to the particular operation but consider the effect on the total activity, for example a longer length pipe may save on pipelaying times but may also require the introduction of a crane into the gang cancelling any advantages. The cost figures produced are 'basic' costs and not the cost to the client, the reasons for this are discussed below.

5.3.5 Further work

The PLEP system yields the estimated cost of construction. This cost estimate is obviously a vital part of the tendering process, and is used subsequently in contract control. However, before the final tender figure is arrived at the estimate has to be transformed into a bid. This process involves the addition (usually) of set percentages to cover profit, overheads etc. Before the tender is submitted the estimate is scrutinised and any obvious errors and omissions are rectified. These are purely mathematical manipulations of all, or part of the BoQ item rates, which facility is not available in the PLEP system. The contractor may also wish to 'front load' the BoQ in order to improve his cash flow, or 'unbalance' the tender if he considers that there are errors in the measured quantities. These more commercial features would make the next logical step in the production of a complete tendering system.

5.4 PERFORMANCE DATA

The performance data was collated from the records available at Bryants. Possible anomolies of data of this kind are caused by differences in the time standards used. This is overcome in the company's system as all production surveying staff use one reference manual.

5.4.1. Data Analysis.

The various analyses of this data investigated the nature of and the factors which affect site efficiency. The analyses confirmed Bramwell's earlier findings that not all of the individual distributions can be assumed to be normally distributed. It is possible to estimate the mean OPI and SPI from a combination of contract factors. However the confidence limits on these estimates are large and consequently it must be concluded that we do not yet have a full understanding of site efficiency. Further studies would be required to consider other more intangible factors such as line management experience, expertise etc. and in the way a labour force is controlled, say by staff to operative raios etc.

The effects of time on the indices was also investigated and this showed that after approximately 45% of the contract duration has elapsed the weekly SPI will be below the mean for the contract. This is probably due to a diminishing of enthusiasm on site, and also that the work will usually be of a more fragmented nature. It is interesting to note that no seasonal effect was detected. This data was obviously obtained from only one contractor and so it is impossible to tell how that company's organisation affected the indices. Comparisons with similar data from other companies may prove illuminating but would be an arduous task.

5.5. SITE RECORDS.

The collection of the site records was a difficult task and much is owed to the diligence and enthusiasm of site line management. The problems of differences between site organisations became apparent, and the method of data collection had to be tailored to suit each particular contract. The level of detail of the records must, by necessity be coarse, as a detailed study of all the operations being performed at one time would have required a large number of observers.

5.5.1 Workmanship

The records contain the duration of construction of finished work, including making good, repairs etc. No distinction is made between very good, and not so good construction, it must be assumed that the quality of work was satisfactory to the clients site representative.

5.5.2 Methods of Working

As mentioned previously the construction of manhole to manhole lengths of pipe is usually performed by one gang. Two different methods were observed for manhole construction. In rural work the pipe laying gang were usually responsible for manhole excavation, shoring and base blinding, before continuing with pipe laying, a separate gang followed on to complete the manhole. In urban locations the pipelaying gang usually completed the manhole. The reason for this is probably due to the need for early reinstatement of roads etc., to maintain access, whereas in rural green field sites this is not so important.

5.6 PROJECT ANALYSIS

The project analysis and simulation suite SIM was again produced for micro-computers, for ease of access. The system is interactive and command driven, thus allowing the user more flexibility to develop the analysis of a project in his own way. The project is represented by a precedence network of operations, each of which is specified by the resources required and the total quantity to be produced.

5.6.1 Simulation

The simulation of each construction operation is based on distributions of the performance data mentioned previously. For each operation the mean and range of durations and costs are determined from thirty simulated estimates. The network simulation produces the mean and range of the total project duration and cost, and the relative criticality of each operation. The accuracy of this approach was investigated by comparing the results to the site records. The system will give the 'correct' answer if the performance data is known accurately enough. The main use of the model however is as a predictor, and in comparison to test its accuracy used in this way the mean durations for two contracts were close to the observed duration, although there was a wider spread of individual results. For the third contract the predicted figures were not so accurate. This discrepancy amplifies the point made earlier in relation to the general question of site efficiency, i.e. the third contract was manifestly more productive than the estimates of mean performance indices would have us believe. Consequently we must conclude that the system works but is greatly affected by the global site efficiency problem. We cannot reduce the inherent variability of construction but we now have a method whereby it can be quantified.

5.6.3 Uses of the System

The main applications of the system will be in any areas where the uncertainty of construction needs to be assessed. For contractors the degree of risk associated with a particular tender figure can be determined. This, which is done at the moment during the working up of an estimate into a bid, on a purely subjective basis can now be done objectively.

5.6.4 Development of the System

This method of construction modelling could readily be extended into contract control. A facility would be needed to input the durations of completed operations. From these figures and the time series effects mentioned previously forecasts of the likely outcome of the project can be made.

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APENDECES

APPENDIX A - BRAMWELL's EXCAVATION MODEL.

This appendix describes the excavation model presented by Bramwell. The revisions which were made to this model are described in Chapter 2.

A.1 Definitions.

Mean Rate of excavation (Rs) - The mean output which can be expected from a hydraulic excavator working at standard performance under pre-determined site conditions.

Theoretical (Solid) bucket capacity (Bc) - The theoretical bucket capacity published by the machine manufacturers.

Proportion of the Theoretical bucket capacity utilised (bc) - The quotient of the observed volume utilised and the theoretical volume available. It is primarily dependent upon the strata being excavated.

Trench shape factor (N) - The ratio of the depth (D) to the width (W) of the excavation

$$N = D/W$$

Excavation time (Et) - The time required to excavate per machine cycle. It is assumed to be affected by the physical characteristics of the trench and the strata being excavated.

Unloading time (Ut) - The time required to unload the excavated spoil per machine cycle. It is assumed to be dependent upon the working radius (R).

A.2 Procedure for Excavation Rate Computation

The mean excavation rate (Rs) is calculated using the following equation:-

$$R_s = \frac{Q_e}{n} \sum_{i=1}^{i=n} \frac{1}{U_t + E_{ti}}$$

The calculation of 'Rs' using the above formula is repetative. Therefore for simplicity use table A.3, as follows.

A.2.1 Having selected a machine determine Bc from fig A.1.

A.2.2 Select the strata grading from table A.1. Using fig A.2 determine bc.

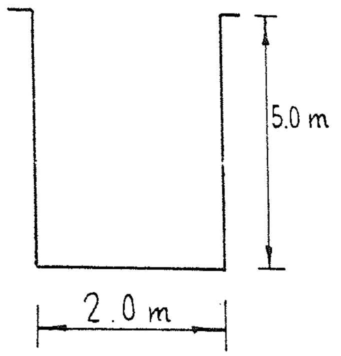
A.2.3 Calculate Qe = Bc x bc.

A.2.4 Knowing the required working radius (R) determine Ut from either fig A.3 or A.4.

A.2.5 Determine the obstruction grading from table A.2.

A.2.6 Divide the depth of the trench into 10. Calculate N for each depth increment. Using figure A.5 determine Et. Enter the results in Table A.3.

A.3 Example of excavation Rate Computation



Working Radius R = 4m

Strata Grading = 8

Obstruction Grading = 3

Use a Hy-mac 570, bucket width = 1350mm, Bc = $0.57 m^3$.

1 Bc = $0.57 m^3$

2 bc = 0.45 (Fig A.2)

3 Qe = 0.57 x 0.45

= $0.256 m^3$

4 Ut = .195 mins (fig A.4)

Table A.3

Qe	Di	W	Ni	Eti	Ut	Ut + Eti
	0.5	2.0	0.25	0.04	0.195	0.235
	1.0	2.0	0.50	0.08		0.275
	1.5	2.0	0.75	0.10		0.295
	2.0	2.0	1.00	0.16		0.355
	2.5	2.0	1.25	0.18		0.375
	3.0	2.0	.175	0.24		0.435
	3.5	2.0	1.75	0.24		0.435
	4.0	2.0	2.00	0.25		0.445
	4.5	2.0	2.25	0.26		0.455
	5.0	2.0	2.25	0.28		0.475
$.256 m^3$					Total	3.70
					Mean	.370 mins

$$\text{Mean Rs} = \frac{60.0 \times .256}{.370}$$

$$= \underline{\underline{41.51}}\ m^3/hr$$

TABLE A.1

STRATA GRADING

DESCRIPTION	GRADING
'ROCK' shall mean those geological strata and individual boulders exceeding 6 cubic feet (0.17m) in size or other masses of hard material outside those strata which necessitate the use of blasting or approved pneumatic tools for their removal. *	1
'MEDIUM ROCK' As 'A' above but not exceeding 6 cubic feet (0.17m) but exceeding 1 cubic foot (0.028m).	2
'SOFT ROCK' As 'B' but not exceeding 1 cubic foot (0.028m) and possessing bedding plains to allow breakage.	3
'SOFT LAMINATED ROCK' As 'C' but with excess laminations or bedding plains (slate, soft sandstone, shale).	4
'COHESIVE SOIL' (stiff) includes clays and marls with up to 20 per cent of gravel having a moisture content not less than the value of the plastic limit (BS 1377) minus 4; also chalk having a saturation moisture content of 20 per cent or greater. *	5-6
'SOFT COHESIVE SOIL' (medium) As '5-6' but excluding marls and including all clays and approximately 10 per cent sand or below.	7
Well-graded granular and dry cohesive soils, include clays or marls containing more than 20 per cent gravel.*	8
Well-graded sand and gravels with uniformity ceofficient exceeding 10, also clinker and spent domestic refuse.	9
Uniformity graded material includes sands and gravels with uniformity coefficient of 10 or less, all silts and pulverised fuel ashes. *	10

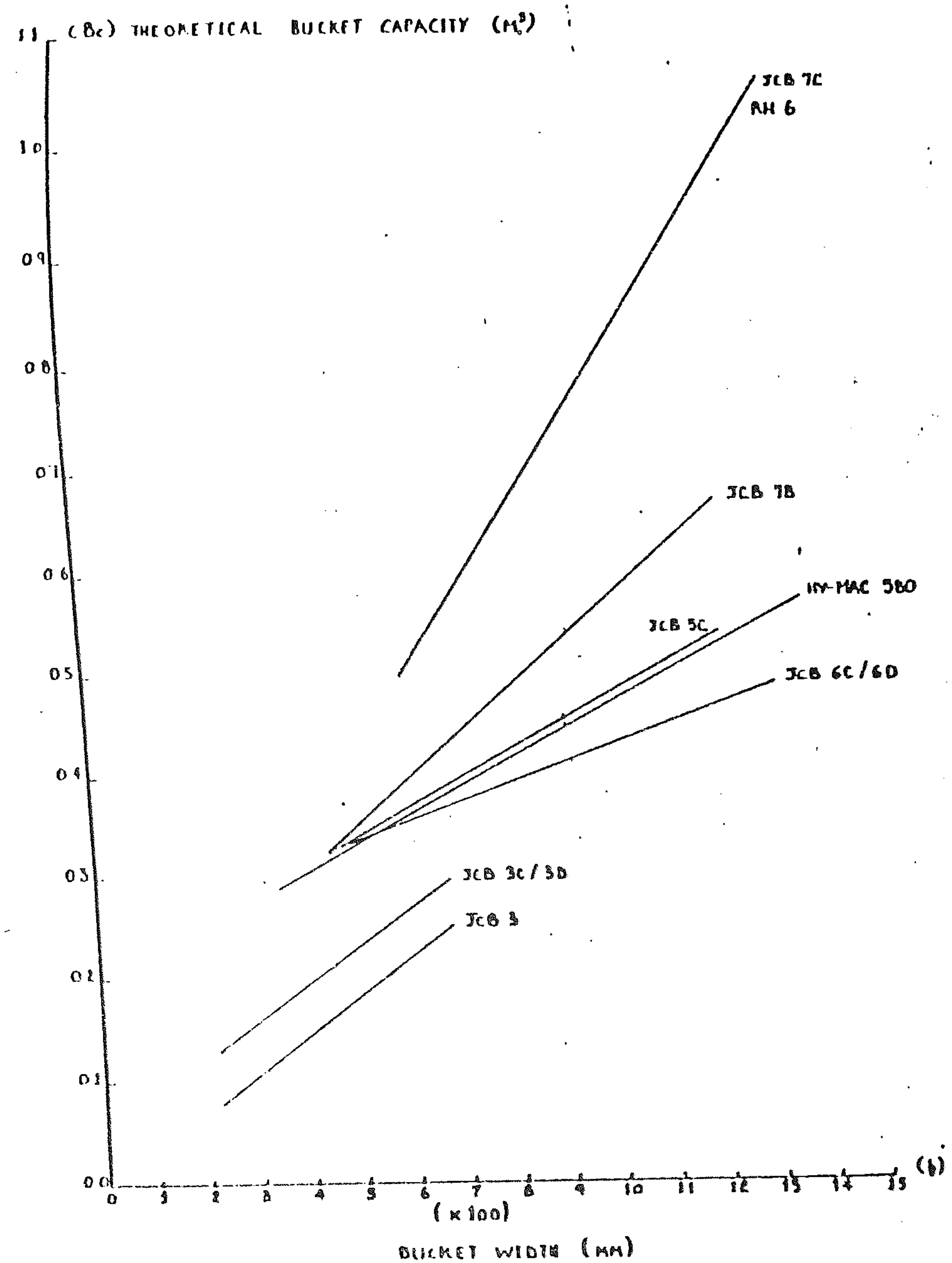
* "specification for Road and Bridge Works". 1969. Clause 601, 1.(iv), 2.(ii), 2.(iii)

TABLE A.2

OBSTRUCTION GRADING

DESCRIPTION	GRADING
Excavation involving the breaking out of metalled road surfaces or other such obstructions situated on top of frequently occurring services.	1
Excavating in ground possessing frequently occurring major services and house connection.	2
(a) Excavating in ground possessing infrequent major services but frequently occurring house services. (b) Excavating in ground possessing infrequent major services and infrequent minor services. (c) Excavating in ground possessing infrequent minor services and for tree roots etc.	3
Excavating in ground possessing minor obstructions only, i.e. tree roots, small quantities of hard core etc.	4
Excavating in ground possessing no obstructions other than those which are an integral part of the strata.	5

Fig. A.1


(Bc) THEORETICAL BUCKET CAPACITY (M³)
JCB 7C
RH 6
JCB 7B
JCB 5C
HY-MAC 580
JCB 6C/6D
JCB 3C/3D
JCB 3
(x 100)
BUCKET WIDTH (MM)

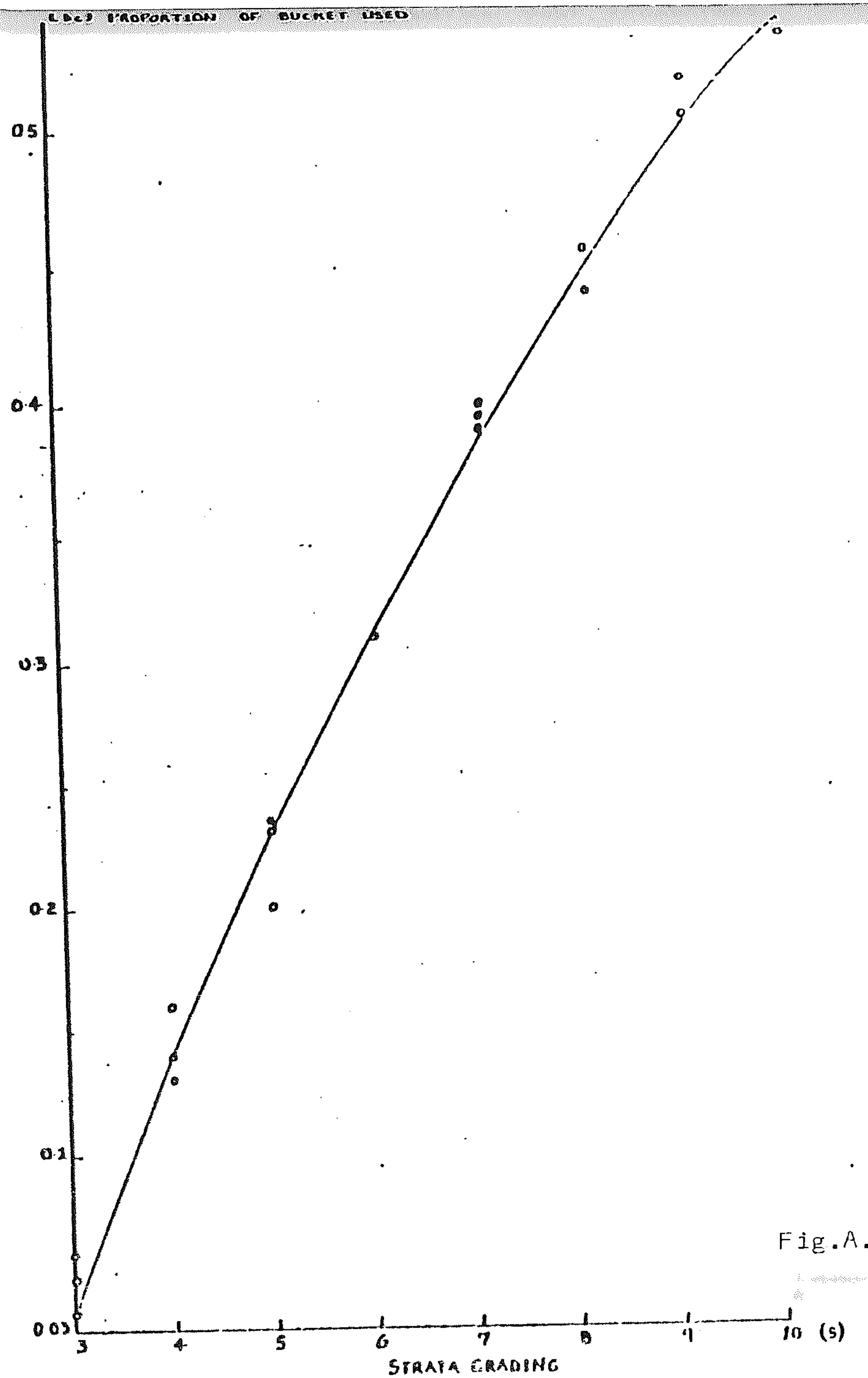

(Bc) PROPORTION OF BUCKET USED
STRATA GRADING

Fig.A.2

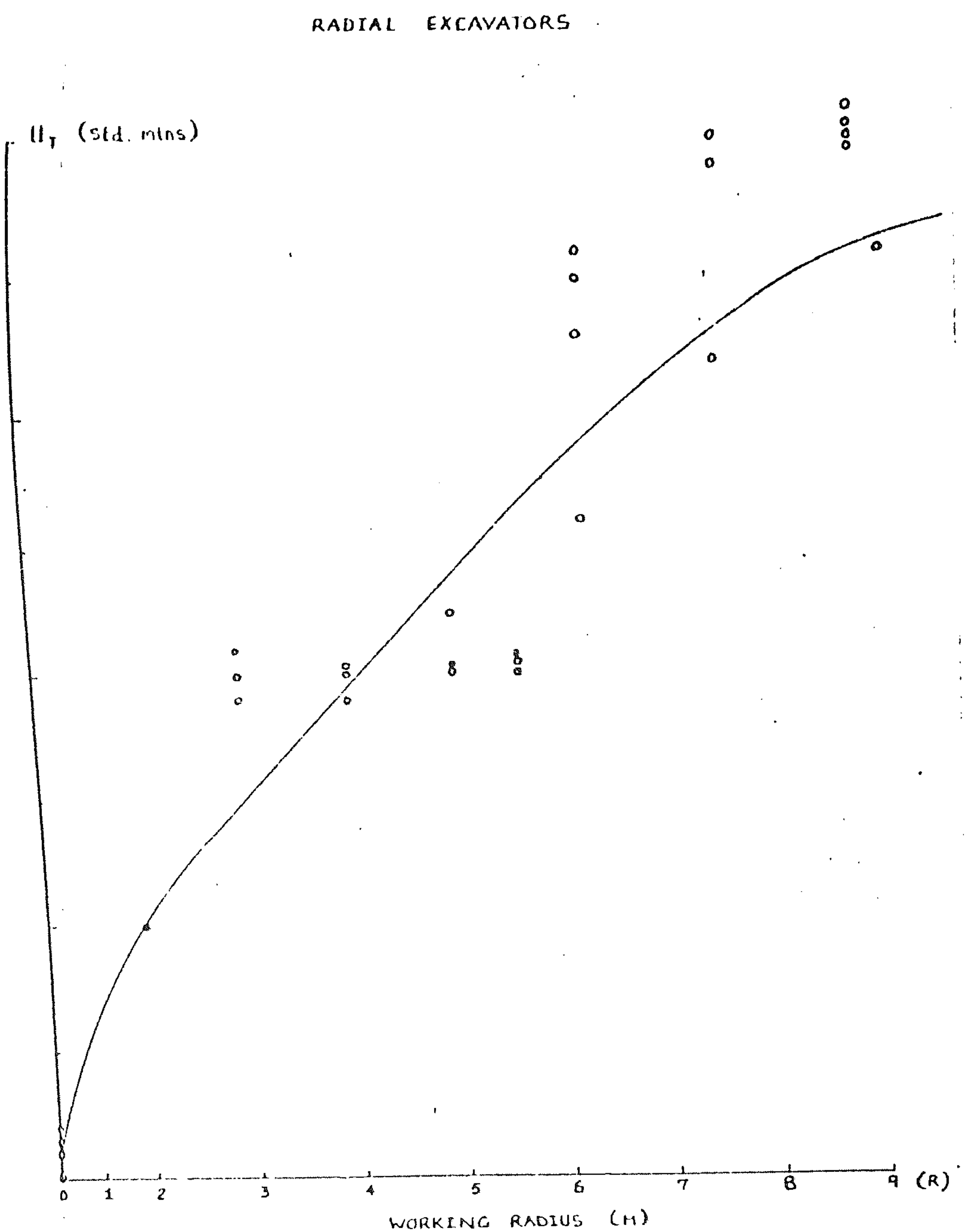

RADIAL EXCAVATORS
U_T (std. mins)
0 1 2 3 4 5 6 7 8 9 (R)
WORKING RADIUS (M)

Fig. A.3

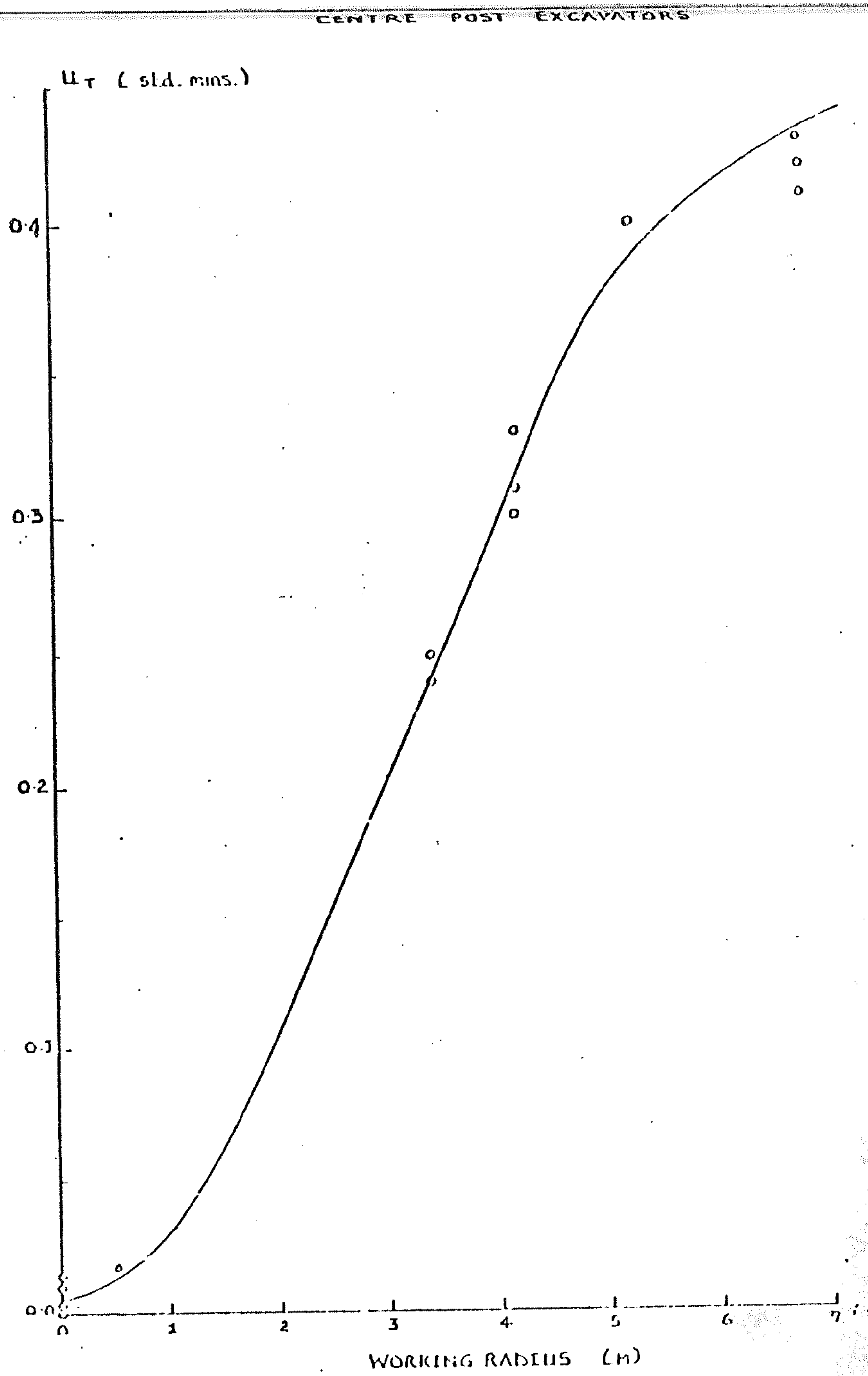

CENTRE POST EXCAVATORS
U_T (std. mins.)
0.4
0.3
0.2
0.1
0.0
0 1 2 3 4 5 6 7
WORKING RADIUS (M)

Fig. A.4

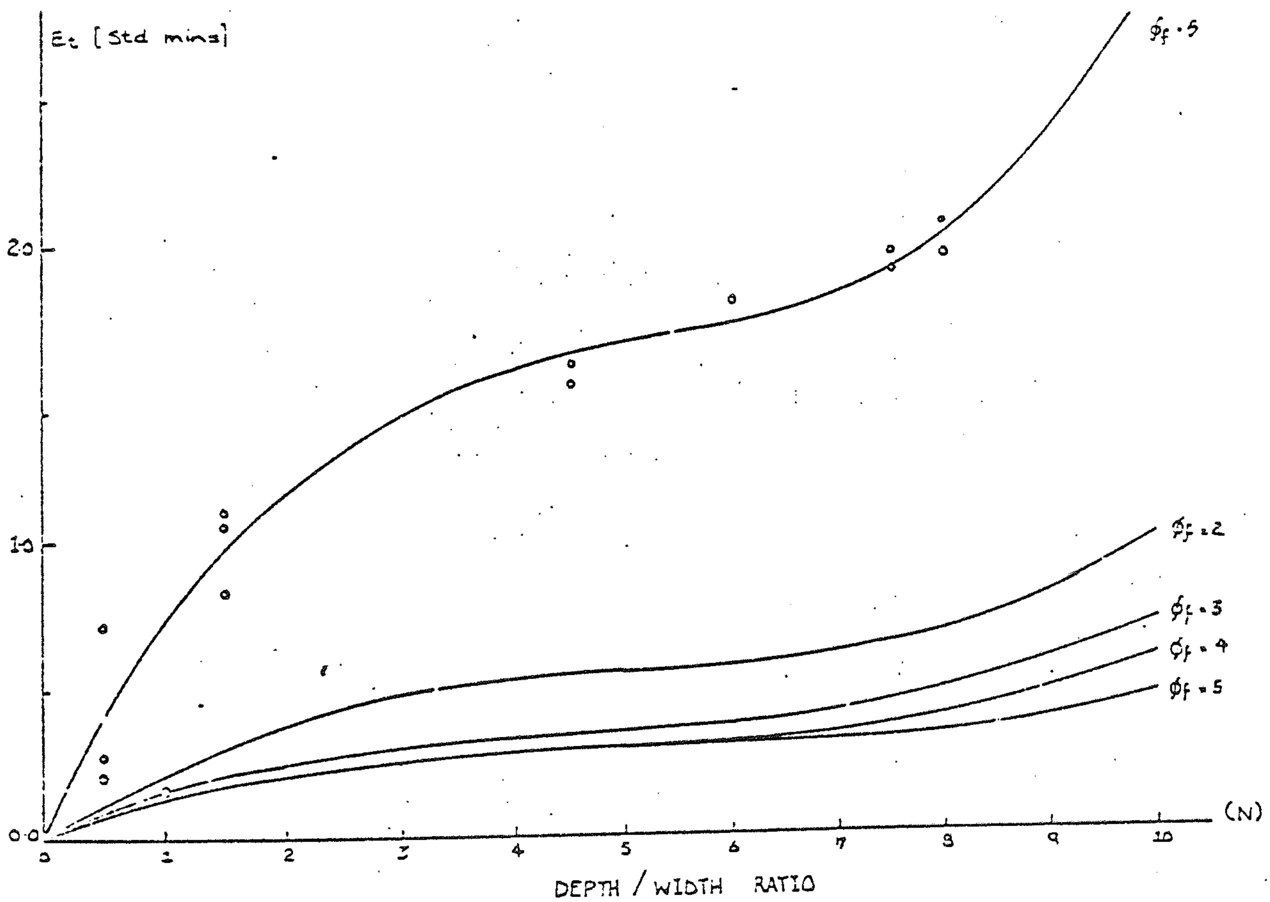

Et [Std mins]
2.0
1.0
0.0
0
1
2
3
4
5
6
7
8
9
10
(N)
DEPTH / WIDTH RATIO
ϕ_f . 5
ϕ_f = 2
ϕ_f = 3
ϕ_f = 4
ϕ_f = 5

Fig. A.5

Appendix B Excavator Lifting Capacities

B.1 Lifting Regulations

The construction (lifting operations) regulations 1961, set out the Statutory requirements for site lifting. Of concern in the selection of excavators for pipe laying are the regulations covering testing and examination of cranes (reg 28), the marking of safe working loads (reg 29), and the indication of safe working loads of jib cranes (reg 30).

This last regulation for the provision of a safe load indicator is relaxed for cranes having a safe working load of one ton or less (reg 30 (4) (c)). However, in certain circumstances lifting machines are exempted from part or all of these three requirements provided an exemption certificate No. 2 is obtained.

B.2 Exemption Certificate No. 2

This exemption certificate will only apply to certain types of plant in particular circumstances providing that additional requirements are fulfilled. The plant in question are crawler tracked shovel excavators and crawler tracked dragline excavators which are temporarily adapted for use as cranes solely by the attahcment of lifting gear to the shovel or bucket. The bucket remains fitted on shovel excavators but can be removed in the case of draglines. In addition the use of excavators as cranes must be for work immediately connected with the excavation, in this case pipelaying.

B.3

When the above conditions are satisfied the excavator can be used as a crane and the maximum safe working load is then as specified by a competent person and shall be not more than that which the machine is designed to lift with that particular bucket and jib or boom. This maximum load is specified on the certificate for different combinations of jib and boom and is assumed constant for all working radii in accordance with the first schedule of the exemption certificate. In addition a means of identification shall be clearly marked on all booms and dipper arms.

B.4 Determination of Safe Working Load

The safe lifting capacity of excavators used for pipelaying is this governed by an exemption certificate which is completed by the machine manufacturers. The lifting capacities are set out in the relevant manufacturers literature and the safe load can be abstracted assuming the worst case which is usually maximum reach, lifting over the side of the machine. It must be noted that the bucket must remain fitted to the machine and hence care must be taken to reduce the specified loads by the weight of the bucket.

Appendix C Programme Description Symbols.

In all programme descriptions and flowcharts the following symbols and convensions have been used.

C.1 User Interaction.

In any examples of the users interaction with the computer the users responses will be underlined.

e.g. DO YOU NEED HELP ? YES.

C.2 Data Handling.

The computer receives data from and transmits data to,various physical hardware devises, these are :

(a) The users terminal.

(b) Disc files.

In programme flowcharts the following are used to show the source or destination of data.

DISPLAY - Write information to the users terminal for his inspection.

STORE - Write information to disc file.

OUTPUT - Write information to disc file, for subsequent printing on a line printer.

INPUT - Access information from the USERS TERMINAL.

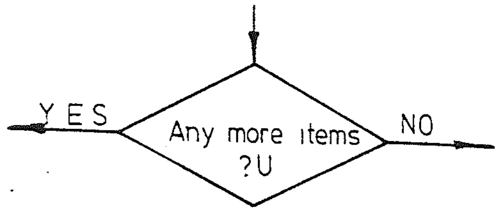
READ - Access information from disc file.

C.3 Decisions.

During execution of the programmes various decisions will be required to determine the next operation. Two basic decision types are encountered.

C.3.1 Users Decision.

Where the computer requires a decision from the user these are represented as follows.



This symbol represents the following sequence of instructions

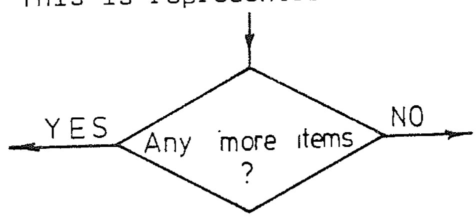
(a) DISPLAY - The question "any more items"

(b) INPUT - The users response YES or NO

(c) Evaluate the users response and branch accordingly.

C.3.2. Internal Decisions.

Where the programme branches according to some internal decision variables. This is represented as follows.

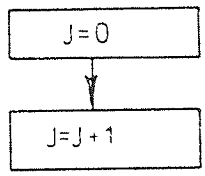


Thus if the total number of items is "J" and the item counter is "I" then the computer will compare the values of 'J' and 'I' and branch accordingly. The user is usually unaware of these internal decisions.

C.4 **Programme Control.**

The logical sequence of execution will be shown by a full line.

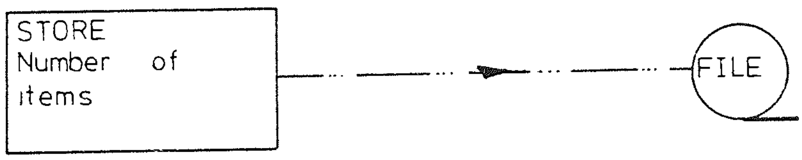
e.g.



C.5 **Data Transmission.**

The flow of information around the system is shown by a chain dotted line.

e.g.



C.6 **Chaining programmes.**

The process of 'chaining' allows the suite to be divided into individual programmes. Upon execution of a chain statement the computer stops execution of the particular programme, loads and then starts execution of the programme specified in the chain statement. The user is unaware of this process and thus it appears that one large programme is being used, whereas more than one programme has actually been executed.

APPENDIX D

BRAMWELL'S PERFORMANCE DATA.

Appendix E Theoretical determination of q

In order to calculate q for each time period values are required for each of three performance indices:-

Site performance Index.

$$S = \frac{Sh + \left\{ (Sh/Pm) * Pu \right\}}{ta} * 100$$

$$= \frac{Sh \left\{ 1 + (Pu/Pm) \right\}}{ta} * 100 \qquad \text{——— (3.1)}$$

Operative performance Index.

$$Ø = (Sh/Pm) * 100 \qquad \text{——— (3.2)}$$

Productive Unmeasured time

$$Pu = \hat{Pu} \, (na.Z) \qquad \text{——— (3.3)}$$

(a) Attendance time

The total attendance time, ta is calculated from the actual gang size, na and is considered in three portions, Pu, Pm and Wt.

$$ta = (na.Z) = (Pm + Pu + Wt) \qquad \text{——— (3.4)}$$

(b) Wasted time component

The wasted time component, Wt is calculated from values of S, Ø and Pu, as follows:-

From (3.2) Sh = (Pm.Ø)/100

Substitute in (i)

$$S = \frac{(Pm.Ø) \left\{ 1 + (Pu/Pm) \right\}}{100.ta} * 100$$

$$S = \frac{Ø \, (Pm + Pu)}{(Pm + Pu + Wt)} \qquad \text{——— (3.5)}$$

From (iv) $Pm + Pu = (na.Z) - Wt$

Substitute in (v)

$$S = \frac{\emptyset \left\{ (na.Z) - Wt \right\}}{(na.Z) - Wt + Wt}$$

Rearranging.

$$Wt = \frac{(na.Z)(\emptyset - S)}{\emptyset} \qquad \text{------------} \quad (3.6)$$

(c) Productive measured time

The productive measured time, Pm is determined from (3.4)

i.e. $Pm = (na.Z) - Pu - Wt$ ------------ (3.7)

(d) Standard hours

The total standard hours, Sh is calculated from (3.2)

$Sh = \emptyset . Pm$ ------------ (3.8)

(e) Quantity produced

The quantity produced in unit time period, q is calculated from the standard hours, Sh, and the standard man hours per unit of production Su,

viz $Sh = Su.q$

$\therefore q = Sh/Su$ ------------ (3.9)

Appendix F - Multivariate Sampling

The observed values of SPI and OPI have been shown to be correlated, ((table 3.14(b)), the problem becomes one of sampling from distributions of these variables such that the sampled values are correlated to the same degree.

Consider a column vector $X = \begin{bmatrix} t_o \\ t_s \end{bmatrix}$

Where $to = \frac{OPI - \overline{OPI}}{\sigma_{OPI}}$, and $ts = \frac{SPI - \overline{SPI}}{\sigma_{SPI}}$

The method of generating sequences of X is based on a multivariate weakly stationary generating process described by Matalas (1967), which is defined as:-

$$\underset{\sim}{X} = \underset{\sim}{A} \cdot \underset{\sim}{\eta} \qquad (3.10)$$

Where A is a 2 x 2 matrix, and η is a column vector, in full this is

$$\begin{bmatrix} t_o \\ t_s \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_2 \end{bmatrix}$$

If we post multiply equation (i) by the transpose of X, X^t:-

$$\underset{\sim}{X}\underset{\sim}{X}^t = \underset{\sim}{A}\underset{\sim}{\eta}[\underset{\sim}{A}\underset{\sim}{\eta}]^t$$

$$\underset{\sim}{X}\underset{\sim}{X}^t = \underset{\sim}{A}\underset{\sim}{\eta}\underset{\sim}{\eta}^t\underset{\sim}{A}^t \qquad (3.11)$$

If η is a random variable with zero mean and unit variance then the mathematical expectation $E(\underset{\sim}{\eta}\underset{\sim}{\eta}^t) = I$ where I is the identity matrix with unit diagonds and zero's elsewhere (Kendall, 1975).

Thus the mathematical expectation of equation (3.11) becomes:-

$$E(\underset{\sim}{X}\underset{\sim}{X}^t) = \underset{\sim}{A}\underset{\sim}{A}^t \qquad (3.12)$$

But $E(XX^t)$ is equal to the correlation matrix of X (Kendall, 1975), thus:-

$$E(\underset{\sim}{X}\underset{\sim}{X}^t) = \underset{\sim}{R}$$

Where $R = \begin{bmatrix} 1 & r \\ r & 1 \end{bmatrix}$ Where r = the correlation coefficients between SPI and OPI.

Substituting for $E(XX^t)$ in (iii) and expanding:-

$$\begin{bmatrix} 1 & r \\ r & 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{bmatrix} \qquad \text{(3.13)}$$

Expanding (iv) results in three equations with four unknowns, and hence we must make a simplifying assumption, we arbitrarily assume that

$a_{21} = 0$, with this condition and expanding (3.13)

$$1 = a_{11}^2 + a_{12}^2 \qquad \text{(3.14)}$$

$$r = a_{12} \cdot a_{22} \qquad \text{(3.15)}$$

$$1 = a_{22}^2 \qquad \text{(3.16)}$$

From (vii) $a_{22} = 1$

from (vi) $a_{12} = r$

and from (v) $a_{11} = (1 - r^2)^{1/2}$

Substituting for A in (i)

$$\begin{bmatrix} t_o \\ t_s \end{bmatrix} = \begin{bmatrix} r & (1-r^2)^{1/2} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_2 \end{bmatrix}$$

Expanding :-

$$t_o = r\eta_1 + (1-r^2)^{1/2}\eta_2 \qquad \text{(3.17)}$$

$$t_s = \eta_2 \qquad \text{(3.18)}$$

Appendix G. Network Definition and Sorting

G.1 Network Definition

To define a network the user needs to input the logical relationships between operations. The input routine is executed following the NET, DEF command, and consists of specifying each operation together with its immediate predecessors. The first logical operation in the network is specified using the standard predecessor, 'start' and network input is terminated with 'end', see fig. G.1 SIM can accept networks which have more than one start and finish operation.

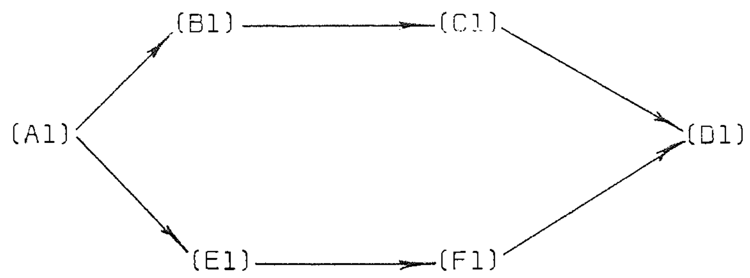
G.2 Network Sorting

The sorting subroutine is executed automatically upon completion of network definition or editing. The objective is to number the operations in the network so that they are accessed in the correct sequence for time analysis, this process will isolate any loops within the network. Before describing this sorting it is necessary to understand the way in which networks are stored within SIM.

G.2.1 Network Storage

The precedence relationships are stored in matrix form. The first row of the matrix contains the object operations, and then each column contains that operation immediate predecessors. The storage of the example network is shown in table G.1. In addition to this matrix a string H$ is set up which contains the codes of all the operations in the network.

Fig. G.1 Example Network



This network could be defined by the following, the users input in underlined.

* B1, A1
* A1, Start (first logical operation)
* C1, B1
* E1, A1
* D1, C1, F1
* F1, E1
* End (End of input)

The asterisk is displayed by SIM as a prompt when more input is required.

Table G.1. Precedence Storage

Object Operation	B1	A1	C1	E1	D1	F1
Predecessors	A1	SS	B1	A1	C1	E1
					F1	

Where SS = start operation

in the order in which they appear in the definition statements, for this example

H$ = ss.B1, A1, C1, E1, D1, F1 , where ss is SIM's internal code for 'start'.

G.2.2. Sorting

To number the operations in the correct sequence each pair of precedence relationships are considered as an inequality. That is if operation X precedes Y, then X must be less than Y in the numbered list. The operation numbers are stored in matrix S which is initially set sequentially from 1 to N, where N is the number of operations in the network. The individual pairs of relationships are considered in turn and if the inequality is not satisfied then the numbers of those operations are interchanged. At the end of a pass through the network, if any changes have been made then the routine is repeated until all the inequalities are satisfied. Alternatively if the inequalities are not satisfied after 10 passes then a loop has been detected. This number of passes was decided upon following trials with example networks, and the loop is isolated by displaying those inequalities which cannot be satisfied. An example of network sorting is shown in Table G.2. The time taken by this sorting depends on the number of operations in the network and also in what order they are input by the user.

Table G.2 Network Sorting

Inequality	Example	Action	H$ S	ss 1	B1 2	A1 3	C1 4	E1 5	D1 6	F1 7
1st Pass										
A1 < B1	3 < 2 ×	Exch A1&B1		1	3	2	4	5	6	7
SS < A1	1 < 2 ✓	No change								
B1 < C1	3 < 4 ✓	No change								
A1 < E1	2 < 5 ✓	No change								
C1 < D1	4 < 6 ✓	No change								
F1 < D1	7 < 6 ×	Exch E1&D1		1	3	2	4	5	7	6
E1 < F1	5 < 6 ✓	No change								
2nd Pass										
A1 < B1	2 < 3 ✓	No change								
ss < A1	1 < 2 ✓	No change								
B1 < C1	3 < 4 ✓	No change								
A1 < E1	2 < 5 ✓	No change								
C1 < D1	4 < 7 ✓	No change								
F1 < D1	6 < 7 ✓	No change								
E1 < F1	5 < 6 ✓	No change								

Final Order

H$	SS	B1	A1	C1	E1	D1	F1
S	1	3	2	4	5	7	6