An evaluation of production output for in situ concrete work

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AN EVALUATION OF PRODUCTION OUTPUT

FOR IN SITU CONCRETE WORK

by

ANDREW DAVID FREEMAN PRICE, B.Sc.


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ABSTRACT

The overall aim of this thesis is to develop reliable methods of measuring output levels for construction plant and labour, with a view to establishing realistic output rates for concreting operations.

This thesis demonstrates that most of the variability in production rates can be quickly explained, leaving relatively constant levels of output for individual construction operations (i.e. basic operation times). The primary factors in determining output rates were found to be work rate, delays and waiting caused by poor management, and poor motivation.

The latter two items accounted for more than fifty per cent of the available working time on many sites, whereas work rate varied only slightly. This last finding may be surprising, but the results indicated that when work was being done the effort applied appeared fairly constant to the observer. However, the time spent working was largely dependent upon the level of motivation induced through the payment system. Where a combination of good direct supervision and satisfactory financial incentives were present, high levels of motivation were observed, conversely, low motivation occurred on sites where minimum day-work payments were present.

Investigations into several construction trades indicate that work study techniques can be modified to meet the requirements of most construction operations, sites and companies, whether the requirements be a complex synthesis of basic operation times or the more simple determination of site efficiency. The key to this portability lies in the isolation of basic operation times via the application of site efficiency factors.
In this thesis, primary work study techniques are identified and discussed. The need for specific construction work study techniques is shown to be of paramount importance.

The results from over seventy concrete pours are combined and statistically analysed to produce realistic output rates and current levels of production.

Site factors are combined and statistically analysed to produce a relationship between efficiency and level of remuneration.

A comparison is drawn between: the production rates achieved on several sites; and the output rates currently being used in the planning and estimating processes.
No portion of the research referred to in this thesis has been submitted in support of an application for another degree or qualification at this or any other university or other institution of learning.
ACKNOWLEDGEMENTS

My sincere thanks goes to Dr Frank Harris for his catalytic guidance and unfailing support, without which this thesis would not have been completed.

I know that Anne, my wife, has suffered in many ways throughout this research; I hope she will now take pride in its completion for she has been a profound source of encouragement.

This research has been undertaken within the subject area Construction Technology and Management in the Department of Civil Engineering at the Loughborough University of Technology. I am grateful to my family, friends and colleagues for their support and constructive advice. In particular I wish to thank Frank Harris, Margaret Emsley for proof reading the thesis during the final stages, Vera Cole for mastering the word processor so competently and cheerfully, Tony Wilson for help with all computing matters and Tony Pettitt of the Mathematics Department for advice on all statistical aspects.

Finally, I wish to express my gratitude to the individuals and organizations who provided considerable assistance during this research. The construction industry is often castigated for its unwillingness to support research, however, I found full co-operation and openness from the following collaborators.
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**Other Collaborators**

In the early stages of this research, several organizations with work study experience and whose work was of a similar nature to construction work were contacted. The following fourteen organizations made varying contributions to the research.

**Contractors with Work Study Data**

- John Laing Construction Ltd.
- Wimpey Construction Ltd.
- Henry Boot Ltd.

**Local Authorities**

- Lincolnshire County Council
- Cornwall County Council
- Nottinghamshire County Council
- Norfolk County Council

**Others**

- Joint Industry Board for the Electrical Contracting Industry
- British Waterways
- Building Services Research and Information Association
- Building Research Association
- Building Advisory Service
- Transport and Road Research Laboratory
- Bircham Newton Training Centre

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CHAPTER ONE

INTRODUCTION
INTRODUCTION

1.1 INTRODUCTION TO SUBJECT MATTER

Information on the production output of construction labour and plant is not generally available; the main reasons for this lie in the estimating process. Data used by planners and estimators are rarely collected from historical records, and it is more usual for such personnel to accumulate output knowledge as experience gained through junior to senior positions in an organization (1.1). In this way the estimator's store of data is gradually "tuned", allowing sufficient tenders to be won at prices which can earn a profit for the company. Consequently, much output data is remembered rather than recorded.

To cope with recent developments in construction plant and methods, planners and estimators have to interpolate new performance data from existing sources, for example, the selection of suitable materials handling equipment and proprietary formwork systems. In addition, there has also been a significant trend towards sub-contracting and many firms are having to manage a different type of work force.
It would, thus, seem logical to encourage the investigation of some of these developments with the view to defining appropriate methods of working and establishing the corresponding performance data. The Dutch, for instance, are already doing this for their own conditions, through the monthly journal BOUWKOSTEN (1.2), which establishes and updates "guidance production times" for construction operations. Such a store of information would also be helpful to small contractors and independent bodies.

Work loads are reducing and skilled operatives are leaving the construction industry to join the manufacturing or service industries where working conditions and payment levels are considerably higher (1.3). Consequently, the construction industry is undergoing its most serious upheaval since the thirties, and the beginning of the eighties is an ideal time for research into the factors affecting efficiency.
1.2 OBJECTIVES

It was against this background that the research described in this thesis was developed, the main objective being the establishment of realistic output values for a major construction operation. Concrete work was chosen as the operation to concentrate upon as it is fundamental to most types of construction work. To achieve this objective, it was necessary to develop specific measurement techniques and investigate any factors causing variation in efficiency levels. This research consequently contains two sub-objectives, namely:

(a) the development of a production analysis method specifically for construction operations; and

(b) the determination of realistic output rates for concreting operations.

1.2.1 Development of a Production Analysis Method Specifically for Construction Operations

For a production analysis method to be effective it should involve defining, observing, recording and analysing the operation under consideration. To transform existing work study techniques into a form suitable for construction operations, it is necessary to:

(a) Ascertain the work study techniques currently being used in the manufacturing and construction industries.

(b) Classify the types of work and idle times occurring on construction sites.

(c) Develop existing production analysis techniques into a form suitable for recording construction operations.

(d) Rationalize the synthesis of elemental data in the build up of standard data.
1.2.2 Establishing Realistic Output Rates

The second sub-objective of this research is to establish realistic output rates for concreting operations. Owing to the variation in output rates from site to site, it is not acceptable to purely concentrate on overall output rates, but detailed consideration is required for different categories of operative time.

Overall output rates depend upon the "total work content" of the operations performed. Total work content usually comprises three categories of operative time, where: "minimum work content" is a measure of the time required to complete a task under ideal situations; any extra work periods, caused by practical limitations or inefficient methods are classified as "added work content"; and idle periods resulting in lost production are known as "lost time", for example, waiting for concrete to arrive on site.

The measurement of site production concentrates upon the measurement and analysis of total work content and its constituent parts, with basic times representing the minimum and added work content of each operation, and site factors accounting for any lost time. Therefore, in order to produce realistic output rates for concreting operations the following steps are required.

(a) The determination of minimum and added work content for concrete operations.
(b) The measurement of the variation in minimum and added work content in relation to the quantity of work produced.
(c) The determination and measurement of the main causes of variation in output rates from site to site.
(d) The investigation of the factors affecting the motivation and productivity of operatives.
(e) The determination of the appropriate relaxation and contingency allowances to apply with the data.
1.3 **METHODOLOGY**

To respond to these objectives, this research primarily comprises development work and field work. After the initial investigations, involving several interviews and a work study literature review, the remaining research is separated into three phases. Figure 1.1 presents a flow chart of the research performed over the three years. There are three sections to this chart, namely: field work and data collection; development work carried out in conjunction with the field work; and a summary of the results relating to each phase of work.
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<td>Isolation of the main causes of lost productivity. The expansion of data collection techniques to also record factors influencing operative motivation and relaxation allowances.</td>
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Figure 1.1 Flow Chart of Research
This thesis contains three main areas of research which can be summarized as: an investigation into the historical background of work study and how this has influenced the techniques used in the construction industry today; an analysis of the time spent working during concreting operations; and an appraisal of the different types of lost time. These three areas of research are now discussed in more detail.

The first area of research (Chapters Two and Three) reviews the historical development of work study and investigates the application of construction work study within individual organizations. In addition, several work study techniques are discussed and the methods currently used to present output data are further developed to represent construction operations more realistically.

The second section demonstrates how standard times are obtained for concrete operations. Chapter Four presents an example of a typical method used throughout this research to collect work study data. This example is used to illustrate how basic element times are measured and how the process of synthesis can be used to determine basic operation times. The results from over seventy concrete pours are presented in Chapter Five. These results are used to determine the basic operation times for concrete operatives, presented in Appendix C. The study results and basic operation times for the main plant items associated with concrete work are presented in Chapter Six.

Basic times are a measure of the actual work required to complete a task. The overall time taken (i.e. standard time) should include allowances for relaxation periods. Chapter Seven concentrates on the scientific validation of relaxation allowances and develops previous research into a more coherent structure suitable for construction operations. A typical relaxation allowance is obtained for concrete operations based on the work done during the concrete pours.
The final section investigates the variation in performance from site to site, thus, the emphasis is transferred from work content to lost time. Chapter Eight discusses the main factors affecting construction productivity and introduces site factors as a method of measuring performance. The site factors measured on several sites for several trades are presented, analysed and discussed in Chapter Nine. A comparison is subsequently made in Chapter Ten, between output rates measured on site and data currently being used by estimators.

The conclusions obtained throughout this report are presented in Chapter Eleven. Recommendations relating to implementation of the research findings and further research are also put forward.

Additional information relevant to this research is presented in six appendices. Important terms used throughout this thesis are presented in Appendix A. Listings of the Minitab programs used to analyse the data in Chapter Five are contained in Appendix B. A selection of computer print-outs are presented in Appendix D, and the resulting basic operation times for concrete operatives are presented in Appendix C. To put the observed variation of operative performance into perspective, traditional motivation theories are reviewed in Appendix E. The theory behind the statistical tests used in the Minitab analysis is discussed in Appendix F.
CHAPTER TWO

WORK STUDY IN PERSPECTIVE
CHAPTER TWO

WORK STUDY IN PERSPECTIVE

2.1 INTRODUCTION TO WORK STUDY

It is the responsibility of the management of any organization to ensure that the available resources are utilized most effectively. Work study is one management tool which can help to achieve this objective and is defined in the "British Standard Glossary of Terms used in work study and organization and methods: BS 3138:1978" as:

"A management service based on those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which lead to the systematic investigation of all the resources and factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement." (2.1)

The objective of any method study is to develop the most economical method of performing a specified task. Work measurement techniques are used to determine how long a certain task should take to complete. Two work measurement techniques suited to typical construction operations are: activity sampling for groups of workers engaged in constantly changing work patterns; and cumulative timing for machine dominated operations with repetitive work patterns.
2.2 HISTORY AND LITERATURE REVIEW

One can only make a guess as to the date when the idea of studying work procedures was initially conceived. However, the relatively advanced construction techniques used thousands of years ago in the erection of many historic civil engineering structures, for example Stonehenge or the Egyptian pyramids, could only have been developed from detailed examination of working methods. Initially, the aim of these early work study techniques was to create viable methods rather than to devise easier and more effective methods.

2.2.1 Leonardo da Vinci

The earliest records of work study techniques being applied in an industrial engineering environment were produced by Leonardo da Vinci (2.2). He built up time standards for shovelling operations, based on a systematic technique involving the breakdown of work into elements and allowances made for relaxation periods.

2.2.2 Pioneers of Work Measurement

F.W. Taylor's investigations are the basis for many of today's work measurement techniques; but prior to Taylor, the records of individuals such as J.R. Perronet (1708-1794), a French civil engineer, indicate that time studies were performed to determine output rates.

Not long after Perronet, secret time trials were advocated by C. Babbage (1798-1871), a mathematician, in order to obtain reliable output data. The secrecy was considered necessary to avoid any deliberate changes in worker speed as a result of being observed. Secret studies are nowadays unacceptable and also totally unwarranted thanks to modern techniques such as worker rating.
2.2.3 F.W. Taylor (1856-1915)

Frederick Winslow Taylor started his working life as an apprentice machinist, progressing through several supervisory levels to the position of Chief Engineer at the Midvale Steel Works, Philadelphia. After holding several other managerial posts he entered the field of management consultancy.

During the early years of his working life Taylor observed that the responsibility for output often lay with the workers, who, in order to preserve pay and jobs, regularly adjusted their performance. Thus, Taylor realized that one reason for low productivity was management's inability to assess what constituted a fair day's work.

Unlike many of his predecessors, Taylor saw that the benefits from secret studies were very limited, and on moving into management he took the view that the cornerstone of any management scheme should be the cooperation of the workforce. Thus, Taylor posited that:

"the principal objective of management should be the maximum prosperity for the employer and also maximum prosperity for each employee". (2.3)

In order to achieve maximum prosperity for all parties the actual division of profit has to be decided upon. Once this has been determined all effort can be directed towards increasing the amount of profit. To ensure that a company remains viable the overall labour costs must remain realistic. The combination of high wages and low labour costs can only be produced when a company is operating efficiently. To help achieve this situation, Taylor introduced a scientific style of management based on the following principles.
(a) **First.** The development of a science for each element of a man's work, thereby replacing the old rule-of-thumb methods.

(b) **Second.** The selection of the best worker for each particular task and then training, teaching, and developing the workman; in place of the former practice of allowing the worker to select his own task and train himself as best he could.

(c) **Third.** The development of a spirit of hearty co-operation between the management and the men in the carrying out of the activities in accordance with the principles of the developed science.

(d) **Fourth.** The division of the work into almost equal shares between the management and the workers, each department taking over the work for which it is the better fitted; instead of the former condition, in which almost all of the work and the greater part of the responsibility were thrown on the men. (2.4)

Taylor was mainly concerned with the work measurement branch of work study and the evaluation of a fair day's performance. His technique involved: dividing a job into basic movements; classifying the basic element times; determining the relaxation and contingency allowances; and calculating a time for the improved method.

Taylor records a number of investigations in his book Scientific Management (2.5); the most notable of these was a study into the conventional shovelling techniques used at the Bethlehem Steel Works at the beginning of this century. Taylor discovered that shovels of the same size were used for materials varying between 3 and 38 lbs. per load. Further studies indicated that the optimal shovel load weighed 28 lbs., thus, different shovel sizes were introduced for different materials. Consequently, a saving of $78,000 was made per year by adopting the revised method, as summarized in Table 2.1.
Table 2.1 Taylor's Study Results

<table>
<thead>
<tr>
<th></th>
<th>Before Study</th>
<th>After Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of workers</td>
<td>500</td>
<td>140</td>
</tr>
<tr>
<td>Tons/man/day</td>
<td>16</td>
<td>59</td>
</tr>
<tr>
<td>Earnings/man/day</td>
<td>$1.15</td>
<td>$1.88</td>
</tr>
</tbody>
</table>

This simple example illustrated that substantial savings were possible through studying individual tasks, and also suggested that the workers lacked the time, skill and motivation required to establish the most effective method.

2.2.4 F.B. Gilbreth (1868-1924) and L.M. Gilbreth

Frank Bunker Gilbreth was of middle class origin and appeared destined for university when he discontinued his studies and entered the building trade as an apprentice builder, at the age of seventeen. His progress over the next ten years was so rapid that he was appointed as Chief Superintendent at the relatively young age of twenty-seven. Between 1895 and 1923 he built up his own construction company, successfully undertaking work in the United States and Great Britain. Over the years Gilbreth thrived on reducing the amount of wasted effort and illogical methods often adopted in the construction industry. As a result his interests in this area became so strong that he gave up his construction business to become a management consultant and, in partnership with his wife, achieved an international reputation for his contribution to the science of motion study.
Mr. and Mrs. Gilbreth were responsible, over a period of time, for consolidating the scientific approach to management techniques. Much of their work was founded on F.B. Gilbreth's famous studies on bricklaying methods (2.6). After systematically observing the working methods employed, he realized that bricklayers usually adopted one of three sets of motions, depending on their intent to work quickly or slowly, or in order to train an apprentice. From this starting point the number of motions involved was reduced from 18 to 5, and, as a direct result of reduced work content, the bricklayers' productivity substantially increased.

As a consultant Gilbreth continued his method studies in many different industries. His success in the search for the best way of performing a task was owed to the simple local system that he adopted. This involved: "defining" the existing situation; "analysing" the task using specialized equipment; "examining" the results; "removing" unnecessary tasks; and "synthesizing" the remaining activities into a new method. Although these basic principles were earlier used by Taylor, Gilbreth's main contribution to work study was to actually lay down detailed instructions on how the study procedure should be implemented.

The Gilbreths' contribution to work study are diverse; the more notable ones include: the application of a motion camera to record certain tasks; the introduction of a micro-analysis system, called 'THEBLIGS' (Gilbreth spelt backwards) (2.7), which breaks down all hand motions into seventeen basic elements; the formulation of a set of rules for the synthesis of elements known as "Rules for Motion Economy and Efficiency"; and the isolation of factors, relating to the worker and environment, affecting the execution of a task.
2.2.5 **C. E. Bedaux (1887-1944)**

Prior to Charles E. Bedaux's (2.8) contribution, time studies merely recorded the actual duration of each element. However, Bedaux recognized that the operatives' speed was an important factor that should be recorded, along with each element of work, to ensure that the correct standard time (measured in 'B' units) was obtained. Basic performance was taken as 60 'B' units per hour, inclusive of relaxation allowances; expected performance was taken as 80 'B' units, for which the worker would receive an additional third of his basic pay. This subsequently became known as the 60/80 scale.

Unfortunately, Bedaux's techniques were largely applied during the thirties depression and were often abused by management. The basic concept behind the Bedaux scale still operates today. However, the actual rating scale has been superseded by the British Standard with a rate of 100 representing 'Standard Performance'.

2.2.6 **L.H.C. Tippett**

L.H.C. Tippett (1935), of the British Cotton Industry Research Board, suggested "a snap reading method of making time studies of machines and operatives in factory surveys" (2.9). From this original concept a method known as "ratio delay" was developed by Morrow (2.10) (1946), and used to quantify delays incidental to performance of work. This type of technique is now known as 'activity sampling' and its application has been discussed in many articles under the specific names of work sampling, random observations, activity ratio and ratio delay.
2.2.7 H.B. Maynard

The rapid advances in manufacturing technology immediately after the second world war, and the increasing use of assembly lines, resulted in more systematic work procedures. The reduction in the number of worker and machine motions made it possible for relatively concise data banks of basic element times to be established. This was foreseen by Taylor some fifty years previously. However, it was H.B. Maynard (2.11) who developed the concept of predetermined motion times into a workable system known as M.T.M. (motion-time-measurement).

2.2.8 Later Developments

Since 1940 basic work study principles have not significantly changed. The majority of later developments are associated with either the application of work study in different environments or the scientific validation of work study accuracy. This stems from the influx of industrial scientists brought about by the unusually high demand for production, resources and equipment immediately after the second world war.

The topics covered by the industrial scientists dealt with many problems. However, two distinct spheres of research have evolved. The first is the application of scientific methods involving a mathematical or statistical process, thus, providing a quantitative basis for management decisions concerning the organization of operations; such techniques are collectively known as 'Operational Research'. The second sphere of research is 'Ergonomics', which is the scientific study of the relationship between man and his working environment.
2.2.9 Recent Trends

In the 1960's and 1970's the world economy was expanding and the demand for labour was high. The resulting increase in labour costs, and need for higher production levels, encouraged the application of work study techniques throughout many industries. From the mid-seventies to the present day British industry has been losing its share of the international market (2.12). To rectify this situation, and preserve British industry, the current government has encouraged the need for greater efficiency, thus re-stimulating interest in work study techniques.

When one considers some of the recent well publicized industrial disputes, resulting from the pursuit of greater efficiencies, it is apparent that some basic management principles are being overlooked, or even deliberately ignored. Two prime examples of this are the dispute at British Leyland arising from the elimination of six minutes 'washing-up' time, and the year long miners' dispute over pit closures resulting in a devastation of the industry's morale. As stated previously, Taylor believed that increased productivity should be achieved via a policy of mutual co-operation between the workers and management. A colleague of his, H. L. Gantt (1861-1919) also had very strong views on ethical practice and stated that:

"The control over labour given to management by the application of the system which I installed was so far-reaching that I refused to install it unless convinced that the management was such that no unfair advantage would be taken to oppress labour." (2.13)

Manufacturing processes are becoming more automated, particularly since the introduction of the silicon chip. As a result, work study techniques are now being used to optimize mechanical efficiency and reduce the workforce. If the application of work study becomes a management weapon rather than a tool, similar repercussions to the thirties could arise, with a detrimental affect on the reputation and acceptability of work study.
2.3  **CONSTRUCTION WORK STUDY TODAY**

The definition given earlier describes work study as a service which measures, examines, investigates and improves efficiency. Strange as it may seem, there is a vast difference in application of this service when the construction and manufacturing industries are compared.

Work study has most of its roots in the building industry. However, since Gilbreth, it has been in the manufacturing industry that work study has been developed and extensively used to improve productivity, with the construction industry showing only a tentative interest.

The tasks performed within the manufacturing industry are highly repetitive, especially on assembly line work. This stable environment has been studied in detail in order to improve productivity. One result has been the development of a work measurement technique called Predetermined Time Motion System (PTMS) (i.e. the synthetic build up of operational time standards by combining pre-set standard times for each physical movement carried out). The PTMS technique is not suited to the construction industry, owing to the flexible co-ordination required to perform most construction operations. The British Leyland dispute on 'washing up time' also illustrates how far the manufacturing industry will go in the refinement of workers' physical actions. In stark contrast to this, the construction worker spends a large proportion of time engaged in ineffective activities, such as double handling of materials or waiting for work, often amounting to several hours per day compared with British Leyland's six minutes.
The author initially intended to determine a current state of the art for construction work study by interviewing several contractors. Unfortunately, the early investigations indicated that very few contractors actively used work study, and it was necessary to contact other organizations, such as Local Authorities, whose work was of a similar nature to that of the construction industry. The following fourteen organizations made varying contributions to the basic principles applied to construction work study throughout this research.

<table>
<thead>
<tr>
<th>Contractors with Work Study Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Laing Construction Ltd.</td>
</tr>
<tr>
<td>Wimpey Construction Ltd.</td>
</tr>
<tr>
<td>Henry Boot Ltd.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Local Authorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincolnshire County Council</td>
</tr>
<tr>
<td>Cornwall County Council</td>
</tr>
<tr>
<td>Nottinghamshire County Council</td>
</tr>
<tr>
<td>Norfolk County Council</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Industry Board for the Electrical Contracting Industry</td>
</tr>
<tr>
<td>British Waterways</td>
</tr>
<tr>
<td>Building Services Research and Information Association</td>
</tr>
<tr>
<td>Building Research Association</td>
</tr>
<tr>
<td>Building Advisory Service</td>
</tr>
<tr>
<td>Transport and Road Research Laboratory</td>
</tr>
<tr>
<td>Bircham Newton Training Centre</td>
</tr>
</tbody>
</table>

Figure 2.1 Contributors to Basic Work Study Principles
2.3.1 **John Laing Construction**

At the time of the visit to John Laing Construction Ltd. they were involved in 220 building contracts, 14 civil engineering and 15 overseas contracts.

John Laing Construction have incorporated work study techniques into their planning and estimating systems since 1950. The majority of data collection was done between 1965-1970, resulting in nine data books containing 380,000 basic element times. These data books cover the main trades and are categorized as excavation, concrete, brickwork, joinery and formwork, external works, scaffolding, drain laying, steel fixing and others.

As a comprehensive library of standard times is available, work study collection is now on a much smaller scale and mainly used to settle disputes or investigate new methods. The three main methods of collecting data are: flyback timing for mechanical operations; M.T.M. for plant maintenance; and activity sampling for the remainder. The factors applied to standard times in order to determine bonus, estimating and planning rates are usually left to individual regions.
2.3.2 Wimpey Construction

The majority of Wimpey Construction's projects involve the construction of timber framed houses. However, their work also includes commercial and industrial type buildings. There are fifteen operational regions with projects throughout the U.K.; each region is allocated a work study engineer. The results from any studies are sent to the main work study department in London, comprising four work study engineers. Any new studies are directed towards reducing costs through method improvement, with the results also used to assist in the setting of planning, estimating and bonus rates.

Rated activity sampling studies are used to collect most of the data. The relaxation allowances are supplied from the main office and learning allowances obtained from previous studies. Activities are generally split up into two areas (i.e. working or ineffective). Standard times are only derived from the working time plus relaxation allowances.

Wimpey Construction were very co-operative and forthcoming with detailed information on studies relating to steel-work erection, concrete floor slab production, pumping concrete, bricklaying, transporting concrete, earthmoving, drain laying and the erection of timber framed houses.
2.3.3 Department of Transport

The Marshall Report (2.14), published in 1970, highlighted the need for increased professionalism and the better use of modern management techniques by Local Highway Authorities. Also, Report No. 29 (2.15) of the Prices and Incomes Board in March 1967 effectively imposed upon Highway Authorities the requirement for operating incentive bonus schemes based on work study data.

In addition to bonus schemes, several County Councils (2.16) also use their work study data to determine estimating and planning times. This has resulted in the development of a computer based system, namely RATE (2.17). The RATE system has cost about £170,000 in direct expenditure on research contracts, and is the result of joint work between the Transport and Road Research Laboratory, the Working Party on Highway Maintenance, the Department of Transport and various County Councils. The RATE System consists of a number of permanent libraries, (a) the Ratebill Library, (b) Operation Libraries, (c) three Price Files (labor, plant, materials); and produces (i) a Bill of Quantities, (ii) the labour, plant and materials required.

2.3.4 Nottinghamshire County Council

The Planning and Transportation Department of Nottinghamshire County Council currently uses work study data (2.18) to determine output rates for estimates and to devise bonus schemes, although the emphasis is mainly on highway maintenance.

Activity sampling and time studies are currently used to update and expand an existing data bank of standard minute values; these are stored within a microcomputer based estimating system. The system has several functions, including the production of unit rates, preparation of quotations, production of programme schedules, and the comparison of alternative methods. The PSM/hr. (Productive Standard Minutes per hour) are obtained from output and productivity statements resulting in a typical value of 40 PSM/hr.
2.3.5 Joint Industry Board for the Electrical Contracting Industry

The Joint Industry Board has produced a "National Library of Work Study Data" (2.19), this provides a basis for the estimating, planning and control of the labour element within the electrical contracting industry.

Rated activity sampling studies are currently used to update and expand the data bank, with techniques such as synthesis and analytical estimating used to extend its coverage. The data bank is subdivided into the following sections. The build up of planning and estimating rates are illustrated in Figure 2.2.

(1) Work Study Data

(a) Method description
Each operation contains a detailed method description upon which the standard times are based.

(b) Operational Standards
This section describes how the standard times are combined to provide operational standards. The standard times include a rating factor, occasional elements, contingency and relaxation allowances.

(ii) Planning Guidelines
The operational standards are used to obtain planning times by applying allowances for daily work, ancillary work and manning levels.

(iii) Estimating Guidelines
This section takes account of any additional work caused by site layout and the variation in performance of individual contractors. The guideline for general performance adjustment is 75 per cent of standard performance.
Figure 2.2 Build up of Planning and Estimating Rates

<table>
<thead>
<tr>
<th>SECTION I</th>
<th>SECTION II</th>
<th>SECTION III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work Study Data</td>
<td>Planning Guidelines</td>
<td>Estimating Guidelines</td>
</tr>
<tr>
<td>Yellow Pages</td>
<td>Red Pages</td>
<td>Brown Pages</td>
</tr>
</tbody>
</table>

**Work Study Observations by the J.I.B.**

- Productivity Services
- Departments & Member Companies

**Method Description**

**Operational Standard Times**

- Rest Allowance
- Basic Element Times
- Occasional Elements
- Contingency Allowance

**Planning Times for Operations (at BSI 100 Performance)**

- Daily Allowance
- Ancillary Work Allowance (Prep, Walking, Liaison etc.)

**Estimating Values**

- Additional Work Allowance
- General Performance Adjustment at 100 - 75%

**To be allowed for by the user**

- Manning Allowance
- Apprentice Allowance
- To be allowed for by the Estimator

**Hourly Rate and Job cost Estimate**
2.3.6 British Waterways Board

The British Waterways Board employs a direct labour force throughout the country and has a central work study department. Standard times (2.20) are available for repetitive work, for example sheet piling and dredging operations; these are used to evaluate bonus rates and gang sizes. The viability of employing management consultants to establish standard times for the remaining operations is currently under consideration. The general procedure used by the British Waterways Board to determine operational standards is summarized below.

(a) The correct gang size is established by producing multiple activity charts showing the amount of time spent working.

(b) Using the correct gang size each individual work element is performed, timed and rated; subsequently, the appropriate relaxation allowance is applied and a standard time obtained.

(c) Allowances for pre-work and post-work are applied.

(d) The variable elements are recorded on site and a typical site value is determined.

(e) The information is presented in report form, and includes the standard times, a method statement and the equipment required.
2.3.7 Building Services Research and Information Service (B.S.R.I.A.)

The B.S.R.I.A. have produced an "Estimator's Guide to Labour Times" (2.21) for heating, ventilating and air conditioning work. This guide is based on data collected from a survey of thirty-seven B.S.R.I.A. members, combined with the results from earlier studies. The information is presented as standard times for each item of work and provides three methods of estimating; namely, "Unit Labour Rate", "Counted Fitting Method" and "Foot Run Method". Three factors are applied to take account of different working conditions; these are listed below.

(a) Task factors
These apply to a relatively short and well defined piece of work and are applied to the basic time according to height, access, etc.

(b) Site factors
These can apply either to the site as a whole or some section of it (e.g. 1st Floor, 2nd Floor).

(c) General factors
These cover conditions that might affect labour costs (e.g. geographical location).
2.3.8 Building Research Establishment

Some research by the Building Research Establishment has been on projects involving the rationalization of house design (2.22) with the view to increasing productivity. The rationalized designs achieved continuity of effort from different trades by reducing delays caused by inter-trade interferences. Full-scale trials, involving individual mock-up houses, were used to test the results.

The studies were performed using activity sampling recorded on coded data sheets, with an optical reader used to analyse the data and present the results. Two of the conclusions drawn from these studies were that:

(a) the number of manhours per dwelling had a ratio of 3:1 from the highest to the lowest.

(b) factors such as size of dwelling, size of contract, rate of building and number of house types, have no consistent affect on the variability of manhours per dwelling when taken individually.
2.3.9 Transport and Road Research Laboratory

The Transport and Road Research Laboratory have, over the last ten years, investigated factors affecting the efficiency of bulk earthworks and road paving operations. The section investigating road paving operations uses two very different data collection techniques, namely CODDLE and COSSIT, as described below. Similar data collection techniques are also used by the earthworks section.

(1) CODDLE

CODDLE (2.23) is a work study based data collection system that has developed from hand recorded activity sampling to automatically recorded cumulative timing. Individual CODDLE studies usually last for four hours; special events are recorded in a notebook and study data is recorded on a cassette using a pre-coded keyboard. The recorded study data includes file number, activity being performed, the machine code (or chainage point) and the cumulative time. When a study has finished, this information is transferred on to nine track computer tape and run through a series of six "SORT" programs with a manual check performed for gross errors.

There have been 150 of these studies recorded although very few have actually been analysed. The recording instruments used are very bulky at the present and could be improved by the application of the portable computers.

(ii) COSSIT

COSSIT is a system for transcribing observations made during the production of road pavements, into a form that matches a model of pavement construction, and facilitates the storage and analysis of the information by computer. This technique is an expansion of the foreman delay survey with each item individually coded, and has been used to collect data over the full contract duration for twenty-three sites.
2.4 CONCLUSIONS

The evidence indicates that similar work study techniques are used by various organizations to collect data, but, there is a wide variation in both the presentation and application of results. This variation often arises because many work study techniques originate from the manufacturing industry and have been adopted by the construction industry without due consideration given to the latter's needs.

Construction work study is mainly used to determine output rates for planning, estimating and bonus schemes, and thus involves work measurement as opposed to method study. The lack of interest in developing improved construction methods by the construction industry, consistently perpetuates the status-quo as far as traditional methods are concerned, and in some instances working methods have remained the same over the last hundred years or so.

In contrast, for example, one of Gilbreth's earlier studies resulted in the development of a special scaffold system designed to improve bricklaying productivity. This scaffold was equipped with a bench or shelf for supporting bricks and could be raised short distances at a time, thus, saving the bricklayer the tiring and unnecessary task of bending down to pick up bricks or mortar off the scaffold floor. However, when one looks around construction sites today bricks are often placed in a stack with no assistance from specially adapted scaffold. This simple example illustrates the limited advances made with some construction methods since the beginning of the century, and the improvement required before construction processes become analogous to the production lines used in the manufacturing industry.
CHAPTER THREE

WORK STUDY APPLIED TO CONSTRUCTION OPERATIONS
CHAPTER THREE

3.0 WORK STUDY APPLIED TO CONSTRUCTION OPERATIONS

3.1 INTRODUCTION

With the majority of resources for work study development coming from the manufacturing industry, the evolved terminology and techniques are specific to that industry. By careful consideration and comparison of construction and manufacturing operations work study techniques can be revised to meet the requirements of the construction industry.

The direct adoption of manufacturing work study techniques, combined with the fact that most work study practitioners do not have a construction background, has certainly curtailed the impact that work study has had on construction productivity. Also, there are several other problems, usually associated with the nature of construction work, which are considered to be the cause of construction industry's reluctance to implement work study techniques on a wider scale; these will now be discussed.

Many construction operations last for short periods of time, say four hours, with a long intervals before any operations are repeated. Thus, the benefits from construction method studies are not always immediate.
There are few work study data banks readily available to the construction industry. Therefore, any contractor wishing to incorporate work study into its management structure usually has to start from scratch, either by establishing a new department or employing outside work study consultants. The lack of basic data is a result of contractors who have already gone to the time and expense of establishing a comprehensive work study library regarding the information as confidential. The restrictive flow of construction work study information means that contractors not only have to collect the data, but they also have to devise suitable methods of data collection and presentation. This closed door policy has contributed to the diverse presentation and application of construction work study that exists today.

Construction operations, especially those with long durations, often require expensive items of plant. This plant is often on site before any study is performed. As on site costs are usually very high, the decision behind the plant selection is unlikely to be countermanded, even if a more effective method is found. In addition, trying new alternatives is not always recommended as the contractor and operatives may have to repeat the learning process. However, the benefits resulting from individual studies could be reaped on subsequent projects.

Manufacturing operations usually consist of short cycles of work performed in a predetermined repetitive sequence: in contrast, activities involved in construction operations are often varied and not performed in any predetermined sequence. Thus, construction work study data collection requires reasonably flexible recording techniques. Also, the time lag between performing a study and implementing any improvements is much more critical for construction operations as many are "here today and gone tomorrow".
Over a period of time, very efficient manufacturing processes have been achieved through a constant detailed refinement of working methods. The construction industry, by comparison, very often operates at low levels of productivity. Therefore, any programme designed to increase construction efficiency should not start with a detailed refinement of operations but a wholesale change in methods and attitudes, which requires very different work study techniques to those currently used in the manufacturing industry.

3.2 WORK STUDY TECHNIQUES

Work study is the systematic measurement, examination and investigation of the current situation in order to effect improvement via the optimum use of the available resources. Work study can be divided into two independent activities; namely method study and work measurement. There are many areas where work study results can be used to improve the efficiency of a contractor; some of the basic applications include:

(a) the calculation of gang sizes;
(b) the determination of job sequences;
(c) the pre-planning of contracts;
(d) the planning of site layouts;
(e) the setting of bonus rates;
(f) the cost comparison of plant and methods;
(g) the design of hand tools to reduce work content.

3.2.1 Method Study

Method study is the technique used to systematically record and analyse existing work procedures, with a view to achieving a reduction in cost by improvement of the methods under consideration. Essentially, a method study should comprise the following stages.
(a) Define the problem.
(b) Record the facts.
(c) Analyse the data.
(d) Propose a course of action.
(e) Put the proposals into effect.
(f) Monitor the consequences.

The above process, as recommended by Harris and McCaffer (3.1) and others, is primarily an investigative and reparatory approach; existing methods are analysed and changed where necessary, with the effects being monitored. There are three method study techniques used to portray operations by some visual means; namely:

(1) **Flow Charts**

Flow charts are used to illustrate the movement of material or plant through a construction process. This involves using symbols on a plan of the work area and is suited to work of a cyclic nature. Figure 3.1 illustrates the five widely recognized symbols presented in BS 3138: 1979.

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>ACTIVITY</th>
</tr>
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<tbody>
<tr>
<td>○</td>
<td>Operation</td>
</tr>
<tr>
<td>□</td>
<td>Inspection</td>
</tr>
<tr>
<td>➔</td>
<td>Transportation</td>
</tr>
<tr>
<td>▼</td>
<td>Storage</td>
</tr>
<tr>
<td>□</td>
<td>Delay</td>
</tr>
</tbody>
</table>

**Figure 3.1 Standard Flow Chart Symbols**
(ii) Process Charts

In some situations it is not feasible to represent the flow of work on a site plan. For example, where several operations are confined to one location. If this is the case, the operation can be illustrated using a process chart, where the sequence of events is represented by symbols only. These are man, material, equipment or outline process charts; the type adopted depends upon the events under consideration.

(iii) Multiple Activity Charts

Multiple activity charts are used to plot a series of interrelated activities against a common time scale, and subsequently assist in selecting and representing an improved method. The activities can represent the work done by individual operatives, whole gangs or items of plant.

3.3.2 Work Measurement Techniques

Work measurement is the application of techniques designed to establish the time for a qualified worker to carry out a specific task at a defined level of performance. Work measurement techniques are, therefore, an integral part of method study during the data collection phase. The information collected during work measurement must record the quantity of work produced and the time required to perform the task.

The work produced during an operation should be measured in terms of effective output. For example, the measurement of work done in fixing reinforcement should include the weight of steel, the complexity of reinforcement details and the distance steel is transported on site.

Time studies are work measurement techniques used to record the times and rates of working for the elements of a specific job carried out under specified conditions, and are used to analyse the data so as to obtain the time necessary for carrying out the job at a defined level of performance. Certain aspects of typical time studies will now be discussed.
(i) **Flyback Timing**

The hands of a stop-watch are returned to zero and restarted at the end of each element. The time for each element is recorded directly, along with an assessment of rate.

(ii) **Cumulative Timing**

The hands of a stop-watch are not stopped and the actual time at the end of each element is recorded. Each element is rated and the duration subsequently obtained by subtraction.

(iii) **Activity Sampling**

Observations are taken either at set or random intervals on a group of workers; both the activities being performed and the rate of work are recorded.

(iv) **Rating**

The objective of any time study is to determine the "realistic time" required to complete a particular operation. The realistic time must take into account the effective work rate of the subjects; this procedure is known as "rating". Rating is, thus, used to assess the worker's rate of working, relative to the observer's concept of standard rating. Rate depends upon speed of movement, effort, dexterity and consistency.

Typical rating assessments, as suggested by BS 3138: 1979, are presented in Figure 3.2. In practice, however, rating is usually carried out only on the working activities, with a 10 point graduation scale, ranging between 50 and 130, being adopted.

<table>
<thead>
<tr>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>125 : Very quick, high skill, highly motivated.</td>
</tr>
<tr>
<td>100 : Brisk, qualified skill, motivated.</td>
</tr>
<tr>
<td>75 : Not fast, average skill, disinterested.</td>
</tr>
<tr>
<td>50 : Very slow, unskilled, unmotivated.</td>
</tr>
</tbody>
</table>

**Figure 3.2 Typical Rating Assessments**
Foreman Delay Survey

Borcharding and Tucker (3.2) in the U.S.A., and subsequently Easton (3.3) in Australia, have shown that the foreman delay survey is a useful management tool designed to determine which factors, other than operative performance, affect productivity. For example, waiting for materials or plant breakdown. Foreman delay surveys are based on operative feedback. They are, therefore, dependent upon the co-operation of the foreman; who identifies, quantifies and records the lost time for each day. Subsequently, the results can be used to improve working methods and monitor revised methods. Although foreman delay surveys can monitor a whole project on a regular basis, and provide up to date information on certain organizational delays, there are also several disadvantages which influenced the decision not to incorporate this technique in the data collection program used in this research; these are listed below.

(a) The foremen will tend to include the lost time caused by poor operative motivation with the delays associated with management organization.

(b) The overall accuracy of the study will always be in doubt because the times are all estimated by the foreman.

(c) It was anticipated that the foremen's co-operation during this research would not extend to work not directly associated with his job.

(d) Foremen usually only spend part of the working day on site, thus, missing a large proportion of the delays.

(e) The technique only allows for large delays to be recorded, however, short delays or interruptions are just as important.
In addition to time study techniques, there are several analytical processes which form an important part of any work measurement exercise. These will now be discussed.

(i) **Synthesis**

Basic operation times can be determined by combining previously established elemental times. This work measurement technique is known as synthesis, and is used extensively in the analysis section of this thesis. One advantage of using synthetic data is that slight variations in working method can be accounted for by adding or omitting the appropriate basic element times.

(ii) **Predetermined Motion Time Systems (PMTS)**

Predetermined motion time systems are the synthetic build up of basic operational times from previously set standards representing basic human movements or mental tasks. This technique is suitable for many manufacturing operations where a limited number of movements are regularly repeated. However, it is not suited to most construction operations owing to the flexible working motions involved.

(iii) **Analytical Estimating**

Analytical estimating is the determination of operational times partially from knowledge and experience of similar types of work, and is, therefore, very useful where only some of the basic element times are available.
3.3 PRESENTATION OF OUTPUT RATES

Reasonable access to construction output rates, including some based on work study techniques, has been provided by organizations within both the public and private sectors. However, the huge variation in presentation of data has been somewhat disappointing. This may be partly attributable to the exclusive organization of each construction project, and individual contractors ensuring that their records are of limited use to fellow bidders, competitors and customers. So it is clear that such data gathered from various sources are unlikely to be comparable, unless, they are standardized by some unified approach.

3.3.1 Current Methods of Presenting Output Data

Output rates can be presented as basic times, standard times or planning times, depending upon their intended use. The basic principle, as laid down in BS 3138: 1979, is to obtain the basic element times to which factors are applied in order to obtain planning times. The British Standard was written to cover a wide range of industries, resulting in numerous policy and contingency allowances, many of which are not appropriate to the construction industry.

Most of the organizations visited build up their standard times as shown in Figure 3.3, but differ in the application of policy allowances used to obtain planning times. The flexibility that presently exists makes it all too easy for existing inefficiencies to be transferred to future work via these policy allowances. This often occurs when future policy allowances are determined by dividing the working day duration by the average value of work, expressed as standard time, currently being performed per day. This obviously results in a realistic policy allowance, but does not facilitate the improvement of productivity by the location of inefficiencies.
In this respect it seems that the British situation is quite disorganized when compared with others on the continent (3,4). For example, Dutch contractors have formed a progressive co-operative, with the charter to provide a pool of output times linked to construction methods. These are updated and published monthly for guidance of the industry and its customers by the journal BOUWKOSTEN.
Selected basic times

<table>
<thead>
<tr>
<th>Work content in standard units of work</th>
<th>Delay contingency allowance</th>
</tr>
</thead>
</table>

STANDARD TIME

Build-up of standard time for operator controlled work

<table>
<thead>
<tr>
<th>Selected basic times + Contingency allowance for</th>
<th>Relaxation allowance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside work</td>
<td>(a)(b)(c)</td>
</tr>
<tr>
<td>Inside work</td>
<td></td>
</tr>
</tbody>
</table>

Machine controlled time

Basic cycle time

Standard cycle time

Standard time

Build-up of standard time for single operator, single machine, machine controlled work with no unoccupied time

Figure 3.3 Current Build-up of Standard Time
3.3.2 Proposed Presentation of Output Data

The main deficiencies in current methods of presenting output data are: the failure to accurately represent the various individual elements relating to complete operations; and the lack of flexibility in representing various levels of performance. The proposed method of presenting output data aims to reduce these deficiencies, by careful consideration of the types of work and idle time occurring during the working day. During this rationalization of construction time standards, it was ensured that: the proposed system related closely to current methods of presentation; and the terminology complied with the British Standard, whilst concentrating on the sections relevant to the construction industry.

The working day for most construction work can be broken down in terms of working time, diverted time, idle time and absence time, as illustrated in Figure 3.4. Consequently, construction operations are classified as unrestricted, semi-restricted or restricted, depending upon the type of idle time involved. The terms used in Figure 3.4 and Figure 3.5 are defined in Appendix A.

In order to comply with current work study terminology, output rates have to be expressed as basic operation times. Thus, the build up of time standards, as illustrated in Figure 3.5, was developed by combining Figures 3.3 and 3.4. The total basic time for an operation includes basic times for excess and ancillary work in addition to the main work elements. The only idle time included in the total basic time are allowances for internal delays (i.e. unavoidable idle periods). A method of determining basic operation times for concrete work is described at length in Chapter Four.
**Figure 3.4 Classification of Work and Idle Times.**

**NOTE:** Bold type indicates terms which are also used in Figure 8.2.
BASIC TIME
EXCESS

BASIC TIME
ANCILLARY

ASSEMBLE BASIC
ELEMENT TIMES
TO OBTAIN BASIC
OPERATION TIME

BASIC TIME
FOR
CONTINGENCY WORK

BASIC TIME
UNRESTRICTED
OPERATION

INTERNAL DELAY
ALLOWANCES

BASIC TIME
RESTRICTED
OPERATION

TOTAL BASIC
TIME

PERSONAL BASIC
NEEDS FATIGUE
ENVIRONMENTAL
STRAIN

FIXED
VARIABLE

SITE FACTORS
(F1xF2xF3xF4)

TOTAL PLANNING
TIME

RELAXATION
ALLOWANCES

TOTAL STANDARD
TIME

Figure 3.5 Proposed Build Up of Time Standards.
Standard times are obtained by combining basic times with relaxation allowances; this process is discussed in Chapter Five. Standard times are only applicable to sufficiently motivated operatives working on well organized sites. This ideal combination is not always the case, and planning times often have to account for large periods of idle time. The majority of idle time associated with construction work relates to individual sites. Hence, site factors are used to represent lost time, as explained in Chapter Eight.
CHAPTER FOUR

A METHOD OF DETERMINING BASIC TIMES FOR
IN SITU CONCRETING OPERATIONS
CHAPTER FOUR

A METHOD OF DETERMINING BASIC TIMES FOR IN SITU CONCRETING OPERATIONS

4.1 INTRODUCTION

The following example illustrates the recording methods used during this research. The operation involves using a crane and skip to pour concrete into two columns, two roof slabs, and infill concrete between several pre-cast concrete units. The dimensions and quantities of work encompassed are presented in Table 4.1, and the operation is illustrated in Figure 4.1.
### Table 4.1 Concrete Dimensions and Quantities

<table>
<thead>
<tr>
<th>Pour</th>
<th>Dimensions</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab 1</td>
<td>width = 2.0m; area = 88.3m²;</td>
<td>volume = 29.9m³</td>
</tr>
<tr>
<td>Slab 2</td>
<td>width = 2.0m; area = 10.6m²;</td>
<td>volume = 3.7m³</td>
</tr>
<tr>
<td></td>
<td>total volume = 33.6m³</td>
<td></td>
</tr>
<tr>
<td>Columns</td>
<td>(0.5m x 0.5m x 3.8m) x 2;</td>
<td>volume = 1.9m³</td>
</tr>
<tr>
<td>Joints</td>
<td>(0.15m x 0.05m x 3.6m) x 12;</td>
<td>volume = 0.3m³</td>
</tr>
<tr>
<td></td>
<td>total volume = 2.2m³</td>
<td></td>
</tr>
</tbody>
</table>

Average distance travelled by skip:

\[
\text{Vertical} = 10.0\,\text{m} \quad \text{Total} = 38.5\,\text{m} \\
\text{Horizontal} = 37.0\,\text{m}
\]

Capacity of concrete lorries = 5m³  
Capacity of skip = 1m³

The example is now divided into three sections: the first illustrates the procedure used to collect the data on site; the second describes how this is translated into basic times for the operation; and the final section demonstrates how these times can be used in the synthetic build up of planning times for other operations.
4.2 DATA COLLECTION

Flyback timing was found to have two main drawbacks: (a) it was not possible to realistically observe more than one cycle of work at a time, for example, the measurement of haul trucks involves several simultaneous cycles; and (b) it was not possible to use one stop-watch and combine activity sampling with flyback timing. To overcome these problems, cumulative timing was used to record operations of a cyclical nature. To simplify the subsequent analysis, the divisions on the stop watch were in hundredths of a minute rather than seconds.

In the manufacturing industry activity sampling observations are taken at predetermined random intervals, to ensure that the regular pattern of the work does not influence the study. When dealing with operatives on the site there is generally a natural random pattern in the work, consequently, activity sampling can be carried out at set intervals for the majority of labour dominated operations.

Data for concrete operations were collected on a specially adapted activity sampling sheets, as illustrated in Figure 4.2, which comprise the following sections.

(i) Activity Sampling

Activity sampling proved successful for recording groups of workers engaged in constantly changing work patterns. After many trials, the procedure finally adopted required an observation to be taken of each operative every five minutes; the activity and rate of work being recorded in the first nine columns. The list of activity codes used in this study are presented in Table 4.2.

(ii) Cumulative Timing

Cumulative timing proved more appropriate for machine dominated operations, where activities were commonly performed in a regular pattern. As the work done by the crane was of a cyclical nature, cumulative times were simply taken at the start and finish of the loading and unloading of the skip. These results being entered in the last five columns of Figure 4.2.
(iii) Comments

Important events not recorded in the activity sampling or cumulative timing sections were noted in the comments column. For example, delays caused by the late arrival of concrete.

Table 4.2 Activities and Codes for Concreting Operations

<table>
<thead>
<tr>
<th>CODE</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Break</td>
</tr>
<tr>
<td>1</td>
<td>Away</td>
</tr>
<tr>
<td>2</td>
<td>Walk</td>
</tr>
<tr>
<td>3</td>
<td>Talk</td>
</tr>
<tr>
<td>4</td>
<td>Recover</td>
</tr>
<tr>
<td>5</td>
<td>Wait</td>
</tr>
<tr>
<td>6</td>
<td>General</td>
</tr>
<tr>
<td>7</td>
<td>Other work</td>
</tr>
<tr>
<td>8</td>
<td>Internal delay</td>
</tr>
<tr>
<td>9</td>
<td>Prepare work area</td>
</tr>
<tr>
<td>10</td>
<td>Clear away</td>
</tr>
<tr>
<td>11</td>
<td>Carry</td>
</tr>
<tr>
<td>12</td>
<td>Search</td>
</tr>
<tr>
<td>13</td>
<td>Instructions/Drawing</td>
</tr>
<tr>
<td>14</td>
<td>Redo work</td>
</tr>
<tr>
<td>15</td>
<td>Clean shutters</td>
</tr>
<tr>
<td>16</td>
<td>Pour concrete</td>
</tr>
<tr>
<td>17</td>
<td>Vibrate</td>
</tr>
<tr>
<td>18</td>
<td>Shovel</td>
</tr>
<tr>
<td>19</td>
<td>Tamp</td>
</tr>
<tr>
<td>20</td>
<td>Trowel</td>
</tr>
<tr>
<td>21</td>
<td>Cover</td>
</tr>
<tr>
<td>22</td>
<td>Jack Hammer</td>
</tr>
</tbody>
</table>
### Figure 4.2 Activity Sampling Study Sheet

<table>
<thead>
<tr>
<th>Additional Activities</th>
<th>Break Points</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Joints in P.C.U.</td>
<td>BP1</td>
<td>Skip arrives at lorry area</td>
</tr>
<tr>
<td></td>
<td>BP2</td>
<td>Skip leaves lorry area</td>
</tr>
<tr>
<td></td>
<td>BP3</td>
<td>Skip arrives at pour area</td>
</tr>
<tr>
<td></td>
<td>BP4</td>
<td>Skip leaves pour area</td>
</tr>
<tr>
<td>Weather: Wet/Cold/Calm</td>
<td>Date: 14 March 1983</td>
<td>REC. Andrew Price</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TIME</th>
<th>Man 1</th>
<th>Man 2</th>
<th>Man 3</th>
<th>Man 4</th>
<th>Comments</th>
<th>Cumulative Timing (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.30</td>
<td>16 100 9 110</td>
<td>9 110 9 110</td>
<td>9 100 9 110</td>
<td>Delays</td>
<td>Note. Start @ 1.30 (=0.00)</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>9 90 18 100</td>
<td>5</td>
<td>9 90</td>
<td>BP1</td>
<td>1 (1.30h)</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>18 100 31 110</td>
<td>9 110 9 100</td>
<td>5</td>
<td>10.80</td>
<td>1.09 9.30 9.75</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>18 100 31 110</td>
<td>5</td>
<td>19 110</td>
<td>BP2</td>
<td>11.90 12.75 12.95</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>18 110 18 90</td>
<td>17 90</td>
<td>4</td>
<td>12.90</td>
<td>13.90 15.25 16.15 16.40</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>18 110 9 90</td>
<td>10 110</td>
<td>17 110</td>
<td>13.25</td>
<td>17.25 21.80 22.40 22.80</td>
<td></td>
</tr>
<tr>
<td>2-00</td>
<td>10 100 10 110</td>
<td>2</td>
<td>50 18 110</td>
<td>BP3</td>
<td>23.80 24.90 25.60 26.10</td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>18 120 31 110</td>
<td>17 60</td>
<td>19 110</td>
<td>26.60</td>
<td>27.60 Lift for joiners</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>16 100 31 70</td>
<td>18 100</td>
<td>4</td>
<td>36.00</td>
<td>36.10</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>18 100 31 100</td>
<td>18 100 31 100</td>
<td>34.00</td>
<td>34.90 35.80 36.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>20 100 5</td>
<td>5</td>
<td>5</td>
<td>37.20</td>
<td>38.00 38.70 38.90</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>20 110 31 100</td>
<td>6 100</td>
<td>5</td>
<td>39.90</td>
<td>40.60 41.60 41.75</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>20 110 31 100</td>
<td>6 100</td>
<td>5</td>
<td>43.90</td>
<td>43.90 Lift for bricklayers</td>
<td></td>
</tr>
<tr>
<td>3-30</td>
<td>20 110 31 100</td>
<td>6 100</td>
<td>5</td>
<td>50.50</td>
<td>51.60 52.30 52.50</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>20 100 110</td>
<td>17 110</td>
<td>19 50</td>
<td>60.50</td>
<td>60.90 61.90 62.50</td>
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</tr>
<tr>
<td>40</td>
<td>20 120 31 110</td>
<td>16 110</td>
<td>19 100</td>
<td>62.30</td>
<td>62.90 63.30 63.50</td>
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</tr>
<tr>
<td>45</td>
<td>20 110 31 110</td>
<td>17 110</td>
<td>19 90</td>
<td>64.50</td>
<td>65.15 65.30 65.40</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>20 110 5</td>
<td>17 110</td>
<td>18 110</td>
<td>66.60</td>
<td>67.15 67.40 67.60</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>20 110 5</td>
<td>17 110</td>
<td>18 110</td>
<td>69.90</td>
<td>70.40 70.70 70.90</td>
<td></td>
</tr>
<tr>
<td>1-00</td>
<td>4 - 31 90</td>
<td>17 110</td>
<td>18 100</td>
<td>73.20</td>
<td>73.80 74.30 74.50</td>
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</tr>
<tr>
<td>05</td>
<td>4 - 31 110</td>
<td>17 110</td>
<td>19 100</td>
<td>75.40</td>
<td>75.90 76.30 76.50</td>
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<tr>
<td>10</td>
<td>20 110 31 100</td>
<td>17 110</td>
<td>19 100</td>
<td>78.70</td>
<td>79.30 79.60 80.00</td>
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</tr>
<tr>
<td>15</td>
<td>20 110 31 100</td>
<td>17 80</td>
<td>18 110</td>
<td>81.00</td>
<td>81.60 81.90 82.10</td>
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<td>20</td>
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<td>5</td>
<td>18 100</td>
<td>87.90</td>
<td>88.50 88.80 89.00</td>
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<tr>
<td>35</td>
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<td>17 100</td>
<td>4</td>
<td>90.20</td>
<td>90.70 91.00 91.20</td>
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</tr>
<tr>
<td>40</td>
<td>20 110 4</td>
<td>17 110</td>
<td>6 90</td>
<td>92.50</td>
<td>93.00 93.20 93.40</td>
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<td>45</td>
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<td>94.80</td>
<td>95.30 95.60 95.80</td>
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<td></td>
<td></td>
<td></td>
<td>101.40</td>
<td>101.90 102.20 102.40</td>
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Figure 4.2 Activity Sampling Study Sheet: Continued

<table>
<thead>
<tr>
<th>Additional Activities</th>
<th>Break Points</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>16c Pour concrete to columns</td>
<td>BP1 Skip arrives at lorry area</td>
<td>L x W x D</td>
</tr>
<tr>
<td>17c Vibrate columns</td>
<td>BP2 Skip leaves lorry area</td>
<td>Slab 1 2.0m x 4.2m x 0.34m</td>
</tr>
<tr>
<td></td>
<td>BP3 Skip arrives at pour area</td>
<td>Slab 2 2.0m x 5.3m x 0.35m</td>
</tr>
<tr>
<td></td>
<td>BP4 Skip leaves pour area</td>
<td>Columns (0.5m x 0.5m x 3.8m) x 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Joints (0.15 x 0.05 x 3.6) x 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skip 1m³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TIME</th>
<th>Man 1 Act. Rate</th>
<th>Man 2 Act. Rate</th>
<th>Man 3 Act. Rate</th>
<th>Man 4 Act. Rate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.55</td>
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<td>100</td>
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<table>
<thead>
<tr>
<th>Cumulative Timing (mins)</th>
<th>PLANT: TOWER CRANE</th>
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<tbody>
<tr>
<td>28 23</td>
<td>BP1 25-25 25-40 25-70</td>
</tr>
<tr>
<td>29 27-30× 33-40</td>
<td>BP2 35-00 35-40</td>
</tr>
<tr>
<td>30 36-60</td>
<td>BP3 38-00 38-50</td>
</tr>
<tr>
<td>31 39-60</td>
<td>BP4 41-20 42-90</td>
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<tr>
<td>32 43-25</td>
<td>Lifts for Bricklayers</td>
</tr>
<tr>
<td>33 47-05</td>
<td>48-60 49-50</td>
</tr>
<tr>
<td>34 50-15 51-25</td>
<td>51-80 52-90</td>
</tr>
<tr>
<td>35 53-50×</td>
<td>52-90</td>
</tr>
<tr>
<td>36 25-80</td>
<td>Not Recorded</td>
</tr>
<tr>
<td>37 30-15 31-20 32-25</td>
<td>Coles</td>
</tr>
<tr>
<td>38 34-45 35-55 36-60</td>
<td>Coles</td>
</tr>
<tr>
<td>39 44-75 45-90</td>
<td>Joints</td>
</tr>
</tbody>
</table>

NOTES - A blank space indicates missing observation.
Figure 4.3 Activity Sampling Summary Sheet

<table>
<thead>
<tr>
<th>ACTIVITY: CODE</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
<th>C11</th>
<th>C12</th>
<th>C13</th>
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<td>11</td>
<td>103</td>
<td>110</td>
<td>113</td>
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<td>TOTAL (OR AVER)</td>
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<td>101</td>
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<td>841</td>
<td>-</td>
<td>-</td>
<td>Av = 17.2%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

NOTE: Rated Activities
Wait = 31x5 = 155 mins
Recover = 10x5 = 50 mins
Idle Time = 70 mins
Away = 4x5 = 20 mins
Ancillary Factor = 830/25 = 1.03
Ancillary work = 25 mins
Site Factor = 855/205 = 1.24

STANDARD TIME (mins)
4.3 BASIC TIMES FOR CONCRETE GANG

4.3.1 Analysis of Gang Data

The activity sampling analysis sheet, illustrated in Figure 4.3, is used to calculate the standard times for this study, and is completed as follows.

(a) The activity sampling results, obtained from the study sheets, are transferred into column C1, this is done by summing the number of occasions each activity occurs at the specified rates. For practical reasons, the rating values are recorded in steps of ten units. For example, it can be seen from Figure 4.3 that the activity "pour" occurs on four occasions at standard rate 100 and once at a rate of 110. In this example, the activities for the slabs are separated from the column activities. From these values, the average rate (C2) can be obtained for each activity.

(b) Overall time (C3) is the number of occasions each activity occurs multiplied by the observation interval (O.I.). Basic time (C4) is the product of the overall time (C3) and average rate (C2) divided by 100. The basic time per unit (C6) is equal to C4/C5. The quantities in this example are two slabs, two columns and some infill work. But, in the following synthetic build up of times the units of work are area and volume of concrete.

(c) The total relaxation allowance (C11), for each activity, includes allowances for basic needs (C7), standing (C8), posture (C9) and load (C10). More detailed information on relaxation allowances is presented in Chapter Seven.
(d) Standard time (C12) is expressed per unit of work, and is calculated from the basic time (C6) plus the appropriate relaxation allowance (C6 x C11/100).

(e) Site factors are calculated at the bottom of Figure 4.3. These are applied to the basic times and realistic planning times are obtained.

4.3.2 Synthetic Data for Concrete Gang

In practice the shape and size of a concrete pour might vary from the example shown. Therefore, for a more general application of the data, it is necessary to relate the basic element times to a set of common variables. For example, a floor slab might have a large surface area and be shallow, while a foundation base or column usually exhibits the opposite characteristics; clearly, area and volume are important controlling variables. In order to establish the relationships between these variables and the basic times, over seventy concrete pours are combined and statistically analysed in later chapters. However, for simplicity, only the data relating to the two roof slabs are used to demonstrate the principles of synthesis.

4 Basic Element Times for Concrete Gang

The following example describes the synthetic build up of basic operation times, based upon basic element times for the concrete gang. The elements relating to volume of concrete are pour and vibrate; those relating to area are shovel, tamp, trowel and cover. The time spent on general work is allocated in proportion to the time spent on each of these six elements, as shown in activities "d" to "i" in Table 4.3. The preparation, clearing and transferring of tools relate to the number of occasions they are each performed.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Variable</th>
<th>Basic Time mins</th>
<th>General (G.)</th>
<th>B.T. + G. mins</th>
<th>Units</th>
<th>B.T. + G. Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>a Prepare Tools</td>
<td>Occasions</td>
<td>40</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>40 mins</td>
</tr>
<tr>
<td>b Clear Tools</td>
<td>Occasions</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>20 mins</td>
</tr>
<tr>
<td>c Transfer Tools</td>
<td>Occasions</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>5 mins</td>
</tr>
<tr>
<td>d Pour Concrete</td>
<td>Volume</td>
<td>25</td>
<td>1.1</td>
<td>26.6</td>
<td>33.6m³</td>
<td>0.792</td>
</tr>
<tr>
<td>e Vibrate Concrete</td>
<td>Volume</td>
<td>115</td>
<td>5.0</td>
<td>120.5</td>
<td>33.6m³</td>
<td>3.586</td>
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<tr>
<td>f Shovel Concrete</td>
<td>Area</td>
<td>123</td>
<td>5.3</td>
<td>128.3</td>
<td>98.9m²</td>
<td>1.300</td>
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<tr>
<td>g Tamp Concrete</td>
<td>Area</td>
<td>69</td>
<td>3.0</td>
<td>72.0</td>
<td>98.9m²</td>
<td>0.728</td>
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<tr>
<td>h Trowel Concrete</td>
<td>Area</td>
<td>147</td>
<td>6.4</td>
<td>153.4</td>
<td>98.9m²</td>
<td>1.550</td>
</tr>
<tr>
<td>i Cover Concrete</td>
<td>Area</td>
<td>98</td>
<td>4.2</td>
<td>102.2</td>
<td>98.9m²</td>
<td>1.034</td>
</tr>
</tbody>
</table>
(11) **Basic Operation Times**

The 25 minutes spent on general work, activity code b, are added to elements (d) to (i) in the ratio of the time spent on each. This gives a basic time, for each activity, inclusive of excess work. Therefore, the basic operation time for a concrete pour can be expressed as follows.

\[
\text{Basic Time} = 60 + 4.38 \text{ Vol.} + 4.61 \text{ Area} \quad \ldots \text{Equation 4.1}
\]

First Pour

\[
\text{Basic Time} = 5 + 4.38 \text{ Vol.} + 4.61 \text{ Area} \quad \ldots \text{Equation 4.2}
\]

Subsequent Pours

The basic operation times obtained using Equations 4.1 and 4.2 include time spent trowelling and covering the concrete. These are not always required, therefore, the appropriate equation should be selected from the following.

\[
\begin{align*}
\text{Basic time} & = 60 + 4.38 \text{ Vol.} + 4.61 \text{ Area} \quad \text{(trowel and cover)} \\
\text{in man} & = 60 + 4.38 \text{ Vol.} + 3.57 \text{ Area} \quad \text{(trowel but not cover)} \\
\text{minutes} & = 60 + 4.38 \text{ Vol.} + 3.06 \text{ Area} \quad \text{(cover but not trowel)} \\
& = 60 + 4.38 \text{ Vol.} + 2.02 \text{ Area} \quad \text{(neither trowel nor cover)}
\end{align*}
\]

To illustrate how the slab depth can affect the basic time per cubic metre, area is replaced in Equation 4.1 by volume and depth. Thus, resulting in Equation 4.3 which is represented graphically in Figure 4.4.

\[
\text{Basic Time} = 60 + 4.38V + 4.61V D 
\]

\[
\text{or}
\]

\[
\begin{align*}
\text{Basic Time} & = 60 + 50.5V \quad \text{when } D = 0.10m \\
& = 60 + 22.8V \quad \text{when } D = 0.25m \\
& = 60 + 15.9V \quad \text{when } D = 0.40m
\end{align*}
\]

\[
V = \text{volume in m}^3. \\
D = \text{depth in m.}
\]
BASIC TIMES FOR CONCRETE GANGS AGAINST VOLUME OF CONCRETE FOR VARIOUS SLAB DEPTHS

B.T. = 60 N1 + 5 N2 + 4.38 Volume + 4.61 Area

SLAB DEPTH:
- 100mm
- 150mm
- 200mm
- 250mm
- 300mm
- 350mm
- 400mm

THE FOLLOWING HAVE TO BE ADDED TO THE GRAPH:
- Prepare and clear away tools = 60 mins.
- Transfer tools per work piece = 5 mins.

FIGURE 4.4
4.4 Basic Times for Tower Cranes

4.4.1 Analysis of Tower Crane Data

In this example, the work done by the tower crane is of a cyclic nature. The work elements contained within each cycle are defined as the time between the break points presented in Table 4.4.

Table 4.4 Break Points for Tower Cranes

<table>
<thead>
<tr>
<th>Break Points</th>
<th>Code (Figure 4.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skip arrives at lorry area</td>
<td>BP1</td>
</tr>
<tr>
<td>Skip leaves lorry area</td>
<td>BP2</td>
</tr>
<tr>
<td>Skip arrives at pour area</td>
<td>BP3</td>
</tr>
<tr>
<td>Skip leaves pour area</td>
<td>BP4</td>
</tr>
</tbody>
</table>

The mean element times for the tower crane are obtained from the cumulative timing results presented in Figure 4.2.

Table 4.5 Mean Element Times for Tower Cranes

<table>
<thead>
<tr>
<th>Elements</th>
<th>Break Points</th>
<th>Mean Element Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Pour into skip</td>
<td>BP2-BP1</td>
<td>1.02</td>
</tr>
<tr>
<td>B Lift full skip</td>
<td>BP3-BP2</td>
<td>0.81</td>
</tr>
<tr>
<td>C Pour into shutters</td>
<td>BP4-BP3</td>
<td>0.42</td>
</tr>
<tr>
<td>D Return empty skip</td>
<td>BP1-BP4</td>
<td>1.02</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>3.27</strong></td>
</tr>
</tbody>
</table>
Total Working Time  =  Mean Element Time x Skip Loads
(T.W.T.)  =  3.27 x 34
= 111.2 minutes

In addition to the working cycle, the crane was subjected to delays; for example, waiting for concrete lorries or being diverted onto other work. These delays were recorded in the comments section in Figure 4.2, and can be summarized as follows.

(i) External delays caused by concrete lorries

Wait for concrete lorries  =  0.00 + 4.13 + 17.90 + 5.91 +
(for each lorry) 3.30 + 13.40 + 5.10 + 28.70

Total External Delays  =  78.40 mins.
(T.E.D.)

Average delay per lorry  =  \frac{78.40}{8} = 9.8 mins.

Average delay per skip  =  \frac{9.8 \times \text{skip size}}{\text{lorry size}} ...Equation 4.4

(ii) Internal delays caused by interference

Wait for concrete gang  =  0.45 + 8.21 = 8.7 mins.
Diverted onto other work  =  3.6 mins.

Internal Delay (I.D.)  =  12.3 mins.

Internal Delay  =  \frac{\text{I.D.}}{\text{T.E.D.} + \text{T.W.T.}}

Internal Delay  =  \frac{12.3}{78.40 + 111.2} x 100 = 7%

In this example, internal delays are seven per cent of total basic time and total external delays.

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11.2 Synthetic Data for Tower Crane

To synthesize data suitable for other pours, it is necessary to combine basic element times with delays for the tower crane. For example: for a given skip size, the pouring times remain fairly constant over a series of pours, but travel time depends upon the distance between pick up point to discharge area.

Pour into skip and shutters \(= 1.02 + 0.42 = 1.44 \text{ mins.} \)
Lift and return skip \(= 0.81 + 1.02 = 1.83 \text{ mins.} \)

The average distance between the pour location and concrete lorries was 38.5 metres, therefore, the ‘no delay cycle time’ can be expressed in general terms, Equation 4.5.

\[
\text{No delay cycle time} = 1.44 + 1.83 \times \frac{D}{38.5} = 1.44 + \frac{D}{21.0} \quad \text{...Equation 4.5}
\]

The total basic crane time per cycle (TBCT) includes the time to place the concrete, plus delays caused by waiting for concrete lorries; and giving assistance to other gangs when concrete is available. Thus, the basic time per cycle (mins.) can be obtained from the following equations.

\[
\text{TBCT per cycle} = \begin{bmatrix}
\text{Pour into skip and shutters} + \\
\text{Travel time for skip} + \\
\text{External Delay}
\end{bmatrix} \text{ x delay allowance}
\]

\[
\text{TBCT per cycle} = \frac{1.44 + \text{Distance} + 9.8 \times \frac{\text{Skip size}}{21.0}}{\text{Lorry size}} \times 1.07 \text{ mins.} \quad \text{.....Equation 4.6}
\]

The relationship presented in Equation 4.6 is used to plot Figure 4.5. The crane time per cycle can be obtained for any skip size, or distance hoisted, given that the time to load and unload concrete is 1.44 minutes and the delay per lorry is 9.8 minutes.
TOTAL CYCLE TIME AGAINST DISTANCE FOR VARIOUS SKIP SIZES

TOTAL BASIC MACHINE = 1.44 + D + 9.8 skip size
CYCLE TIME 21 lorry load

DELAY PER LORRY, 9.8 mins.
NUMBER OF SKIPS PER LORRY LOAD

POUR INTO SKIP AND SHUTTERS
BASIC TIME = 1.44 mins.

BASIC CYCLE TIME NO DELAYS

SEVEN PER CENT TO BE APPLIED TO ALLOW FOR INTERFERENCE TO THE CRANE FROM OTHER GANGS

FIGURE 4.5
4.5 **BALANCING OF RESOURCES**

The concrete gang works in conjunction with the tower crane. Consequently, the pouring, shovelling, vibrating, tamping and trowelling are usually all done during the machine controlled time: the preparation and transfer of tools are often performed outside the machine controlled time. Thus, using Equation 4.2, the basic time for the crane controlled work (BTCC) is expressed as shown below.

\[
BTCC = \frac{\text{Vol} (4.38 + 3.57)}{d} \text{ mins.} \quad \text{...Equation 4.7}
\]

Where \(d\) is the depth of the slab in metres.

To ensure that the size of the concrete gang is balanced with the crane, the output rates during the basic machine controlled time are equated to give the optimum gang size.

\[
\begin{align*}
\text{Output rate for crane} & = \frac{\text{Skip size (m}^3\text{)} \times 60}{\text{TBCT}} \quad (\text{m}^3/\text{hr}) \\
\text{Output rate for men} & = \frac{\text{Volume} \times \text{Gang Size} \times 60}{\text{BTCC}} \quad (\text{m}^3/\text{hr})
\end{align*}
\]

...Equation 4.8

...Equation 4.9

Equations 4.8 and 4.9 are combined to produce Equation 4.10 and Figure 4.7, both of which can be used to determine the optimum gang size.

\[
\text{Gang size} = \frac{\text{Skip Size} \times \text{BTCC}}{\text{TBCT} \times \text{Volume}} \quad \text{...Equation 4.10}
\]
OUTPUT RATES DURING CRANE CONTROLLED TIME AGAINST:

a. GANGL SIZE AND SLAB DEPTH FOR CONCRETE GANG

b. CYCLE TIME AND SKIP SIZE FOR CRANE.

OUTPUT RATES FOR CONCRETE GANG ARE OBTAINED FROM EQUATION 4.9

OUTPUT RATES FOR CRANES ARE OBTAINED FROM EQUATION 4.8

SLAB DEPTH
400mm
350mm
300mm
250mm
200mm
150mm
100mm

SKIP SIZE
2.00 cu. m.
1.50 cu. m.
1.00 cu. m.
0.75 cu. m.
0.50 cu. m.

FIGURE 4.6
CHAPTER FIVE

RESULTS AND ANALYSIS OF BASIC ELEMENT TIMES

FOR CONCRETE OPERATIVES
5.1 RESULTS FOR CONCRETE OPERATIVES

The build up of synthetic data from one study was illustrated by an example presented in Chapter Four. In order to establish the reliability of the assumptions made in this example, the results from seventy concrete pours are combined and analysed. The analysis is performed on the PRIME mainframe computer using a statistical package called Minitab (5.1).

The results for each concrete pour are presented in Table 5.2. The basic element times for each pour, obtained from activity sampling performed on site, are presented in columns C3 to C11; the concrete dimensions are presented in columns C13 to C17.

Table 5.1 gives the codes for the different methods of placing concrete, and the codes for the different types of pour. These codes are respectively entered into columns C2 and C12 of Table 5.2. The information presented in Table 5.2 was transferred on to the Prime computer and saved in the file 'data', thus, enabling a statistical analysis to be performed using the Minitab package. This analysis tests the assumptions made in Chapter Four during the build up of synthetic data, modifies these assumptions where appropriate and establishes a model for calculating basic times for concreting operations.
### Table 5.1 Codes for Method and Type of Pour

<table>
<thead>
<tr>
<th>Code</th>
<th>Method (C2)</th>
<th>Code</th>
<th>Type (C12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Direct pour</td>
<td>1</td>
<td>Slab</td>
</tr>
<tr>
<td>2</td>
<td>0.5 cu. m. skip</td>
<td>2</td>
<td>Beam</td>
</tr>
<tr>
<td>3</td>
<td>Pump</td>
<td>3</td>
<td>Wall</td>
</tr>
<tr>
<td>4</td>
<td>1.0 cu. m. skip</td>
<td>4</td>
<td>Columns</td>
</tr>
</tbody>
</table>
Table 5.2 Basic Element Times for each Concrete Pour

<table>
<thead>
<tr>
<th>BASIC ELEMENT TIMES (MINS)</th>
<th>CONCRETE DIMENSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>S</td>
<td>E</td>
</tr>
<tr>
<td>1 1 1 21 1 9 15 24 36 29 19 10 20 1 7.30 4.90 4.90 24.30 0.25</td>
<td></td>
</tr>
<tr>
<td>2 1 11 9 12 28 48 24 0 0 1 6.10 4.90 4.90 24.30 0.25</td>
<td></td>
</tr>
<tr>
<td>3 1 1 11 9 15 24 36 29 19 10 20 1 7.30 4.90 4.90 24.30 0.25</td>
<td></td>
</tr>
<tr>
<td>4 1 1 1 19 11 15 9 60 25 29 0 0 1 6.10 4.90 4.90 24.30 0.25</td>
<td></td>
</tr>
<tr>
<td>5 1 11 1 14 12 19 23 32 16 10 3 1 3.10 4.50 4.50 20.60 0.15</td>
<td></td>
</tr>
<tr>
<td>6 1 11 1 14 12 19 23 32 16 10 3 1 3.10 4.50 4.50 20.60 0.15</td>
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<tr>
<td>7 1 11 1 14 12 19 23 32 16 10 3 1 3.10 4.50 4.50 20.60 0.15</td>
<td></td>
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<tr>
<td>8 2 1 11 14 12 19 23 32 16 10 3 1 3.10 4.50 4.50 20.60 0.15</td>
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<tr>
<td>9 1 1 * 51 79 51 1 40 130 9 1 1 18.0 6.65 38.8 25.20 0.60</td>
<td></td>
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<tr>
<td>10 1 11 38 1 14 12 19 23 32 16 10 3 1 * 20.9 0.50 17.4 8.70 2.40</td>
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<tr>
<td>11 1 11 15 15 24 24 27 144 21 1 16 1 9.10 4.50 5.00 40.50 0.22</td>
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<tr>
<td>12 1 11 15 15 24 24 27 144 21 1 16 1 9.10 4.50 5.00 40.50 0.22</td>
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<tr>
<td>13 1 1 11 65 1101 30 79 150 58 43 1 1 9.10 4.50 5.00 40.50 0.22</td>
<td></td>
</tr>
<tr>
<td>14 1 11 16 10 16 0 3 1 * 0 1 1 3.00 0.60 0.70 0.40 5.00</td>
<td></td>
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<tr>
<td>15 1 11 16 10 16 0 3 1 1 0 1 3.00 0.60 0.70 0.40 5.00</td>
<td></td>
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<tr>
<td>16 1 11 16 10 16 0 3 1 1 0 1 3.00 0.60 0.70 0.40 5.00</td>
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<tr>
<td>17 1 1 11 12 15 22 33 65 16 16 1 1 2.30 2.00 2.00 0.25</td>
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<tr>
<td>18 1 11 1 12 15 22 33 65 16 16 1 1 2.30 2.00 2.00 0.25</td>
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<td>19 1 11 1 12 15 22 33 65 16 16 1 1 2.30 2.00 2.00 0.25</td>
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<td>20 1 11 11 57 1 1 68 60 82 95 10 79 1 1 21.0 5.35 5.72 30.70 0.68</td>
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<td>21 1 1 12 15 22 33 65 16 16 1 1 2.30 2.00 2.00 0.25</td>
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<td>25 1 1 1 12 15 22 33 65 16 16 1 1 2.30 2.00 2.00 0.25</td>
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<td>39 1 1 1 12 15 22 33 65 16 16 1 1 2.30 2.00 2.00 0.25</td>
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<td>40 1 1 1 12 15 22 33 65 16 16 1 1 2.30 2.00 2.00 0.25</td>
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Table 5.2 Basic Element Times for each Concrete Pour :- Continued

BASIC

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145 I *
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5.50 1 5.101 9.601 49.00
0.16
7.90 I 5.10 9.60 I 49.00
12.14 1 5.50 I 9.50 52.00
0.23
2.10
23.0 I 3.10 I 3.50 I 10.90
0.20
6.00 I 2.00 I 10.0 I 20.00
12.90 I 1.40
3.50
18.0 I 3.70
12.1
12.01 1.10
0.90
13.30
3.80
0.50
0.25
0.95 I 0.50
119.5
97.00 0.35
34.0 1 2.00
98.90
33.0
0.35
33.6 I 3.00
1.00
1.80 I 0.50
0.50 3.80
29.0 1714.00
0.37
65.0 I 8.00
0.50
3.80
0.25
0.95 1 0.50
3.80
0.50
0.25
0.95 I 0.50
7.50 8.00 60.00 0.42
25.3
3.80
14.70 0.70 2.50
0.25
12.5
4.80
10.5 I 50.00 0.25
30.7
15.7 I 1c2.3
0.30
6.50
12.5 I 81.140
28.5
6.50
0.35
6.00
30.6
0.33
15.5 I 92.70
0.145
1.06
2.25
1.05 I 0.47
16.5
6.50
7.70 I 50.00 0.33
30.3
15.5 1101.00 0.30
6.50
12.5
60.00 0.26
14.80
15.7
1.2* I 0.82
0.6?
2.25
1.85
9.60 I 2.90
1.00
0.35
0.30
0.35
1.00
0.30 I 9.60 I 2.90
0.26
15.7
4.80
12.5 I 60.00
0.80
1.145
1.16
2.25
1.86
10.4
10.5 1105.00 0.311
37.0
0.214
2.140
0.60
0.20 I 0.60
15.0
5.140 I 11.3 60.80
0.25
0.20 I 0.60
0.36
2.140
0.90
9.50 18.4 I 136.0
0.30
41.0
0.20 0.60 I 0.12
2.140
0.30
4.60 2.40
1.70
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5.2 *METHOD OF ANALYSIS*

The following analysis combines the results from the seventy concrete pours presented in Table 5.2, and tests the assumptions made in the example used in Chapter Four. From the results of this analysis a more detailed model, which can be used to calculate basic times for a wide range of concreting operations, is constructed. The earlier example presented in Chapter Four assumes that:

(a) the basic element times relating to the volume of concrete are pour and vibrate;
(b) the basic element times relating to area are shovel, tamp, trowel and cover;
(c) the basic element times for preparing, clearing and transferring of tools depends upon the number of occasions each is performed; and
(d) the time spent on general work relates to the time taken to pour, vibrate, shovel, tamp, trowel and cover the concrete.

These assumptions may be translated into the following mathematical expression. In the analysis of basic element times the validity of this expression is established and values are determined for constants a, b, c, d, e, f, g, h, i and j.

\[
\text{Basic Time (manhours)} = aN + bN1 + cN2 + V (d + e) x (1 + j) + A (f + g + h + i) x (1 + j)
\]

Where: 
- \( N \) = number of times the tools are prepared
- \( N1 \) = number of times the tools are cleared away
- \( N2 \) = number of times the tools are transferred
- \( V \) = volume of concrete
- \( A \) = area of concrete
- \( a, b, c \) = basic times per occasion to prepare, clear and transfer tools
- \( d, e \) = basic times per cubic metre to pour and vibrate
- \( f, g, h, i \) = basic times per square metre to shovel, tamp, trowel, and cover,
- \( j \) = allowance for general work
5.3 ANALYSIS OF BASIC ELEMENT TIMES

5.3.1 Introduction

The following investigation could have been based on a multiple regression analysis using the four dimensions against either:

(a) the total basic times for individual studies, obtained by summing columns C3 to C11 in Table 5.2; or
(b) the individual basic element times, i.e. treating columns C3 to C11 separately.

The majority of concrete pours have at least one activity which is not performed, for example trowel and cover. If the former approach is adopted in the analysis, the obtained correlation coefficients would be affected, and the resulting model would not accurately represent operations where some activities are not performed. Thus, the following analysis is based upon individual basic element times; the resulting equations are used to build the generalized concrete model.

The first stage in testing the earlier assumptions is to analyse each activity separately (i.e. data in columns C3 to C11), this involves using eight individual Minitab programs. The program investigating the general activity includes the findings of the first eight programs. To check the reliability of the resulting model, a final set of programs compares the predicted times with the measured times. The results obtained from these individual programs are discussed in the remainder of this chapter and program listings are presented in Appendix B. Extracts from the computer print-outs are presented in Appendix D. These include the results from the two programs analysing the preparation of tools and the tamping of concrete, and print-outs from the programs checking the analysis.
There are four main progressive steps in this section of the analysis; these come under the headings of correlation, graphs, one way ANOVA test and multiple regression analysis. The theories behind these steps are summarized in Appendix F. The whole analysis is primarily investigative, and to account for the trends indicated in each step, the analysis can either omit the next step or backtrack to one of the previous steps.

In controlled laboratory tests correlation coefficients between either: 0.90 and 1.00; or -0.90 and -1.00, are often required. However, values as low as 0.60 are often acceptable in the field of human sciences. For this type of research correlation coefficients around: ±0.90 are very high; 0.80 are good but indicate that there may be an additional variable which has some influence and also requires consideration; 0.70 are reasonable but indicates there may be two groups of results; 0.50 are considered to be too low to prove a direct relationship but do indicate a trend.

The first stage in the analysis is to correlate the individual basic element times with volume, area, and depth of concrete; the results are shown in Table 5.3. In the pours studied there is some correlation between volume, area and depth, therefore, checks are carried out throughout the analysis to ensure that any cross-correlation is taken into account.
### Table 5.3 Correlation Coefficients (R)

<table>
<thead>
<tr>
<th></th>
<th>Volume</th>
<th>Area</th>
<th>Depth</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepare tools</td>
<td>0.503</td>
<td>0.368</td>
<td>0.081</td>
<td>0.241</td>
</tr>
<tr>
<td>Pour</td>
<td>0.795</td>
<td>0.661</td>
<td>-0.043</td>
<td>0.804</td>
</tr>
<tr>
<td>Vibrate</td>
<td>0.841</td>
<td>0.591</td>
<td>0.192</td>
<td>0.639</td>
</tr>
<tr>
<td>Shovel</td>
<td>0.786</td>
<td>0.889</td>
<td>-0.486</td>
<td>0.648</td>
</tr>
<tr>
<td>Tamp</td>
<td>0.807</td>
<td>0.928</td>
<td>-0.414</td>
<td>0.806</td>
</tr>
<tr>
<td>Trowel</td>
<td>0.572</td>
<td>0.831</td>
<td>-0.356</td>
<td>0.582</td>
</tr>
<tr>
<td>General</td>
<td>0.695</td>
<td>0.693</td>
<td>-0.246</td>
<td>0.814</td>
</tr>
<tr>
<td>Clear tools</td>
<td>0.731</td>
<td>0.660</td>
<td>-0.208</td>
<td>0.693</td>
</tr>
<tr>
<td>Cover</td>
<td>0.716</td>
<td>0.669</td>
<td>-0.225</td>
<td>0.695</td>
</tr>
<tr>
<td>Volume</td>
<td>---</td>
<td>0.831</td>
<td>-0.116</td>
<td>0.695</td>
</tr>
<tr>
<td>Area</td>
<td>---</td>
<td>---</td>
<td>-0.450</td>
<td>0.693</td>
</tr>
<tr>
<td>Depth</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>-0.246</td>
</tr>
</tbody>
</table>
5.3.2 Prepare Tools (PRTOOL)

(i) Correlation
The correlation coefficients (R) in Table 5.3 indicate that there is little correlation between the time taken to prepare tools and either the volume, depth or area of concrete.

(ii) Graphs
The Minitab plots of time taken to prepare tools against volume and area, using codes for the method of placement and type of pour, show considerable scatter with no obvious grouping of results.

(iii) Anova
In the first anova test, the times for preparing tools are separated into groups depending on the method of placement; the results indicate that there is no significant difference between the groups. The second anova test indicates that for the half cubic metre skip method the time taken to prepare tools per cubic metre is greater than the times required for the other methods. This is probably because small volumes of concrete are usually associated with this method.

(iv) Regression Analysis
Regression analyses are performed on volume, and volume with area; the resulting equations are presented below. There is little difference between the two correlation coefficients, hence, the relationship based on volume alone is used to plot Figure 5.1, and subsequently adopted in the generalized concrete model. The correlation coefficients for this activity are the lowest obtained in the analysis and only indicate a trend. There may be other variables, such as site layout, which exhibit a greater influence on the time taken to prepare tools. Taken in isolation, the resulting equation may appear inaccurate but it is combined with eight others at a later stage.

\[
\text{PRTOOLS} = 11.8 + 0.581 \text{ VOLUME} - 0.0345 \text{ AREA} \quad R^2 = 25.7 \quad \text{ALL POURS}
\]

\[
\text{PRTOOLS} = 11.7 + 0.501 \text{ VOLUME} \quad R^2 = 25.3 \quad \text{ALL POURS}
\]
TIME TO PREPARE TOOLS AGAINST VOLUME OF CONCRETE

FIGURE 5.1
5.3.3 Pour Concrete (POUR)

(i) Correlation
The overall correlation between the time required to pour concrete and the volume of concrete is very good, resulting in a value of 0.795.

(ii) Graphs
The initial Minitab plot of time taken to pour concrete against volume has some scatter associated with both the method of placement and the type of pour.

(iii) Anova Tests
The first anova test indicates a difference in the basic element time caused by the method of placement; this results in a F statistic of 2.19. A more significant difference is obtained in the anova test based on the type of pour, resulting in a F statistic of 13.10. As the results for walls and beams are similar, they are combined for a third anova test; the resulting F statistic is 19.95.

(iv) Graphs
The results from the anova tests show that there is a significant difference between the basic element times for different types of pour. Three graphs are plotted to investigate this further: Figure 5.2 plots time taken to pour concrete against volume for slabs; Figure 5.3 plots time taken to pour concrete against volume for beams and walls. These two figures have little scatter and the results are consistent with the previous steps in the analysis.

The values for columns are plotted in Figure 5.4 and large variations in times are indicated. For example, the time taken to pour columns with two cubic metres of concrete varies from 5 minutes to 55 minutes. This discrepancy results from an earlier decision to combine the times for several columns poured together in order to improve the accuracy of the activity sampling. Consequently, if the pour times are divided by the appropriate number of columns; the resulting times for pouring individual columns vary between 5 and 15 minutes.
Regression Analysis

The three equations resulting from the regression analysis are presented below. If the columns are treated as individual items the low coefficient would significantly increase. However, the adopted expression combines columns, ensuring that the resulting equation is consistent with those obtained for the other activities.

\[ \text{PAJR} = 5.15 + 1.67 \times \text{VOLUME} = 69.8 \]
\[ \text{POUR} = 16.10 + 1.18 \times \text{VOLUME}_{\text{BEAMS AND WALLS}} = 61.4 \]
\[ \text{PIJR} = 2.79 + 9.65 \times \text{VOLUME}_{\text{_COLUMNS}} = 36.8 \]
TIME TAKEN TO POUR CONCRETE AGAINST VOLUME OF CONCRETE FOR SLABS

[Graph showing the relationship between time taken to pour concrete and volume of concrete for slabs]
TIME TAKEN TO POUR CONCRETE AGAINST VOLUME OF CONCRETE FOR BEAMS AND WALLS

FIGURE 5.3
TIME TAKEN TO POUR CONCRETE AGAINST VOLUME OF CONCRETE FOR COLUMNS

![Graph showing the relationship between time taken to pour concrete and the volume of concrete for columns.](image)
5.3.4 Vibrate Concrete (VIBR)

(i) Correlation
There is very good correlation between vibration time and the volume of concrete, resulting in a correlation coefficient of 0.841. However, it is also necessary to investigate the variations caused by the type of pour.

(ii) Graphs
The initial Minitab plot of vibration against volume indicates that there is a significant difference between the times for columns and the rest of the data.

(iii) Anova Test
The anova test confirms that there is a significant difference between the vibration times per metre cubed for various shapes of pour. The times are therefore separated into different groups for: slabs, walls or beams, and columns.

(iv) Regression Analysis
The subsequent regression analysis shows that within each of the above categories there is high correlation between the vibration times and volume of concrete, resulting in correlation coefficients of 0.91, 0.92 and 0.90 respectively. The relationships established from the regression analysis are presented below; Figures 5.5, 5.6 and 5.7 are plots of vibration times against volume of concrete for the different types of pour.

\[
\begin{align*}
\text{VIBRATE} &= 3.46 \ \text{VOLUME} \quad R^2 = 82.8 \quad \text{SLABS} \\
\text{VIBRATE} &= 5.69 \ \text{VOLUME} \quad R^2 = 84.6 \quad \text{WALLS AND BEAMS} \\
\text{VIBRATE} &= 22.80 \ \text{VOLUME} \quad R^2 = 81.0 \quad \text{COLUMNS}
\end{align*}
\]
TIME TAKEN TO VIBRATE CONCRETE AGAINST VOLUME OF CONCRETE FOR SLABS

Figure 5.5
TIME TAKEN TO VIBRATE CONCRETE AGAINST VOLUME OF CONCRETE FOR WALLS AND BEAMS
TIME TAKEN TO VIBRATE CONCRETE AGAINST VOLUME OF CONCRETE FOR COLUMNS

FIGURE 5.7
5.3.5 **Shovel Concrete (SHOVEL)**

(i) **Correlation**

The correlation between time spent shovelling concrete and both area and volume are good, giving respective correlation coefficients of 0.889 and 0.786. However, there is also some negative correlation between time and the depth of concrete, -0.486.

(ii) **Graphs**

The initial Minitab plots of shovel against area, volume and depth indicate that the time taken to shovel concrete relates best to the area of concrete, as illustrated in Figure 5.8.

(iii) **Anova Test**

The one way anova test, of time required to shovel per square metre against type of pour, confirms that the depth of concrete has no significant affect.

(iv) **Regression Analysis**

There is very little increase in the $R^2$ value when depth is included in the regression analysis, therefore, the relationship between shovel and area, as shown below, is adopted.

\[
\text{SHOVEL} = 8.07 + 0.737 \text{ AREA} \quad R^2 = 79.0 \quad \text{ALL POURS}
\]
TIME TAKEN TO SHOVEL CONCRETE AGAINST AREA OF CONCRETE

FIGURE 5.8
5.3.6 Tamp Concrete (TAMP)

(i) Correlation

There is very good correlation between the time required to tamp and area of concrete, resulting in a correlation coefficient of 0.928. There is also some correlation between tamp and both volume and depth of concrete.

(ii) Graphs

Figure 5.9 plots the time spent tamping concrete against area of concrete; as there is very little scatter no anova tests are required.

(iii) Regression Analysis

The regression analysis of tamp and area produces a $R^2$ value of 84.3. When depth is also included there is no significant increase in the $R^2$ value, hence, the following equation is adopted.

\[ TAMP = 10.7 + 1.12 \times AREA \quad R^2 = 86.2 \quad \text{ALL POURS} \]
TIME TAKEN TO TAMP CONCRETE AGAINST AREA OF CONCRETE

Figure 5.9
5.3.7 Trowel Concrete (TROWEL)

(i) Correlation

The correlation between the time spent trowelling and the area of concrete is 0.831.

(ii) Graphs

The Minitab plot of trowelling time against area suggests that there are two significantly different groups of results. When the results are investigated further, it becomes obvious that the main influencing factor is the quality of finish required. The quality of finish varies considerably between sites, from concrete reservoirs requiring double trowelling to car parks where no trowelling is necessary. Hence, for the trowelling activities the pours are classified as:

(a) very good finish with repeat trowelling;
(b) trowelled once for a normal finish; or
(c) no trowelling required.

(iii) Anova

The anova test used on the first two groups of pours indicates a significant difference in the trowelling times per square metre, as illustrated by Figures 5.10 and 5.11.

(iv) Regression Analysis

The equations resulting from the regression analysis are presented below. The high intercept on the y axis is caused by the extra work often required around the edge of the slab when a good finish is necessary.

\[
\begin{align*}
\text{TROWEL} &= 27.6 + 2.79 \text{ AREA} & R^2 &= 81.6 & \text{DOUBLE TROWEL} \\
\text{TROWEL} &= 1.51 \text{ AREA} & R^2 &= 88.4 & \text{SINGLE TROWEL}
\end{align*}
\]
TIME TAKEN TO DOUBLE TROWEL CONCRETE AGAINST AREA OF CONCRETE

![Graph showing the relationship between time taken to double trowel concrete and area of concrete.](image-url)
TIME TAKEN TO SINGLE TROWEL CONCRETE AGAINST AREA OF CONCRETE

Figure 5.11
5.3.8 **Cover Concrete (COVER)**

(1) **Correlation**

The correlation coefficients for the time required to cover concrete against area, volume and depth are 0.669, 0.716 and -0.225, respectively. It is initially assumed that the time relates to the area of concrete covered, and increases as the depth of concrete becomes larger. However, the correlation coefficient for the resulting regression equation \( \text{COVER} = 7.81 + 0.490 \text{ AREA} + 1.45 \text{ DEPTH} \) shows no improvement on the correlation coefficient, 0.669, obtained using area alone.

(ii) **Graphs**

The Minitab plot of time spent covering concrete per square metre against depth indicates a linear relationship expressed as:

\[
\frac{\text{COVER}}{\text{AREA}} = K_1 + K_2 \cdot \text{DEPTH}
\]

Where

\[
K_1 = \text{Y Intercept}
\]

\[
K_2 = \text{Gradient}
\]

Alternatively, this can be written as

\[
\text{COVER} = K_1 \cdot \text{AREA} + K_2 \cdot \text{VOLUME}
\]

(iii) **Regression Analysis**

A regression analysis is carried out to determine \( K_1 \) and \( K_2 \), resulting in the equation presented below. The correlation coefficient, 0.742, for this equation is an improvement on the coefficient, 0.669, obtained when area is the only variable.

\[
\text{COVER} = 8.62 + 0.861 \text{ VOLUME} + 0.202 \text{ AREA} \quad R^2 = 55.2 \text{ ALL POORS}
\]
5.3.9 Clear Tools Away (CLEAR)

(i) **Correlation**

The correlation coefficients for clear tools away, with volume, area and depth, are 0.731, 0.660 and -0.208, respectively. These are very similar values to those obtained for covering concrete.

(ii) **Graphs**

The initial Minitab plot of time spent clearing tools away against volume of concrete clearly shows two separate groups of results; those for pumping concrete and those for other methods of placement, as plotted in Figures 5.12 and 5.13.

(iii) **Anova Tests**

Four one way anova tests are used to investigate how both methods of placement and type of pour affect the time required to clear the tools away. The results agree with the grouping indicated by the figures.

(iv) **Regression Analysis**

The data is separated into the two groups and a regression analysis carried out on both, resulting in the following equations. When area is also included in the regression analysis the $R^2$ values are not significantly increased.

\[
\text{CLEAR} = 6.83 + 0.310 \text{ VOLUME} \quad R^2 = 48.1 \quad \text{OTHERS}
\]
\[
\text{CLEAR} = 16.20 + 0.859 \text{ VOLUME} \quad R^2 = 64.4 \quad \text{PUMP}
\]
TIME TAKEN TO CLEAR TOOLS AWAY AGAINST VOLUME OF CONCRETE FOR PUMPING METHODS

FIGURE 5.12
TIME TAKEN TO CLEAR TOOLS AWAY AGAINST VOLUME OF CONCRETE FOR SKIP AND DIRECT POUR METHODS

FIGURE 5.13
5.3.10 General Work (GENERAL)

In order to determine variables influencing the amount of general work, two separate investigations are carried out. The variables used in the first investigation are volume, area and depth of pour. In the second investigation, the total times spent on the main activities, excluding general work, are taken as the main variables.

(I) **FIRST INVESTIGATION**

(i) **Correlation**

The correlation coefficients for general work against area, volume and depth are 0.693, 0.695 and -0.246 respectively.

(ii) **Graphs**

The initial Minitab plots, of general work against volume, area and depth of concrete, all contain a large degree of scatter with no apparent grouping of results.

(iii) **Anova Tests**

An anova test is performed on the method of placement and general work per cubic metre. At this stage there is no significant difference between these groups, although the indications are that the times for the half cubic metre skip are slightly higher.

(iv) **Regression Analysis**

The regression analysis, using both area and depth as variables, results in a correlation coefficient of 0.670. This is a slight reduction on the value of 0.693 obtained when area is the only variable.

\[
\text{GENERAL} = 7.49 + 0.379 \text{ AREA} + 0.995 \text{ DEPTH} \quad R^2 = 48.5 \quad \text{ALL POURS}
\]

\[
\text{GENERAL} = 9.59 + 0.361 \text{ AREA} \quad R^2 = 48.1 \quad \text{ALL POURS}
\]
(II) **SECOND INVESTIGATION**

In order to determine the activities most closely correlated to the quantity of general work, the total times are calculated for the following groups of activities.

- **C20**: Pour, vibrate, shovel, tamp, trowel.
- **C21**: Prepare tools, clear tools, cover.
- **C42**: All the above activities.

(i) **Correlation**

The correlation coefficients obtained for the groups are: 0.769 for C20; 0.559 for C21; and 0.790 for C42. These values are a significant improvement on those obtained in the first investigation.

(ii) **Regression Analysis**

The correlation coefficients, obtained for the following regression equations, indicate that it is more appropriate to combine the two groups of activities (i.e., C42).

\[
\text{GENERAL} = 1.81 + 0.0998 \times C20 + 0.0576 \times C21 \quad R^2 = 59.3 \quad \text{ALL POURS}
\]

\[
\text{GENERAL} = 0.70 + 0.0949 \times C42 \quad R^2 = 62.5 \quad \text{ALL POURS}
\]
(III) COMBINATION OF INVESTIGATIONS ONE AND TWO

To enable the allowance for general work to be applied as a percentage of the time spent on other activities, the regression analysis is repeated with the intercept set to zero. Also, the activity times are divided into two groups and plotted in Figures 5.14 and 5.15: the times for methods using a skip are put into the first group; the times for methods using either direct placement or pumping are put into the second group. A final regression analysis is performed on these two groups, resulting in the following equations with improved correlation coefficients; these are adopted in the generalized concrete model.

GENERAL = 0.1300 x C42 \hspace{1cm} R^2 = 80.1 \hspace{1cm} \text{SKIP}

GENERAL = 0.0775 x C42 \hspace{1cm} R^2 = 62.1 \hspace{1cm} \text{DIRECT + PUMP}
TIME SPENT ON GENERAL WORK AGAINST TIME SPENT ON OTHER ACTIVITIES FOR SKIP METHODS

FIGURE 5.14
TIME SPENT ON GENERAL WORK AGAINST TIME SPENT ON OTHER ACTIVITIES FOR PUMPED AND DIRECT POUR METHODS

FIGURE 5.15
5.4 GENERALIZED CONCRETE MODEL

The additional times required to prepare the work area and clear away the pipeline used in pumping operations are the only significant variations in individual basic times associated with the method of placement. Most of the variations in basic times are caused by the shape of pour, hence, basic operation times are presented separately for slabs, beams, walls and columns. The generalized concrete model also allows vibration, trowelling and covering to be treated as optional activities.

The regression equations obtained in the main analysis are summarized in Table 5.4. However, before these relationships were used to produce the basic operation times presented in the Appendix C, a check was carried out to ensure that the values measured on site corresponded to those predicted by the model. The four programs used to check the model are listed in Appendix B with the results presented in Appendix D. The first two programs (i.e. 'TEST1.MINEXEC' and 'TEST2.MINEXEC') checked the expressions for the individual activities, for example pouring concrete. The third and fourth programs (i.e. 'TEST3.MINEXEC' and 'TEST4.MINEXEC') used the generalized concrete model to calculate a basic time for each operation. The correlation between the values obtained from the model and the times measured on site was very high (i.e. 0.962). It can, therefore, be concluded that the generalized model accurately represents the seventy concrete pours measured on site.
### Table 5.4 Generalized Concrete Model

<table>
<thead>
<tr>
<th>OPERATION</th>
<th>EQUATION</th>
<th>CORRELATION COEFFICIENT</th>
<th>VARIABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRTOOLS</td>
<td>$11.70 + 0.501 \times V$</td>
<td>$R = 0.50$</td>
<td>ALL POURS</td>
</tr>
<tr>
<td>POUR</td>
<td>$5.45 + 1.670 \times V$</td>
<td>$R = 0.84$</td>
<td>SLABS</td>
</tr>
<tr>
<td>POUR</td>
<td>$16.10 + 1.160 \times V$</td>
<td>$R = 0.60$</td>
<td>BEAMS AND WALLS</td>
</tr>
<tr>
<td>POUR</td>
<td>$4.79 + 9.650 \times V$</td>
<td>$R = 0.61$</td>
<td>COLUMNS</td>
</tr>
<tr>
<td>VIBRATE</td>
<td>$3.46 \times V$</td>
<td>$R = 0.91$</td>
<td>SLABS</td>
</tr>
<tr>
<td>VIBRATE</td>
<td>$5.69 \times V$</td>
<td>$R = 0.92$</td>
<td>WALLS AND BEAMS</td>
</tr>
<tr>
<td>VIBRATE</td>
<td>$22.80 \times V$</td>
<td>$R = 0.90$</td>
<td>COLUMNS</td>
</tr>
<tr>
<td>SHOVEL</td>
<td>$8.07 + 0.737 \times A$</td>
<td>$R = 0.89$</td>
<td>ALL POURS</td>
</tr>
<tr>
<td>TAMP</td>
<td>$10.7 + 1.120 \times A$</td>
<td>$R = 0.93$</td>
<td>ALL POURS</td>
</tr>
<tr>
<td>TROWEL</td>
<td>$27.6 + 2.790 \times A$</td>
<td>$R = 0.90$</td>
<td>DOUBLE TROWEL</td>
</tr>
<tr>
<td>TROWEL</td>
<td>$1.510 \times A$</td>
<td>$R = 0.94$</td>
<td>SINGLE TROWEL</td>
</tr>
<tr>
<td>COVER</td>
<td>$8.62 + 0.861 \times V$</td>
<td>$R = 0.74$</td>
<td>ALL POURS</td>
</tr>
<tr>
<td>CLEAR</td>
<td>$6.83 + 0.310 \times V$</td>
<td>$R = 0.69$</td>
<td>OTHERS</td>
</tr>
<tr>
<td>CLEAR</td>
<td>$16.20 + 0.859 \times V$</td>
<td>$R = 0.80$</td>
<td>PUMP</td>
</tr>
<tr>
<td>GENERAL</td>
<td>$0.1300 \times C42$</td>
<td>$R = 0.895$</td>
<td>SKIP</td>
</tr>
<tr>
<td>GENERAL</td>
<td>$0.0775 \times C42$</td>
<td>$R = 0.768$</td>
<td>DIRECT AND PUMP</td>
</tr>
</tbody>
</table>

When:  
- $V =$ VOLUME  
- $A =$ AREA  
- $C42 =$ SUM OF ACTIVITIES EXCLUDING GENERAL  
- $R =$ CORRELATION COEFFICIENT  
- $0.27 < R < 0.67$ where $A$ and $B$ are 95% CONFIDENCE LIMITS FOR $R$
CHAPTER SIX

RESULTS AND ANALYSIS OF BASIC ELEMENT TIMES

FOR CONCRETE PLANT
CHAPTER SIX

RESULTS AND ANALYSIS OF BASIC ELEMENT TIMES

FOR CONCRETE PLANT

6.2 INTRODUCTION

The generalized concrete model (Table 5.4) can be used to calculate basic times for the work performed by the operatives. However, in order to obtain realistic output rates for concreting operations, basic times for the site transportation of concrete have to be calculated. The site transportation of concrete can be separated into three operations (i.e. cranage, pumping and direct pour). In this chapter the results of studies on these three operations are presented and basic times are established.

6.2 RESULTS FOR CRANAGE OPERATIONS

Cycle times are obtained from studies carried out on seven sites for a variety of cranage operations. The results for mobile cranes and tower cranes are analysed and presented separately. The work performed by cranes during concrete operations is usually cyclic and can be represented by the following elements:

(a) pour concrete into skip;
(b) lift full skip to the required location;
(c) pour concrete into shutters;
(d) return empty skip.
### Table 6.1 Basic Element Times for Mobile Cranes

<table>
<thead>
<tr>
<th>Skip Size (m³)</th>
<th>Basic Element Times (mins)</th>
<th>Total Cycle (mins)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pour Into Skip</td>
<td>Lift</td>
<td>Pour Into Shutter</td>
</tr>
<tr>
<td>0.38</td>
<td>0.38</td>
<td>0.52</td>
<td>0.21*</td>
</tr>
<tr>
<td>0.38</td>
<td>0.38</td>
<td>0.34</td>
<td>0.55</td>
</tr>
<tr>
<td>0.38</td>
<td>0.95</td>
<td>0.60</td>
<td>0.64</td>
</tr>
<tr>
<td>0.90</td>
<td>0.96</td>
<td>0.54</td>
<td>0.71</td>
</tr>
<tr>
<td>0.90</td>
<td>1.20</td>
<td>0.80</td>
<td>2.83*</td>
</tr>
<tr>
<td>0.90</td>
<td>0.97</td>
<td>0.52</td>
<td>0.95*</td>
</tr>
<tr>
<td>0.90</td>
<td>0.90</td>
<td>1.27</td>
<td>1.05</td>
</tr>
<tr>
<td>0.90</td>
<td>1.01</td>
<td>0.76</td>
<td>1.81</td>
</tr>
<tr>
<td>0.90</td>
<td>1.14</td>
<td>1.03</td>
<td>1.10</td>
</tr>
<tr>
<td>0.50</td>
<td>0.68</td>
<td>0.61</td>
<td>0.59*</td>
</tr>
<tr>
<td>0.50</td>
<td>0.70</td>
<td>0.61</td>
<td>0.72*</td>
</tr>
<tr>
<td>0.50</td>
<td>0.84</td>
<td>0.56</td>
<td>1.16</td>
</tr>
<tr>
<td>0.50</td>
<td>0.58</td>
<td>0.56</td>
<td>1.36</td>
</tr>
<tr>
<td>0.50</td>
<td>0.48</td>
<td>0.56</td>
<td>1.11</td>
</tr>
</tbody>
</table>

**NOTE:** * Denotes slabs
6.2.2 Basic Element Times for Tower Cranes

Table 6.2 contains the basic element times obtained from thirteen studies on tower cranes. To simplify the work cycle, the total distance travelled by the skip is taken as the sum of both vertical and horizontal distances.

<table>
<thead>
<tr>
<th>Skip Size (m³)</th>
<th>Basic Element Times (mins)</th>
<th>Total Times (mins)</th>
<th>Distances Travelled (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pour Lift Pour Return Lift Total</td>
<td>Horiz.</td>
<td>Vert.</td>
</tr>
<tr>
<td>0.75</td>
<td>1.20 1.88 0.58* 1.78</td>
<td>3.66</td>
<td>5.44</td>
</tr>
<tr>
<td>0.84</td>
<td>1.07 0.73 0.40* 1.06</td>
<td>1.79</td>
<td>3.26</td>
</tr>
<tr>
<td>0.84</td>
<td>1.22 0.66 0.41* 0.88</td>
<td>1.54</td>
<td>3.17</td>
</tr>
<tr>
<td>0.84</td>
<td>1.02 0.81 0.42* 1.02</td>
<td>1.83</td>
<td>3.27</td>
</tr>
<tr>
<td>0.84</td>
<td>0.92 0.48 0.52* 0.78</td>
<td>1.26</td>
<td>2.70</td>
</tr>
<tr>
<td>0.84</td>
<td>1.08 0.61 0.85* 0.50</td>
<td>1.11</td>
<td>3.04</td>
</tr>
<tr>
<td>0.84</td>
<td>1.09 0.50 0.57* 0.45</td>
<td>0.95</td>
<td>2.61</td>
</tr>
<tr>
<td>1.00</td>
<td>1.25 2.13 2.40 0.97</td>
<td>3.10</td>
<td>6.75</td>
</tr>
<tr>
<td>1.00</td>
<td>1.16 0.92 0.56* 1.11</td>
<td>2.03</td>
<td>3.75</td>
</tr>
<tr>
<td>1.00</td>
<td>1.16 0.89 0.77* 1.02</td>
<td>1.91</td>
<td>3.84</td>
</tr>
<tr>
<td>1.00</td>
<td>0.97 2.24 1.54 1.20</td>
<td>3.44</td>
<td>5.95</td>
</tr>
<tr>
<td>1.00</td>
<td>1.03 1.47 0.44* 1.11</td>
<td>2.58</td>
<td>4.05</td>
</tr>
<tr>
<td>0.50</td>
<td>0.85 1.69 0.56* 1.22</td>
<td>2.91</td>
<td>4.32</td>
</tr>
</tbody>
</table>

NOTE: * Denotes slabs
The basic element times presented in Table 6.1 relate to mobile cranes and are used to plot Figures 6.1, 6.2 and 6.3. The basic element times presented in Table 6.2 relate to tower cranes and are used to plot Figures 6.1, 6.4 and 6.5. Some of the activity times are combined for mobile and tower cranes; for example, "pour into skip" and "pour into shutters".

6.2.3 **Cycle Times for Mobile Cranes**

(i) **Pour into Skip**

The time taken to pour concrete into the skip depends upon the skip size and can be obtained from Figure 6.1.

(ii) **Lift Full Skip**

The time required to lift the skip also depends upon the skip size and can be obtained from Figure 6.2.

(iii) **Pour into Shutters**

A large proportion of the time spent pouring concrete into the shutters involves positioning the skip, consequently, the basic element time relates to the type of pour. The average values for several types of pour are:

- Slabs = 1.06 mins.
- Others = 1.26 mins.

(iv) **Return empty skip**

The average basic time taken to return the empty skip for short distances is:

- Return skip = 0.55 mins.

(v) **Calculation of Cycle Times**

The above basic element times are combined and the results used to plot Figure 6.3, from which total cycle times can be obtained.
6.2.4 Cycle Times for Tower Cranes

The tower crane basic times for "pour concrete into skip" and "pour concrete into shutters" are combined with the values for mobile cranes.

(1) Travel Times

The travel times (full and empty) relate to the distance travelled by the skip and are plotted on Figure 6.4. To obtain the travel times when the crane rotates, the circular distance travelled by the skip is used (i.e. not just the distance between the load and discharge areas). If the total distance travelled is less than thirty metres, the tower crane action is similar to that of a mobile crane and the travel time for mobile cranes are used.

(ii) Calculation of Cycle Times

Figure 6.5 combines the basic element times for tower cranes, taking into account the skip size and distance travelled, and can be used to determine cycle times.
TIME TAKEN TO LIFT FULL SKIP AGAINST SKIP SIZE FOR MOBILE CRANES

Legend

BEST FIT

X MEAN VALUES

OBSERVED VALUES
TIME TAKEN TO LIFT FULL SKIP AND RETURN EMPTY SKIP AGAINST TOTAL DISTANCE TRAVELLED, FOR TOWER CRANES

Legend
BEST FIT
OBSERVED VALUES

TRAVEL TIME MINS.

TOTAL DISTANCE TRAVELLED BY SKIP M.
CYCLE TIME AGAINST TOTAL DISTANCE TRAVELLED
FOR TOWER CRANES

ADD 0.65 mins. ONTO CYCLE TIME IF NOT POURING SLABS

Legend
1.00 cu. m. SKIP
0.50 cu. m. SKIP
0.25 cu. m. SKIP

FIGURE 6.5
Output rates for most cranage operations can be calculated from the following equation, where cycle time is obtained from the appropriate figure.

Output rate for crane = \( \frac{\text{Skip Size} \times 60}{\text{Basic Cycle Time}} \) (m\(^3\)/hr)

The main external delays to the overall operation are caused by the non-arrival of concrete. On the sites studied the ready mixed concrete lorries were found to be on average seven minutes late, owing to a variety of reasons. It is not always suitable to apply this delay as a site factor, or percentage, as the applied value depends on the basic cycle time. The delays per skip cycle caused by the non-arrival of concrete can be expressed as shown below.

Cycle delay = \( \frac{\text{Average Delay} \times \text{Skip Size}}{\text{Lorry Size}} \)
Consider the following two examples, where the average delay per lorry load is seven minutes.

(a) A tower crane with a half cubic metre skip and an average cycle time of five minutes would have a basic output rate of six cubic metres per hour (from Figure 6.5). If the capacity of the concrete lorry was five cubic metres the delay to each cycle would be:

\[
\text{cycle delay} = \frac{7 \times 0.5}{5} = 0.7 \text{ mins.}
\]

\[
\text{percentage delay} = \frac{0.7 \times 100}{5} = 14\%.
\]

(a) A mobile crane with a 0.90 cubic metre skip would have an average cycle time of 3.1 minutes and a basic output rate of 17.4 cubic metres per hour (from Figure 6.3.). If the capacity of the concrete lorry was five cubic metres, the delay to each cycle would be:

\[
\text{cycle delay} = \frac{7 \times 0.9}{5} = 1.26 \text{ mins.}
\]

\[
\text{percentage delay} = \frac{1.26 \times 100}{3.1} = 41\%.
\]

These two examples illustrate that for the same average lorry delay the percentage delay can vary considerably for different operations. However, in practice the average lorry delays can be controlled by management, thus reducing the very high percentage delays. The planning rate for cranes should include site factors \(F_3\) and \(F_4\) in addition to the waiting time caused by any delays and can be expressed as shown below.

\[
\text{Planning rate} = \frac{\text{Skip Size} \times 60}{(\text{Basic Cycle Time} + \text{Waiting})} \times \frac{1}{(F_3 \times F_4)} \quad \text{(m}^3/\text{hr)}
\]
6.3 RESULTS FOR PUMPING OPERATIONS

6.3.1 Actual Times for Pumping Activities

The results presented in Table 6.3 were collected from several sites, using cumulative timing techniques. In all of the studies the maximum concrete slump was 75 mm. The actual pumping times are per lorry load and involve the following activities:

(a) pumping concrete;
(b) waiting for lorries to change around;
(c) waiting for lorries to arrive;
(d) pump moving position;
(e) waiting for men to perform the last operation.

6.3.2 Pumping and Output Rates

In all operations the pumping distances are well within the capabilities of the pump. The main cause of variation in the time spent actually pumping concrete is the pipe diameter, with distance having little effect. Thus, the results in Table 6.4 are presented separately for 150 mm. and 100 mm. diameter pipes, and give values for the following activities.

(i) Pumping Rates

The pumping times in Table 6.4 represent the pump capabilities and are determined by taking the weighted mean pumping times from Table 6.3.

(ii) Pump, Change and Move Rates

These rates include the time to: pump the concrete; change the lorries around; and move the pump when necessary. If an operation is well organized, as in the first three studies, 1.93 minutes are required to change the lorries around, and 0.07 minutes per cubic metre are required to move the concrete pump. Consequently, the mean pumping rates, inclusive of ‘change’ and ‘move’ activities, are calculated and presented in Table 6.4.

(iii) Output Rates

The minimum, maximum and mean output rates are calculated from the total times presented in Table 6.3.
### Table 6.3: Mean Times for Pumping Activities

<table>
<thead>
<tr>
<th>Study</th>
<th>Pipe dia.</th>
<th>Lorry Load cu.m.</th>
<th>No. Loads</th>
<th>Mean Times per Lorry Load</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>6</td>
<td>26</td>
<td>10.2</td>
<td>6.96</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>6</td>
<td>9</td>
<td>13.9</td>
<td>10.15</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>6</td>
<td>11</td>
<td>14.4</td>
<td>8.26</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>6</td>
<td>7</td>
<td>14.1</td>
<td>6.50</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>5.8</td>
<td>11</td>
<td>19.1</td>
<td>6.77</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>6</td>
<td>6</td>
<td>26.2</td>
<td>10.00</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>6</td>
<td>6</td>
<td>25.2</td>
<td>9.20</td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>6</td>
<td>5</td>
<td>24.2</td>
<td>11.30</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>6</td>
<td>4</td>
<td>29.2</td>
<td>9.00</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>6</td>
<td>5</td>
<td>32.3</td>
<td>14.32</td>
</tr>
</tbody>
</table>

**Note:**
- **Total** = Total time for one lorry load
- **Pump** = Time spent actually pumping
- **Change** = Time lorries spent changing position
- **Wait** = Time spent waiting for lorry
- **Move** = Time spent moving concrete pump
- **Men** = Time spent waiting for concrete gang
- **Distance** = One way distance between load and discharge area
6.3.3 Planning Rates

Most of the observed pumping operations involved concrete volumes between 24 and 54 cubic metres. The values presented in Table 6.3 show that these quantities can easily be pumped within two hours. Thus, actual output rates are often limited by the performance of the concrete gang rather than the pump. On larger pours 40m³/hr can be used as a planning rate, but allowances for starting up the work and cleaning the pump should be taken into account.

Table 6.4 Pumping and Output Rates (m³/hr)

<table>
<thead>
<tr>
<th>Rates (m³/hr)</th>
<th>150mm diameter pipes</th>
<th>100mm diameter pipes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping Rate</td>
<td>52.5</td>
<td>38.2</td>
</tr>
<tr>
<td>Pump, Change and Move Rate</td>
<td>37.9</td>
<td>29.8</td>
</tr>
<tr>
<td>Minimum Output Rate</td>
<td>25.5</td>
<td>11.1</td>
</tr>
<tr>
<td>Maximum Output Rate</td>
<td>35.3</td>
<td>25.9</td>
</tr>
<tr>
<td>Mean Output Rate</td>
<td>30.4</td>
<td>17.1</td>
</tr>
</tbody>
</table>
6.11 RESULTS FOR DIRECT POUR OPERATIONS

6.11.1 Introduction

Large quantities of concrete can be poured directly from ready-mix lorries in a relatively short period of time, consequently the operatives' rate of placement is usually the controlling factor. However, direct placement of concrete is not normally used for columns or walls.

6.11.2 Planning Rates

Planning rates for pouring concrete directly from ready-mix lorries should be determined from the basic operation times for the concrete gang. However, on some sites it may be necessary for the lorries to transport the concrete over considerable distances, therefore, the resulting basic time for the concrete gang should be compared with the basic time for the lorries. Concrete was poured directly from lorries in twelve of the pours presented in Table 5.2. The following basic elements have been extrapolated from these pours and can be used to calculate basic operation times for lorries.

(a) The basic time required to discharge one load of six cubic metres into a slab or base is seven minutes.

(b) The basic time required to discharge one load of six cubic metres into a beam is eighteen minutes.

(c) The basic time required to manoeuvre between discharge points, in the same locality, is two minutes.

(d) The basic time required to prepare for the first load and clean down afterwards is five minutes.
6.4.3 Calculation of Planning Rates for Direct Pours

The following example calculates the planning rate for pouring an in situ concrete beam using the direct pour method. The basic times for the concrete gang are obtained from Appendix C, and the basic times for the lorries are obtained from the previous page.

(i) Operation Information

<table>
<thead>
<tr>
<th>Volume of concrete</th>
<th>18 cu. m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of concrete</td>
<td>10 sq. m.</td>
</tr>
<tr>
<td>Method</td>
<td>Direct pour</td>
</tr>
<tr>
<td>Gang size</td>
<td>3 men</td>
</tr>
<tr>
<td>Number of lorry manoeuvres</td>
<td>6</td>
</tr>
</tbody>
</table>

(ii) Basic Times for Concrete Gang

Basic Operation Time = 305 man mins.

Duration = 305/3 = 102 mins.

(iii) Basic Time for Lorry

Discharge concrete = (18 x 7)/6 = 21 mins.

Manoeuvre lorry = 2 x 6 = 12 mins.

Prepare/clean down = 5 mins.

Total Basic Time = 38 mins.

The above calculation shows that the time spent pouring the beam by the concrete gang is larger than the time spent on site by the ready-mix lorry. The planning time is determined by applying a site factor (see Chapter Eight) to the concrete gang's duration.

i.e. Planning Time = 102 x Site Factor
CHAPTER SEVEN

CALCULATING STANDARD TIMES
CHAPTER SEVEN

CALCULATING STANDARD TIMES

7.1 INTRODUCTION

To establish a library of standard times based on work study techniques, it is necessary to predetermine what allowances should be applied to the basic element times. The most common of these is the relaxation allowance, but, there is a gross disparity in the values being awarded by different firms for the same relaxation factor (7.1). Generally, the origins of relaxation allowances for construction work are unknown and the values used are sometimes simply borrowed from similar manufacturing situations. Such ambiguity clearly highlights not only the need for the standardization of rest allowances, but also for an in depth review of the theoretical validation behind them. For example, the relaxation allowances for construction work, as recommended by Harris and McCaffer (7.2), presented in Figure 7.1, are typical but as yet unproven values.

This chapter reviews traditional methods of calculating relaxation allowances and investigates the ambiguities which arise when the results are applied to construction operations. A system more appropriate to construction operations is developed and summarized in Figure 7.15. This system is based on several ergonomic theories; these are discussed and developed further with construction operations in mind.
<table>
<thead>
<tr>
<th>1. Fixed Allowance</th>
<th>MEN</th>
<th>WOMEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Effort &amp; Dexterity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light work Medium</td>
<td>Heavy Lifting Very Heavy (50 Kg Arm Lifts)</td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>6</td>
<td>12.0</td>
</tr>
<tr>
<td>Continuous</td>
<td>Severe Restriction</td>
<td></td>
</tr>
<tr>
<td>3. Posture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twisting Bending</td>
<td>Bending Overhead</td>
<td></td>
</tr>
<tr>
<td>of Movement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Low (25°C)</td>
<td>Medium (26-35°C)</td>
<td>High (above 36°C)</td>
</tr>
<tr>
<td>4. Fatigue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regular eye movement Detailed work Exacting work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Good Poor Good Poor Good Poor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Visual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Normal Considerable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humming (Machines) Pile Driver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Noise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Normal Above normal Excessive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Concentration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Dust or Protective Extremely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Working Conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Good Fumes Clothes needed Unpleasant</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7.1 Typical Relaxation Allowances
The later discussion of site factors presented in Chapter Nine shows that the motivation of construction operatives often produces idle periods exceeding the required relaxation period. However, relaxation allowances are still a very important aspect of construction planning as they indicate optimal levels of performance.

7.2 TRADITIONAL CALCULATION OF RELAXATION ALLOWANCES

Relaxation allowances are normally applied individually to the basic time of each work element; the resulting standard element times are combined and standard times for the complete operations are obtained. Most relaxation allowances fall into the categories of either 'fixed allowances' or 'variable allowances'.

7.2.1 Fixed Allowances

Fixed allowances take into account the operatives "personal needs" and "basic fatigue", and are considered a minimum requirement. The personal needs allowance is applied to every task and enables the worker to attend to activities such as washing or obtaining a drink; a typical value is six per cent of the basic time. The basic fatigue allowance is the minimum value required to accommodate moderate expenditure and to alleviate monotony; a typical value is four per cent for a worker who is seated and engaged on light work with normal movements in good working conditions. The majority of tasks in the construction industry are usually allocated a fixed allowance of ten per cent of basic time, with only a few requiring more than seventeen per cent.

7.2.2 Variable Allowances

Very often fixed allowances, alone, are not sufficient to protect the long and short term health of the worker. This problem is overcome by supplementing the fixed allowance with a "variable allowance", comprising: "additional fatigue allowances" where additional inputs of physical or mental work arise; and
"environmental allowances" to account for any adverse working conditions. Additional fatigue allowances are applied on an elemental basis, whereas, environmental allowances are usually applied on a daily basis.

A traditional method of calculating standard times for a typical concreting operation is presented in Table 7.1. The relaxation allowances applied in this example are based on values recommended by LAMSAC (7.3). The total relaxation allowance comprises factors for the following.

a) Basic Allowance.
b) Standing or Sitting Allowance.
c) Posture and Movement.
d) Energy Output.

### Table 7.1 Calculation of Standard Times

<table>
<thead>
<tr>
<th>ELEMENTS</th>
<th>Basic Time (mins)</th>
<th>Relaxation Allowance (%)</th>
<th>Total Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Work</td>
<td>25</td>
<td>10 2 0 1</td>
<td>13</td>
</tr>
<tr>
<td>Prepare Tools</td>
<td>40</td>
<td>10 2 0 1</td>
<td>13</td>
</tr>
<tr>
<td>Clear Tools Away</td>
<td>20</td>
<td>10 2 0 1</td>
<td>13</td>
</tr>
<tr>
<td>Pour Concrete</td>
<td>25</td>
<td>10 2 0 1</td>
<td>13</td>
</tr>
<tr>
<td>Vibrate Concrete</td>
<td>115</td>
<td>10 2 0 4</td>
<td>16</td>
</tr>
<tr>
<td>Shovel Concrete</td>
<td>123</td>
<td>10 2 2 6</td>
<td>20</td>
</tr>
<tr>
<td>Tamp Concrete</td>
<td>69</td>
<td>10 2 3 4</td>
<td>19</td>
</tr>
<tr>
<td>Trowel Concrete</td>
<td>147</td>
<td>10 2 4 4</td>
<td>20</td>
</tr>
<tr>
<td>Cover Concrete</td>
<td>98</td>
<td>10 2 0 1</td>
<td>13</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>662</strong></td>
<td></td>
<td><strong>17</strong></td>
</tr>
</tbody>
</table>
When traditional systems for determining relaxation allowances are compared with classic ergonomic theories several inconsistencies occur. These inconsistencies can result from either the method used to build up relaxation allowances or their subsequent application.

Most discrepancies resulting from the build up of relaxation allowances arise because the calculations are performed on an elemental basis. For example: the personal needs factor represents a minimum period of time and, therefore, should not be applied to individual elements but to complete operations; no account is taken of the opportunity to recover during waiting periods or whilst performing elements requiring little effort; the effort factor does not take into account which part of the body is being used or the number of times an operation is performed; and allowances are sometimes made for factors having no affect on overall fatigue.

The majority of manufacturing operations involve elements of work requiring uniform levels of effort with very few interruptions, and as a result these discrepancies have little or no affect. In contrast, construction operations often involve work elements requiring considerably different levels of effort with regular interruptions; consequently, the discrepancies cannot be ignored. It is for this reason that a detailed investigation is performed to establish a more theoretical valid system for determining construction relaxation allowances.
At this stage it is important to emphasize that relaxation allowances are applied to ensure that the worker has time to attend to personal needs, whilst ensuring ability to recover from the metabolic, mental and postural cost of the work. The previously discussed discrepancies arise because these two types of allowances are combined on an elemental basis. For this reason "basic allowances" are now treated as a minimum level of relaxation; with "health and safety" allowances accounting for mental cost, environmental cost, metabolic cost and local muscle fatigue, as summarized below.

(i) Mental Cost (concentration or boredom)

Some tasks require minimal muscular activity or energy expenditure but can still cause some fatigue; for example, mental tiredness. The construction operations under consideration are predominantly physical, therefore, a detailed investigation into relaxation allowances for mental fatigue is not required.

(ii) Environmental Cost

Environmental allowances are used to allow for abnormal working conditions resulting from the affect of weather, dust, fumes or noises. Basic allowances are often increased to accommodate any adverse environmental conditions.

(iii) Metabolic Cost

Large loads applied to the body as a whole over a period of time cause a debit from the metabolic store, and relaxation periods are required to replenish it.

(iv) Local Muscle Fatigue

Local muscle fatigue occurs with little metabolic cost when either poor postures are adopted, or small loads are consistently applied to the same group of muscles. Local muscle fatigue can be either static or dynamic depending upon the frequency of loading.
7.4 RELAXATION ALLOWANCES FOR THE METABOLIC COST OF WORK

When loads are applied to the body as a whole, it is possible to determine the metabolic cost in terms of energy output by measuring the oxygen consumption over a period of time (7.4). Previous research (7.5) has shown that over an eight hour working day an acceptable work level is approximately equivalent to a third of the maximum oxygen intake rate ($\text{VO}_2$ per hour). The variation in recommended values arises because it is not actual fatigue that can be measured, but the sensation of fatigue which depends upon the level of drive or motivation present.

Research by Astrand (7.6) indicated that the maximum oxygen intake ranged between 2.29 and 3.17 litres per minute (i.e. on average 2.73 litres per minute) for a variety of building operatives. One litre of oxygen consumed per minute is equivalent to 350 watts, therefore, the acceptable work level over an eight hour day is approximately 300 watts ($0.333 \times 350 \times 2.73$). The benchmarks for various types of activities presented in Table 7.2 have been established (7.7) by the direct measurement of oxygen intake whilst performing each activity.

**Table 7.2 Work Rate Bench Marks**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable Work Level (A.W.L.)</td>
<td>300</td>
</tr>
<tr>
<td>Relaxation Rate standing (R.R.)</td>
<td>130</td>
</tr>
<tr>
<td>Relaxation Rate sitting (R.R.)</td>
<td>105</td>
</tr>
<tr>
<td>Dangerous Work Rate (D.W.R.)</td>
<td>750</td>
</tr>
</tbody>
</table>
7.4.1 Calculation of Actual Work Rate in Terms of Energy Expenditure

In order to calculate relaxation allowances for metabolic tasks, it is necessary to compare the actual energy used with the acceptable work level. This can be done by: direct measurement of the volume of oxygen consumed; adopting existing bench marks; or using existing models. Existing energy bench marks should be adopted wherever possible. However, when these are not available one of the following models could be used. The direct measurement of oxygen consumed during a specific task is difficult to achieve and, therefore, should only be used in special circumstances.

(i) The Aberg Model

The Aberg Model (7.8) takes the form of:

\[(\text{VO}_2)\text{ consumed} = \text{Basic Metabolism} + \text{Posture} + \text{Body Motion} + \text{Load Motion}\]

\[(\text{K1}) + (\text{K2}) + (\text{K3} + \text{K4}) + (\text{K5} + \text{K6} + \text{K7} + \text{K8})\]

Table 7.3 Factors for the Aberg Model

<table>
<thead>
<tr>
<th>Factor</th>
<th>Power</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>85 watts</td>
<td>Basic metabolism</td>
</tr>
<tr>
<td>K2</td>
<td>29 watts</td>
<td>Sitting</td>
</tr>
<tr>
<td></td>
<td>34 watts</td>
<td>For a body</td>
</tr>
<tr>
<td>K3</td>
<td>56 watts</td>
<td>Standing</td>
</tr>
<tr>
<td>K4</td>
<td>205 watts/(m/sec)</td>
<td>Standing bent</td>
</tr>
<tr>
<td>K5</td>
<td>790 watts/(m/sec)</td>
<td>Walking</td>
</tr>
<tr>
<td>K6</td>
<td>65 watts/kg/(m/sec)</td>
<td>Bend + rise</td>
</tr>
<tr>
<td>K7</td>
<td>3 watts/kg/(m/sec)</td>
<td>Horizontal arm work</td>
</tr>
<tr>
<td>K8</td>
<td>119 watts/kg/(m/sec)</td>
<td>Horizontal carrying</td>
</tr>
<tr>
<td></td>
<td>82 watts/kg/(m/sec)</td>
<td>Lift up</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lift down</td>
</tr>
</tbody>
</table>
The Aberg Model was originally presented as a general formula in Imperial Units. This general formula has been converted into S.L units, and separated into the body and load motions associated with construction operations. The converted results are presented in Table 7.3 and 7.4, and used to plot Figures 7.2 and 7.3. The power expended when the body is stationary with no loads applied is equal to $K_1$ plus $K_2$: power expended whilst standing is 119 watts (i.e. $85 + 34$); power expended whilst sitting is 114 watts (i.e. $85 + 29$).

### Table 7.4 Converted Aberg Formula

<table>
<thead>
<tr>
<th>Case Description</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Carry an object</td>
<td>$P = 119 + L(205+3W)$</td>
</tr>
<tr>
<td>(b) Lift an object stationary body seated</td>
<td>$P = 114 + 119WL$ (Lift Up)</td>
</tr>
<tr>
<td></td>
<td>$= 114 + 82WL$ (Lift Down)</td>
</tr>
<tr>
<td></td>
<td>$= 114 + 65WL$ (Lift Horizontal)</td>
</tr>
<tr>
<td>(c) Lift object and body</td>
<td>$P = 119 + L(790+119W)$ (Lift Up)</td>
</tr>
<tr>
<td></td>
<td>$P = 119 + L(790+82W)$ (Lift Down)</td>
</tr>
<tr>
<td>(d) Body motion and light loads</td>
<td>Determine power by using the above equations but with $W=0$.</td>
</tr>
</tbody>
</table>

Where:

- $P$ represents power in watts.
- $L$ represents velocity in metres per second.
- $W$ represents weight in kilograms.
Power relating to both basic metabolic rate (i.e. K1) and body motion (i.e. K2 to K4) can be obtained from Figure 7.2. For example, the power consumed whilst walking at 0.4 metres per second is approximately 170 watts, as illustrated by the chain-line on Figure 7.2.

Power relating to load motion (i.e. K5 to K8) can be obtained from Figure 7.3, reading in an anti-clockwise direction. For example, the power required to lift a 50kg weight at a speed of one metre per second is 5.95 kilowatts, as illustrated by the chain line on Figure 7.3. To determine the total metabolic cost (or total power) the values obtained from Figures 7.2 and 7.3 should be combined. The right-hand side of Figure 7.3 was drawn for lifting objects upwards, with power obtained from the Y-axis. The left-hand side of Figure 7.3 can be used to determine the power consumed whilst lowering objects or moving them horizontally.
POWER AGAINST VELOCITY FOR
OBJECT DISPLACEMENT, FROM ABERG

FIGURE 7.3
(ii) The Spitzer and Hettinger Model

The Spitzer and Hettinger model (7.9) comprises three sections and takes the form of the following equation. The 76.7 watts is an allowance for basic metabolism. Factors "A" and "B" represent the power elements relating to body posture and type of activity, and are obtained from Tables 7.5 and 7.6, respectively.

\[
\text{Total Power} = (A + B + 76.7) \text{ watts.}
\]

**Table 7.5 Power Relating to Body Posture (A)**

<table>
<thead>
<tr>
<th>Body Posture</th>
<th>Power (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting</td>
<td>21</td>
</tr>
<tr>
<td>Kneeling</td>
<td>36</td>
</tr>
<tr>
<td>Squatting</td>
<td>36</td>
</tr>
<tr>
<td>Standing</td>
<td>42</td>
</tr>
<tr>
<td>Bent over</td>
<td>56</td>
</tr>
<tr>
<td>Walking</td>
<td>118 to 244</td>
</tr>
<tr>
<td>Climbing unladen</td>
<td>52 per metre rise</td>
</tr>
</tbody>
</table>

**Table 7.6 Power Relating to Type of Activity (B)**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Power (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade of activity</td>
</tr>
<tr>
<td></td>
<td>Light</td>
</tr>
<tr>
<td>Hand work</td>
<td>21-42</td>
</tr>
<tr>
<td>One arm work</td>
<td>49-84</td>
</tr>
<tr>
<td>Both arms work</td>
<td>105-140</td>
</tr>
<tr>
<td>Body work</td>
<td>174-279</td>
</tr>
</tbody>
</table>

592-801

Very heavy
(iii) The Pandolf Model

Givoni and Goldman (7.10) developed an empirical relationship for energy expenditure prediction as a function of speed, external load, body weight, grade and terrain. This relationship was limited to speeds ranging from 0.7 to 2.5 metres per second. However, Pandolf et al (7.11) subsequently developed the following relationship for wider application.

\[ M = 1.5W + 2.0(W+L)(L/W)^2 + n(W+L)(1.5V^2 + 0.35VG) \]

Where:
- \( M \) = metabolic rate, watts.
- \( W \) = subject weight, kg.
- \( L \) = external load, kg.
- \( n \) = terrain factor (1 for treadmill).
- \( V \) = velocity m/sec.
- \( G \) = slope.

The above expression can be simplified by considering a standard worker of 70kg, and assuming that positive and negative gradients cancel each other out. Two of the variables are, thus, eliminated and the following equation obtained.

\[ M = 1.5\times70 + 2.0(70+L)(L/70)^2 + n(70+L)(1.5V^2 + 0) \]

\[ M = 105 + 2.0(70+L)(L/70)^2 + n(70+L)1.5V^2 \]

The Aberg, Spitzer and Hettinger, and Pandolf models can all be used to determine the metabolic work rate associated with various tasks. However, the model selected often depends upon the type of operation and the information available. The Aberg model is best suited to single activities where detailed information relating to the applied load and velocity of movement are available. The Spitzer and Hettinger model is best suited to operations where the tasks can be classified as light, medium or heavy work. The Pandolf model is only suited to operations involving the horizontal transportation of loads.
7.4.2 Derivation of Relaxation Formulae for Metabolic Cost

The methods discussed previously can be used to determine the metabolic cost of individual work elements. Construction operations, however, usually involve several activities with varying work loads. To calculate relaxation allowances for these operations, it is necessary to combine the metabolic cost of the individual elements over a minimum period of say thirty minutes. The resulting mean work rate (M.W.R.) is subsequently equated to the acceptable work load level (A.W.L.), and the appropriate relaxation allowance obtained. To simplify the procedure of calculating relaxation allowances, Equations 7.1 and 7.2 can be adopted. These equations are derived by equating the energy expenditure during both the working and relaxation periods to the acceptable work level (Table 7.2). The resulting equations are used to plot Figure 7.1 (Wt = working time, Rt = relaxation time).

\[
\text{Work} + \text{Relaxation} = \text{Acceptable Work Level}
\]

\[
(M.W.R.)Wt + (R.R.)Rt = (A.W.L.)(Wt + Rt)
\]

\[
(M.W.R.)Wt + (R.R.)Rt = 300(Wt + Rt)
\]

But Relaxation Allowance (R.A.) = \[\frac{Rt}{Wt} \times 100\%\]

Thus:

\[Rt = Wt(R.A.)\]

Substituting for Rt

\[
(M.W.R.)Wt + (R.R.)Wt(R.A.) = 300( Wt + Wt(R.A.) )
\]

\[-300(R.A.) + (R.R)(R.A.) = 300 - M.W.R.\]

\[
R.A. = \frac{(M.W.R.) - 300}{300 - (R.R)} \times 100\%
\]

The relaxation rate (R.R.) is obtained from existing benchmarks, using Table 7.2, and substituted into the above equation, hence:

Seated Relaxation .. R.A. = 0.513(M.W.R.) - 154 Equation 7.1
(R.R. = 105)

Standing Relaxation .. R.A. = 0.588(M.W.R.) - 176 Equation 7.2
(R.R. = 130)
RELAXATION ALLOWANCES FOR METABOLIC WORK

![Graph showing relaxation allowances for metabolic work](image)

- **Standing Relaxation from Equation 7.2**
- **Seated Relaxation from Equation 7.1**

**Figure 7.4**
7.4.3 Relaxation Allowance Calculation for Metabolic Work

The following example calculates relaxation allowances for an operation involving metabolic work. The operation under consideration involves six activities each having different durations and work rates, as summarized in Table 7.7.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>DURATION</th>
<th>WORK RATE</th>
<th>ENERGY EXPENDITURE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(mins)</td>
<td>(watts)</td>
<td>(joules)</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>350</td>
<td>7000</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>450</td>
<td>13500</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>500</td>
<td>5000</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>150</td>
<td>4500</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>200</td>
<td>1000</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>400</td>
<td>16000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>135</td>
<td>---</td>
<td>117000</td>
</tr>
</tbody>
</table>

The relaxation allowance for the above operation is determined by calculating the mean work rate, and substituting the obtained value into Equation 7.2, as shown below.

\[
\text{MEAN WORK RATE} = \frac{\text{TOTAL ENERGY EXPENDITURE}}{\text{TOTAL DURATION}}
\]

\[
\text{M.W.R.} = \frac{117000}{135} = 348 \text{ watts}
\]

Standing Relaxation R.A. = 0.588 (M.W.R.) - 176  Equation 7.2

\[
\text{R.A.} = 28.6\%
\]

BASIC TIME = T.B.T. = 135 mins.

STANDARD TIME = 135 x 1.286 = 174 mins.
The Effect of Idle Time on Metabolic Cost

In the previous example a relaxation allowance is calculated for a typical operation. Depending upon the level of efficiency this operation may be subjected to delays of varying duration. During these periods some recovery can take place, thus, reducing the additional period required for relaxation. Rather than repeat the calculations for every combination of work and idle time, it is possible to calculate the reduced relaxation allowance from a generalized equation.

The generalized relaxation equation is derived by calculating the mean work rate inclusive of delays (M.W.R.), and substituting the obtained value into Equation 7.2. The mean work rate is calculated by combining the non-delay work rate (W.R.) with the recovery rate (R.R. is equal to 130 watts when standing). If "a" represents the percentage of overall time spent working, the mean work rate can be obtained from the following equation.

\[
\text{Mean work rate (M.W.R.)} = \frac{(W.R.)a + 130(100-a)}{100} \text{ watts}
\]

Standing Relaxation R.A. = 0.588( M.W.R. ) - 176 \hspace{1cm} \ldots \text{Equation 7.2}

Substituting for (M.W.R.)

\[
\text{R.A.} = \frac{0.588( (W.R.)a + 130(100-a) ) - 176}{100}
\]

Figure 7.5 was plotted from the above equation and can be used to determine the required relaxation allowance, if work rate and percentage of time spent working are known. The relaxation allowance should be applied to both working and idle times, as shown below.

BASIC TIME \hspace{0.5cm} (B.T.) = \hspace{0.5cm} \text{WORKING TIME + IDLE TIME}

STANDARD TIME \hspace{0.5cm} (S.T.) = \hspace{0.5cm} \frac{( B.T. ) \times ( 100 + \text{R.A.} )}{100}
7.4.5 The Effect of Combined Work Loads

Most construction operations include both work and idle periods resulting from a combination of individual tasks. In order to determine the appropriate relaxation allowance for complete operations, it is necessary to combine the partial relaxation allowances for the individual tasks. This procedure is illustrated for an operation with the following constituent parts.

(a) In the first task "a" per cent of the basic time (B.T.1) is spent working at a rate of A watts, resulting in a required partial relaxation allowance of "x" per cent, obtained from either Figure 7.4 or Equation 7.2.

(b) In the second task "b" per cent of the basic time (B.T.2) is spent working at a rate of B watts, resulting in a required partial relaxation allowance of "y" per cent, obtained from either Figure 7.4 or Equation 7.2.

(c) In the third task "c" per cent of the basic time (B.T.3) is spent working at a rate of C watts, resulting in a required partial relaxation allowance of "z" per cent, obtained from either Figure 7.4 or Equation 7.2.

\[
\begin{align*}
\text{TOTAL BASIC TIME} & = (B.T.1 + B.T.2 + B.T.3) \\
\text{TOTAL RELAXATION TIME} & = x(B.T.1) + y(B.T.2) + z(B.T.3) \\
\text{T.R.A.} & = \frac{x(B.T.1) + y(B.T.2) + z(B.T.3)}{(B.T.1 + B.T.2 + B.T.3)}
\end{align*}
\]

... Equation 7.3
### 7.4.6 Relaxation Allowance Calculation for Combined Tasks

The following example illustrates how the relationship expressed in Equation 7.3 can be used to calculate the relaxation allowance for an operation comprising the three tasks summarized in Table 7.8.

**Table 7.8 Information Relating to Total Operation**

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration mins</th>
<th>Work Rate watts</th>
<th>% Time spent working</th>
<th>% Time spent standing</th>
<th>Partial R.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>600</td>
<td>80</td>
<td>20</td>
<td>122%</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>525</td>
<td>70</td>
<td>30</td>
<td>63%</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>365</td>
<td>100</td>
<td>0</td>
<td>39%</td>
</tr>
</tbody>
</table>

\[
T.R.A. = \frac{x(B.T.1) + y(B.T.2) + z(B.T.3)}{(B.T.1 + B.T.2 + B.T.3)}
\]

... Equation 7.3

\[
T.R.A. = \frac{122(20) + 63(40) + 39(30)}{20 + 40 + 30}
\]

\[
= 68\%
\]

**BASIC TIME**

\[
T.B.T. = 90 \text{ minutes}
\]

**STANDARD TIME**

\[
90 \times 1.68 = 151 \text{ minutes}
\]
7.5 RELAXATION ALLOWANCES FOR LOCAL MUSCLE FATIGUE

Local muscle fatigue usually occurs at low levels of energy output where loads are applied to a localized group of muscles. Local muscle fatigue can be either static or dynamic, depending upon the frequency of loading.

7.5.1 Static Muscle Fatigue

Rohmert (7.12) established an empirical relationship between applied static force, expressed as a percentage of maximum force, and maximum holding time. This relationship is represented by Equation 7.4 and illustrated in Figure 7.6. Rohmert also showed that up to fifteen per cent of the maximum force could be held indefinitely, and that the maximum force could not be held for more than six seconds.

\[
T_{\text{max}} = \frac{126}{p} - \frac{36}{p^2} + \frac{6}{p^3} - 90 \quad \ldots \text{Equation 7.4}
\]

where: \(T_{\text{max}} = \) Maximum Holding Time (seconds)

\(p = \) Applied Force / Maximum Force

![Figure 7.6 Rohmert's Curve](image-url)
Rohmert went on to produce a solution for calculating the relaxation allowance required to compensate for local muscle fatigue, given the holding time and the percentage of the maximum force developed. The relationships between recovery time, loading time, maximum holding time, applied force and maximum force are presented in Equation 7.5 and illustrated by Figure 7.7.

\[
T_{rec} = \frac{18(T)^{1.4}(P-0.15)^{0.5}}{T_{max}}
\]

Equation 7.5

where:

- \( P \) = Applied Force/Maximum Force
- \( T_{max} \) = Max holding time (mins.)
- \( T_{rec} \) = Recovery time (mins.)
- \( T \) = Loading time (mins.)
PERCENTAGE RELAXATION ALLOWANCES FOR VARIOUS COMBINATIONS OF HOLDING FORCES AND HOLDING TIMES

FIGURE 7.7
7.5.2 *Relaxation Allowance Calculation for Local Muscle Fatigue*

If a force with a maximum holding time ($T_{\text{max}}$) of three minutes is applied for one minute ($T$), the appropriate relaxation allowance ($R.A.$) is obtained from Figures 7.6 and 7.7, as shown below.

\[
T = 1 \text{ min} = 60 \text{ secs.} \\
T_{\text{max}} = 3 \text{ min} = 180 \text{ secs.} \\
P = 30\% \\
R.A. = 200\% 
\]

In some construction operations a rest period is automatically available after a load has been encountered. If this rest period is less than the required relaxation period, the maximum strength is subsequently reduced. Thus, the above method of calculating relaxation allowances is an over-estimate because it is not necessary to fully return to the maximum starting strength before resuming work.

Figure 7.8 illustrates the relationships between fatigue, recovery and time. If the full recovery period is not taken, there will be a residual degree of fatigue when work is restarted. The affect of several short "work-recovery" cycles is similar to that of dynamic muscle fatigue, and the relaxation allowance calculations are even more complex.

*Figure 7.8. Degree of Local Muscle Fatigue*
7.5.3 Relaxation Allowances for Static Loads

Corlett (7.13) investigated the relationships between holding time in minutes and the percentage of maximum force being applied, for both static pull and static torque experienced during normal postures. The equations Corlett produced as 'best fit' lines for his experimental data are presented below.

\[ \log e y = 3.32 - 0.042x \quad \text{for static pull} \]
\[ \log e y = 2.52 - 0.043x \quad \text{for static torque} \]
\[ x = \% \text{ of maximal force} \]
\[ y = \text{holding time (mins.)} \]

The above equations, Corlett's experimental results and the theoretical relationships as developed by Monod and Rohmert are all plotted in Figure 7.9. The following conclusions are drawn from a comparison of these theoretical and experimental results.

(a) Corlett's experimental results for static torques are closer to Rohmert's equation than those produced by the above equations.

(b) Corlett states that the results are "by no means asymptotic to the Y axis, even at 10% of the force". However, this probably arises because insufficient data were obtained, for example, only one point is plotted for loads less than 15% of the maximum. Also, no correction is taken for the affect of body weight.

(c) Corlett's experimental results show a distinct difference between static torque and static pull. This suggests that the relationship between time and load is dependent on the type of muscle loading, although Rohmert states that this is not so. Using Corlett's experimental results, the relaxation allowances obtained from Figure 7.7 vary considerably for different muscle groups, as illustrated by the following example.
MAXIMUM HOLDING TIME AGAINST PERCENTAGE OF MAXIMUM FORCE BEING APPLIED THEORETICAL AND EXPERIMENTAL RESULTS

ROHMERT -- \( T_{\text{max}} = -90 + \frac{126}{p} - \frac{36}{p^2} + \frac{6}{p^3} \) secs.

MONOD -- \( T_{\text{max}} = \frac{2.5}{0.01P - 0.14} \) secs.

S.P.B.F. -- \( \log T_{\text{max}} = 3.32 - 0.042P \) mins.

S.T.B.F. -- \( \log T_{\text{max}} = 2.52 - 0.043P \) mins.

LEGEND
△ STATIC PULL -- EXPERIMENTAL
× STATIC TORQUE -- EXPERIMENTAL
☐ ROHMERT
★ MONOD
★ STATIC PULL -- BEST FIT
★ STATIC TORQUE -- BEST FIT

FIGURE 7.9
Consequently, Corlett has presented insufficient data to conclusively prove that there is a significant difference between static pull and static torque. Therefore, the relationships produced by Rohmert for calculating maximum holding times (Equation 7.4) and the appropriate relaxation allowances (Equation 7.5) have been adopted in this research. The following example calculates relaxation allowances for static pull and static torque.

The relaxation allowances for two loading conditions are determined. The first case considers a static pull load with maximum holding time of 250 seconds being applied for 30 seconds. The second case involves a static torque load with maximum holding time of 250 seconds being applied for 30 seconds. The applied forces are initially obtained from Corlett's "best-fit" lines presented in Figure 7.9, and the relaxation allowances subsequently obtained from Figure 7.7. Also, the applied forces and corresponding relaxation allowances are obtained using Rohmert's curves.

**Table 7.9 Relaxation Allowances for Static Pull and Torque**

<table>
<thead>
<tr>
<th>Comments</th>
<th>Corlett Static Torque</th>
<th>Corlett Static Pull</th>
<th>Rohmert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>30 seconds</td>
<td>30 seconds</td>
<td>30 seconds</td>
</tr>
<tr>
<td>Maximum holding time</td>
<td>250 seconds</td>
<td>250 seconds</td>
<td>250 seconds</td>
</tr>
<tr>
<td>Applied force, Figure 7.9</td>
<td>27%</td>
<td>46%</td>
<td>24%</td>
</tr>
<tr>
<td>Relaxation allowance from Figure 7.7</td>
<td>50%</td>
<td>250%</td>
<td>25%</td>
</tr>
</tbody>
</table>
7.5.4 Abnormal Postures

In certain tasks, it is necessary for the operative to adopt awkward postures and, thus, experience local muscle fatigue. The most recent work done in this area has been the development of the OWAS (7.14) group of postures. These are illustrated in Figure 7.10, and the maximum holding times are given for typical postures adopted whilst performing a simple tapping task. The postures are classified by the location of the task being performed in terms of the percentage of maximum working height and distance. The postures are numbered (1 to 16) and the actual location of the task being performed is illustrated, along with the region of pain, in Figure 7.11.

![Figure 7.10](image-url)
Figures 7.10 and 7.11 show that, for certain postures, body weight can be more significant than the actual task being performed, and that for different postures different muscle groups are critical. Rohnert's method of calculating relaxation allowances uses holding time and force developed (expressed as a percentage of the maximum force), thus, the holding times in Figure 7.10 can be used to calculate relaxation allowances for different types of posture.

To determine the relaxation allowance required when static load and poor posture are both present, the force developed by the static load and an equivalent force developed by the posture should be combined and used with Figure 7.7. To simplify this procedure, the holding times for various postures have already been converted into an equivalent developed forces and presented in Table 7.10. The OWAS postures (1 to 16) are divided into seven groups depending on the maximum holding time. Figure 7.6 is used to convert these holding times into an equivalent percentage of the maximum developed forces.
### Table 7.10 Posture Groups

<table>
<thead>
<tr>
<th>New Group</th>
<th>OWAS Postures</th>
<th>Holding Time (mins)</th>
<th>F/Fmax. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>D</td>
<td>4,5,6</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>E</td>
<td>7,8,9</td>
<td>5</td>
<td>23</td>
</tr>
<tr>
<td>F</td>
<td>10 to 15</td>
<td>3.5</td>
<td>28</td>
</tr>
<tr>
<td>G</td>
<td>16</td>
<td>1.5</td>
<td>36</td>
</tr>
</tbody>
</table>

The maximum holding times presented in Table 7.10 are obtained from research relating to the OWAS group of postures (7.15). These results are for the same light tapping task performed in various postures. The equivalent percentages of maximum force (F/Fmax) being applied are caused by the adopted posture and the appropriate values are obtained from Figure 7.6. When calculating relaxation allowances, this equivalent force (F/Fmax) can be used either on its own or combined with static loads.
7.5.5 Dynamic Muscle Fatigue

Dynamic muscle fatigue is usually associated with tasks involving repeated loading cycles. The relaxation period required for dynamic muscle fatigue is dependent upon both the degree of fatigue reached during the loaded part of the work cycle and the recovery available during the unloaded periods.

![Diagram of Dynamic Muscle Fatigue]

**Figure 7.12 Degree of Dynamic Muscle Fatigue**

The recovery time for both static and dynamic work depends upon the degree of fatigue reached (i.e. the percentage reduction in maximum load). Therefore, it is necessary to classify dynamic work in terms of the ratio of "load time:unload time", as well as the percentage maximum force being applied. In Rohmert's formula, Equation 7.6, these are represented by Neff. for the number of completed cycles and Nel. for fifteen per cent of the maximum number of cycles.
REFA (7.16) have produced the simplest solution for determining relaxation allowances associated with dynamic work. This involves classifying the task in terms of steps in strain, and relating the required relaxation allowance to the duration of uninterrupted work, as shown in Figure 7.13.

heavy dynamic  \[ R.A. = 1.9(t)^{0.145} \left( \frac{\text{Neff.}}{\text{Nel.}} - 1 \right) 100\% \]
muscular work

Note:

- \( t \) = duration of working period (construction)
- Neff. = number of completed cycles
- Nel. = fifteen per cent of the maximum number of cycles.

...Equation 7.6

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RELAXATION ALLOWANCES FOR DYNAMIC MUSCLE FATIGUE

LENGTH OF UNINTERRUPTED WORK PERIOD
1 min.
1–3 min.
3–5 min.
5–10 min.
10–30 min.
30–60 min.
60–120 min.

FIGURE 7.13
7.5.6 Optimization of Rest Pauses

The degree of fatigue reached during both static and dynamic work depends upon the frequency of loading, therefore, it may be possible to increase productivity by optimizing rest pauses. The relationship between degree of fatigue and time is illustrated in Figure 7.14 for two similar tasks with different rest pause arrangements.

![Figure 7.14 Degree of Fatigue Reached with Time](image-url)
In Rohmert's investigation (7.17) into the optimization of rest pauses, he posited that short but frequent breaks are more economic than infrequent but longer breaks as:

(a) "it ensures short working periods with a small average degree of fatigue as well as the frequent experience of the high rate of recovery at the beginning of a break."

(b) "well as by a psychological output-increasing effect while working up to a scheduled break."

On inspection those two statements by Rohmert appear to be founded on unsound logic, thus, putting into doubt the possible benefits to be obtained from short regular breaks.

Firstly, Figure 7.14 indicates that a high rate of recovery can only be obtained when a high degree of fatigue has been reached. As frequent breaks reduce the level of fatigue at the end of each work cycle, only low rates of recovery can be achieved. Also, if short breaks are taken there will still be some residual fatigue at the beginning of the next work cycle, and the rate of increase in fatigue will be greater.

Rohmert's second statement also fails to correspond to the actions of a typical construction operative, as there is a definite winding down period before and after official breaks on the majority of sites.
The previous sections in this chapter present the theoretical background to the figures and equations used for the calculation of construction relaxation allowances. The following flow chart has been developed in order to simplify the choice of appropriate figures or equations used when calculating relaxation allowances. As a note of caution, once this flow chart has been used and the relaxation allowances calculated, a check should be performed to ensure that the value obtained is not less than the basic allowance.
Is the load applied to the whole body?

**YES**

**NO**

**METABOLIC COST**

Are existing bench marks suitable?

**YES**

**NO**

Can existing models be used?

**YES**

**NO**

From direct measurement.

Determine work rate, in watts for each activity.

Is idle time part of the operation?

**YES**

**NO**

Determine the partial relaxation allowance from Figure 7.5.

Determine the total relaxation allowance from Equation 7.3.

Is relaxation taken standing or sitting?

**If sitting**

Use Equation 7.1.

**If standing**

Use Equation 7.2.

**LOCAL MUSCLE FATIGUE**

What is the loading type?

**DYNAMIC**

due to:

- Heavy work.
- Light work.

**STATIC**

due to:

- Bad Posture.
- Applied Load.

Determine posture type from Fig 7.10 and hence the equivalent F/Fmax from Table 7.10.

The F/Fmax values for posture and load are added together when applied to the same muscle group.

**Figure 7.15 Relaxation Allowance Flow Chart**
7.7 CALCULATION OF RELAXATION ALLOWANCES FOR CONCRETE WORK

The following example calculates a general relaxation allowance for the majority of concreting operations, this is based upon the results from seventy concrete pours presented in Table 5.2. The basic times for each element of concrete work are summated and presented in Table 7.11. The percentage time spent on each activity is subsequently calculated and used to determine a standard relaxation allowance for most concreting operations. Figure 7.16 illustrates the path taken on the relaxation allowance flow chart relating to most concrete operations. Loading is generally applied to the body as a whole rather than any individual muscle group, therefore, the metabolic cost of the work is the main criterion. As there are no existing benchmarks, the power output is determined from the Spitzer and Hettinger model (Tables 7.5 and 7.6). The resulting relaxation allowance is twenty per cent of the basic time, slightly higher than the seventeen per cent obtained in Table 7.1 using more traditional methods. Although some subjective assessment is required the values can be checked by performing the individual tasks and recording the oxygen consumed over set periods. A sensitivity analysis is performed in Table 7.11 in order to determine how relaxation allowances are influenced by errors made in the assessment of the power associated with individual activities. In this sensitivity analysis a ten per cent error is applied to two activities (i.e. vibrate concrete and cover concrete). Consequently, a ten per cent error in the assessment of power consumed during vibration changes the relaxation allowance by 18 per cent; and a ten per cent error in the assessment of power consumed whilst covering concrete changes the relaxation allowance by 2 per cent.
Is the load applied to the whole body?

YES

NO

METABOLIC COST

Are existing bench marks suitable?

YES

NO

Can existing models be used?

YES

NO

From direct measurement.

Determine work rate, in watts for each activity.

Is idle time part of the operation?

YES

NO

Determine the partial relaxation allowance from Figure 7.5.

Is relaxation taken standing or sitting?

If sitting use

Equation 7.1.

If standing use

Equation 7.2.

Determine posture type from Fig 7.10 and hence the equivalent F/Fmax or Equation 7.6 from Table 7.10. 7.4.

The F/Fmax values for posture and load are added together when applied to the same muscle group.

Determine relaxation allowance from either Figure 7.7 or Equation 7.5.

Figure 7.16 Relaxation Allowance Flow Chart—Example
## Table 7.11 Relaxation Allowance Calculation for Concrete Operatives

<table>
<thead>
<tr>
<th>Activity</th>
<th>Total Basic Times (mins.)</th>
<th>Percentage Times P.T.</th>
<th>Power (watts)</th>
<th>T x P.T. (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
<td>T x P.T.</td>
</tr>
<tr>
<td>Prepare Tools</td>
<td>953</td>
<td>6</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>Pour Concrete</td>
<td>2112</td>
<td>12</td>
<td>42</td>
<td>174</td>
</tr>
<tr>
<td>Vibrate Concrete</td>
<td>3443</td>
<td>20</td>
<td>56</td>
<td>174</td>
</tr>
<tr>
<td>Shovel Concrete</td>
<td>2340</td>
<td>14</td>
<td>87</td>
<td>209</td>
</tr>
<tr>
<td>Tamp Concrete</td>
<td>3536</td>
<td>21</td>
<td>87</td>
<td>209</td>
</tr>
<tr>
<td>Trowel Concrete</td>
<td>2096</td>
<td>12</td>
<td>36</td>
<td>130</td>
</tr>
<tr>
<td>General Work</td>
<td>1606</td>
<td>9</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>Clear Tools Away</td>
<td>568</td>
<td>3</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>Cover Concrete</td>
<td>561</td>
<td>3</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>17215</strong></td>
<td><strong>100</strong></td>
<td><strong>333.31</strong></td>
<td><strong>333.34</strong></td>
</tr>
</tbody>
</table>

### Sensitivity Analysis

**Assume 10% Error in Power Assessment**

#### Above Example

**In Vibrate Activity**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>333.34 watts</td>
<td>339.48 watts</td>
<td>334.44 watts</td>
</tr>
</tbody>
</table>

**In Cover Activity**

<table>
<thead>
<tr>
<th>Error</th>
<th>R.A. (0.588)</th>
<th>R.A. (0.588 + 6.14)</th>
<th>R.A. (0.588 + 1.10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.588 - 176</td>
<td>0.588(339.48) - 176</td>
<td>0.588(334.44) - 176</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Error</th>
<th>R.A. (20%)</th>
<th>R.A. (23.6%)</th>
<th>R.A. (20.65%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20%</td>
<td>1%</td>
<td>3%</td>
</tr>
</tbody>
</table>

**Note:**

- A = Power relating to body posture, from Table 7.5.
- B = Power relating to type of activity, from Table 7.6.
- C = Basic metabolism (76.7 watts).
- T = Total power relating to individual activities, from Spitzer and Hettinger (A + B + C).
It was observed in this research, however, that there was a considerable amount of idle time associated with construction operations which is available as a substitute for relaxation allowances. The site factors dealing with this aspect, presented in Chapter Nine (Tables 9.1 to 9.5), can be used to compare theoretical relaxation allowances and actual idle time. These total site factors, inclusive of official breaks, are presented in Table 7.12. The values show that actual idle periods for the in situ concrete gang greatly exceed the relaxation required.

<table>
<thead>
<tr>
<th>Trade</th>
<th>Maximum Site Factor</th>
<th>Minimum Site Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>In situ concrete</td>
<td>2.98</td>
<td>1.42</td>
</tr>
<tr>
<td>Formwork</td>
<td>2.50</td>
<td>1.27</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>1.75</td>
<td>1.16</td>
</tr>
<tr>
<td>Structural steel-work</td>
<td>1.54</td>
<td>1.23</td>
</tr>
<tr>
<td>Pre-cast concrete</td>
<td>1.47</td>
<td>1.29</td>
</tr>
</tbody>
</table>

Relaxation allowances have long been the traditional method of establishing standard times for production planning and estimating in the manufacturing industry. However, the above figures indicate that relaxation allowances appear to have little relevance to performance in the construction industry as there is a considerable amount lost time caused by other factors. The method devised during this research, and presented in Chapter Eight, uses site factors to accommodate lost time in the setting of planning rates. These site factors should always be checked to ensure that the appropriate relaxation periods are available.
CHAPTER EIGHT

CALCULATING PLANNING TIMES
CHAPTER EIGHT

CALCULATING PLANNING TIMES

8.1 INTRODUCTION

The previous chapter illustrates how allowances for the physical cost of work should be applied to basic time in order to establish a standard time for a specific task. In practice, standard time is rarely achieved as the actual relaxation period taken often exceeds the time required for recovery. Thus, planning time should take into account the basic operation time and an allowance for the factors affecting productivity.

8.2 FACTORS AFFECTING CONSTRUCTION PRODUCTIVITY

The "Real Work Content" of any operation is the least possible time it can be completed in. However, at the design and planning stages mistakes can be made, resulting in an "Added Work Content" even before the job has even started. Also, while the work is in progress management and operatives can cause idle periods, i.e. "Ineffective Time". Therefore, the total number of man hours for an operation can be classified as shown in Figure 8.1 and described in Table 8.1.
Figure 8.1 Work Content and Ineffective Time
### Table 8.1 Description of Added Work Content and Ineffective Time

**Added Work Content Caused By Design Errors Will Occur If:**

(a) the structure is designed such that the most economical construction methods cannot be used;
(b) there is a wide variety in the type of units or only short production runs are possible;
(c) a material is not up to the correct specifications and therefore difficult to work with;
(d) the specifications are too high and excess work is required to achieve them.

**Added Work Content Caused By Method Of Working Will Occur if:**

(a) the incorrect size or type of plant is selected;
(b) the site layout causes wasted effort by the incorrect positioning of site accommodation, batching plants, material stores and workshops;

**Ineffective Time Will Occur If Management Fails To Ensure That:**

(a) operatives are given the opportunity to acquire skill and speed by standardizing temporary works or providing continuity of operations;
(b) the work does not come up to the clients specification;
(c) the order of work is planned in detail eliminating waiting time;
(d) the materials are on site where and when they are required;
(e) the plant is kept free from breakdowns by regular maintenance;
(f) worker fatigue is kept to a minimum by good working conditions;
(g) the correct safety precautions are taken.

**Worker Ineffective Time Will Occur If:**

(a) the operatives are not fully motivated, resulting in extended breaks, excess relaxation or deliberately working at a reduced rate;
(b) work has to be repeated due to bad workmanship;
(c) the operatives do not observe current safety regulations.
The site manager can, by applying accurate planning techniques, reduce the element of lost time under his control; but it is important to realize that even if all the waiting time is eliminated, the planned output rates will only be achieved if the labour force is sufficiently motivated. The proposed build up of construction planning times, from basic operation times and site factors, incorporates the concept of adding various inefficiencies onto the real work content, as illustrated by Figure 8.1.

8.3 SITE FACTORS

To accommodate various levels of efficiency, adjustments are made to total basic time for changes in work rate, idle or wasted time and breaks. In this research these adjustments are expressed as factors, and can be determined from activity sampling or cumulative timing results. The relationships between the working day, site factors and total basic time are illustrated in Figure 8.2 and expressed in Equation 8.1.
Figure 8.2 Application of Site Factors to Basic Times
The relationship between working day (WD) and total basic time (TBT) is, therefore, expressed as:

\[ WD = TBT \times F1 \times F2 \times F3 \times F4 \]  ...Equation 5.1

Given that:

\[ F1 = \frac{TBT}{BT} \]  (THIS IS NOT A SITE FACTOR BUT RELATES TO THE OPERATION)

\[ F1 = \frac{WT}{TBT} \]  ... WORK RATE

\[ F2 = \frac{AT}{WT} = \frac{WT + W + R}{WT} \]  ... IDLE TIME

\[ F3 = \frac{WH}{AT} \]  ... EXTRA BREAKS

\[ F4 = \frac{WD}{WH} \]  ... ABSENCE

The procedure for building up planning times from basic element times, allowing for different site conditions, is summarized below.

(a) Determine the basic operation time by combining the basic element times, work contingency allowances and internal delay allowances where appropriate.

(b) Determine the basic operation time for site ancillary work.

(c) In order to obtain standard time, calculate and apply the relaxation allowances to the basic time, taking into account any internal delay allowance already incorporated.

(d) In order to obtain planning times, apply the total site factor \((FT = F1 \times F2 \times F3 \times F4)\) to the basic time.
This relationship between working day (W.D.) and total basic time (T.B.T.), as expressed in Equation 8.1, is used in Chapter Nine to quantify the efficiency of several sites in terms of site factors. The values are subsequently applied to the general concrete model (Table 5.6) and compared with estimators' data as a means of validating the model.

The following example illustrates how the site factors were calculated for the Formwork gang on Site 3 (as presented in Table 9.2). The average durations for each activity were determined from several days of activity sampling.

**Table 8.2 Sample Calculation of Site Factors**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration Hours</th>
<th>Site Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working Day</td>
<td>8.50</td>
<td></td>
</tr>
<tr>
<td>Official Breaks</td>
<td>1.35</td>
<td>$F_4 = \frac{WD}{WH} = 1.19$</td>
</tr>
<tr>
<td>Working Hours</td>
<td>7.50</td>
<td></td>
</tr>
<tr>
<td>Extra Breaks</td>
<td>1.61</td>
<td>$F_3 = \frac{AT}{WT} = 1.29$</td>
</tr>
<tr>
<td>Attendance Time</td>
<td>5.54</td>
<td></td>
</tr>
<tr>
<td>External Delay + Relaxation</td>
<td>1.77</td>
<td>$F_2 = \frac{AT}{WT} = 1.47$</td>
</tr>
<tr>
<td>Working Time</td>
<td>3.77</td>
<td></td>
</tr>
<tr>
<td>Work Rate</td>
<td>0.37</td>
<td>$F_1 = \frac{WT}{TBT} = 1.11$</td>
</tr>
<tr>
<td>Total Basic Time</td>
<td>3.40</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER NINE

ACTUAL SITE FACTORS
CHAPTER NINE

ACTUAL SITE FACTORS

9.1 INTRODUCTION

The build up of planning times, from basic element times and site factors, is discussed in Chapters Seven and Eight. In this chapter site factors obtained from several sites are presented for in situ concrete, formwork, reinforcement, structural steel-work and precast concrete gangs. The main causes of variation in gang performance are ascertained and the relevance of site factors in determining production times for construction operations demonstrated.

9.2 MEASURED SITE FACTORS

Studies, on eleven constructions sites were carried out on the above trades in order to determine actual site factors. Summaries of the observed site factors are presented in Tables 9.1 to 9.5. The data are set out in relation to the level of remuneration to illustrate the marked impact that this single variable appears to have on the site factor values. The rates of pay quoted have been adjusted for a base year of 1983 using Baxter Indices.
Table 9.1 Site Factors for Six Concrete Ganga

<table>
<thead>
<tr>
<th>SITE</th>
<th>PAY £/Hr</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.78</td>
<td>0.98</td>
<td>1.26</td>
<td>1.04</td>
<td>1.14</td>
<td>1.46</td>
</tr>
<tr>
<td>2</td>
<td>2.51</td>
<td>1.05</td>
<td>1.72</td>
<td>1.12</td>
<td>1.18</td>
<td>2.39</td>
</tr>
<tr>
<td>3</td>
<td>2.03</td>
<td>1.02</td>
<td>1.86</td>
<td>1.32</td>
<td>1.19</td>
<td>2.98</td>
</tr>
<tr>
<td>4</td>
<td>2.80</td>
<td>1.03</td>
<td>1.28</td>
<td>1.01</td>
<td>1.22</td>
<td>1.62</td>
</tr>
<tr>
<td>4</td>
<td>2.80</td>
<td>1.10</td>
<td>1.32</td>
<td>1.01</td>
<td>1.22</td>
<td>1.79</td>
</tr>
<tr>
<td>5</td>
<td>2.87</td>
<td>1.07</td>
<td>1.45</td>
<td>1.05</td>
<td>1.22</td>
<td>1.99</td>
</tr>
</tbody>
</table>

Table 9.2 Site Factors for Six Formwork Ganga

<table>
<thead>
<tr>
<th>SITE</th>
<th>PAY £/Hr</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.44</td>
<td>0.98</td>
<td>1.10</td>
<td>1.03</td>
<td>1.14</td>
<td>1.27</td>
</tr>
<tr>
<td>2</td>
<td>3.90</td>
<td>1.03</td>
<td>1.34</td>
<td>1.19</td>
<td>1.18</td>
<td>1.94</td>
</tr>
<tr>
<td>3</td>
<td>3.64</td>
<td>1.11</td>
<td>1.47</td>
<td>1.29</td>
<td>1.19</td>
<td>2.50</td>
</tr>
<tr>
<td>4</td>
<td>4.22</td>
<td>1.00</td>
<td>1.10</td>
<td>1.01</td>
<td>1.18</td>
<td>1.31</td>
</tr>
<tr>
<td>4</td>
<td>2.53</td>
<td>1.09</td>
<td>1.36</td>
<td>1.02</td>
<td>1.22</td>
<td>1.84</td>
</tr>
<tr>
<td>5</td>
<td>3.10</td>
<td>1.00</td>
<td>1.31</td>
<td>1.02</td>
<td>1.22</td>
<td>1.63</td>
</tr>
</tbody>
</table>
### Table 9.3 Site Factors for Six Reinforcement Gangs

<table>
<thead>
<tr>
<th>SITE</th>
<th>PAY £/Hr</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.22</td>
<td>0.96</td>
<td>1.03</td>
<td>1.03</td>
<td>1.11</td>
<td>1.16</td>
</tr>
<tr>
<td>2</td>
<td>4.00</td>
<td>0.96</td>
<td>1.07</td>
<td>1.08</td>
<td>1.18</td>
<td>1.31</td>
</tr>
<tr>
<td>3</td>
<td>3.00</td>
<td>0.96</td>
<td>1.18</td>
<td>1.30</td>
<td>1.19</td>
<td>1.75</td>
</tr>
<tr>
<td>4</td>
<td>3.08</td>
<td>1.01</td>
<td>1.20</td>
<td>1.03</td>
<td>1.22</td>
<td>1.52</td>
</tr>
<tr>
<td>4</td>
<td>3.08</td>
<td>1.01</td>
<td>1.18</td>
<td>1.02</td>
<td>1.22</td>
<td>1.48</td>
</tr>
<tr>
<td>5</td>
<td>3.25</td>
<td>1.02</td>
<td>1.19</td>
<td>1.06</td>
<td>1.22</td>
<td>1.57</td>
</tr>
</tbody>
</table>

### Table 9.4 Site Factors for Five Structural Steel-work Gangs

<table>
<thead>
<tr>
<th>SITE</th>
<th>PAY £/Hr</th>
<th>F1</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>4.00</td>
<td>1.29</td>
<td>1.00</td>
<td>1.12</td>
<td>1.14</td>
<td>1.11</td>
<td>1.42</td>
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<tr>
<td>7</td>
<td>3.50</td>
<td>1.14</td>
<td>1.00</td>
<td>1.21</td>
<td>1.16</td>
<td>1.10</td>
<td>1.54</td>
</tr>
<tr>
<td>8</td>
<td>3.70</td>
<td>1.36</td>
<td>1.00</td>
<td>1.01</td>
<td>1.11</td>
<td>1.10</td>
<td>1.23</td>
</tr>
<tr>
<td>9</td>
<td>4.00</td>
<td>1.28</td>
<td>1.00</td>
<td>1.18</td>
<td>1.10</td>
<td>1.11</td>
<td>1.44</td>
</tr>
<tr>
<td>10</td>
<td>3.70</td>
<td>1.37</td>
<td>1.00</td>
<td>1.28</td>
<td>1.05</td>
<td>1.12</td>
<td>1.51</td>
</tr>
</tbody>
</table>
### Table 9.5 Site Factors for Eight Pre-cast Concrete Ganges

<table>
<thead>
<tr>
<th>SITE</th>
<th>PAY £/Hr</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>4.30</td>
<td>1.12</td>
<td>1.00</td>
<td>1.09</td>
<td>1.05</td>
<td>1.11</td>
</tr>
<tr>
<td>12</td>
<td>3.50</td>
<td>1.23</td>
<td>1.00</td>
<td>1.23</td>
<td>1.09</td>
<td>1.10</td>
</tr>
<tr>
<td>13</td>
<td>3.60</td>
<td>1.40</td>
<td>1.00</td>
<td>1.12</td>
<td>1.13</td>
<td>1.12</td>
</tr>
<tr>
<td>14</td>
<td>3.40</td>
<td>1.28</td>
<td>1.00</td>
<td>1.15</td>
<td>1.10</td>
<td>1.12</td>
</tr>
<tr>
<td>15</td>
<td>4.20</td>
<td>1.29</td>
<td>1.00</td>
<td>1.11</td>
<td>1.11</td>
<td>1.10</td>
</tr>
<tr>
<td>16</td>
<td>4.50</td>
<td>1.22</td>
<td>1.00</td>
<td>1.13</td>
<td>1.14</td>
<td>1.10</td>
</tr>
<tr>
<td>17</td>
<td>4.50</td>
<td>1.29</td>
<td>1.00</td>
<td>1.06</td>
<td>1.17</td>
<td>1.11</td>
</tr>
<tr>
<td>18</td>
<td>4.50</td>
<td>1.15</td>
<td>1.00</td>
<td>1.10</td>
<td>1.12</td>
<td>1.12</td>
</tr>
</tbody>
</table>
TOTAL SITE FACTOR AGAINST REMUNERATION

Legend

Δ CONCRETE GANGS
× FORMWORK GANGS
☐ STEELWORK GANGS
☒ REINFORCEMENT GANGS
☐ PRE-CAST CONCRETE GANGS

FIGURE 9.1
9.3 ANALYSIS OF SITE FACTORS

There are numerous variables affecting operative performance; however, the following analysis concentrates on the relationship between total site factor (FT) and hourly pay (P) for five trades, as illustrated in Figure 9.1, which indicates an inverse relationship between performance and remuneration independent of trade. Three types of relationship are thus investigated in each stage of the analysis; namely straight line, inverse and log.

There are two points on Figure 9.1, relating to joiners, which deviate considerably from the trend. Consequently, the following analysis has three stages: the first omits these two points from the analysis; the second includes these two points; the third includes these two points and investigates possible causes of the divergence. In each stage the relationship between total site factor and hourly pay investigated by regression analysis using the Minitab package. The resulting equations and coefficients of determination ($R^2$) are presented for the individual stages in the analysis.

(i) Stage One

In Figure 9.1 total site factors (FT) are plotted against hourly pay, for the thirty-one gangs. The two points with large deviation are excluded from this stage of the analysis. Initially, a straight line relationship is investigated resulting in a correlation coefficient ($R$) of -0.806. Secondly, two inverse relationships are used, thus improving the correlation to 0.934. Finally, simple log relationships are investigated with the best correlation coefficient being 0.938. The regression equations and correlation coefficients resulting from this stage of the analysis are presented in Table 9.6. As there is only a slight improvement in correlation when logs are introduced, the following equation is selected to represent the relationship between total site factors and pay.

\[
FT = 0.863 + 7.88/P^2 \\
R = 0.934
\]
<table>
<thead>
<tr>
<th>Equations</th>
<th>Coefficient of Determination ($R^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$FT = 3.05 - 0.413 , P$</td>
<td>65.0%</td>
</tr>
<tr>
<td>$FT = 0.105 + 5.01/P$</td>
<td>81.4%</td>
</tr>
<tr>
<td>$FT = 0.863 + 7.88/P^2$</td>
<td>87.3%</td>
</tr>
<tr>
<td>$FT = 3.43 - 3.41 \log P$</td>
<td>73.5%</td>
</tr>
<tr>
<td>$FT = 3.43 + 1.71 \log(1/P^2)$</td>
<td>73.5%</td>
</tr>
<tr>
<td>$\log FT = 0.636 - 0.826 \log P$</td>
<td>79.7%</td>
</tr>
<tr>
<td>$\log FT = 0.636 + 0.413 \log(1/P^2)$</td>
<td>79.7%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Correlation Coefficients ($R$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAY</td>
</tr>
<tr>
<td>Log FT</td>
</tr>
<tr>
<td>FT</td>
</tr>
</tbody>
</table>
(ii) Stage Two

The equation resulting from the first stage of the analysis closely represents the data used. The second stage is performed to determine the relationship best representing all thirty-one gangs. The two stray points in Figure 9.1 now are included. The result is a reduction in the correlation coefficients obtained: -0.702 for the straight line relationship; 0.792 for the inverse relationship; and 0.791 for the log relationship. The resulting regression equations and correlation coefficients are presented in Table 9.7. The equation presented below is selected to represent the relationship between total site factor and remuneration.

\[
F_T = 0.955 + 7.42/P^2 \quad R = 0.792
\]
### Table 9.7 Regression Equations for Stage Two

<table>
<thead>
<tr>
<th>Equations</th>
<th>Coefficient of Determination ($R^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$FT = 3.05 - 0.400P$</td>
<td>49.2%</td>
</tr>
<tr>
<td>$FT = 0.231 + 4.75/P$</td>
<td>59.1%</td>
</tr>
<tr>
<td>$FT = 0.955 + 7.42/P^2$</td>
<td>62.9%</td>
</tr>
<tr>
<td>$FT = 3.40 - 3.27 \log P$</td>
<td>54.3%</td>
</tr>
<tr>
<td>$FT = 3.40 + 1.64 \log 1/P^2$</td>
<td>54.3%</td>
</tr>
<tr>
<td>$\log FT = 0.628 - 0.789 \log P$</td>
<td>58.5%</td>
</tr>
</tbody>
</table>

### Correlation Coefficients ($R$)

<table>
<thead>
<tr>
<th></th>
<th>PAY</th>
<th>FT</th>
<th>1/P</th>
<th>1/P^2</th>
<th>Log P</th>
<th>Log 1/P^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\log FT$</td>
<td>-0.740</td>
<td>-</td>
<td>0.783</td>
<td>0.791</td>
<td>-0.765</td>
<td>0.765</td>
</tr>
<tr>
<td>FT</td>
<td>-0.702</td>
<td>-</td>
<td>0.769</td>
<td>0.792</td>
<td>-0.737</td>
<td>0.737</td>
</tr>
</tbody>
</table>

183
(iii) **Stage Three**

The two points exhibiting excessive divergence in Figure 9.1 are associated with the formwork gangs. This divergence represents a reduction in performance when compared with other gangs. On inspection of Tables 9.1 to 9.5, this divergence appears to be caused by the large pay differential between the concretors and joiners on the same site. Thus, it is postulated that the low productivity of concrete gangs receiving minimum payments reduces the efficiency of joiners receiving substantially higher wages. As the work done by reinforcement fixers, steel erectors and pre-cast concrete erectors is of an independent subcontract nature, they are not significantly affected by pay differentials.

Stage three of the analysis investigates this divergence with the objective of establishing a realistic relationship, between performance and remuneration, which takes into account the pay differential between joiners and concretors on the same site.

The correlation coefficient for the straight line relationship is now 0.713; this is only a slight improvement on the value obtained in stage two. The correlation for the inverse relationship is now 0.866, this lies half-way between the corresponding values obtained in stages one and two. The best correlation from the simple log relationships is now 0.804, again this is half-way between the two corresponding values obtained in the previous stages. The regression equations and correlation coefficients, obtained during stage three of the analysis, are presented in Table 9.8. The following equations are selected to represent the relationship between total site factors and remuneration.

Joiners  
\[ FT = 0.883 + 7.52P^2 + 2.29/Pc^2 \]  
\[ R = 0.866 \]

Other Gangs  
\[ FT = 0.883 + 7.52P^2 \]

Note:  
\[ P = \text{Level of pay (£/hr)} \]  
\[ Pc = \text{Difference between joiners and concretors pay on the same site.} \]
<table>
<thead>
<tr>
<th>Equations</th>
<th>Coefficient of Determination ($R^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT = 3.04 - 0.404 P + 0.045 Pc</td>
<td>50.9</td>
</tr>
<tr>
<td>FT = 0.195 + 4.79/P + 0.0455 Pc</td>
<td>60.8</td>
</tr>
<tr>
<td>FT = 0.925 + 7.48/P^2 + 0.045 Pc</td>
<td>64.4</td>
</tr>
<tr>
<td>FT = 0.168 + 4.79/P + 0.728 Pc</td>
<td>66.7</td>
</tr>
<tr>
<td>FT = 0.158 + 4.79/P + 2.23/Pc^2</td>
<td>70.8</td>
</tr>
<tr>
<td>FT = 0.895 + 7.50/P^2 + 0.745/Pc</td>
<td>70.6</td>
</tr>
<tr>
<td>FT = 0.883 + 7.52/P^2 + 2.29/Pc^2</td>
<td>75.0</td>
</tr>
<tr>
<td>FT = 0.473 + 4.41/P - 0.0354 (P-Pc+1)</td>
<td>60.1</td>
</tr>
<tr>
<td>FT = 0.50 + 4.24/P - 0.0066 (P-Pc+1)^2</td>
<td>60.7</td>
</tr>
<tr>
<td>FT = 1.15 + 6.91/P^2 - 0.0366 (P-Pc+1)</td>
<td>63.8</td>
</tr>
<tr>
<td>FT = 1.15 + 6.64/P^2 - 0.007 (P-Pc+1)^2</td>
<td>64.6</td>
</tr>
<tr>
<td>Log FT = 0.630 - 0.760 Log P - 0.0324 Log (P-Pc+1)</td>
<td>58.9</td>
</tr>
<tr>
<td>Log FT = 0.624 - 0.796 Log P + 0.0682 Log (1+Pc)</td>
<td>61.4</td>
</tr>
</tbody>
</table>
9.4 DISCUSSION OF RESULTS

The very high correlation obtained in the analysis shows that a very good relationship exists between total site factor and hourly pay, as represented by the following equation.

\[ FT = 0.663 + \frac{7.88}{P^2} \quad R = 0.934 \]

However, this relationship is sometimes affected by the level of pay received by other gangs, particularly in the case of joiners. Figure 9.1 shows that the above relationship holds true for the five trades studied, with some grouping of results. For example, concrete operatives generally received the lowest level of pay, and are thus grouped towards the left in Figure 9.1, but are still represented by the above equation.

Other factors, such as site conditions, level of direct supervision or site organization, can affect motivation. However, the high correlation obtained in the analysis justifies this rather simplistic expression used to represent the relationship between incentives and motivation. The analysis has produced a basic equation with very good correlation, however, the inclusion of any additional factors would complicate the resulting expression without any significant improvement in the correlation.

Figure 8.1 shows the different types of ineffective time and work content contained in the total time taken to perform most construction operations. Real work content is the least possible time a task can be completed in. Added work content relates to decisions made during the design or planning stages, and is a measure of additional work performed. Ineffective time comprises idle periods caused by both management and operatives.

When determining overall efficiency levels all four additions to the real work content should be considered. Losses caused by management can contribute to three of the five sections in Figure 8.1, consequently, the quality of site management and level of site
supervision are important variables affecting site productivity. However, this research focuses upon total ineffective time, as opposed to added work content.

On construction sites lost production can be caused by designers, site management and operatives, but it is very difficult to allocate any loss to one particular source. Management and operative ineffective times are often intertwined and difficult to separate. For example, when an operation is delayed owing to poor management, say waiting for materials, the operatives have two options; they can wait for the material to arrive or continue on some other task. Well motivated operatives can, therefore, reduce the ineffective time caused by site management by diverting onto other work.

In this chapter a relationship between remuneration level and total ineffective time is established. The remuneration level is not only a measure of operative motivation but also indirectly corresponds to the level of site supervision. It was observed that operatives receiving higher rates of pay were prepared to be subjected to higher levels of direct site supervision. And, it is a fair assumption that management paying high rates consider their operatives a valuable asset requiring full attention and good supervision; conversely, it does not cost the contractor a considerable amount if operatives receiving minimum rates are not fully utilised.

The high correlation obtained between basic time and work content for concrete operatives, see Chapter Five, indicates that the main variations in output rates are associated with ineffective time. On construction sites, the majority of managerial efforts are directed towards the optimization of site profitability rather than increasing individual operation efficiency, and it is often necessary for site managers to sacrifice operational efficiency in order to complete critical operations. For example, during the construction of a multistorey building, concrete may be poured using either cranes or pumps, but, the deciding factor is usually not the work content involved in the two methods, but the difference between overall pour times.
CHAPTER TEN

COMPARISON OF ACTUAL SITE FACTORS WITH

CONTRACTORS' ESTIMATING DATA
10.1 BUILD UP ESTIMATING DATA

The basic operation times obtained by synthesizing elements using the equations on page 104 represent the irreducible time of concrete work in man-minutes. However, to enable basic operation times to be compared with realistic estimating data, adjustments have to be made for ancillary work, site efficiency and bonus rates. Weather, holidays and overheads are also generally included in the labour cost element of any estimate.
10.2 **EXAMPLE OF AN ESTIMATED DURATION BASED ON WORK STUDY DATA**

The following estimate of duration is for pouring a concrete slab (200mm deep, with an area of fifty square metres and a volume of ten cubic metres) using a crane and skip. The duration calculated below is presented in Table 10.1, along with values for other pours. The basic operation time for this operation is obtained from Table C1 in Appendix C.

\[
\text{Basic Operation Time (B.O.T.)} = 395 \text{ man-minutes}
\]

\[
\text{Estimate Duration (E.D.)} = \frac{\text{B.O.T.} \times \text{FT}}{60}
\]

The average value of the observed total site factors for the concrete operatives is 2.04, from Table 9.1.

\[
\text{Estimate Duration (E.D.)} = \frac{395 \times 2.04}{60} = 13.4 \text{ man-hours}
\]

10.3 **CONTRACTORS' ESTIMATING DATA**

Estimating data has been obtained from several sources, these are: four contractors (C1 - C4); two local authorities (L1 - L2); and three published sources (i.e. Griffiths' building price book (10.1), Spence Geddes' estimating for building and civil engineering works (10.2), and Comprehensive Builders Price Book (10.3). These values are used to estimate the time required to pour concrete for slabs, walls and columns, the results are presented in Tables 10.1, 10.2 and 10.3. These durations are inclusive of non-productive time, but exclusive of weather allowances.
### Table 10.1 Estimated Durations (man-hours) for Pouring Slabs

<table>
<thead>
<tr>
<th>SLAB DIMENSIONS</th>
<th>WORK STUDY DATA</th>
<th>CONTRACTORS</th>
<th>LOCAL AUTHORITIES</th>
<th>PUBLISHED DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DEPTH (mm)</td>
<td>AREA (m²)</td>
<td>VOLUME (m³)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BOT</td>
</tr>
<tr>
<td>100</td>
<td>50</td>
<td>5</td>
<td></td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>10</td>
<td></td>
<td>10.9</td>
</tr>
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<td></td>
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<td>20</td>
<td></td>
<td>20.8</td>
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<td>30.7</td>
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<td>6.6</td>
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<td>23.3</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>60</td>
<td></td>
<td>34.5</td>
</tr>
<tr>
<td>400</td>
<td>25</td>
<td>10</td>
<td></td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>25</td>
<td></td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>40</td>
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<td>14.7</td>
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<td>150</td>
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<td>80</td>
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<td>18.7</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>120</td>
<td></td>
<td>26.7</td>
</tr>
</tbody>
</table>
Table 10.2 Estimated Durations (man-hours) for Pouring Walls (5m long)

<table>
<thead>
<tr>
<th>WALL DIMENSIONS</th>
<th>WORK STUDY DATA</th>
<th>CONTRACTORS</th>
<th>LOCAL AUTHORITIES</th>
<th>PUBLISHED DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIDTH (m)</td>
<td>DEPTH (m)</td>
<td>VOLUME (m$^3$)</td>
<td>BOT</td>
<td>ED</td>
</tr>
<tr>
<td>0.10</td>
<td>4.0</td>
<td>2.0</td>
<td>1.7</td>
<td>3.5</td>
</tr>
<tr>
<td>0.20</td>
<td>2.0</td>
<td>5.0</td>
<td>1.8</td>
<td>3.7</td>
</tr>
<tr>
<td>0.40</td>
<td>2.5</td>
<td>5.0</td>
<td>2.2</td>
<td>4.5</td>
</tr>
<tr>
<td>0.80</td>
<td>1.3</td>
<td>5.0</td>
<td>2.5</td>
<td>5.1</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>VOLUME OF CONCRETE (m³)</th>
<th>WORK STUDY DATA</th>
<th>CONTRACTORS</th>
<th>LOCAL AUTHORITIES</th>
<th>PUBLISHED DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BOT</td>
<td>ED</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>0.5</td>
<td>1.2</td>
<td>2.4</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td>1.0</td>
<td>1.5</td>
<td>3.1</td>
<td>3.4</td>
<td>1.2</td>
</tr>
<tr>
<td>2.0</td>
<td>2.2</td>
<td>4.5</td>
<td>6.8</td>
<td>2.1</td>
</tr>
<tr>
<td>3.0</td>
<td>2.7</td>
<td>5.5</td>
<td>10.2</td>
<td>3.1</td>
</tr>
<tr>
<td>4.0</td>
<td>3.4</td>
<td>6.9</td>
<td>13.6</td>
<td>4.1</td>
</tr>
</tbody>
</table>

Table 10.3 Estimated Durations (man-hours) for Pouring Columns (4m High)
### Table 10.11 Ratio of Estimated Durations to Basic Operation Times

<table>
<thead>
<tr>
<th></th>
<th>CONTRACTORS</th>
<th>LOCAL AUTHORITIES</th>
<th>PUBLISHED DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
<td>C3</td>
</tr>
<tr>
<td>DEPTH (mm)</td>
<td>100</td>
<td>1.57</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>2.30</td>
<td>2.95</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>2.99</td>
<td>3.58</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>3.19</td>
<td>5.53</td>
</tr>
<tr>
<td>WIDTH (mm)</td>
<td>100</td>
<td>3.74</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>4.99</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>4.82</td>
<td>3.24</td>
</tr>
<tr>
<td></td>
<td>800</td>
<td>4.66</td>
<td>3.04</td>
</tr>
<tr>
<td>VOLUME (m³)</td>
<td>&lt;1.0</td>
<td>2.00</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>3.06</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>3.74</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>4.01</td>
<td>1.21</td>
</tr>
<tr>
<td>MEAN</td>
<td></td>
<td>3.42</td>
<td>2.41</td>
</tr>
</tbody>
</table>
FIGURE 10.1 CONTRACTORS' DATA hours AGAINST WORK STUDY DURATIONS hours
10.4 COMPARISON OF BASIC OPERATION TIMES WITH ESTIMATING DATA

A comparison can be made between basic operation times and estimated durations by using the values presented in Tables 10.1, 10.2 and 10.3. The estimated durations obtained from the contractors' data are approximately three times higher than the basic operation times, Table 10.4. This indicates that the two sources are compatible and the main differences arises because:

(i) The results obtained from the sites visited indicate that site factors (FT) ranging between 1.16 and 2.98 should be applied to convert basic operation times into realistic planning times.

(ii) The basic times for concrete operations are based upon the work done by the concrete gang. However, the estimated durations include any general operatives servicing this gang.

(iii) The actual cost of an operation represents a combination of the time taken and the cost of labour inclusive of bonus paid. However, estimates are usually based upon the operatives basic wage, and consequently the estimated duration is larger than the actual.

(iv) The ratio of contractors' estimated durations to basic operation times increases as the size of pour increases, Table 10.4. The shape of most concrete pours corresponds to the smaller pours in Tables 10.1 to 10.3, thus, the duration for the majority of pours is accurately predicted using the contractors' own data. However, the rates used by contractors do not accurately predict output rates for the larger and more unusual pours, as illustrated by the large differences between the contractors' data for pours greater than forty cubic meters, Figure 10.1. Equally, because the generalized model is mainly based on small pours, care is needed when extrapolating planning times for large pours.
Bonus rates are normally paid at a third of the operatives' basic pay. To illustrate the degree of correlation between the two groups of results, a site factor of 2.5 is applied to the work study data and the obtained durations are plotted, on Figure 10.1, against the contractors' durations which are based upon the estimated durations minus a third to allow for bonus incentives.

In contrast to the good correlation between the work study data and contractors' data, the durations estimated from traditional published sources (i.e. Griffiths' and Spence Geddes') are three times greater than the contractors'. Also, research by Fleming (10.4) shows that there has been little change in these published rates since 1900. This obviously puts the credibility of such sources into question. However, the values obtained from the first edition of Comprehensive Builders' Prices Book are more realistic.

Most of the work undertaken by local authorities' own workforce involves highway maintenance and small remedial work, with any large structural projects being put out to tender, consequently, suitable estimating data were only obtained from two local authorities. These rates indicated a wide variability in data used by the two local authorities.
CHAPTER ELEVEN

CONCLUSIONS, RECOMMENDATIONS AND

FURTHER RESEARCH
11.1 CONCLUSIONS

In this thesis the author has sought to describe the development of construction work study and its constituent parts. One of the main findings was that work study techniques could be modified to meet the requirements of most construction operations, sites and companies, whether the requirements were complex synthesis of basic operation times or the more simple determination of site efficiency. The key to this portability lay in the isolation of basic operation times via the application of site efficiency factors.

The author has also demonstrated that most of the variability in production rates can be quickly explained, leaving relatively constant levels of output for individual construction operations (i.e. basic operation times). On construction sites lost production can be caused by designers, site management and operatives, but it is very difficult to allocate any loss to one particular source. Management and operative ineffective times are often intertwined and difficult to separate. For example, when an operation is delayed owing to poor management, say waiting for materials, the operatives have two options; they can wait for the material to arrive or continue on some other task. Well motivated operatives can, therefore, reduce the ineffective time caused by site management by diverting onto other work.
Figure 8.1 contains five sections and shows the different types of ineffective time and work content contained in the total time taken to perform most construction operations. Real work content represents the least possible time a task can be completed in. Added work content relates to decisions made during the design or planning stages (i.e. design added work content and method added work content), and is a measure of additional work performed. Ineffective time comprises idle periods caused by both management and operatives (i.e. management ineffective time and operative ineffective time).

When determining overall efficiency levels all four additions to the real work content should be considered. Losses caused by management mainly contribute to three of these additions (design added work content, method added work content and management ineffective time), consequently, the quality of site management and level of site supervision are important variables affecting site productivity. However, this research focuses upon total ineffective time and operative motivation, as opposed to added work content and degree of management control. In contrast, research by Horner (11.1) in the Department of Civil Engineering at Dundee University concentrated upon the relationship between degree of management control and site productivity. One of Horner’s main findings was the indication that, at low levels of management control, there was a positive relationship between productivity and the degree of control.

In addition to the development of construction work study and the measurement of site efficiency, realistic output rates have been determined for a wide range of concreting operations. The conclusions resulting from these three objectives have been discussed throughout this thesis. They are now collectively summarized and presented in four sections.
11.1.1 Background and Modification of Traditional Techniques

The first section, comprising Chapters Two and Three, contained a review of the historical background to work study and an investigation into how this influenced the techniques currently used within the construction industry. The evidence indicated that, although similar work study techniques were used by various organizations to collect data, a wide variation existed in both the presentation and application of the results. This variation often arose because many work study techniques originated from the manufacturing industry and were adopted by the construction industry without adequate consideration given to the latter's needs.

Contractors mainly used work study to determine output rates for planning, estimating and bonus schemes, thus, work measurement techniques were more popular than method studies. The lack of drive in developing improved construction methods has perpetuated the status-quo as far as traditional construction methods are concerned, and in some instances working methods have remained the same over the last hundred years or so (2.24).

The main deficiencies in current methods of presenting output data were found to be: the failure to accurately represent the various individual elements relating to complete operations; and the lack of flexibility when dealing with different levels of operative performance. In order to reduce these deficiencies, the different types of work and idle time usually associated with construction work were carefully considered in the development of a more systematical approach to the presentation of output data. During this rationalization of construction time standards, it was also ensured that the developed method of presenting data was compatible with current methods and complied with the relevant terminology used in the British Standard. The working day was broken down in terms of working time, diverted time, idle time and absence time, as illustrated in Figure 3.4. Consequently, construction operations were classified as unrestricted, semi-restricted or restricted, depending upon the type of idle time involved.
11.1.2 Determination of Basic Operation Times

The second section demonstrated how basic times were obtained for concreting operations, beginning with the results from just one study and subsequently expanded to include results from over seventy concrete pours. The results from the single study were used to illustrate the data collection process adopted throughout this research, along with the process of synthesizing basic operation times. In addition, the data obtained from several pours were used to determine basic operation times for major items of construction plant.

The example presented in Chapter Four provided the author with the framework to derive a systematical approach in the development of construction work study. The framework comprised several sub-systems which were described and modified throughout this thesis. The main sub-systems were work measurement, relaxation allowances, operative motivation and site factors.

The work measurement techniques applied during data collection were mainly activity sampling and cumulative timing, as described in Chapter Four. Activity sampling proved successful when recording groups of workers engaged in constantly changing work patterns. After many trials, the adopted procedure involved taking observations every five minutes with the activity and work rate being recorded. The intervals between observations were reduced where smaller gangs were involved. Cumulative timing proved more appropriate for machine dominated operations where activities were commonly performed in regular patterns. To simplify the whole procedure, data for concrete operations were recorded on specially adapted activity sampling sheets, and the initial analyses were performed on activity sampling summary sheets, as illustrated by Figures 4.2 and 4.3.
11.1.3 Determination of Standard Times

It is impossible to establish a library of standard times without predetermining what allowances should be applied to the basic times. In work study data based libraries one of the most common factors is the relaxation allowance. However, even in the manufacturing industry where there is a relatively limited number of operations, a gross disparity exists between the relaxation allowances being awarded for the same type of task.

The validity of traditional methods used to calculate relaxation allowances was investigated, and a system more appropriate to construction operations was developed. In the first instance, this involved a review of the theoretical basis of existing methods and concentrated upon the two types of fatigue pertinent to construction operations (i.e. metabolic and local muscle). Standard times for concreting operations were subsequently obtained by combining basic times and relaxation allowances.

A flow chart was developed in order to simplify the methods used to calculate construction relaxation allowances. This flow chart was used to establish which equations and figures, presented in Chapter Seven, were applicable to concreting operations. The results from all the concrete pours were then used to determine a general relaxation allowance for concrete operatives. The value obtained using the new approach was found to be twenty per cent of the basic time, as opposed to the seventeen per cent obtained using a more traditional approach. Consequently, the standard time for any concreting operation was found to be equal to the basic time plus twenty per cent for relaxation.

Standard times were only applicable to sufficiently motivated operatives working on well organized operations. On several of the construction sites, this ideal combination was not always the case, and planning times often had to account for large periods of idle time. The majority of idle time associated with construction work related to individual sites, hence, site factors were used to represent lost time, as explained in Chapter Eight.
The final section investigated the variation in performance from site to site with the emphasis being transferred from work content to lost time. On the construction sites visited, there was a wide variety of payment schemes in existence, (for example, the level of remuneration for concrete operatives varied between £2.03/hr and £3.78/hr). As a result some operatives were highly motivated whilst others had little or no motivation. Standard times, by definition, only apply to uninterrupted work performed by well motivated operatives. Therefore, some form of adjustment, other than the addition of relaxation allowances, was required to convert basic times into realistic construction planning and estimating data. When applied to construction operations standard times lose some of their traditional meaning, however, they still have an important role to play as they indicate optimal levels of performance.

The main possible causes of lost construction production were initially discussed in terms of work content and ineffective time, and the concept, of using site factors to account for lost production or as a measure of performance, was introduced. It was observed that there was a considerable amount of idle time associated with construction operations which were available as a substitute for relaxation allowances. The site factors dealing with this aspect, presented in Chapter Nine (Tables 9.1 to 9.5), were compared with theoretical relaxation allowances. These total site factors, inclusive of official breaks, were presented in Table 7.12. The values showed that actual idle periods for the in situ concrete gangs greatly exceeded the relaxation required. The site factors, presented in Figure 9.1, also suggested that the idle periods associated with operations performed by more highly motivated operatives (e.g. the pre-cast concrete gangs) did not greatly exceed the required relaxation allowances.
Relaxation allowances have long been the traditional method of establishing standard times for production planning and estimating in the manufacturing industry. However, the above figures indicate that relaxation allowances appear to have little relevance to performance in the construction industry as there is a considerable amount of lost time caused by other factors. The method devised, and presented in Chapter Eight, uses site factors to accommodate lost time in the setting of planning rates. Before these site factors are applied, they should always be checked to ensure that the appropriate relaxation periods are available.

The high correlation obtained between basic time and work content for concrete operatives, see Chapter Five, indicated that the main variations in output rates were associated with ineffective time. In Chapter Nine, a relationship between remuneration level and total ineffective time was established. The very high correlation obtained in the analysis ($R = 0.934$) showed that a very good relationship existed between total site factor and hourly pay. However, this relationship was slightly affected by the level of pay received by other gangs, but Figure 9.1 showed that the relationship represented all five trades studied.

The high correlation obtained justifies this rather simplistic expression used to represent the relationship between incentives and motivation. Other factors, such as site conditions, level of direct
supervision or site organization, do affect motivation; but further work would be needed to fully understand the relationship between these additional variables.

On construction sites, the majority of managerial efforts are directed towards the optimization of site profitability rather than increasing individual operation efficiency, and it is often necessary for site managers to sacrifice operational efficiency in order to complete critical operations. For example, during the construction of a multistorey building, concrete may be poured using either cranes or pumps, however, the deciding factor is usually not the work content involved in the two methods, but the difference between overall pour times.

The remuneration levels were not only a measure of operative motivation but also indirectly corresponded to the level of site supervision. It was observed that operatives receiving higher rates of pay were prepared to be subjected to higher levels of direct site supervision. And it is a fair assumption that management paying high rates consider their operatives a valuable asset requiring full attention and good supervision; conversely, it does not cost the contractor a considerable amount if operatives receiving minimum rates are not fully utilized.

Estimating data were obtained from several sources (i.e. four contractors, two local authorities, and three published sources). In order to compared these values with the work study data, they were used to estimate the time required to pour concrete for slabs, walls and columns. The estimated durations obtained from the contractors' data were found to be compatible with the work study data. However, the durations estimated from traditional published sources (i.e. Griffiths' and Spence Geddes') were found to be three times greater than the contractors' values. Also, research by Fleming (10.4) shows that there has been little change in these published rates since 1900. This obviously puts the credibility of such sources into question. However, the values obtained from the first edition of Comprehensive Builders' Prices Book were found to be more realistic.
11.2 RECOMMENDATIONS

As far as the future is concerned, more people working independently in industry, but pooling their information in a standardized form, would provide a forum for an exchange of information on methods of working with the hope of improving construction productivity.

Initially, construction work study is likely to more effective if the applications are directed towards work improvement on individual sites, rather than the collection of output rates. Only when it becomes clear that more efficient methods of working are possible, will feedback data begin to be pooled for subsequent use.

In the manufacturing industry most operations are performed in a predefined order with delays and interruptions easily avoided, and as a result output levels can be accurately predicted. In this type of environment bonus schemes can be effectively introduced and operative motivation easily controlled. In general, incentive schemes improve the operatives' motivation and encourages them to reduce the amount of idle time. The majority of incentive schemes in the manufacturing industry are based on standard times obtained from a combination of basic times and relaxation allowances. However, owing to the excessive idle periods on many construction sites this combination is not applicable when calculating realistic planning rates. The combination of basic times and site factors, as developed in this research, is more appropriate and also provides the site manager with a measure of site performance. The construction industry should be made aware of the large variation that currently exists between sites and encouraged to make better use of incentive schemes with the view to improving operative motivation and increasing productivity.

The comparison made, in Chapter Ten, between productivity achieved on construction sites and output rates presented in published sources, highlights the need for more realistic output rates to be assembled and made available to general users.
11.3 FURTHER RESEARCH

Throughout this thesis, the author has made several recommendations for further research and development, these are now summarized and others added.

The establishment of basic operation times usually involves on site measurement followed by a detailed analysis, and can often be a very tedious and time consuming process. Current research (11.2) in the Department of Civil Engineering at Loughborough University is aimed at improving the situation by utilizing portable microcomputers such as the EPSON and APRICOT. The format presented in Figure 4.2 has been adopted on the EPSON for work measurement on site, and the initial stage of any subsequent analysis is performed on the APRICOT and follows the format shown in Figure 4.3. In addition to the reduction in time spent collecting and analysing data, the use of computers should encourage a more standardized approach.

It has been demonstrated, by concentrating upon the work performed by the operatives, that the variability between the basic times for different methods of placing concrete was relatively low, and that lost time was a good measure of efficiency. In other operations, such as falsework erection, work content often depends on the adopted method, and thus, efficiency is a combination of work content and lost time. Further research is, therefore, required into work content before absolute levels of efficiency can be determined for all construction trades. The author also recognizes the need for more research on the productivity of materials handling systems (i.e. pumps, cranes) before any statistically valid conclusions can be drawn.

In this research a relationship between level of remuneration and site efficiency was established for several trades. Research by Horner indicated a relationship between degree of management control and site efficiency. If a relationship between overall management control, level of direct site supervision and level of remuneration were to be measured the compatibility between these two could be firmly established.
APPENDIX A

CONSTRUCTION WORK STUDY TERMINOLOGY
APPENDIX A

CONSTRUCTION WORK STUDY TERMINOLOGY

A.1 INTRODUCTION

This appendix contains definitions relating to the terminology used within this thesis and is sub-divided into four sections. The definitions in the first section relate to the terminology used in the general discussion of construction work study as presented in Chapter Three. The remaining sections are directly associated with the terminology used in Figures 3.4, 3.5 and 8.2.
Work Study

A management service based on those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which lead to the systematic investigation of all the resources and factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement.

Method Study

The systematic recording and critical examination of existing and proposed ways of doing work, as a means of developing and applying easier and more effective methods and reducing costs.

Work Measurement

The application of techniques designed to establish the time for a qualified worker to carry out a specific job at a defined level of performance.

Time Study

A work measurement technique for recording the times and rates of working for the elements of a specific job carried out under specified conditions, and for analysing the data in order to obtain the time necessary for carrying out the job at a defined level of performance.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flyback Timing</td>
<td>The hands of the stop-watch are returned to zero and restarted at the end of each element. The time for each element is recorded directly, along with an assessment of rate.</td>
</tr>
<tr>
<td>Cumulative Timing</td>
<td>The hands of the stop-watch are not stopped but the actual time at the end of each element is recorded. Each element is rated and the duration subsequently obtained by subtraction.</td>
</tr>
<tr>
<td>Activity Sampling</td>
<td>Observations are taken either at set or random intervals on a group of workers, with both the activities being performed and the rate of work recorded.</td>
</tr>
<tr>
<td>Rating</td>
<td>Rating is used to assess the worker's rate of working relative to the observer's concept of standard rating (rate depends upon speed of movement, effort, dexterity and consistency).</td>
</tr>
</tbody>
</table>
Figure 3.4 Classification of Work and Idle Times.

NOTE: Bold type indicates terms which are also used in Figure 8.2.
# A.3 Classification of Work and Idle Times — Figure 3.4

<table>
<thead>
<tr>
<th><strong>Working Day</strong></th>
<th>The official daily hours beyond which overtime is paid. The working day comprises both absence and attendance time.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Absence Time</strong></td>
<td>The period of the working day when the operative is absent from work.</td>
</tr>
<tr>
<td><strong>Attendance Time</strong></td>
<td>The period of the working day that the operative spends at his place of work. There are three types of attendance time, namely working, diverted and idle time.</td>
</tr>
<tr>
<td><strong>Working Time</strong></td>
<td>The actual time taken to carry out the work, and includes the following.</td>
</tr>
<tr>
<td><strong>Inside Machine Controlled Time</strong></td>
<td>The work which can be performed within the machine controlled time.</td>
</tr>
<tr>
<td><strong>Outside Machine Controlled Time</strong></td>
<td>The work which must be done outside the machine controlled time.</td>
</tr>
<tr>
<td><strong>Element Time</strong></td>
<td>The time spent on productive work elements.</td>
</tr>
<tr>
<td><strong>Excess Time</strong></td>
<td>The additional time caused by a deviation from the specified method or materials.</td>
</tr>
</tbody>
</table>
Ancillary Time
The remaining time which cannot be classified as productive or excess but is necessary for the completion of an operation.

Diverted Time
The time the worker is engaged on other operations.

Idle Time
The period of attendance time not spent working. It can take the form of relaxation or delays.

Relaxation Allowance
An additional time to the basic time intended to provide the worker the opportunity to recover from the physiological and psychological effects of carrying out work under specified conditions and to allow attention to personal needs.

Additional Relaxation
The time taken over and above the official relaxation when there is work available.

Delays
Periods of time when the operative is available for work but is prevented from doing so by the lack of work or materials.

External Delays
The delays caused by factors outside the operatives' control (e.g. waiting for concrete).

Internal Delays
The unavoidable delays which occur when an operative is working within a gang or with a machine.

Official Breaks
The time officially set aside for tea breaks but does not include lunch breaks.
<table>
<thead>
<tr>
<th>Extra Breaks</th>
<th>The periods during which the worker is not available for work owing to additional breaks, early finishes or late starts.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unrestricted Operation</strong></td>
<td>An operation in which the output is solely controlled by the operative (e.g. fixing reinforcement).</td>
</tr>
<tr>
<td><strong>Semi-restricted Operation</strong></td>
<td>An operation which can be affected by external delays (e.g. waiting for concrete).</td>
</tr>
<tr>
<td><strong>Restricted Operation</strong></td>
<td>An operation in which the output is affected by internal delays (e.g. waiting for an excavator to finish before laying pipes).</td>
</tr>
</tbody>
</table>
Figure 3.5 Proposed Build Up of Time Standards.
<p>| <strong>Element</strong> | A distinct part of a specified operation selected for convenience of observation and analysis. (Types: repetitive, occasional, constant, variable, manual, machine, governing, foreign). |
| <strong>Operation</strong> | A unit of work used for planning or control purposes based on a combination of elements. |
| <strong>Basic Element Time</strong> | The time required to perform an element of work at standard rate. |
| <strong>Basic Operation Time</strong> | The time required to complete an operation at standard rate. |
| <strong>Standard Rate</strong> | The average rate at which qualified workers will perform, so long as they are sufficiently motivated and carry out the work to the specified method. |
| <strong>Standard Time</strong> | The total time required to complete a job at standard performance. It includes basic time, contingency allowances and relaxation allowances. |
| <strong>Contingency Allowance</strong> | A small allowance of time which may be included in the total basic time to meet legitimate and expected items of work or delays. Their precise measurement is often uneconomical because of their infrequent or irregular occurrence. |</p>
<table>
<thead>
<tr>
<th><strong>Basic Excess Time</strong></th>
<th>This is the additional work caused by the deviation from the standard method and can be attributed to either the operation or the site. (e.g. the time spent carrying reinforcement which has been unloaded in the wrong area).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Ancillary Time</strong></td>
<td>This is the necessary work which is part of an operation (e.g. maintenance of plant), or site organization (e.g. walking to canteen) and cannot appropriately be classified as productive.</td>
</tr>
<tr>
<td><strong>Policy Allowance</strong></td>
<td>Under exceptional circumstances an additional allowance applied to the standard time in order to provide a satisfactory level of earnings.</td>
</tr>
</tbody>
</table>
Figure 8.2 Application of Site Factors to Basic Times
A.5 APPLICATION OF SITE FACTORS TO BASIC TIMES — FIGURE 8.2

(i) **Internal Delays (Interference)**
This is the time when the operative is prevented from working owing to the nature of the task. This is generally of a low order when dealing with construction operatives as there is invariably some other work available. Internal delays become significant when machines are involved and the operatives or machine have enforced idle periods.

(ii) **Work Rate Time**
The main cause of variation in work rate is the skill of the operative. As most operations occur on a regular basis and are performed by experienced workers there is generally little variation in rating levels. However, when an operation of a complex nature occurs, the variation can be very high because the operative is in a learning situation.

(iii) **External Delays**
These occur for a wide variety of reasons and are mainly caused by poor site organization. They often lie outside the control of the operations involved, for example waiting for materials.

(iv) **Relaxation**
When work is available the only viable reason for not doing it is the motivation of the operative. Official relaxation allowances are normally provided and can be taken during other periods of lost time.

(v) **Extra Breaks**
The periods during which the worker is not available for work owing to additional breaks, early finishes or late starts, and is related to low motivation but is within the control of site management.

(vi) **Official Breaks**
The periods officially allocated to tea breaks but does not include lunch breaks.
APPENDIX B

LISTING OF MINITAB PROGRAMS
B.1 PROGRAM 'ONE.MINEXEC'

B.1.1 PREPARE TOOLS

RETR 'data'
CONST
CORR C1-C17
ONeway C16 C2
ONeway C17 C2
ONeway C13 C2
ONeway C16 C12
ONeway C17 C12
ONeway C13 C12
OMIT '*' C3 C2, C63 C62
ONeway C63 C62
PLOT C3 C13
PLOT C3 C16
LPLOT C3 C13 C2
LPLOT C3 C16 C12
LPLOT C3 C13 C12
OMIT '*' C3 C2, C63 C62
ONeway C63 C62
CORR C3 C13
REgr C3 1 C13
MEAN C3
LPLOT C3 C16 C2
REgr C3 2 C13 C16
CORR C3 C13 C16
LET C30=C3/C13
OMIT '*' C30 C2, C90 C62
ONeway C90 C62
TABLE C2 C12;
DATA C3;
MEAN C3.
CHOOSE 1 C12 C3 C13, C21 C22 C23
PLOT C22 C23
REgr C22 1 C23
CHOOSE 3 C12 C3 C13, C21 C22 C23
PLOT C22 C23
REgr C22 1 C23
CHOOSE 4 C12 C3 C13, C21 C22 C23
PLOT C22 C23
REgr C22 1 C23
B.1.2 FOUR CONCRETE

RETR 'data'
CONST
CORR C4 C13
LPLOT C4 C13, C2
PLOT C4 C13
REGR C4 1 C13
LET C20=C4/C13
OMIT '*': C20 C2 , C80 C62
ONEWAY C80 C62
CHOOSE 2 C2 C4 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CORR C4 C13
LPLOT C4 C13, C12
PLOT C4 C13
REGR C4 1 C13
LET C20=C4/C13
OMIT '*': C20 C12 , C80 C72
ONEWAY C80 C72
CHOOSE 1 C12 C4 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CHOOSE 2 C12 C4 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CHOOSE 3 C12 C4 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CHOOSE 4 C12 C4 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
REDO 3 C12 2 C12
LET C20=C4/C13
OMIT '*': C20 C12 , C80 C72
ONEWAY C80 C72
CHOOSE 2 C12 C4 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CHOOSE 4 C12 C4 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
LET C22=C22/C30
LET C23=C23/C30
REGR C22 1 C23
PLOT C22 C23
B.1.3 VIBRATE CONCRETE

RETR 'data'
CONST
CORR C5 C13
L.PLOT C5 C13, C12
PLOT C5 C13
REGR C5 1 C13
LET C20=C5/C13
OMIT '*' C20 C12 , C80 C72
ONEWAY C80 C72
NOCO
CHOOSE 1 C12 C5 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CONS
REGR C22 1 C23
CHOOSE 2 C12 C5 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CHOOSE 3 C12 C5 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CHOOSE 4 C12 C5 C13, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
NOCO
REGR C22 1 C23
RECO 2 C12 , 3 C12
CHOOSE 3 C12 C5 C13, C21 C22 C23
CORR C22 C23
PLOT C22 C23
CONS
REGR C22 1 C23
NOCO
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
B.1.4 SHOVEL CONCRETE

RETR 'data'
CONST
CORR C6 C13 C16 C17
REGR C6 2 C16 C17
PLOT C6 C13
PLOT C6 C16
PLOT C6 C17
REGR C6 1 C16
LET C30 = C6/C16
OMIT 'a' C30 C12 , C90 C72
ONEWAY C90 C72

B.1.5 TAMP CONCRETE

RETR 'data'
CONST
CORR C7 C13 C16 C17
REGR C7 2 C16 C17
PLOT C7 C13
PLOT C7 C16
PLOT C7 C17
REGR C7 1 C16

B.1.6 TROWEL CONCRETE

RETR 'data'
CONST
CORR C8 C13 C16 C17
REGR C8 2 C16 C17
PLOT C8 C13
PLOT C8 C16
PLOT C8 C17
REGR C8 1 C16
RECO 0 C18 2 C18
WRITE C18
OMIT 'a' C8 C18 , C68 C78
ONEWAY C68 C78
LET C68 = C8/C16
OMIT 'a' C8 C18 , C68 C78
ONEWAY C68 C78
LPLOT C8 0 360 C13 0 80 C18
CHOOSE 1 C18 C8 C16 , C20 C21 C22
OMIT 1 C18 C8 C16 , C23 C24 C25
PLOT C21 C22
PLOT C24 C25
REGR C21 1 C22
REGR C24 1 C25
CORR C21 C22
CORR C24 C25
NOCO
REGR C24 1 C25
B.1.7 CLEAR TOOLS AWAY

RETR 'data'
CONST
CORR C10 C13 C16 C17
REGR C10 2 C16 C17
REGR C10 2 C13 C16
REGR C10 2 C13 C17
PLOT C10 C13
PLOT C10 C16
PLOT C10 C17
LET C40=C10/C13
OMIT '**' C10 C2, C70 C62
ONEWAY C70 C62
OMIT '**' C40 C2, C95 C62
ONEWAY C95 C62
OMIT '**' C40 C12, C95 C72
ONEWAY C95 C72
OMIT '**' C10 C12, C70 C72
ONEWAY C70 C72
LPLOT C10 C13 C2
LPLOT C10 C13 C12
RECO 1 2 C2 4 C2
CHOOSE 4 C2 C10 C13, C21 C22 C23
PLOT C22 C23
REGR C22 1 C23
CORR C22 C23
MEAN C2
CHOOSE 3 C2 C10 C13, C21 C22 C23
PLOT C22 C23
REGR C22 1 C23
CORR C22 C23
MEAN C2

B.1.8 COVER CONCRETE

RETR 'data'
CONST
CORR C11 C13 C16 C17
REGR C11 1 C16
REGR C11 2 C16 C17
REGR C11 2 C16 C13
LPLOT C11 C13 C12
LPLOT C11 C16 C12
LPLOT C11 C17 C12
LET C50=C11/C16
LPLOT C50 C17 C12
B.1.9 *GENERAL WORK*

RETR 'data'
PRINT C1-C17
CONST
CORR C9 C13 C16 C17
REGR C9 2 C16 C17
REGR C9 1 C16
PLOT C9 C13
PLOT C9 C16
PLOT C9 C17
LET C20=C9/C13
OMIT '*' C20 C2, C80 C62
ONEWAY C80 C62
OMIT '*' C9 C2, C69 C62
ONEWAY C69 C62
LLOT C9 0 90 C13 0 40, C2
RETR 'data'
CONST
RECO '*' C3 0 C3
RECO '*' C4 0 C4
RECO '*' C5 0 C5
RECO '*' C6 0 C6
RECO '*' C7 0 C7
RECO '*' C8 0 C8
RECO '*' C10 0 C10
RECO '*' C11 0 C11
LET C20=C4+C5+C6+C7+C8
LET C21=C3+C10+C11
LET C42=C20+C21
SUBS 525 10 C42
SUBS 605 21 C42
CORR C9 C20 C21 C42
PLOT C9 C20
PLOT C9 C21
PLOT C9 C42
REGR C9 2 C20 C21
LET C30=C9/C42
OMIT '*' C30 C2, C90 C62
ONEWAY C90 C62
LLLOT C9 C42 C2
LLLOT C9 0 80 C42 0 500, C2
REGR C9 1 C42
CORR C9 C42
REGR C9 1 C42
CORR C9 C42
LET C20=C9/C13
OMIT '*' C20 C2, C80 C62
ONEWAY C80 C62
CHOOSE 1 C2 C9 C42, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CHOOSE 2 C2 C9 C42, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
CHOOSE 3 C2 C9 C42, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23

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CHOOSE 4 C2 C9 C42, C21 C22 C23
REGR C22 1 C23
CORR C22 C23
PLOT C22 C23
RECO 3 C2 1 C2
RECO 4 C2 2 C2
OMIT '*' C30 C2, C90 C62
ONEWAY C90 C62
CHOOSE 1 C2 C9 C42, C31 C32 C33
PLOT C32 C33
REGR C32 1 C33
NOCO
REGR C32 1 C33
CONS
CORR C32 C33
CHOOSE 2 C2 C9 C42, C31 C32 C33
PLOT C32 C33
REGR C32 C33
NOCO
REGR C32 1 C33
CORR C32 C33
END

B.2 PROGRAM 'TEST1_MINEXEC'
RETR 'data'
NAME C1 'TEST'
NAME C2 'METHOD'
NAME C3 'PTOOLS'
NAME C4 'POUR'
NAME C5 'TIPRATE'
NAME C6 'SHOVEL'
NAME C7 'TAMP'
NAME C8 'TROWEL'
NAME C9 'GENERAL'
NAME C10 'CTOOLS'
NAME C11 'COVER'
NAME C12 'TYPE'
NAME C13 'VOLUME'
NAME C14 'WIDTH'
NAME C15 'LENGTH'
NAME C16 'AREA'
NAME C17 'DEPTH'
NAME C19 'SUB-TOTAL'
LET C20=C4+C5+C6+C7+C8
LET C21=C3+C10+C11
LET C22=C20+C21+C9
LET C19=C20+C21
LET C43=11.7+0.501*C13
LET C44=5.45+1.67*C13
LET C45=3.46*C13
LET C46=8.07+0.737*C16
LET C47=10.7+1.12*C16
LET C48=27.6+2.79*C16
LET C50=6.83+0.310*C13
LET C51=8.62+0.861*C13+0.202*C16
LET K5=1.1300
LET K6=1.0775
LET C52=16.10+1.18*C13
LET C53=4.79+9.65*C13
LET C54=5.69*C13
LET C55=22.8*C13
LET C56 = 9.37 + 0.5119 \times C13
LET C57 = 1.51 \times C16
LET C58 = 5.00
LET C59 = 13.2 + 0.8118 \times C13
LET C60 = 5.43 + 4.02 \times C13
RECO 1 2 C2 0 C36
RECO 3 C36 1 C36
RECO 4 C36 0 C36
RECO 3 C2 1 C37
RECO 2 4 C37 0 C37
LET C38 = C37 - 1
RECO 1 C12 0 C32
RECO 2 C12 0 C33
RECO 3 C12 0 C34
RECO 4 C12 0 C35
SIGN C32 C32
SIGN C33 C33
SIGN C34 C34
SIGN C35 C35
LET C32 = C32 - 1
LET C33 = C33 - 1
LET C34 = C34 - 1
LET C35 = C35 - 1
RECO -1 C32 1 C32
RECO -1 C33 1 C33
RECO -1 C34 1 C34
RECO -1 C35 1 C35
LET C44 = C44 \times C32 + C52 \times (C33 + C34) + C53 \times C35
LET C45 = C45 \times C32 + C54 \times (C33 + C34) + C55 \times C35
LET C48 = C48 \times C18 + C57 \times C68
LET C50 = (C50 + C56 \times C36)
LET C49 = K5 \times C37 + K6 \times C38
LET C70 = (C43 + C44 + C45 + C46 + C47 + C48 + C50 + C51) \times C49
LET C71 = C70 / C49
PLOT C3 C43
REGR C3 1 C43
CORR C3 C43
PLOT C4 C44
REGR C4 1 C44
CORR C4 C44
PLOT C5 C45
REGR C5 1 C45
CORR C5 C45
PLOT C6 C46
REGR C6 1 C46
CORR C6 C46
PLOT C7 C47
REGR C7 1 C47
CORR C7 C47
PLOT C8 C48
REGR C8 1 C48
CORR C8 C48
PLOT C9 C49
REGR C9 1 C49
CORR C9 C49
PLOT C10 C50
REGR C10 1 C50
CORR C10 C50
PLOT C11 C51
REGR C11 1 C51
CORR C11 C51
SAVE 'temp'
END
B.3  PROGRAM 'TEST2.MINEXEC'

RETR 'temp'
RECO 1 C3 0 C3
RECO 1 C4 0 C4
RECO 1 C5 0 C5
RECO 1 C6 0 C6
RECO 1 C7 0 C7
RECO 1 C8 0 C8
RECO 1 C10 0 C10
RECO 1 C11 0 C11
LET C20=C4+C5+C6+C7+C8
LET C21=C3+C10+C11
LET C22=C20+C21+C9
LET C19=C20+C21
SUBS 525 10 C19
SUBS 605 21 C19
LET C49=C19*(C49-1)
PLOT C9 C49
REGR C9 1 C49
CORR C9 C49
PRINT C9 C19 C37 C38
LET C49=(1.152*C19-8.63)*C37+(1.068*C19+4.00)*C38
LET C49=C49-C19
PLOT C9 C49
REGR C9 1 C49
CORR C9 C49
SAVE 'general'
END

B.4  PROGRAM 'TEST3.MINEXEC'

RETR 'temp'
NAME C19 'SUB'
NAME C22 'TOTAL'
SIGN C3 C23
SIGN C4 C24
SIGN C5 C25
SIGN C6 C26
SIGN C7 C27
SIGN C8 C28
SIGN C9 C29
SIGN C10 C30
SIGN C11 C31
RECO 0 C23 1 C23
RECO 0 C24 1 C24
RECO 0 C25 1 C25
RECO 0 C26 1 C26
RECO 0 C27 1 C27
RECO 0 C28 1 C28
RECO 0 C29 1 C29
RECO 0 C30 1 C30
RECO 0 C31 1 C31
RECO 1 C23 0 C23
RECO 1 C24 0 C24
RECO 1 C25 0 C25
RECO 1 C26 0 C26
RECO 1 C27 0 C27
RECO 1 C28 0 C28

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RECO * C23 0 C29
RECO * C30 0 C30
RECO * C31 0 C31
LET C43=C43*C23
LET C44=C44*C24
LET C45=C45*C25
LET C46=C46*C26
LET C47=C47*C27
LET C48=C48*C28
LET C49=C49*C29
LET C50=C50*C30
LET C51=C51*C31
LET C71=C43+C44+C45+C46+C47+C48+C50+C51
LET C70=(1.152*C71-8.63)*C37+(1.068*C71+4.00)*C38
LET C49=C70-C71
RECO * C3 0 C3
RECO * C4 0 C4
RECO * C5 0 C5
RECO * C6 0 C6
RECO * C7 0 C7
RECO * C8 0 C8
RECO * C10 0 C10
RECO * C11 0 C11
LET C20=C4+C5+C6+C7+C8
LET C21=C3+C10+C11
LET C22=C20+C21+C9
SUBS * 10 C22
SUBS * 21 C22
LET C19=C20+C21
PLOT C22 C70
CORR C22 C70
PLOT C22 0 600 C70 0 600
LLOT C22 0 600 C70 0 600 C2
LLOT C22 0 600 C70 0 600 C12
REGR C22 1 C70
NOCO
REGR C22 1 C70
PLOT C19 C71
CORR C19 C71
PLOT C19 0 600 C71 0 600
LLOT C19 0 600 C71 0 600 C2
LLOT C19 0 600 C71 0 600 C12
REGR C19 1 C71
CONS
REGR C19 1 C71
PRINT C19 C71 C22 C70 C37 C38
END
B.5  PROGRAM 'TEST.MINEXEC'

RETR 'temp'
NAME C19 'SUB'
NAME C22 'TOTAL'
SIGN C3 C23
SIGN C4 C24
SIGN C5 C25
SIGN C6 C26
SIGN C7 C27
SIGN C8 C28
SIGN C9 C29
SIGN C10 C30
SIGN C11 C31
RECO 0 C23 1 C23
RECO 0 C24 1 C24
RECO 0 C25 1 C25
RECO 0 C26 1 C26
RECO 0 C27 1 C27
RECO 0 C28 1 C28
RECO 0 C29 1 C29
RECO 0 C30 1 C30
RECO 0 C31 1 C31
RECO 0 C23 0 C23
RECO 0 C24 0 C24
RECO 0 C25 0 C25
RECO 0 C26 0 C26
RECO 0 C27 0 C27
RECO 0 C28 0 C28
RECO 0 C29 0 C29
RECO 0 C30 0 C30
RECO 0 C31 0 C31
LET C43=C43*C23
LET C44=C44*C24
LET C45=C45*C25
LET C46=C46*C26
LET C47=C47*C27
LET C48=C48*C28
LET C49=C49*C29
LET C50=C50*C30
LET C51=C51*C31
LET C71=C43+C44+C45+C46+C47+C48+C50+C51
LET C70=1.130*C71*C37+1.0775*C71*C38
LET C49=C70-C71
RECO 0 C3 0 C3
RECO 0 C4 0 C4
RECO 0 C5 0 C5
RECO 0 C6 0 C6
RECO 0 C7 0 C7
RECO 0 C8 0 C8
RECO 0 C10 0 C10
RECO 0 C11 0 C11
LET C20=C4+C5+C6+C7+C8
LET C21=C3+C10+C11
LET C22=C20+C21+C9
SUBS 0 10 C22
SUBS 21 C22
LET C19=C20+C21
PLOT C22 C70
CORR C22 C70
PLOT C22 0 600 C70 0 600
LPLT C22 0 600 C70 0 600 C2
LPLT C22 0 600 C70 0 600 C12
REGR C22 1 C70
NOCO
REGR C22 1 C70
PLOT C19 C71
CORR C19 C71
PLOT C19 0 600 C71 0 600
LPLT C19 0 600 C71 0 600 C2
LPLT C19 0 600 C71 0 600 C12
REGR C19 1 C71
CONS
REGR C19 1 C71
PRINT C19 C71 C22 C70 C37 C38
END
APPENDIX C

BASIC OPERATION TIMES FOR CONCRETE GANGS
APPENDIX C

BASIC OPERATION TIMES FOR CONCRETE GANGS

C.1 INTRODUCTION

In this appendix, basic operation times are presented for the concrete operatives. The data for slabs, beams, walls and columns are presented separately, taking into account the method of placement.

The relevant equations, for example those relating to slabs, are selected from the generalized concrete model and presented under the following headings:

(a) Fixed Activities;
(b) Variable Activities;
(c) Method Related Activities.

These equations are used to determine basic times for most concreting operations. In order to simplify the equations, certain aspects relating to the variable activities were assumed, for example, all pours were taken to be covered. The times required to clean the shutters prior to concrete placement are also included.

The basic operation times, based on the simplified equations, and a description of each operation are presented under the following headings:

(a) Operational Statement;
(b) Method Statement;
(c) Method Description;
(d) Materials and Tools Required;
(e) Basic Operation Times (Tables);
(f) Operational Information (Diagrams).
C.2 BASIC OPERATION TIMES FOR CONCRETE SLABS

The following equations, obtained from the generalized concrete model presented in Table 5.4, can be used to calculate the basic operation times for concreting slabs.

(1) Fixed Activities

CLEAN = 0.00 + 1.000 x A
PRTOOLS = 11.70 + 0.501 x V
POUR = 5.45 + 1.670 x V
SHOVEL = 8.07 + 0.737 x A
TAMP = 10.70 + 1.120 x A
CLEAR = 6.83 + 0.310 x V

TOTAL = 42.75 + 2.481 x V + 2.857 x A

(ii) Variable Activities

VIBRATE = 3.46 x V
TROVEL = 27.6 + 2.790 x A
TROVEL = 1.510 x A
COVER = 8.62 + 0.861 x V + 0.202 x A

(iii) Method Related Activities

CLEAR = 9.37 + 0.549 x V
GENERAL = 0.1300 x C42
GENERAL = 0.0775 x C42

When V = VOLUME
A = AREA
C42 = SUM OF OTHER ACTIVITIES

If a concrete slab requires vibrating, trowelling once and covering, the basic operation time can be obtained by applying one of the following equations.

BASIC TIME = (51.4 + 6.81V + 4.57A) x 1.0775 DIRECT
BASIC TIME = (51.4 + 6.81V + 4.57A) x 1.130 SKIP
BASIC TIME = (60.7 + 7.36V + 4.57A) x 1.0775 PUMP
C.2.1 Concrete Slabs Poured Using a Crane and Skip

(i) Operation

Pour concrete into a slab using a crane and skip.

(ii) Method

The two main items of work within this operation are the transportation of concrete by the crane and subsequent placement by the concrete gang.

(iii) Method Description: Concrete Gang

One man cleans the shutters before the rest of the gang arrives. The tools and work area are prepared before the crane begins to transport the concrete. The concrete is trowelled as work progresses, but it is not covered until all the other activities have been completed.

(iv) Materials and Tools Required

(a) Shovel
(b) Vibrator (+1 on standby)
(c) Trowel
(d) Tamp
(e) Rake
(f) Knee Pads
(g) Covers
(h) Compressor
(i) Crane
(j) Skip

(v) Basic Operation Times

The basic operation times, presented in Table C1, are for concrete slabs which require vibrating, trowelling once and covering.

<table>
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<th>Vol. (m³)</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
<th>350</th>
<th>400</th>
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<td>165</td>
<td>140</td>
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<td>120</td>
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<td>269</td>
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<td>200</td>
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<td>485</td>
<td>430</td>
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<td>690</td>
<td>570</td>
<td>510</td>
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<td>1745</td>
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<td>955</td>
<td>882</td>
<td>780</td>
<td>641</td>
<td>570</td>
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</tbody>
</table>
Figure C1: OPERATIONAL INFORMATION.

Method Statement:
The placement of concrete into a slab using a crane and skip for site transportation.

Fetch and prepare tools.
Clean shutters with airline.
Soak deck with water.

Pour concrete into skip.

Pour concrete into slab.

Vibrate concrete.
Shovel concrete.

Tamp concrete.
On wide pours internal tamp supports have to be removed.
Trowel finish slab. This is sometimes omitted or done twice.

Cover and protect slab from weather.

Clean and remove tools.
C.2.2 Concrete Slabs Poured Using Mobile or Static Pumps

(i) Operation

This operation involves pouring concrete slabs using either a mobile or static pump.

(ii) Method

The two main items of work within this operation are the pumping and subsequent placement by the concrete gang.

(iii) Method Description: Concrete Gang

One man cleans the shutters before the rest of the gang arrives. The tools and work area are prepared before starting to pump the concrete. The concrete is trowelled as work progresses, but is not covered until all the other activities have been completed.

(iv) Materials and Tools Required

(a) Shovel
(b) Vibrator (+1 on standby)
(c) Trowel
(d) Tamp
(e) Rake
(f) Knee Pads
(g) Covers
(h) Compressor
(i) Concrete Pump

(v) Basic Operation Times

The basic times presented in Table C2 are for concrete slabs which require vibrating, trowelling once and covering.

<table>
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<th>Vol. Cu.m.</th>
<th>100</th>
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<th>200</th>
<th>250</th>
<th>300</th>
<th>350</th>
<th>400</th>
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<td>945</td>
<td>875</td>
<td>775</td>
<td>645</td>
<td>580</td>
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</table>
**Figure C2: OPERATIONAL INFORMATION.**

**Method Statement:**
The placement of concrete into a slab by either static or mobile pumps.

- Fetch and prepare tools.
- Clean shutters with airline.
- Soak deck with water.
- Pour concrete into pump.
- Pour concrete into slab.
- Vibrate concrete.
- Shovel concrete.
- Tamp concrete. On wide pours internal tamp supports have to be removed.
- Trowel finish slab. This is sometimes omitted or done twice.
- Cover and protect slab from weather.
- Clean and remove tools.
C.2.3 Concrete Slabs Poured Directly from a Lorry

(i) Operation

Concrete is poured directly into a slab from ready-mix lorry.

(ii) Method

The two main items of work within this operation are the direct pouring of concrete and subsequent placement by the concrete gang.

(iii) Method Description: Concrete Gang

One man cleans the shutters before the rest of the gang arrives. The tools and work area are prepared before starting to pump the concrete. The concrete is trowelled as work progresses, but is not covered until all the other activities have been completed.

(iv) Materials and Tools Required

(a) Shovel
(b) Vibrator (+1 on standby)
(c) Trowel
(d) Tamp
(e) Rake
(f) Knee Pads
(g) Covers
(h) Compressor

Basic Operation Times

The basic times presented in Table C3 are for concrete slabs which require vibrating, trowelling once and covering.

Table C3 Basic Operation Times (mins.)

<table>
<thead>
<tr>
<th>Vol. Cu.m.</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
<th>350</th>
<th>400</th>
<th>500</th>
<th>750</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>195</td>
<td>155</td>
<td>135</td>
<td>120</td>
<td>115</td>
<td>110</td>
<td>105</td>
<td>100</td>
<td>90</td>
<td>85</td>
</tr>
<tr>
<td>5.0</td>
<td>338</td>
<td>256</td>
<td>215</td>
<td>190</td>
<td>175</td>
<td>165</td>
<td>155</td>
<td>140</td>
<td>125</td>
<td>115</td>
</tr>
<tr>
<td>10.0</td>
<td>621</td>
<td>457</td>
<td>375</td>
<td>325</td>
<td>290</td>
<td>270</td>
<td>250</td>
<td>230</td>
<td>195</td>
<td>180</td>
</tr>
<tr>
<td>15.0</td>
<td>904</td>
<td>660</td>
<td>535</td>
<td>460</td>
<td>410</td>
<td>375</td>
<td>350</td>
<td>315</td>
<td>265</td>
<td>240</td>
</tr>
<tr>
<td>20.0</td>
<td>1187</td>
<td>860</td>
<td>695</td>
<td>595</td>
<td>530</td>
<td>485</td>
<td>450</td>
<td>400</td>
<td>335</td>
<td>300</td>
</tr>
<tr>
<td>25.0</td>
<td>1470</td>
<td>1060</td>
<td>855</td>
<td>730</td>
<td>650</td>
<td>590</td>
<td>545</td>
<td>485</td>
<td>405</td>
<td>360</td>
</tr>
<tr>
<td>30.0</td>
<td>1755</td>
<td>1260</td>
<td>1015</td>
<td>865</td>
<td>770</td>
<td>695</td>
<td>645</td>
<td>570</td>
<td>470</td>
<td>425</td>
</tr>
<tr>
<td>35.0</td>
<td>2035</td>
<td>1460</td>
<td>1174</td>
<td>1000</td>
<td>885</td>
<td>805</td>
<td>740</td>
<td>655</td>
<td>540</td>
<td>485</td>
</tr>
<tr>
<td>40.0</td>
<td>2320</td>
<td>1660</td>
<td>1335</td>
<td>1135</td>
<td>1065</td>
<td>910</td>
<td>840</td>
<td>740</td>
<td>610</td>
<td>545</td>
</tr>
</tbody>
</table>
**Method Statement:**
The direct placement of concrete into a slab from a ready-mix lorry.

- Fetch and prepare tools.
- Clean shutters with airline.
- Soak deck with water.
- Pour concrete into slab.
- Vibrate concrete.
- Shovel concrete.
- Tamp concrete. On wide pours internal tamp supports have to be removed.
- Trowel finish beam. This is sometimes omitted or done twice.
- Cover and protect slab from weather.
- Clean and remove tools.
C.3 BASIC OPERATION TIMES FOR CONCRETE BEAMS

The following equations, derived from the generalized concrete model presented in Table 5.4, can be used to calculate the basic operation times for concreting beams.

(i) Fixed Activities

CLean = 5.00 + 1.500 x V
FR Tools = 11.70 + 0.501 x V
Pour = 16.10 + 1.180 x V
Shovel = 8.07 + 0.737 x A
Tamp = 10.70 + 1.120 x A
Clear = 6.83 + 0.310 x V

Total = 58.40 + 3.491 x V + 1.857 x A

(ii) Variable Activities

Vibrate = 5.69 x V
Trowel = 27.6 + 2.790 x A
Trowel = 1.510 x A
Cover = 8.62 + 0.861 x V + 0.202 x A

(iii) Method Related Activities

Clear = 9.37 + 0.549 x V
General = 0.1300 x C42
General = 0.0775 x C42

When V = VOLUME
A = AREA
C42 = SUM OF OTHER ACTIVITIES

If a concrete beam requires vibrating, trowelling once and covering, the operation basic time can be obtained by applying one of the following equations.

BASIC TIME = (67.0 + 10.04V + 3.57A) x 1.0775 DIRECT
BASIC TIME = (67.0 + 10.04V + 3.57A) x 1.130 SKIP
BASIC TIME = (76.4 + 10.59V + 3.57A) x 1.0775 PUMP
C.3.1 Concrete Beams Poured Using a Crane and Skip

(i) Operation

This operation involves pouring concrete into beams, using a crane and skip.

(ii) Method

The two main items of work within this operation are the transportation of concrete by the crane and subsequent placement by the concrete gang.

(iii) Method Description: Concrete Gang

One man cleans the shutters before the rest of the gang arrives. The tools and work area are prepared before the crane begins to transport the concrete. The concrete is trowelled as work progresses but is not covered until all the other activities have been completed.

(iv) Materials and Tools Required

(a) Shovel
(b) Vibrator (+1 on standby)
(c) Trowel
(d) Tamp
(e) Rake
(f) Knee Pads
(g) Covers
(h) Compressor
(i) Crane
(j) Skip

(v) Basic Operation Times

The basic operation times, presented in Table C4, are for concrete beams which require vibrating, trowelling once and covering.

<table>
<thead>
<tr>
<th>Vol. (Cu.m)</th>
<th>Area (Sq. m.)</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
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<tr>
<td>2</td>
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<td>106</td>
<td>115</td>
<td>125</td>
<td>130</td>
<td>140</td>
<td>160</td>
<td>180</td>
<td>200</td>
<td>220</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>130</td>
<td>135</td>
<td>145</td>
<td>155</td>
<td>160</td>
<td>180</td>
<td>200</td>
<td>220</td>
<td>240</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>150</td>
<td>160</td>
<td>170</td>
<td>175</td>
<td>185</td>
<td>205</td>
<td>225</td>
<td>245</td>
<td>265</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>175</td>
<td>185</td>
<td>190</td>
<td>200</td>
<td>205</td>
<td>225</td>
<td>245</td>
<td>270</td>
<td>285</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>195</td>
<td>205</td>
<td>215</td>
<td>220</td>
<td>230</td>
<td>250</td>
<td>270</td>
<td>290</td>
<td>310</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>220</td>
<td>230</td>
<td>235</td>
<td>245</td>
<td>250</td>
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<td>335</td>
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<tr>
<td>14</td>
<td></td>
<td>245</td>
<td>250</td>
<td>260</td>
<td>265</td>
<td>275</td>
<td>295</td>
<td>315</td>
<td>335</td>
<td>355</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>265</td>
<td>275</td>
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<td>290</td>
<td>300</td>
<td>320</td>
<td>340</td>
<td>360</td>
<td>380</td>
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<tr>
<td>18</td>
<td></td>
<td>290</td>
<td>295</td>
<td>305</td>
<td>310</td>
<td>320</td>
<td>340</td>
<td>360</td>
<td>380</td>
<td>400</td>
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<tr>
<td>20</td>
<td></td>
<td>310</td>
<td>320</td>
<td>325</td>
<td>335</td>
<td>345</td>
<td>365</td>
<td>385</td>
<td>405</td>
<td>425</td>
</tr>
</tbody>
</table>
Method Statement:
The placement of concrete into a beam using a crane and skip for site transportation.

Fetch and prepare tools.
Clean shutters with airline.
Soak beam with water.

Pour concrete into skip.
Pour concrete into beam.

Vibrate concrete.
Shovel concrete.

Tamp concrete.
On wide pours internal tamp supports have to be removed.

Trowel finish beam.
This is sometimes omitted or done twice.

Cover and protect beam from weather.

Clean and remove tools.
C.3.2 Concrete Beams Poured Using Mobile or Static Pumps

(i) Operation

This operation involves pouring concrete beams, using either a mobile or static pump.

(ii) Method

The two main items of work within this operation are the pumping of concrete and subsequent placement by the concrete gang.

(iii) Method Description: Concrete Gang

One man cleans the shutters before the rest of the gang arrives. The tools and work area are prepared before starting to pump the concrete. The concrete is trowelled as work progresses, but is not covered until all the other activities have been completed.

(iv) Materials and Tools Required

(a) Shovel
(b) Vibrator (+1 on standby)
(c) Trowel
(d) Tamp
(e) Rake
(f) Knee Pads
(g) Covers
(h) Compressor
(i) Concrete Pump

(v) Basic Operation Times

The basic operation times, presented in Table C5, are for concrete beams which require vibrating, trowelling once and covering.

<table>
<thead>
<tr>
<th>Cu.m</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
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<td>2</td>
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<td>120</td>
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<td>135</td>
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<td>180</td>
<td>200</td>
<td>220</td>
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<tr>
<td>4</td>
<td>135</td>
<td>145</td>
<td>150</td>
<td>160</td>
<td>165</td>
<td>185</td>
<td>205</td>
<td>225</td>
<td>245</td>
</tr>
<tr>
<td>6</td>
<td>160</td>
<td>165</td>
<td>175</td>
<td>180</td>
<td>190</td>
<td>210</td>
<td>230</td>
<td>250</td>
<td>270</td>
</tr>
<tr>
<td>8</td>
<td>180</td>
<td>190</td>
<td>195</td>
<td>205</td>
<td>210</td>
<td>230</td>
<td>250</td>
<td>270</td>
<td>290</td>
</tr>
<tr>
<td>10</td>
<td>205</td>
<td>210</td>
<td>220</td>
<td>230</td>
<td>235</td>
<td>255</td>
<td>275</td>
<td>295</td>
<td>315</td>
</tr>
<tr>
<td>12</td>
<td>225</td>
<td>235</td>
<td>240</td>
<td>250</td>
<td>260</td>
<td>275</td>
<td>295</td>
<td>315</td>
<td>335</td>
</tr>
<tr>
<td>14</td>
<td>250</td>
<td>260</td>
<td>265</td>
<td>275</td>
<td>280</td>
<td>300</td>
<td>320</td>
<td>340</td>
<td>360</td>
</tr>
<tr>
<td>16</td>
<td>275</td>
<td>280</td>
<td>290</td>
<td>295</td>
<td>305</td>
<td>325</td>
<td>340</td>
<td>360</td>
<td>380</td>
</tr>
<tr>
<td>18</td>
<td>295</td>
<td>305</td>
<td>310</td>
<td>320</td>
<td>325</td>
<td>345</td>
<td>365</td>
<td>385</td>
<td>405</td>
</tr>
<tr>
<td>20</td>
<td>320</td>
<td>325</td>
<td>335</td>
<td>340</td>
<td>350</td>
<td>370</td>
<td>385</td>
<td>405</td>
<td>425</td>
</tr>
</tbody>
</table>

Table C5: Basic Operation Times (mins.)
**Figure 05: OPERATIONAL INFORMATION.**

**Method Statement:**
The placement of concrete into a beam by either static or mobile pumps.

<table>
<thead>
<tr>
<th>Fetch and prepare tools.</th>
<th>Clean shutters with airline.</th>
<th>Soak beam with water.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pour concrete into pump.</td>
<td>Pour concrete into beam.</td>
<td>Vibrate concrete.</td>
</tr>
<tr>
<td>Shovel concrete.</td>
<td></td>
<td>Tamp concrete.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trowel finish beam.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>This is sometimes omitted or done twice.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cover and protect beam from weather.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clean and remove tools.</td>
</tr>
</tbody>
</table>
C.3.3 **Concrete Beams Poured Directly from a Lorry**

(i) **Operation**

Concrete is poured directly into a beam from ready-mix lorry.

(ii) **Method**

The two main items of work within this operation are the direct pouring of concrete and subsequent placement by the concrete gang.

(iii) **Method Description: Concrete Gang**

One man cleans the shutters before the rest of the gang arrives. The tools and work area are prepared before starting to pump the concrete. The concrete is trowelled as work progresses, but is not covered until all the other activities have been completed.

(iv) **Materials and Tools Required**

(a) Shovel  
(b) Vibrator (+1 on standby)  
(c) Trowel  
(d) Tamp  
(e) Rake  
(f) Knee Pads  
(g) Covers  
(h) Compressor

(v) **Basic Operation Times**

The basic operation times, presented in Table C6, are for concrete beams which require vibrating, trowelling once and covering.

<table>
<thead>
<tr>
<th>Cu.m</th>
<th>Area (Sq. m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>123</td>
</tr>
<tr>
<td>6</td>
<td>145</td>
</tr>
<tr>
<td>8</td>
<td>165</td>
</tr>
<tr>
<td>10</td>
<td>190</td>
</tr>
<tr>
<td>12</td>
<td>210</td>
</tr>
<tr>
<td>14</td>
<td>230</td>
</tr>
<tr>
<td>16</td>
<td>250</td>
</tr>
<tr>
<td>18</td>
<td>275</td>
</tr>
<tr>
<td>20</td>
<td>295</td>
</tr>
</tbody>
</table>
**Method Statement:**
The direct placement of concrete into a beam from a ready-mix lorry.

- Fetch and prepare tools.
- Clean shutters with airline.
- Soak beam with water.

- Pour concrete into beam.
- Vibrate concrete.
- Shovel concrete.

- Tamp concrete.
  On wide pours internal tamp supports have to be removed.

- Trowel finish beam.
  This is sometimes omitted or done twice.

- Cover and protect beam from weather.
- Clean and remove tools.
C.4 BASIC OPERATION TIMES FOR CONCRETE WALLS

The following equations, obtained from the generalized concrete model presented in Table 5.4, can be used to calculate the basic operation times for concreting walls.

(i) **Fixed Activities**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEAN</td>
<td>$5.00 + 1.500 \times V$</td>
</tr>
<tr>
<td>PRTOOLS</td>
<td>$11.70 + 0.501 \times V$</td>
</tr>
<tr>
<td>POOR</td>
<td>$16.10 + 1.180 \times V$</td>
</tr>
<tr>
<td>SHOVEL</td>
<td>$8.07 + 0.737 \times A$</td>
</tr>
<tr>
<td>TAMPA</td>
<td>$10.70 + 1.120 \times A$</td>
</tr>
<tr>
<td>CLEAR</td>
<td>$6.83 + 0.310 \times V$</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$58.40 + 3.491 \times V + 1.857 \times A$</td>
</tr>
</tbody>
</table>

(ii) **Variable Activities**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIBRATE</td>
<td>$5.69 \times V$</td>
</tr>
<tr>
<td>TROWEL</td>
<td>$27.6 + 2.790 \times A$</td>
</tr>
<tr>
<td>DOUBLE TROWEL</td>
<td></td>
</tr>
<tr>
<td>TROWEL</td>
<td>$1.510 \times A$</td>
</tr>
<tr>
<td>SINGLE TROWEL</td>
<td></td>
</tr>
<tr>
<td>COVER</td>
<td>$8.62 + 0.861 \times V + 0.202 \times A$</td>
</tr>
</tbody>
</table>

(iii) **Method Related Activities**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEAR</td>
<td>$9.37 + 0.549 \times V$</td>
</tr>
<tr>
<td>GENERAL</td>
<td>$0.1300 \times C42$</td>
</tr>
<tr>
<td>GENERAL</td>
<td>$0.0775 \times C42$</td>
</tr>
<tr>
<td>PUMP</td>
<td>$0.1300 \times \text{SUM OF OTHER ACTIVITIES}$</td>
</tr>
<tr>
<td>SKIP</td>
<td>$0.0775 \times \text{SUM OF OTHER ACTIVITIES}$</td>
</tr>
</tbody>
</table>

When \( V = \text{VOLUME} \)

A = \text{AREA}

C42 = \text{SUM OF OTHER ACTIVITIES}

If a concrete wall requires vibrating, trowelling once and covering, the basic operation times can be obtained by applying one of the following equations.

\[
\text{BASIC TIME} = (67.0 + 10.04V + 3.57A) \times 1.0775 \quad \text{DIRECT}
\]

\[
\text{BASIC TIME} = (67.0 + 10.04V + 3.57A) \times 1.130 \quad \text{SKIP}
\]

\[
\text{BASIC TIME} = (76.4 + 10.59V + 3.57A) \times 1.0775 \quad \text{PUMP}
\]
C.4.1 **Concrete Walls Poured Using a Crane and Skip**

(i) **Operation**

This operation involves pouring concrete into walls, using a crane and skip.

(ii) **Method**

The two main items of work within this operation are the transportation of concrete by the crane and subsequent placement by the concrete gang.

(iii) **Method Description: Concrete Gang**

One man cleans the shutters before the rest of the men arrive. The tools and work area are prepared before the crane begins to transport the concrete. The concrete is trowelled as work progresses, but is not covered until all the other activities have been completed.

(iv) **Materials and Tools Required**

(a) Shovel  
(b) Vibrator (+1 on standby)  
(c) Trowel  
(d) Tamp  
(e) Rake  
(f) Knee Pads  
(g) Covers  
(h) Compressor  
(i) Crane  
(j) Skip

(v) **Basic Operation Times**

The basic operation times, presented in Table C7, are for concrete walls which require vibrating, trowelling once and covering.

**Table C7 Basic Operation Times (mins.)**

<table>
<thead>
<tr>
<th>Volume (Cu.m.)</th>
<th>Area (Sq. m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>2.0</td>
<td>100</td>
</tr>
<tr>
<td>2.5</td>
<td>105</td>
</tr>
<tr>
<td>3.0</td>
<td>110</td>
</tr>
<tr>
<td>4.0</td>
<td>125</td>
</tr>
<tr>
<td>5.0</td>
<td>134</td>
</tr>
<tr>
<td>7.5</td>
<td>160</td>
</tr>
<tr>
<td>10.0</td>
<td>190</td>
</tr>
<tr>
<td>15.0</td>
<td>245</td>
</tr>
<tr>
<td>20.0</td>
<td>305</td>
</tr>
<tr>
<td>25.0</td>
<td>360</td>
</tr>
</tbody>
</table>
Method Statement:
The placement of concrete into a wall using a crane and skip for site transportation.

Fetch and prepare tools.
Clean shutters with airline.
Soak wall with water.

Pour concrete into skip.
Pour concrete into wall.

Vibrate concrete.
Shovel concrete.

Tamp concrete.
On wide pours internal tamp supports have to be removed.
Trowel finish wall.
This is sometimes omitted or done twice.

Cover and protect wall from weather.

Clean and remove tools.
C.4.2 **Concrete Walls Poured Using Mobile or Static Pumps**

(i) **Operation**

This operation involves pouring concrete walls using either a mobile or static pump.

(ii) **Method**

The two main items of work within this operation are the pumping of concrete and subsequent placement by the concrete gang.

(iii) **Method Description: Concrete Gang**

One man cleans the shutters before the rest of the gang arrives. The tools and work area are prepared before starting to pump the concrete. The concrete is trowelled as work progresses, but is not covered until all the other activities have been completed.

(iv) **Materials and Tools Required**

(a) Shovel  
(b) Vibrator (+1 on standby)  
(c) Trowel  
(d) Tamp  
(e) Rake  
(f) Knee Pads  
(g) Covers  
(h) Compressor  
(i) Concrete Pump

(v) **Basic Operation Times**

The basic operation times, presented in Table C8, are for concrete walls which require vibrating, trowelling once and covering.

<table>
<thead>
<tr>
<th>Volume (Cu.m.)</th>
<th>Area (Sq. m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>2.0</td>
<td>105</td>
</tr>
<tr>
<td>2.5</td>
<td>110</td>
</tr>
<tr>
<td>3.0</td>
<td>120</td>
</tr>
<tr>
<td>4.0</td>
<td>130</td>
</tr>
<tr>
<td>5.0</td>
<td>140</td>
</tr>
<tr>
<td>7.5</td>
<td>170</td>
</tr>
<tr>
<td>10.0</td>
<td>200</td>
</tr>
<tr>
<td>15.0</td>
<td>255</td>
</tr>
<tr>
<td>20.0</td>
<td>310</td>
</tr>
<tr>
<td>25.0</td>
<td>370</td>
</tr>
</tbody>
</table>
Method Statement:
The placement of concrete into a wall by either static or mobile pumps.

Fetch and prepare tools.
Clean shutters with airline.
Soak wall with water.

Pour concrete into pump.

Pour concrete into wall.

Vibrate concrete.
Shovel concrete.

Tamp concrete.
On wide pours internal tamp supports have to be removed.

Trowel finish wall.
This is sometimes omitted or done twice.

Cover and protect wall from weather.

Clean and remove tools.
C.5 BASIC OPERATION TIMES FOR CONCRETE COLUMNS

The following equations, obtained from the generalized concrete model presented in Table 5.4, can be used to calculate the basic operation times for concreting columns.

(i) **Fixed Activities**

- CLEAN = \(5.00 + 1.500 \times V\)
- PROTOLLS = \(11.70 + 0.501 \times V\)
- POUR = \(4.79 + 9.650 \times V\)
- SHOVEL = \(8.07 + 0.737 \times A\)
- TAM\(P =\) \(10.70 + 1.120 \times A\)
- CLEAR = \(6.83 + 0.310 \times V\)

\[ \text{TOTAL} = 47.09 + 11.96 \times V + 1.857 \times A \]

(ii) **Variable Activities**

- VIBRATE = \(22.80 \times V\)
- TROWEL = \(27.60 + 2.790 \times A\)
  - DOUBLE TROWEL
- TROWEL = \(1.510 \times A\)
  - SINGLE TROWEL
- COVER = \(8.62 + 0.861 \times V + 0.202 \times A\)

(iii) **Method Related Activities**

- CLEAR = \(9.37 + 0.549 \times V\)
  - PUMP
- GENERAL = \(0.1300 \times C_{42}\)
  - SKIP
- GENERAL = \(0.0775 \times C_{42}\)
  - DIRECT OR PUMP

When \(V = \text{VOLUME}\)

\(A = \text{AREA}\)

\(C_{42} = \text{SUM OF OTHER ACTIVITIES}\)

For concrete columns which require vibrating, trowelling once and covering, the basic operation times can be obtained by applying one of the following equations.

\[ \text{BASIC TIME} = (55.7 + 35.62V + 3.57A) \times 1.0775 \]  DIRECT

\[ \text{BASIC TIME} = (55.7 + 35.62V + 3.57A) \times 1.130 \]  SKIP

\[ \text{BASIC TIME} = (65.1 + 36.17V + 3.57A) \times 1.0775 \]  PUMP
C.5.1 Concrete Columns Poured Using a Crane and Skip

(i) Operation

This operation involves pouring concrete into columns, using a crane and skip.

(ii) Method

The two main items of work within this operation are the transportation of concrete by the crane and subsequent placement by the concrete gang.

(iii) Method Description: Concrete Gang

One man cleans the shutters before the rest of the gang arrives. The tools and work area are prepared before the crane begins to transport the concrete. The concrete is trowelled as work progresses, but is not covered until all the other activities have been completed.

(iv) Materials and Tools Required

(a) Shovel
(b) Vibrator (+1 on standby)
(c) Trowel
(d) Tamp
(e) Rake
(f) Knee Pads
(g) Covers
(h) Compressor
(i) Crane
(j) Skip

(v) Basic Operation Times

The basic operation times, presented in Table C9, are for concrete columns which require vibrating, trowelling once and covering.

Table C9 Basic Operation Times (mins.)

<table>
<thead>
<tr>
<th>Volume Cu. m.</th>
<th>First Pour</th>
<th>Subsequent Pours</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>85</td>
<td>70</td>
</tr>
<tr>
<td>0.75</td>
<td>95</td>
<td>80</td>
</tr>
<tr>
<td>1.00</td>
<td>105</td>
<td>90</td>
</tr>
<tr>
<td>1.50</td>
<td>125</td>
<td>110</td>
</tr>
<tr>
<td>2.00</td>
<td>145</td>
<td>130</td>
</tr>
<tr>
<td>2.50</td>
<td>165</td>
<td>150</td>
</tr>
<tr>
<td>3.00</td>
<td>185</td>
<td>170</td>
</tr>
<tr>
<td>3.50</td>
<td>205</td>
<td>190</td>
</tr>
<tr>
<td>4.00</td>
<td>225</td>
<td>210</td>
</tr>
<tr>
<td>4.50</td>
<td>245</td>
<td>230</td>
</tr>
</tbody>
</table>
**Figure C9: OPERATIONAL INFORMATION.**

**Method Statement:**
The placement of concrete into a column using a crane and skip for site transportation.

<table>
<thead>
<tr>
<th>Action</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetch and prepare tools.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Clean shutters with airline.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Soak column with water.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Pour concrete into skip.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Pour concrete into column.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Vibrate concrete.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Shovel concrete.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Tamp concrete.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Trowel finish column. This is sometimes omitted or done twice.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Cover and protect column from weather.</td>
<td>![Image]</td>
</tr>
<tr>
<td>Clean and remove tools.</td>
<td>![Image]</td>
</tr>
</tbody>
</table>
C.5.2 Concrete Columns Poured Using Mobile or Static Pumps

(i) Operation

This operation involves pouring concrete columns, using either a mobile or static pump.

(ii) Method

The two main items of work within this operation are the pumping of concrete and subsequent placement by the concrete gang.

(iii) Method Description: Concrete Gang

One man cleans the shutters before the rest of the gang arrives. The tools and work area are prepared before starting to pump the concrete. The concrete is trowelled as work progresses, but is not covered until all the other activities have been completed.

(iv) Materials and Tools Required

(a) Shovel
(b) Vibrator (+1 on standby)
(c) Trowel
(d) Tamp
(e) Rake
(f) Knee Pads
(g) Covers
(h) Compressor
(i) Concrete Pump

(v) Basic Operation Times

The basic operation times, presented in Table C10, are for concrete columns which require vibrating, trowelling once and covering.

Table C10 Basic Operation Times (mins.)

<table>
<thead>
<tr>
<th>Volume Cu. m.</th>
<th>First Pour</th>
<th>Subsequent Pours</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>90</td>
<td>70</td>
</tr>
<tr>
<td>0.75</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>1.00</td>
<td>110</td>
<td>90</td>
</tr>
<tr>
<td>1.50</td>
<td>130</td>
<td>120</td>
</tr>
<tr>
<td>2.00</td>
<td>150</td>
<td>130</td>
</tr>
<tr>
<td>2.50</td>
<td>170</td>
<td>150</td>
</tr>
<tr>
<td>3.00</td>
<td>185</td>
<td>165</td>
</tr>
<tr>
<td>3.50</td>
<td>205</td>
<td>185</td>
</tr>
<tr>
<td>4.00</td>
<td>225</td>
<td>205</td>
</tr>
<tr>
<td>4.50</td>
<td>245</td>
<td>225</td>
</tr>
</tbody>
</table>
Method Statement:
The placement of concrete into a column by either static or mobile pumps.

Fetch and prepare tools.
Clean shutters with airline.
Soak column with water.

Pour concrete into pump.
Pour concrete into column.

Vibrate concrete.
Shovel concrete.

Tamp concrete.
Trowel finish column. This is sometimes omitted or done twice.

Cover and protect column from weather.
Clean and remove tools.
APPENDIX D

COMPUTER PRINT-OUTS
APPENDIX D

COMPUTER PRINT-OUTS

D.1 SELECTED PRINT-OUTS FROM ANALYSIS PROGRAMS

This appendix contains a selection of computer print-outs obtained during the analysis which is presented in Chapter Five. The first two selected print-outs were obtained during the analyses of the times taken to prepare tools and tamp the concrete. In the analysis, the results extrapolated from these two print-outs were combined with the results from six other programs and used to construct the generalized model. Once this model was constructed four more programs were used to test the predicted durations with the measured durations. The print-outs from three of these four programs ('TEST1.MINEXEC', 'TEST2.MINEXEC' and 'TEST3.MINEXEC') are also included in this appendix.
### Print-Out from Analysis of Preparing Tools

**MINITAB RELEASE 8.1.1 *** COPYRIGHT - PENN STATE UNIV. 1981
APRIL 24, 1986 *** Loughborough University, of Technology
STORAGE AVAILABLE 150000

---

--- RETR 'data'

--- CONST

--- CORR C1-C17

<table>
<thead>
<tr>
<th>TEST METHOD PETOOLS</th>
<th>POUR VIBRATE</th>
<th>SHOVEL</th>
<th>TAM(\text{P})</th>
<th>TROWEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>METHOD</td>
<td>0.469</td>
<td>-0.161</td>
<td>0.203</td>
<td></td>
</tr>
<tr>
<td>PTOOLS</td>
<td>-0.161</td>
<td>0.175</td>
<td>0.189</td>
<td>0.300</td>
</tr>
<tr>
<td>POUR</td>
<td>0.175</td>
<td>0.072</td>
<td>0.292</td>
<td>0.540</td>
</tr>
<tr>
<td>VIBRATE</td>
<td>0.072</td>
<td>0.060</td>
<td>0.114</td>
<td>0.262</td>
</tr>
<tr>
<td>SHOVEL</td>
<td>0.060</td>
<td>0.154</td>
<td>0.135</td>
<td>0.233</td>
</tr>
<tr>
<td>TAM(\text{P})</td>
<td>0.154</td>
<td>0.186</td>
<td>-0.041</td>
<td>0.054</td>
</tr>
<tr>
<td>TROWEL</td>
<td>0.186</td>
<td>0.186</td>
<td>0.241</td>
<td>0.804</td>
</tr>
<tr>
<td>GENERAL</td>
<td>0.031</td>
<td>0.241</td>
<td>0.068</td>
<td>-0.028</td>
</tr>
<tr>
<td>CLTOOLS</td>
<td>0.241</td>
<td>0.446</td>
<td>0.503</td>
<td>0.483</td>
</tr>
<tr>
<td>COVER</td>
<td>0.446</td>
<td>0.200</td>
<td>0.087</td>
<td>-0.172</td>
</tr>
<tr>
<td>TYPE</td>
<td>0.200</td>
<td>0.124</td>
<td>0.179</td>
<td>0.503</td>
</tr>
<tr>
<td>VOLUME</td>
<td>0.124</td>
<td>-0.002</td>
<td>0.200</td>
<td>0.517</td>
</tr>
<tr>
<td>WIDTH</td>
<td>-0.002</td>
<td>0.015</td>
<td>0.044</td>
<td>0.577</td>
</tr>
<tr>
<td>LENGTH</td>
<td>0.015</td>
<td>0.158</td>
<td>0.123</td>
<td>0.368</td>
</tr>
<tr>
<td>AREA</td>
<td>0.158</td>
<td>-0.010</td>
<td>0.147</td>
<td>0.081</td>
</tr>
<tr>
<td>DEPTH</td>
<td>-0.010</td>
<td>-0.010</td>
<td>-0.208</td>
<td>-0.225</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GENERAL CLTOOLS COVER TYPE VOLUME WIDTH LENGTH AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLTOOLS 0.814</td>
</tr>
<tr>
<td>COVER 0.693 -0.046</td>
</tr>
<tr>
<td>TYPE -0.397 -0.266 -0.329</td>
</tr>
<tr>
<td>VOLUME 0.695 0.731 0.716 -0.363</td>
</tr>
<tr>
<td>WIDTH 0.662 0.642 0.317 -0.623 0.654</td>
</tr>
<tr>
<td>LENGTH 0.271 0.248 0.535 -0.342 0.570 0.157</td>
</tr>
<tr>
<td>AREA 0.693 0.660 0.669 -0.527 0.831 0.888 0.471</td>
</tr>
<tr>
<td>DEPTH -0.246 -0.208 -0.225 0.796 -0.116 -0.521 -0.307</td>
</tr>
</tbody>
</table>

--- ONEWAY C16 C2

**ANALYSIS OF VARIANCE**

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<thead>
<tr>
<th>DUE TO</th>
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<th>SS</th>
<th>MS=SS/DF</th>
<th>F-RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>FACTOR</td>
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<td>33381.</td>
<td>11127.</td>
<td>5.79</td>
</tr>
<tr>
<td>ERROR</td>
<td>66</td>
<td>126916.</td>
<td>1923.</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>69</td>
<td>160297.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
LEVEL  N  MEAN  ST. DEV.
1   12  24.8  19.1
2   14  11.9  15.5
3   15  75.2  66.2
4   29  31.3  45.7

POOLED ST. DEV. = 43.9

INDIVIDUAL 95 PERCENT C. I. FOR LEVEL MEANS
(BASED ON POOLED STANDARD DEVIATION)

-----
1
2
3
4
-----

LEVEL  N  MEAN  ST. DEV.
1   12  0.61  0.59
2   14  2.37  1.97
3   15  0.59  0.96
4   29  1.94  2.28

POOLED ST. DEV. = 1.79

INDIVIDUAL 95 PERCENT C. I. FOR LEVEL MEANS
(BASED ON POOLED STANDARD DEVIATION)

-----
1
2
3
4
-----

-- ONEWAY C17 C2

ANALYSIS OF VARIANCE

DUE TO  DF  SS  MS=SS/DF  F-RATIO
FACTOR  3  38.07  12.69  3.94
ERROR  66  212.40  3.22
TOTAL  69  250.47

LEVEL  N  MEAN  ST. DEV.
1   12  0.61  0.59
2   14  2.37  1.97
3   15  0.59  0.96
4   29  1.94  2.28

POOLED ST. DEV. = 1.79

INDIVIDUAL 95 PERCENT C. I. FOR LEVEL MEANS
(BASED ON POOLED STANDARD DEVIATION)

-----
1
2
3
4
-----

-- ONEWAY C13 C2

ANALYSIS OF VARIANCE

DUE TO  DF  SS  MS=SS/DF  F-RATIO
FACTOR  3  652.  652.  3.68
ERROR  66  11704.  177.
TOTAL  69  13661.
LEVEL	N	MEAN	ST. DEV.
1	12	10.9	6.3
2	14	5.0	5.4
3	15	21.0	17.3
4	29	14.2	15.5

POOLED ST. DEV. = 13.3

INDIVIDUAL 95 PERCENT C.I. FOR LEVEL MEANS
(BASED ON POOLED STANDARD DEVIATION)

--- ONEWAY C16 C12

ANALYSIS OF VARIANCE

DUE TO  DF  SS  MS = SS/DF  F-RATIO
FACTOR  3   48779.  16260.  9.62
ERROR   66  111518.  1690.   
TOTAL   69  160297.   

LEVEL	N	MEAN	ST. DEV.
1	41	57.7	52.6
2	6	14.4	11.0
3	9	4.4	2.8
4	14	0.5	0.4

POOLED ST. DEV. = 41.1

INDIVIDUAL 95 PERCENT C.I. FOR LEVEL MEANS
(BASED ON POOLED STANDARD DEVIATION)

--- ONEWAY C17 C12

ANALYSIS OF VARIANCE

DUE TO  DF  SS  MS = SS/DF  F-RATIO
FACTOR  3   187.984  62.661  66.19
ERROR   66  62.485  0.947   
TOTAL   69  250.469   

265
<table>
<thead>
<tr>
<th>LEVEL</th>
<th>N</th>
<th>MEAN</th>
<th>ST. DEV.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41</td>
<td>0.335</td>
<td>0.311</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>0.633</td>
<td>0.449</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>4.306</td>
<td>2.136</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>3.518</td>
<td>1.274</td>
</tr>
</tbody>
</table>

POOLED ST. DEV. = 0.973

**INDIVIDUAL 95 PERCENT C. I. FOR LEVEL MEANS**

(BASED ON POOLED STANDARD DEVIATION)

```
--------+---------+---------+---------+---------+---------+---------+
   1    | *****   |         |         |         |         |         |
   2    | *-------| *-------|         |         |         |         |
   3    | *-------| *-------|         |         |         |         |
   4    |         |         |         |         |         |         |
        +---------+---------+---------+---------+---------+---------+
      -7.0    | 0.0     | 7.0     | 14.0    | 21.0    | 28.0    | 35.0    
```

**-- ONEWAY C13 C12**

**ANALYSIS OF VARIANCE**

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<th>F-RATIO</th>
</tr>
</thead>
<tbody>
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<td>FACTOR</td>
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<td>2724</td>
<td>908.</td>
<td>5.48</td>
</tr>
<tr>
<td>ERROR</td>
<td>66</td>
<td>10937</td>
<td>166.</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>69</td>
<td>13661</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**LEVEL**

<table>
<thead>
<tr>
<th>N</th>
<th>MEAN</th>
<th>ST. DEV.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41</td>
<td>16.9</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>9.2</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>17.7</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>1.6</td>
</tr>
</tbody>
</table>

POOLED ST. DEV. = 12.9

**INDIVIDUAL 95 PERCENT C. I. FOR LEVEL MEANS**

(BASED ON POOLED STANDARD DEVIATION)

```
--------+---------+---------+---------+---------+---------+---------+
   1    |         | *******|         |         |         |         |
   2    | *-------| *-------|         |         |         |         |
   3    | *-------| *-------|         |         |         |         |
   4    |         |         |         |         |         |         |
        +---------+---------+---------+---------+---------+---------+
      -7.0    | 0.0     | 7.0     | 14.0    | 21.0    | 28.0    | 35.0    
```

**-- Omit 'C' C3 C2, C63 C62**

**-- ONEWAY C63 C62**

**ANALYSIS OF VARIANCE**

<table>
<thead>
<tr>
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<th>MS=SS/DF</th>
<th>F-RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>FACTOR</td>
<td>3</td>
<td>661</td>
<td>220.</td>
<td>1.29</td>
</tr>
<tr>
<td>ERROR</td>
<td>49</td>
<td>8352</td>
<td>170.</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>52</td>
<td>9013</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

266
LEVEL  N  MEAN  ST. DEV.
1     6   9.3   6.1
2    12  16.5   9.2
3    12  21.6  10.6
4   23  19.1  16.5

POOLED ST. DEV. = 13.1

INDIVIDUAL 95 PERCENT C.I. FOR LEVEL MEANS
(BASED ON POOLED STANDARD DEVIATION)

--- H.O.T C3 C13
PR TOOLS
60.+  *
   -
   -
40.+  ***
   -
   -  *  
   -  *
20.+  2  2  2  
   4  **
   4  **  2  2
   -  *
   -  2  *
0.+  22  

--- VOLUME
0.  15.  30.  45.  60.  75.

17 MISSING OBSERVATIONS
17 MISSING OBSERVATIONS

--- L.PLOT C3 C13 C2
PRTOOLS
60.+ D
- - -
- D C B D D
- D C C C B
- - B
- B 2 2 2 D 2 2 C
- 4 D B C D 4 D A B 2 A 2
- C 2 2 A A
0.+ 22D
+-------------------------------+VOLUME
0. 15. 30. 45. 60. 75.

17 MISSING OBSERVATIONS
-- LPLLOT C3 C16 C12
PRTOOLS
60.+    A
-  
-  
-    C    A
40.+    CC  A    A
-  
-    D  3
-    C
-    D
20.+  2A  A  3AA  A
-    4  A  AA  A
-    42  A  A  2  AA
-    D
-    22
0.+  32
+-------------------------------------------+VOLUME
0.  15.  30.  45.  60.  75.

17 MISSING OBSERVATIONS

-- LPLLOT C3 C13 C12
PRTOOLS
60.+    A
-  
-  
-    C    A
40.+    CC  A    A
-  
-    D  AA  A
-    C
-    D
20.+  A  2A  2  A  2  A
-    4  A  AA  A
-    4A  A  A  2  A  2
-    D
-    2  B  B
0.+  22A
+-------------------------------------------+AREA
0.  80.  160.  320.  400.

17 MISSING OBSERVATIONS

-- OMIT ' ' C3 C2 , C63 C62
-- ONEWAY C63 C62

ANALYSIS OF VARIANCE

<table>
<thead>
<tr>
<th>DUE TO</th>
<th>DF</th>
<th>SS</th>
<th>MS=SS/DF</th>
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LEVEL  N  MEAN  ST. DEV.
1    6  9.3  6.4
2   12 16.5  9.2
3   12 21.6 10.6
4  23 19.1 16.5

POOLED ST. DEV. = 13.1

INDIVIDUAL 95 PERCENT C. I. FOR LEVEL MEANS
(BASED ON POOLED STANDARD DEVIATION)

\[
\begin{array}{cccc}
  & 1 & 2 & 3 \\
 1 & I & I & I \\
 2 & I & I & I \\
 3 & I & I & I \\
 4 & I & I & I \\
\end{array}
\]

-- CORR C3 C13
CORRELATION OF PRTOOLS AND VOLUME = 0.503

-- REGR C3 1 C13
53 CASES USED
17 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS
\[ Y = 11.7 + 0.501 X_1 \]

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<thead>
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<th>COLUMN</th>
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<th>T-RATIO</th>
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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 11.49
WITH (53 - 2) = 51 DEGREES OF FREEDOM

R-SQUARED = 25.3 PERCENT
R-SQUARED = 23.9 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.
DURBIN-WATSON STATISTIC = 1.48
-- MEAN C3
   AVERAGE = 17.981

-- LOT C3 C16 C2
PROOOLS
60. D
   -
   -
   - D C
40. DB D D
   -
   - D 3
   - B
   - B
20. 2D A 3CD C
   - 4 D BC D
   - 4 A B 2 CC
   - C
   - 22
0. 32
   +---------------------------------------------+ AREA
   0. 80. 160. 240. 320. 400.

17 MISSING OBSERVATIONS

-- REGR C3 2 C13 C16
53 CASES USED
17 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS
Y = 11.8 + 0.584 X1 -0.0345 X2

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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 11.57
WITH (53 - 3) = 50 DEGREES OF FREEDOM

R-SQUARED = 25.7 PERCENT
R-SQUARED = 22.7 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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FURTHER ANALYSIS OF VARIANCE
SS EXPLAINED BY EACH VARIABLE WHEN ENTERED IN THE ORDER GIVEN

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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 1.47

-- CORR C3 C13 C16

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-- LET C30=C3/C13
-- OMIT 'a' C30 C2 , C90 C62
-- ONEWAY C90 C62

ANALYSIS OF VARIANCE

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LEVEL | N | MEAN | ST. DEV. |
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POOLED ST. DEV. = 4.28

INDIVIDUAL 95 PERCENT C. I. FOR LEVEL MEANS
(BASED ON POOLED STANDARD DEVIATION)

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272
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CELL CONTENTS --
PRTOOLS:DATA
MEAN

273
-- CHOOSE 1 C12 C3 C13 , C21 C22 C23

-- PLOT C22 C23

C22

60.+

---

40.+

---

20.+

---

0.+

------------------------+$C23$

0. 15. 30. 45. 60. 75.

11 MISSING OBSERVATIONS

-- REGR C22 1 C23

30 CASES USED

11 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS

\[
Y = 12.6 + 0.1122 X1
\]

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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS S = 11.90
WITH (30 - 2) = 28 DEGREES OF FREEDOM

R-SQUARED = 21.7 PERCENT
R-SQUARED = 18.9 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.
DURBIN-WATSON STATISTIC = 1.66
CHOOSE 3 C12 C3 C13, C21 C22 C23

PLOT C22 C23

60.+

40.+

20.+

0.+

--- REGR C22 1 C23

7 CASES USED
2 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS

\[ Y = 13.2 + 0.848 X_1 \]

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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS

\[ S = 14.09 \]

WITH (7-2) = 5 DEGREES OF FREEDOM

R-SQUARED = 31.3 PERCENT
R-SQUARED = 17.5 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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DURBIN-WATSON STATISTIC = 0.51

--- CHOOSE 4 C12 C3 C13, C21 C22 C23
-- PLOT C22 C23

C22
30.+
20.+
10.+
0.+

C23

0.0 1.0 2.0 3.0 4.0 5.0

-- REGR C22 1 C23

THE REGRESSION EQUATION IS
\[ y = 5.43 + 4.02 X_1 \]

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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
\[ S = 7.513 \]
WITH (14-2) = 12 DEGREES OF FREEDOM

R-SQUARED = 26.3 PERCENT
R-SQUARED = 20.1 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 1.80

276
D.1.2 Print-Out from Analysis of Tamping Concrete

--- RETR 'data'
--- CONST
--- CORR C7 C13 C16 C17

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-- REGR C7 2 C16 C17

THE REGRESSION EQUATION IS

\[ Y = 10.4 + 1.12X_1 + 0.139X_2 \]


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<tr>
<th>Variable</th>
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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS S = 21.88
WITH (70-3) = 67 DEGREES OF FREEDOM
R-SQUARED = 86.2 PERCENT
R-SQUARED = 85.7 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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FURTHER ANALYSIS OF VARIANCE

SS EXPLAINED BY EACH VARIABLE WHEN ENTERED IN THE ORDER GIVEN

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R Denotes an obs. with a large st. res.
X Denotes an obs. whose X value gives it large influence.

DURBIN-WATSON STATISTIC = 0.91
-- PLOT C7 C13
TAMP
420.+

-- PLOT C7 C16
TAMP
420.+
THE REGRESSION EQUATION IS

\[ y = 10.7 + 1.12 x_1 \]

THE ST. DEV. OF \( Y \) ABOUT REGRESSION LINE IS

\[ S = 21.72 \]

WITH (70 - 2) = 68 DEGREES OF FREEDOM

R-SQUARED = 86.2 PERCENT

R-SQUARED = 85.9 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

<table>
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<tr>
<th></th>
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279
R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.
DURBIN-WATSON STATISTIC = 0.91

-- END

END OF EXECUTION OF STORED INSTRUCTIONS

*** MINITAB *** STATISTICS DEPT * PENN STATE UNIV. * RELEASE 81.1 * STORAGE AVAILABLE 150000
D.2 PRINT-OUT FROM TEST PROGRAMS
-- retr 'data'
-- NAME C1 'TEST'
-- NAME C2 'METHOD'
-- NAME C3 'PROTOOLS'
-- NAME C4 'POUR'
-- NAME C5 'VIBRATE'
-- NAME C6 'SHOVEL'
-- NAME C7 'TAMP'
-- NAME C8 'TROWEL'
-- NAME C9 'GENERAL'
-- NAME C10 'CLTOOLS'
-- NAME C11 'COVER'
-- NAME C12 'TYPE'
-- NAME C13 'VOLUME'
-- NAME C14 'WIDTH'
-- NAME C15 'LENGTH'
-- NAME C16 'AREA'
-- NAME C17 'DEPTH'
-- NAME C19 'SUB-TOTAL'
-- LET C20=C4+C5+C6+C7+C8
-- LET C21=C3+C10+C11
-- LET C22=C20+C21+C9
-- LET C19=C20+C21
-- LET C43=11.7+0.501*C13
-- LET C44=5.45+1.67*C13

D.2.1 Print-Out from Program 'TEST1.MINEXEC'
-- LET $C_5 = 3.46 \times C_{13}$
-- LET $C_6 = 8.07 + 0.737 \times C_{16}$
-- LET $C_7 = 10.7 + 1.12 \times C_{16}$
-- LET $C_8 = 27.6 + 2.79 \times C_{16}$
-- LET $C_9 = 6.83 + 0.310 \times C_{13}$
-- LET $C_{10} = 8.62 + 0.861 \times C_{13} + 0.202 \times C_{16}$
-- LET $K_5 = 1.1300$
-- LET $K_6 = 1.0775$
-- LET $C_{11} = 16.10 + 1.18 \times C_{13}$
-- LET $C_{12} = 4.79 + 9.65 \times C_{13}$
-- LET $C_{13} = 5.69 \times C_{13}$
-- LET $C_{14} = 22.8 \times C_{13}$
-- LET $C_{15} = 9.37 + 0.549 \times C_{13}$
-- LET $C_{16} = 1.51 \times C_{16}$
-- LET $C_{17} = 5.00$
-- LET $C_{18} = 13.2 + 0.848 \times C_{13}$
-- LET $C_{19} = 5.43 + 4.02 \times C_{13}$
-- RECO 1 2 C2 0 C36
-- RECO 3 C36 1 C36
-- RECO 4 C36 0 C36
-- RECO 3 C2 1 C37
-- RECO 2 4 C37 0 C37
-- LET $C_{38} = C_{37} - 1$
-- RECO -1 C38 1 C38
-- RECO 1 C12 0 C32
-- RECO 2 C12 0 C33
-- RECO 3 C12 0 C34
-- RECO 4 C12 0 C35

283
-- SIGN C32 C32
  0 NEGATIVE VALUES 41 ZERO VALUES 29 POSITIVE VALUES
-- SIGN C33 C33
  0 NEGATIVE VALUES 6 ZERO VALUES 64 POSITIVE VALUES
-- SIGN C34 C34
  0 NEGATIVE VALUES 9 ZERO VALUES 61 POSITIVE VALUES
-- SIGN C35 C35
  0 NEGATIVE VALUES 14 ZERO VALUES 56 POSITIVE VALUES
-- LET C32=C32-1
-- LET C33=C33-1
-- LET C34=C34-1
-- LET C35=C35-1
-- RECO -1 C32 1 C32
-- RECO -1 C33 1 C33
-- RECO -1 C34 1 C34
-- RECO -1 C35 1 C35
-- LET C44=C44*C32+C52*(C33+C34)+C53*C35
-- LET C45=C45*C32+C54*(C33+C34)+C55*C35
-- LET C48=C48*C18+C57*C68
-- LET C50=(C50+C56*C36)
-- LET C49=K5*C37+K6*C38
-- LET C70=(C43+C44+C45+C46+C47+C48+C50+C51)*C49
-- LET C71=C70/C49
-- PLOT C3 C43
-- PLOTTOOLS
60.+
  
40.+
  
20.+
  
0.+
  23
9.0 18.0 27.0 36.0 45.0 54.0
17 MISSING OBSERVATIONS

-- REGR C3 1 C43
53 CASES USED
17 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS
\[ Y = 0.0230 + 0.999 X_1 \]

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<tr>
<th>COLUMN</th>
<th>COEFFICIENT</th>
<th>ST. DEV.</th>
<th>T-RATIO</th>
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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS \( S = 11.49 \)
WITH \((53 - 2) = 51\) DEGREES OF FREEDOM

R-SQUARED = 25.3 PERCENT
R-SQUARED = 23.9 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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<tr>
<th>DUE TO</th>
<th>DF</th>
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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.
DURBIN-WATSON STATISTIC = 1.48

-- CORR C3 C43
CORRELATION OF PRTOOLS AND C43 = 0.503
-- PLOT C4 C44

POUR

150.+
- - -
- - -
- - -
- - -
- - -

100.+
- - -
- - -
- - -
- - -
- - -

50.+
- - -
- - -
- - -
- - -
- - -

0.+
* * * * * *
* * * * * *
2223**2**
3294 2 **

+-----------------------------+---C44
0.  30.  60.  90.  120.  150.

1 MISSING OBSERVATIONS

-- REGR C4 1 C44

69 CASES USED
1 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS
Y = -0.0099 + 1.00 X1

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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 15.17
WITH (69 - 2) = 67 DEGREES OF FREEDOM

R-SQUARED = 68.0 PERCENT
R-SQUARED = 67.5 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 1.96

-- CORR C4 C44

CORRELATION OF FOUR AND C44 = 0.825

-- PLOT C5 C45

VIBRATE

10 MISSING OBSERVATIONS

-- REGR C5 1 C45

60 CASES USED
10 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS

Y = -3.80 + 1.04 X1

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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS S = 24.99
WITH (60-2) = 58 DEGREES OF FREEDOM
R-SQUARED = 83.6 PERCENT  
R-SQUARED = 83.3 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

<table>
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R DENOTES AN OBS. WITH A LARGE ST. RES.  
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 2.32

-- CORR C5 C45

CORRELATION OF VIBRATE AND C45 = 0.914

-- PLOT C5 C46

SHOVEL

270.

-- REGR C5 1 C46

69 CASES USED  
1 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS

Y = -0.0012 + 1.00 X1
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The ST. DEV. of Y about regression line is \( S = 18.45 \)
with \( (69-2) = 67 \) degrees of freedom.

R-SQUARED = 79.0 PERCENT
R-SQUARED = 78.7 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

<table>
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\( R \) DENOTES AN OBS. WITH A LARGE ST. RES.
\( X \) DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 2.01

-- Corr C6 C46
CORRELATION OF SHOVEL AND C46 = 0.889

-- PLOT C7 C47
TAMP

--- Chart ---

--- Diagram ---

289
THE REGRESSION EQUATION IS
Y = 0.0077 + 0.996 X1

ST. DEV. T-RATIO =
COLUMN COEFFICIENT OF COEF. COEF./S.D.
-- 0.008 3.573 0.00
X1 C47 0.99619 0.04843 20.57

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 21.72
WITH (70-2) = 68 DEGREES OF FREEDOM

R-SQUARED = 86.2 PERCENT
R-SQUARED = 85.9 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

<table>
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<tr>
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<td>199548.1</td>
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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 0.91

CORRELATION OF TAMP AND C47 = 0.928
-- PLOT C8 C48

TROWEL
300.+
- - - -
200.+
- - - -
100.+
- 2
- 5
0. + -

+----------------------------------------+-------+
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36 MISSING OBSERVATIONS

-- REGR C8 1 C48

34 CASES USED
36 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS
Y = - 1.17 + 1.01 X1

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<tr>
<th>COLUMN</th>
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<th>T-RATIO = COEF/S. D.</th>
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<tr>
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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS S = 22.33
WITH (34-2) = 32 DEGREES OF FREEDOM

R-SQUARED = 87.7 PERCENT
R-SQUARED = 87.3 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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<thead>
<tr>
<th>DUE TO</th>
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<th>MS=SS/DF</th>
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<td>15959.1</td>
<td>498.7</td>
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<td>129607.8</td>
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<th>ST. DEV.</th>
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<td>146</td>
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<td>263</td>
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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.
DURBIN-WATSON STATISTIC = 2.09
-- CORR C8 C48

CORRELATION OF TROWEL AND C48 = 0.936

-- PLOT C10 C50

CLTOOLS
90.+
- - -
60.+
- -
30.+
- -
0.+

+---------+---------+---------+---------+---------+---------+---------+
|       |       |       |       |       |       |       |
| 5.    | 20.   | 35.   | 50.   | 65.   | 80.   |       |

43 MISSING OBSERVATIONS

-- REGR C10 C50

27 CASES USED
43 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS

$Y = 0.0066 + 0.999 X_1$

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<th>COLUMN</th>
<th>COEFFICIENT</th>
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<td>0.00</td>
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<td>0.99918</td>
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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS

$S = 7.467$

WITH (27 - 2) = 25 DEGREES OF FREEDOM

R-SQUARED = 82.9 PERCENT
R-SQUARED = 82.3 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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<thead>
<tr>
<th>DUE TO</th>
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<td>ROW</td>
<td>C50</td>
<td>CLTOOLS</td>
<td>VALUE</td>
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<td>-----</td>
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<td>-------</td>
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<td>72.00</td>
<td>72.84</td>
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<td>36</td>
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<tr>
<td>55</td>
<td>30.4</td>
<td>45.00</td>
<td>30.36</td>
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</table>

R denotes an obs. with a large st. res.
X denotes an obs. whose x value gives it large influence.

DURBIN-WATSON STATISTIC = 1.75

-- CORR C10 C50

Correlation of CLTOOLS and C50 = 0.911

-- PLOT C11 C51

Cover
120.+
   -
   -
   -
   -
   * 80.+
   -
   -
   -
   -
   -
   - 40.+
   -
   - 2 3
   -
   -
   - 0.+
   - 2
   *

+-----------------------------------------+C51
   0.  30.  60.  90.  120.  150.

49 missing observations

-- REGR C11 1 C51

21 cases used
49 cases contained missing values

The regression equation is
\[ Y = -0.0054 + 1.00 \times X1 \]

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>COEFFICIENT</th>
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The st. dev. of y about regression line is \( S = 18.33 \)

With \((21 - 2) = 19\) degrees of freedom

293
R-SQUARED = 55.2 PERCENT
R-SQUARED = 52.8 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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<tr>
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<tr>
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MS = SS/DF

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<td>71</td>
<td>*</td>
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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 2.58

-- CORR C11 C51

CORRELATION OF COVER AND C51 = 0.743

-- SAVE 'temp'

-- END

END OF EXECUTION OF STORED INSTRUCTIONS

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APRIL 21, 1986 *** Loughborough University of Technology
STORAGE AVAILABLE 150000

-- RETR 'temp'

-- RECO #1 C3 0 C3
-- RECO #1 C4 0 C4
-- RECO #1 C5 0 C5
-- RECO #1 C6 0 C6
-- RECO #1 C7 0 C7
-- RECO #1 C8 0 C8
-- RECO #1 C10 0 C10
-- RECO #1 C11 0 C11

-- LET C20=C4+C5+C6+C7+C8
-- LET C21=C3+C10+C11
-- LET C22=C20+C21+C9
-- LET C19=C20+C21

-- SUBS 525 10 C19
-- SUBS 605 21 C19

-- LET C49=C19*(C49-1)

-- PLOT C9 C49

GENERAL
150.+
  -
  -
  -
100.+
  -
  -
  -
50.+
  * * *
  -
  * * *
  -
  * * *
  -
  2 * *
  -
  5*34 *
  -
  4 2*122 *
  -
  7*22 *
0.+
  +---------------------+---------------------+---------------------+---------------------+---------------------+---------------------+
  0.  30.  60.  90.  120.  150.

2 MISSING OBSERVATIONS
-- REGR C9 1 C49

68 CASES USED
2 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS
\[ Y = 0.0141 + 0.999 X_1 \]

<table>
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<tr>
<th>COLUMN</th>
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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
\( S = 13.46 \)
WITH (68-2) = 66 DEGREES OF FREEDOM

R-SQUARED = 72.1 PERCENT
R-SQUARED = 71.6 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.

DURBIN-WATSON STATISTIC = 1.39

-- CORR C9 C49

CORRELATION OF GENERAL AND C49 = 0.849
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<th>C38</th>
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<tr>
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<td>9</td>
<td>143.00</td>
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<td>20</td>
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<td>147.00</td>
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<td>1.</td>
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62  10.  130.00  0.  1.
63  25.  285.00  1.  0.
64  10.  50.00  0.  1.
65  5.  150.00  0.  1.
66  5.  45.00  0.  1.
67  35.  495.00  0.  1.
68  0.  15.00  0.  1.
69  0.  45.00  0.  1.
70  30.  125.00  0.  1.

-- LET C49=(1.152*C19-8.63)*C37+(1.068*C19+4.00)*C38
-- LET C49=C49-C19

-- PLOT C9 C49

GENERAL

2 MISSING OBSERVATIONS

-- REGR C9 C49
68 CASES USED
2 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS
Y = -0.09990 + 1.00 X1

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<th>COLUMN</th>
<th>COEFFICIENT</th>
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<th>T-RATIO =</th>
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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS S = 12.83
WITH (68-2) = 66 DEGREES OF FREEDOM
R-SQUARED = 74.6 PERCENT
R-SQUARED = 74.3 PERCENT, ADJUSTED FOR D.F.
### Analysis of Variance

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<th>SS</th>
<th>MS = SS/DF</th>
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R denotes an obs. with a large std. res.
X denotes an obs. whose x value gives it large influence.

Durbin-Watson statistic = 1.47

-- corr C9 C49

Correlation of General and C49 = 0.864

-- Save 'general'

-- end

End of execution of stored instructions

---

*** Minitab *** Statistics Dept. * Penn State Univ. * Release 81.1 *
Storage available 150000
MINITAB RELEASE 81.1  *** COPYRIGHT - PENN STATE UNIV. 1981  
APRIL 21, 1986  *** Loughborough University, of Technology 
STORAGE AVAILABLE 150000

--
-- RETR 'temp'
-- NAME C19 'SUB'
-- NAME C22 'TOTAL'
-- SIGN C3 C23
  0 NEGATIVE VALUES  5 ZERO VALUES  48 POSITIVE VALUES

-- SIGN C4 C24
  0 NEGATIVE VALUES  0 ZERO VALUES  69 POSITIVE VALUES

-- SIGN C5 C25
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-- SIGN C6 C26
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-- SIGN C7 C27
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-- SIGN C8 C28
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-- SIGN C9 C29
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-- SIGN C10 C30
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-- SIGN C11 C31
  0 NEGATIVE VALUES  0 ZERO VALUES  21 POSITIVE VALUES

-- RECO 0 C23 1 C23
-- RECO 0 C24 1 C24
-- RECO 0 C25 1 C25
-- RECO 0 C26 1 C26
-- RECO 0 C27 1 C27
-- RECO 0 C28 1 C28
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-- LET C43=C43*C23
-- LET C44=C44*C24
-- LET C45=C45*C25
-- LET C46=C46*C26
-- LET C47=C47*C27
-- LET C48=C48*C28
-- LET C49=C49*C29
-- LET C50=C50*C30
-- LET C51=C51*C31
-- LET C71=C43+C44+C45+C46+C47+C48+C50+C51
-- LET C70=(1.152*C71-8.63)*C37+(1.068*C71+4.00)*C38
-- LET C49=C70-C71
-- RECO 1 C3 0 C3
-- RECO 1 C4 0 C4
-- RECO 1 C5 0 C5
RECO C6 0 C6
RECO C7 0 C7
RECO C8 0 C8
RECO C10 0 C10
RECO C11 0 C11
LET C20=C4+C5+C6+C7+C8
LET C21=C3+C10+C11
LET C22=C20+C21+C9
SUBS 10 C22
SUBS 21 C22
LET C19=C20+C21
PLOT C22 C70
TOTAL
1500.
1000.
500.
0.

4 MISSING OBSERVATIONS

CORR C22 C70
CORRELATION OF TOTAL AND C70 = 0.962
- LPLOT C22 0 600 C70 0 600 C12

TOTAL
600.+
  -
  -
  -
400.+
  -
  -
  -
200.+
  -
  -
  -
0.+

4 POINTS OUT OF BOUNDS
4 MISSING OBSERVATIONS

- REGR C22 1 C70

66 CASES USED
4 CASES CONTAINED MISSING VALUES

THE REGRESSION EQUATION IS
Y = -10.0 + 1.02 X1

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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
S = 61.86
WITH (66-2) = 64 DEGREES OF FREEDOM

R-SQUARED = 92.6 PERCENT
R-SQUARED = 92.4 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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### Analysis of Variance

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### Residuals

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<td>12.10</td>
<td>-195.38</td>
<td>-3.22R</td>
</tr>
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</table>

**Note:**
- R denotes an observation with a large standardized residual.
- X denotes an observation whose X value gives it large influence.

**Durbin-Watson Statistic = 1.94**

---

**Regression Model:**

Y = + 0.995 X1

**Standard Deviation:**

S = 61.73

**Degrees of Freedom:**

65 - 1 = 64

---

**Correlation Table:**

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**Analysis of Variance (Revised):**

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**Residuals (Revised):**

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<th>ST.DEV.</th>
<th>Pred. Y</th>
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<th>ST.RES.</th>
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<td>-195.38</td>
<td>-3.22R</td>
</tr>
</tbody>
</table>

**Note:**
- R denotes an observation with a large standardized residual.
- X denotes an observation whose X value gives it large influence.

**Durbin-Watson Statistic = 1.91**
-- PLOT C19 C71

SUB
1500.
  
  
  1000.
  
  
  500.
  
  
  0.

-- CORE C19 C71

CORRELATION OF SUB AND C71 = 0.967

-- PLOT C19 0 600 C71 0 600

SUB
600.
  
  
  400.
  
  
  200.
  
  
  0.

2 POINTS OUT OF BOUNDS
THE REGRESSION EQUATION IS

\[ Y = + 1.01 \times X_1 \]
ST. DEV. T-RATIO =

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THE ST. DEV. OF Y ABOUT REGRESSION LINE IS S = 51.81
WITH ( 70- 1) = 69 DEGREES OF FREEDOM

ANALYSIS OF VARIANCE

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R DENOTES AN OBS. WITH A LARGE ST. RES.
X DENOTES AN OBS. WHOSE X VALUE GIVES IT LARGE INFLUENCE.
DURBIN-WATSON STATISTIC = 1.95

-- CONS
-- REGR C19 1 C71

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WITH ( 70- 2) = 68 DEGREES OF FREEDOM
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R-SQUARED = 93.4 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

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R DENOTES AN OBS. WITH A LARGE ST. RES.
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<td>0.</td>
<td>1.</td>
</tr>
<tr>
<td>68</td>
<td>15.00</td>
<td>45.37</td>
<td>15.00</td>
<td>52.45</td>
<td>0.</td>
<td>1.</td>
</tr>
<tr>
<td>69</td>
<td>45.00</td>
<td>67.64</td>
<td>45.00</td>
<td>76.24</td>
<td>0.</td>
<td>1.</td>
</tr>
<tr>
<td>70</td>
<td>125.00</td>
<td>129.53</td>
<td>155.00</td>
<td>142.34</td>
<td>0.</td>
<td>1.</td>
</tr>
</tbody>
</table>

--- END ---

END OF EXECUTION OF STORED INSTRUCTIONS

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STORAGE AVAILABLE 150000
APPENDIX E

OPERATIVE MOTIVATION
APPENDIX E

OPERATIVE MOTIVATION

E.1 INTRODUCTION

The early results of this research indicated that there was a distinct relationship between remuneration, motivation and site efficiency. Consequently, observations taken on later site visits were used to quantify this relationship and determine the relevance of the major motivation theories to the construction industry.

E.2 REVIEW OF MAJOR MOTIVATION THEORIES

The main purpose of any theory is to relate important variables associated with a particular topic. The usefulness of any theory depends upon its ability to account for a wide diversity of variables, whilst combining them into a cohesive and succinct form. The important variables influencing motivation are the individual's characteristics, type of job, working environment and productivity. There are five main theories on motivation; these concentrate on the first three variables with the most important, productivity, being sparsely investigated. The individual's motivational factors have, therefore, been subjected to thorough examination, but the affect of these factors on productivity has been limited to the subjective assessment of the individual's desire to perform.
None of the existing motivation theories cover all situations, and the selection of one or more to suit certain conditions is often a matter of personal opinion. However, it is possible to select a combination of theories suited to the narrow band of jobs associated with construction operatives.

The early theories of Maslow (E.1), McClelland (E.2), and Atkinson (E.3) are primarily models based on the individual's motivation, although job-related and work environment variables are not entirely ignored. The main emphasis is placed on the individual's characteristics and the role played by personal needs in determining work behaviour.

Herzberg's (E.4) model attaches more importance to the nature of the task and whether a job allows for recognition, advancement and achievement, whilst earlier researchers concentrated on the individual and working environment. Herzberg's "two-factor theory" advances the argument that intrinsic rewards are the key to increasing job performance and satisfaction. The interrelationships between the major variables are ignored, as in previous "need theories", although many are implicit in his model.

The relationships between the main variables associated with operative motivation have been investigated in several theories. For example, Loche (E.5) focused upon the interaction between task characteristics and personal aspiration levels; whilst Adams's (E.6) theory of inequity investigated the relationships between the individual's attitudes towards input, outcomes and reward practices.

Lawler's expectancy-valence theory (E.7) acknowledges the variation in individuals' needs, and that people have different beliefs that certain actions will lead to the desired rewards. The expectancy-valence model points out how job related variables can affect future expectancies and emphasizes that certain job attitudes may serve as intrinsic rewards.
E.2.1 Maslow's Hierarchy of Needs

Maslow's hierarchical model is based on the principle that an individual's needs can be classified into five basic groups, as summarized in Figure E.1. Also incorporated is the concept that needs are arranged in levels of prepotency; the lower need being the dominant motivational factor which monopolizes consciousness until it is gratified, upon which the next need becomes active. Thus, the satisfaction of a particular need reduces its power to motivate. At the highest level Maslow proposed that the "satisfaction-importance" relationship is reversed and gratification increases motivation.

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSIOLOGICAL</td>
<td>food, water and air.</td>
</tr>
<tr>
<td>SAFETY</td>
<td>security, stability, absence of pain.</td>
</tr>
<tr>
<td>AFFILIATION</td>
<td>belong or receive affection.</td>
</tr>
<tr>
<td>ESTEEM</td>
<td>personal feelings of achievement or self-esteem, recognition or respect from others.</td>
</tr>
<tr>
<td>SELF-ACTUALIZATION</td>
<td>self fulfillment or the realization of one's potential.</td>
</tr>
</tbody>
</table>

Figure E.1 Maslow's Hierarchy of Needs
E.2.2 Achievement Motivation Theory

Murray's Achievement Theory (E.8) was derived from the concept that there is a separate need for each type of human behaviour. Murray suggests that these needs are not predetermined but part of a learning process; for example, an individual whose needs for achievement are aroused will attempt to become involved in areas where he can excel. Murray posits that each need comprises of two elements, a directional component towards which the motive is directed, and an intensity component representing the strength of the motive.

These needs, according to Murray, can either be active or dormant. A dormant need does not necessarily have a weak intensity component, but the lack of opportunity has restricted its growth. Murray's theory is similar to Maslow's because they are both hypothetical statements based upon clinical observations, rather than empirical research with behaviour being determined by need orientated goals.

Considerable research has been carried out by McClelland and Atkinson, resulting in the presentation of a formal model of motivated behaviour, based on several principles originating from earlier research. Atkinson's theory takes the starting point that individuals have the potential to exhibit a variety of behaviour patterns. The aroused motives, and hence the behaviour generated, depends upon the relative strength (or state of readiness) of the individual's motives and the stimuli presented by the situation.

Atkinson's model represents the level of motivation created by the "need for achievement" although it extends to explain behaviour related to the "need for power" and the "need for affiliation". The model holds that the aroused motivation is a joint multiplication factor of: the original strength of the basic motive (M); the level of expectancy that the goal can reach (E); and the perceived value of the incentive (I), as represented by the following expression.

\[ \text{Aroused Motivation} = M \times E \times I \]
E.2.3 Motivation/Hygiene Theory

Frederick Herzberg's motivation/hygiene theory, sometimes known as two-factor theory, has two distinct aspects: the first being a theoretical standpoint on work behaviour; the second focuses upon the practical aspects of job enrichment and its affect on behaviour.

Herzberg began his initial research on motivation in the 1950's, and had a tremendous impact on the experimental side of validating theories on motivation. The majority of previous research, for example Maslow's need hierarchy and Murray and Atkinson's work on achievement motivation, was based on inferences from personal insight and experience. Herzberg's systematical style in dealing with the problem of motivation involved keeping his theory simple and basing it on empirical data. This resulted in Herzberg's work being well received by managers, especially as he offered recommendations aimed at improving motivation via job enrichment.

Herzberg's two-factor theory was based on a study of 200 engineers and accountants. In this study each individual was asked to rank events in their work which led to either extreme dissatisfaction or extreme satisfaction. The resulting conclusions were that the job satisfaction consisted of events capable of causing satisfaction and other events capable of causing dissatisfaction. These events were found to belong to one of two separate scales and not opposite ends of the same scale. The important satisfiers were found to be related to the nature of the work and the subsequent rewards. For example, the opportunity to fulfil the individual's needs for self-actualization and self-realization. The main dissatisfiers were associated with the working environment such as company policy. The three main criticisms of the two-factor theory are that:
(a) People tend to claim credit for the work they have done when things go well, but blame the failure of their working environment when problems occur.

(b) The experiments are a measure of peak (extreme) feelings, which results in instantaneous events having the greatest measured affect. For example, an operative may be satisfied with his pay on a long term basis but is not likely to exhibit extreme feelings of satisfaction.

(c) Murray states that a need can be dormant owing to a lack of possible expression, and events an individual has no control over cannot serve as a stimuli to his needs. For example, supervision, or company policy.

E.2.4 Equity Theories

Equity theories were developed along a similar line of thought by several theorists working independently, in contrast to the earlier theories usually associated with a line of thought presented by an individual. These earlier theories focused on the identification of the motivational factors, for example, the characteristics of the individual or work environment. However, equity theories concentrated on the process of generating behaviour. The concept of measuring the motivating factors in terms of the perceived rather than actual situation was also introduced. Adams states in his theory of inequity that:

"Inequity exists for a Person whenever he perceives that the ratio of his outcomes to inputs and the ratio of Other's outcomes to Other's inputs are unequal." (E.6)

Inputs are the contribution an individual makes towards his work; these may be skill, age or effort. Outcomes are the rewards an individual receives through his endeavours, these may be pay or status.
E.2.5 Expectancy/Valence Theory

The initial observations leading to the expectancy/valence theory originated in the 1930's when Tolman (E.9) began to introduce expectancies, and Lewin (E.10) presented the idea of valence (value). The main thrust of the expectancy/valence theory is the relationship between variables affecting behaviour rather that the identification of the variables. The development of this theory has resulted in a number of versions, each having a slightly different emphasis. A more detailed review of these versions is discussed by Henemen and Schwab (E.11). These earlier theories were mainly formulated on the principle that:

\[ \text{MOTIVATION} = \text{EXPECTANCY} \times \text{VALENCE}. \]

Vroom (E.12) devised a form of motivational assessment and measurement system in his valence theory of 1964. This was then amended by Lawler (E.8) taking into account later developments, resulting in Lawler's comprehensive expectancy/valence theory based on the following premises.

(a) People have preferences among the various outcomes that are potentially available to them.
(b) People have expectancies about the likelihood that an action (effort) on their part will lead to the intended behaviour or performance.
(c) People have expectancies about the likelihood that certain outcomes will follow their behaviour.
(d) In any situation, the actions a person chooses to take are determined by the expectancies and preferences that person has at the time.

In Lawler's model, the motivational force is a product of expectancies concerning outcomes and the value (valence) assigned to these outcomes. Vroom's assignment of values to expectancies can range from 0 (for absolutely no belief that an outcome will follow) to +1.0 (for complete certainty that an outcome will follow). The values assigned to valence can range from -1.0 (when the subject
strongly prefers not to achieve the stated outcome) to +1.0 (when the subject has a strong preference to reaching the stated outcome). The probability assigned to the expectancies that an outcome will follow a particular action \((E \rightarrow O)\) is the product of these two probabilities.

(a) The expectancy that he will accomplish his intended performance \((E \rightarrow P)\).
(b) The expectancy that reaching the intended performance will lead to certain outcomes \((P \rightarrow O)\).

The determinants of a person's \(E \rightarrow P\) expectancies are shown in Figure E.2. The single most important of these factors is the individual's perception of a situation. Past experiences are also important as perception is part of the overall learning process. People with low self-esteem usually underestimate the probability of their own success, and are therefore difficult to motivate with rewards linked to success.

![Figure E.2 Determinants of E→P Expectancies](image-url)
The determinants of $P \rightarrow O$ expectancies are shown in Figure E.3. Again, the most influential of these are the actual situation, previous experiences in similar situations and comments made by people about the situation. A person who thinks he can significantly control what happens to him will have high $P \rightarrow O$ expectancies.

![Diagram of Determinants of $P \rightarrow O$ Expectancies]

**Figure E.3 Determinants of $P \rightarrow O$ Expectancies**

The valence of an outcome is determined by the perceived fairness of the input - output balance. The presence of inequity, as stated by Adams, will motivate an individual to redress the situation.
An important point in Lawler's Expectancy Motivation Model is that while some outcomes are sought after as a goal in themselves, others (Outcome V5) are seen as paths leading to future outcomes (Outcome V4), as illustrated in Figure E.4. For example, an initial outcome may be recognition with the final goal being promotion.

The motivational strengths of individual outcomes can be summated to obtain the overall motivational strength for a given situation. This can be represented by the following formula, as developed by Lawler.

\[ \text{Motivation Strength} = (E \rightarrow P) \times ((P \rightarrow 0)(V)) \]

where \( V \) = Valence

For example, at the start of a contract a steel fixer may rate his probability of reaching a certain performance as 0.70 and the probability of then receiving a full bonus as 0.90. The perceived probability of receiving a full bonus is therefore +0.63 (i.e. 0.70 \times 0.90). Also, at the end of the project he may realize that the probability of this level of performance resulted in him being out of work sooner is 1.0. The value assigned to receiving a full bonus could be +1.0 and the value assigned to being out of work sooner could be -0.8. The motivational strength caused by these two factors is therefore +0.07, as calculated below.

\[
\text{Expectancy Valence} = \text{Motivational Strength}
\]

Bonuses = \(0.70 \times 0.90 \times (+1.0) = 0.63\)

No work = \(0.70 \times 1.00 \times (-0.80) = -0.56\)

\[+0.07\]
Legend:
I = Instrumentality perception
V3 = Valence of third outcome
E = Expectancy

Figure E.4 Lawler's Expectancy Motivation Model
E.2.6  Relationship between Motivation and Performance

A hypothetical relationship between performance and degree of motivation was posited by Vroom. In which there are three main determinants influencing job performance, namely motivation, skill, strength and clarity of job objectives; these can be expressed as:

Performance = motivation x ability x job clarity.

This relationship holds true for most situations. However, when motivation is very high, resulting in pressure to perform, ability may be impaired, (i.e. more haste less speed).

E.2.7  Summary of Major Motivation Theories

The five theories on motivation have been discussed in order to show how the Expectancy/Valence theory was developed. The main problem with this theory is that, although it is very mathematic in structure, all the input values are dependent on subjective assessments and predictions. The main advantage of this system is that motivational strengths of different goals can be quantified and combined, this enables comparisons of different situations to be made. The earlier models are still appropriate, and often preferred, when the motivational strength of one goal is significantly greater that the remainder.

Maslow's hierarchy of needs should be divided into two separate stages. The first stage in the hierarchy contains the basic physiological and safety needs, which have to be satisfied before the next stage can operate. The attainment of these first stage needs is not sufficient on its own to create motivation, hence the second stage in the hierarchy. The second stage needs are "Affiliation", "Esteem" and "Self-Actualization" and represent the motivating goals in the Expectancy/Valence model.
Maslow realized that individuals wish to feel necessary in their work, gain respect from their employer and colleagues, and to identify with a specific skill. However, few jobs contain all these and Herzberg observed that management try to increase job satisfaction by providing extrinsic rewards such as improved earnings. The transient nature of the construction industry has restricted the use of non-materialistic motivators, although the monotonous factory environment is often avoided. Consequently, financial incentives are the predominant methods used to improve operative motivation.

E.3.1 Financial Incentives

The payment of financial incentives in the construction industry is an inherent part of wage structures and of paramount importance in industrial relations. The remainder of this appendix describes the various types of incentive schemes currently operating on construction sites, and also compares the attitudes of management and labour towards the payment of incentives and the affect on motivation.

E.3.2 Types of Incentive Schemes

Research undertaken by Mackenzie (E.13) was based on a survey of thirty contractors, and showed that a wide variety of incentive schemes were in operation. However, many of the schemes were very similar, the following groups being identified.

1. Piecework Schemes

A large proportion of construction companies pay their workforce in accordance with one of the National Work Rule Agreements, as opposed to piecework incentive schemes. However, nearly all contractors also employ a large element of sub-contractor labour, who generally work to a schedule of prices (piecework).
(ii) **Direct 100% Schemes**

Mackenzie found this to be the most widely used type of incentive scheme among the contractors he visited, although several variations were encountered. The variations in direct schemes are as a result of the actual calculation of bonus paid, these are:

(a) 'Hours saved' (e.g. target = X hours/pipe laid)
(b) 'Cash' (e.g. target = £X/pipe laid)
(c) 'Output' (e.g. target = £X/pipe laid/week)

(iii) **Direct, Geared Schemes**

The majority of geared direct schemes work on an hours saved basis, with the percentage increase in performance not rewarded by the same percentage increase in bonus payment. The extent of gearing is usually between forty and ninety per cent.

(iv) **Indirect Schemes**

Indirect schemes are used where operatives are involved in providing a service rather than a finished product, and the level of performance is difficult to determine. For example, a general labourer may have his bonus linked to performance of the concrete gang.

(v) **Banded Schemes**

Banded schemes are based on the same principles as the other schemes, but there are distinct steps instead of a linear relationship between performance and bonus paid. This type of scheme is not very common but is effective where the work performed is complex and varied.
(vi) Merit Schemes

Merit schemes are paid not as a bonus but as a reward for experience or qualifications. The most common type being the payment made to a ganger above the normal rate. The payment in this type of scheme may involve variable daywork rates, increased bonus rates or other one-off benefits.

(vii) Policy Schemes

Very few contractors have formal policy schemes, although some provisions are made for adjustments to be made for any fluctuations in labour demand. Policy schemes introduced to attract key individuals are difficult to remove once the demand has passed.

E.3.3 Ranking of Operatives' Needs

As previously discussed, an individual is not merely motivated by the actual rewards he receives but also by how he perceives the benefits. The perceived ranking of operatives' needs has been researched by Wilson (E.14) from the operatives' point of view and by Mackenzie (E.15) from the management point of view. A comparison of the results is presented in Table E.1.
### Table E.1 Comparison of Incentive Rankings

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Physiological Needs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earnings</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Short travel to and from site</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td><strong>Safety Needs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical/Safety/Working Conditions</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Welfare Conditions</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Job Security</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td><strong>Belonging Needs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Friendliness of site</td>
<td>4±</td>
<td>10</td>
</tr>
<tr>
<td>Work with people as a team</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Work on a well organized site</td>
<td>4±</td>
<td>2</td>
</tr>
<tr>
<td>Good relations and management</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Fringe benefits</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td><strong>Need for esteem</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recognition from management/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>work-mates</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Working for a successful company</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>Working for a modern company</td>
<td>15±</td>
<td>-</td>
</tr>
<tr>
<td><strong>Need for self-actualisation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Challenge in the job</td>
<td>17</td>
<td>-</td>
</tr>
<tr>
<td>Job freedom</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Plenty of time for personal/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>family life</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Prospects for promotion</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>Opportunities for training</td>
<td>20</td>
<td>12±</td>
</tr>
<tr>
<td>Ability to make use of, and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>develop skills</td>
<td>8</td>
<td>-</td>
</tr>
</tbody>
</table>
From the simplified ranking system used in both studies, and the results presented in Table E.1, it would appear that management have misinterpreted the importance of some of the operatives' needs. The management survey suggests that, given the opportunity to increase earnings through increased output, the site operative will readily accept poor working conditions. However, the operatives' survey suggests that the need for increased earnings is overshadowed by a greater need for improved safety and physical working conditions.

The second factor misinterpreted by management is job security. It is thought by the majority of management that this was quite a powerful incentive, particularly towards the end of a project. However, job security was given a very low ranking by the operatives, probably because moving at the end of a project has become an accepted facet of construction work. The low ranking given by the operatives to needs such as esteem and self-activation probably stems from the lack of opportunity to obtain these rewards in the construction industry.

E.3.4 Construction Operative Performance

The motivation theories discussed in this appendix are complex and are aimed at identifying factors which affect operative motivation, rather than measuring results in terms of productivity. For example, Maslow, Murray and Herzberg all concentrate on the isolation of the individual's basic needs. Thus, several complex hypotheses, relating motivational strength to the individual's basic needs, have developed with little or no quantitative measurements made. The complexity of existing motivation theories renders them virtually useless in any quantitative assessment of relationships between incentives and productivity. A more simplistic approach is taken during this research and a quantitative relationship between motivation and production is developed. Productivity is measured in terms of site factors and some of the variables affecting operative motivation are isolated. For example, Figure E.5 illustrates the relationship between site factors and level of remuneration. This figure has been extracted from Chapter 9.
TOTAL SITE FACTOR AGAINST REMUNERATION

Legend

- Δ CONCRETE GANGS
- × FORMWORK GANGS
- □ STEELWORK GANGS
- ■ REINFORCEMENT GANGS
- XX PRE-CAST CONCRETE GANGS

FIGURE E5
APPENDIX F

BASIC STATISTICAL THEORIES
APPENDIX F

BASIC STATISTICAL THEORIES

F.1 INTRODUCTION

Chapters Five and Nine investigate the degree of relationship between several variables, and determine how well linear or other equations describe or explain these relationships.

To assist in these investigations a statistical package called MINITAB is used. This appendix outlines the main theories used throughout these statistical investigations.

F.2 MEASURES OF VARIATION

A sample can be described by the location of co-ordinates when plotted on a graph. However, characteristics describing both the location and the manner of dispersion provides considerably more information about the sample than does a single measure only describing the location of the data. Several quantities that can be used as 'measures of dispersion' are: the 'mean absolute deviation', the 'variance', and the 'standard deviation'.

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F.2.1 Mean Absolute Deviation

The 'mean absolute deviation' (denoted by M.A.D.) is the numerical (i.e. positive) value of the deviation of each observation \( (X_i) \) from the sample mean \( \overline{X} \). The mean absolute deviation is sometimes referred to as the 'mean deviation' or 'average deviation' and can be expressed as:

\[
\text{M.A.D.} = \frac{\sum |X_i - \overline{X}|}{n}
\]

Where \( |X_i - \overline{X}| \) is the absolute value of \( (X_i - \overline{X}) \).

The mean absolute deviation is easy to calculate and simple to interpret. However, this measure of dispersion does not lend itself to further statistical investigations as absolute values are not suitable for mathematical analysis.

F.2.2 Variance and Standard Deviation

To accommodate measures of variation in more detailed analysis it is important to remove any absolute values. One solution may be to define a 'mean signed deviation' as shown below.

\[
\text{'Mean signed deviation'} = \frac{\sum (X_i - \overline{X})}{n}
\]

However, this definition does not produce much information about the overall variation in the data, because \( \sum (X_i - \overline{X}) \) is always zero. To obtain the most suitable measure, non-negative values are required whilst avoiding absolute values. This is achieved by squaring the individual values, the sum of which is called the 'sum of squares'.
To convert the 'sum of squares' into a measure of variation we have to divide by the number (n) of sample observations. The obtained value is called the 'sample mean squared deviation' and is defined as:

\[ S^2 = \frac{\sum (X_i - \bar{X})^2}{n} \]

Usually the sum of squares is divided by \( n-1 \) rather than by \( n \), because the resulting value represents a better estimate of the standard deviation of a population from which the sample is taken. In this research \( n-1 \) is taken as the denominator and 'sample variance' is defined as:

\[ S^2 = \frac{\sum (X_i - \bar{X})^2}{n - 1} \]

In order to obtain a measure of dispersion having the same units as the observed values, it is necessary to take the square root of the sample variance. The obtained value is known as the 'sample standard deviation' (S) and is defined as follows:

\[ S = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n - 1}} \]

**F.3 LINEAR-CORRELATION**

If \( X \) and \( Y \) denote the two variables under consideration, a scatter diagram shows the location of points (\( X, Y \)) on a rectangular co-ordinate system. If these points are close to a straight line, as in Figures F.1 to F.2, there is 'linear' correlation. If the points lie near some curve, there is non-linear correlation, as in Figure F.3. If the points do not lie near either, they are 'uncorrelated', as in Figure F.4. If \( Y \) increases as \( X \) increases (Figure F.1) there is positive or direct correlation. If \( Y \) decreases as \( X \) increases (Figure F.2) there is negative or inverse correlation.
Figure F.1  Positive Linear Correlation

Figure F.2  Negative Linear Correlation
Figure F.3  Non-Linear Correlation

Figure F.4  Uncorrelated Results
Several plots are produced as part of the statistical analysis presented in Chapter 5. These plots are used in a qualitative manner to determine how well a given line or curve describes the relationship between two variables. Some of the scatter diagrams are selected and plotted in Figures 5.1 to 5.15.

F.4 LEAST SQUARES REGRESSION LINES

The method of least squares is used to determine actual relationships between variables. If there is a linear relationship between the two variables, the 'best-fit' line can be expressed in terms of its y-intercept (a) and its slope (b) as shown below.

\[ Y = a + bX \]

The best-fit line is obtained by minimizing the sum of the squares of the deviations of the predicted y-values from the observed y-values. This is known as the 'method of least squares' and the values of 'a' and 'b' can be obtained from the following equations (F.1).

\[ a = \frac{(\Sigma Y)(\Sigma X^2) - (\Sigma X)(\Sigma XY)}{N\Sigma X^2 - (\Sigma X)^2} \]

\[ b = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{N\Sigma X^2 - (\Sigma X)^2} \]
The 'total variation' of \( Y \) is defined as the sum of the squares of the deviations of the \( Y \) values from the mean value (\( \overline{Y} \)). This total variation can be separated into 'unexplained variation' and 'explained variation', as follows.

By definition 'total variation' = \( \sum (Y - \overline{Y})^2 \)

If \( Y_e \) represents the value of \( Y \) for given values of \( X \) as estimated from the best-fit line, then:

\[
Y - \overline{Y} = (Y - Y_e) + (Y_e - \overline{Y})
\]

Squaring both sides and then summing produces:

\[
\sum (Y - \overline{Y})^2 = \sum (Y - Y_e)^2 + \sum (Y_e - \overline{Y})^2 + 2 \sum (Y - Y_e)(Y_e - \overline{Y})
\]

As the last sum is zero, total variation can be expressed as:

\[
\text{total variation} = \sum (Y - Y_e)^2 + \sum (Y_e - \overline{Y})^2
\]

The first sum in the above equation is called the 'unexplained variation' because the deviations \( Y - Y_e \) are random and unpredictable. The second term is called the 'explained variation' because the deviations \( Y_e - \overline{Y} \) have a definite pattern.

The ratio of the explained variation to total variation is called the coefficient of determination. If there is no explained variation, i.e. the total variation is all unexplained, this ratio is zero. Conversely, if there is no unexplained variation, i.e. the total variation is all explained, the ratio is one. This ratio is defined as:

\[
R^2 = \frac{\sum (Y_e - \overline{Y})^2}{\sum (Y - \overline{Y})^2}
\]
The quantity $R$ is known as the 'coefficient of correlation' and varies between -1 and +1. To avoid confusion between these two terms the coefficients of determination are expressed as percentages throughout this thesis.

The previous expression (for $R^2$) is very general and can be used for both linear and non-linear relationships. However, if a linear relationship is assumed, the following 'product-moment formula' can be derived, resulting in the following expression:

$$R = \frac{\sum (X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum (X-\bar{X})^2 \sum (Y-\bar{Y})^2}}$$

F.6 ANALYSIS OF VARIANCE

Essentially, the analysis of variance is a technique which separates the variation that is present into independent components; these components are subsequently analysed in order to test certain hypotheses. In its simplest form this technique is known as the one-way analysis of variance.

The time taken to perform certain activities (e.g. vibrate concrete) often relates to the type of construction (i.e. slabs, walls, beams or columns). Consequently, it is sometimes appropriate to separate observations into different samples. Where this is the case, one-way ANOVA tests are performed to test the hypothesis that the means of the different samples are significantly different.

In a one-way analysis of variance each observation is classified into one sample, and the hypothesis that: "the means of these samples are equal" is tested. This hypothesis is tested by calculating the ratio of the "among samples mean square" to the "within samples mean square", (MSC/MSE). The hypothesis is rejected if this value (known as the F statistic) exceeds the upper-point of the F-distribution having the appropriate degrees of freedom. The level of significance is the probability of rejecting the hypothesis when it is, in fact, true. This value is taken as 0.025.
F.6.1 Example of Analysis of Variance

The following example has been extracted from Appendix D, to illustrate how the one-way analysis of variance was used to determine if time taken to prepare the tools was dependent upon the method used to pour the concrete.

Table F.1 Example of Analysis of Variance

```
-- ONEWAY C63 C62

ANALYSIS OF VARIANCE

<table>
<thead>
<tr>
<th>DUE TO</th>
<th>DF</th>
<th>SS</th>
<th>MS = SS/DF</th>
<th>F-RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>FACTOR</td>
<td>3</td>
<td>661.</td>
<td>220.</td>
<td>1.29</td>
</tr>
<tr>
<td>ERROR</td>
<td>49</td>
<td>8352.</td>
<td>170.</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>52</td>
<td>9013.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LEVEL     N | MEAN | ST. DEV.
1         6  | 9.3  | 6.4
2         12 | 16.5 | 9.2
3         12 | 21.6 | 10.6
4         23 | 19.1 | 16.5

POOLED ST. DEV. = 13.1

INDIVIDUAL 95 PERCENT C. I. FOR LEVEL MEANS
(BASED ON POOLED STANDARD DEVIATION)

-----------------------------------------------------------------------------------
  1                     2                     3                     4
-7.0                  0.0                  7.0                  14.0
-----------------------------------------------------------------------------------
  21.0                  28.0                  35.0
-----------------------------------------------------------------------------------
```
Formulate the null and alternative hypotheses

\( H_0 : \) Means are all equal.
\( H_1 : \) Means are not all equal.

Form the above table \( F = 1.29 \)

Calculate from F-Tables \( F = [k-1, n-k] \)

\( = \) level of significance \( = 0.025 \)
\( n = \) number of observations \( = 53 \)
\( k = \) number of samples \( = 4 \)

\( F_{0.025} [4-1, 53-4] \)
\( F_{0.025} [3, 49] \)

\( = 3.4 \)

\( \Rightarrow F < F_0 \)
\( 1.29 < 3.4 \)

\( \Rightarrow \) We accept \( H_0 \)

This test shows that the time taken to prepare the tools is not dependent upon the method used to pour the concrete.
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