A SUBSIDENCE MONITORING PROGRAM FOR AHMADU BELLO UNIVERSITY DAM, ZARIA.

BY

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A Thesis submitted to the Postgraduate School, Ahmadu Bello University, in Partial Fulfillment of the requirements for the degree of M.Sc. Land Surveying.

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June, 1987.

DECLARATION

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All quotation marks are distinguished by quotation marks and the sources of information specifically acknowledged by means of references.

Paul Dare Oluyori

CERTIFICATION

This thesis entitled, A SUBSIDENCE MONITORING PROGRAM FOR A.B.U. DAM, ZARIA, by P. D. Oluyori meets the regulations governing the award of the degree of M.Sc Land Surveying of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

1. Chairman, Supervisory Committee Date

2. Member, Supervisory Committee Date

3. Member, Supervisory Committee Date

4. Head of Department Date

5. Dean, Postgraduate School Date

ACKNOWLEDGEMENT

I wish to acknowledge the immense assistance given me by the supervisor, Mr. B. A. Neequaye, for painstakingly guiding me through this project.

I also thank Professor N. J. Field for suggesting this topic to me and coming to my aid in difficult periods. Also, big thanks to Mr. Bammeke and other lecturers for their contributions in various ways.

Mention must be made of Adamu Luka who was with me throughout the field observations. May God bless him. I am very grateful. So also my good friends Haruna Abdu and Joe Nwadiallor for what they are to me.

To my friends, Ola Osheidu, Tunde Osanubi (Arilo), Charles Dare, Gab Olorunfemi, Funsho M. Arokoyo, Jagger Daudu, Mr. and Mrs Julius Aniyi and others, I am very grateful.

Finally, I am grateful to my relations the OLUYORIS: Kan Oluyori, Kunle, Ayo, Yinka, Gbenro, Femi, Mr. & Mrs Soji, Mr. and Mrs. Balogun, Captain and Mrs Olutunmogun, Pa Joel Ajibola, Chief M. O. Oluyori and others for their encouragement and endurance.

May God bless you All.

ABSTRACT

A research project dealing with the determination and monitoring of subsidence (vertical movements) of A.B.U. Dam as a result of increase in volume of water in the reservoir, causing sudden load (causative effects) on the dam is discribed. It is of great interest and importance to design a program to detect, direction of these movements so as to plan (an) appropriate measure(s) against the disastrous consequences of such movements. These require precise instruments of high measuring accuracy and reliability, refined survey methods incorporating quick and frequent check operations and analysis of results. The Dam is an earth dam. A review of current monitoring techniques was given. Repeated Precise levellings of elevation of monitoring stations were made before the start of rainfall (low water level) in April, and after maximum rainfall (highest water level) has been recorded, in August. An approach whereby upper and lower stadia staff readings were not recorded but using only the center hair reading of both left and right graduations on staff was adopted. The advantages of this method were stated. Rigorous least squares adjustment was carried out. Analysis of the data by Chi square test was done to determine the acceptability of the levelling. It is acceptable

at the 95% confidence limit. The deformation analysis was done using the "Karlsrue" procedure and it is based on the general hypothesis test. The measurements show movement (subsidence) of monitoring stations and hence the dam. These movements can be attributed to the effect of sudden load on the dam. The results also suggest the need for such a monitoring program. Recommendations are given at the end.

DEDICATION

Foremost to my Creator, God for His blessings and direction and guidance up to this stage of my life.

To my father Prince Ayo V. Oluyori and mother Victoria Adesola for their endurance and encouragement. May God grant you good health and long eventful life (amen).

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CHAPTER 1

1. INTRODUCTION

The subject matter of this research project is the Ahmadu Bello University Dam in Zaria. This is an earthdam on River Kubani.

Since the dam was built in 1973 and the subsequent filling up during the wet season of the same year, there has been no known or available records of measurements observed for the purpose of monitoring movements on the dam.

Because all structures move, a monitoring program to determine movements of the dam becomes a valuable venture. The trend of movements can be used to deffer-entiate between destructive and harmless movements. In fact, Rutenbeck (1982) declared that "a monitoring program for historic structures is of little value unless destructive movements can be separated from movements that are harmless" and that "No measuring system can warn of instant collapse of a structure". This implies that only a monitoring program can be used to monitor the trend of movements which may lead to collapse. This further depends on the use of appropriate equipment and field techniques.

Any earth or structural movements of the dam can best be monitored by taking measurements when water in the reservior is at its minimum and maximum

levels. The movements may be due to either the weight of water in the reservoir or water seepage from the dam to the surrounding underground rocks leading to build up of stresses which may cause destruction of the dam leading to considerable human losses and demage to properties.

The importance of carrying out periodic measurements using precise instruments and refined field procedures of points located in the vicinity of the dam cannot be overstated.

Large seasonal movements could be expected in buildings resting on expansive soils. As the moisture conditions in the soil change, its volume also changes and forces the building to move. Other structures may show little or no seasonal movements, if resting on a sound foundation, other than changes in the instrumentation method itself.

Detection of these movements is necessary because they give information needed in engineering design, provide a check on the reliability of assumptions relating to the elastic behavior of structures or for safety measures and also of considerable interest to geophysicists.

In Bomford (1980), it is stated that the causes of crustal or structural movements are questions for geophysics and that geodesy is only concerned with

the measurement of the movements.

Bomford (1962) stated that "to detect and measure movements is a straightforward geodetic task" and that geodetic programmes must be designed with some knowledge of where and what are to be expected.

The choice of period (epoch) between which observations have to be repeated is very important in a project of this nature. The epoch could be years depending on how active the area under study is or the magnitude of expected movement. This project based its period of observation on low water level (close to start of rainfall in April) and highest level (after maximum rainfall had been recorded in August).

Instruments normally used for deformation studies should of necessity be accurate and rugged. Accuracy implies ability of instruments to measure up to desired accuracy and rugged to mean stability of instruments under field conditions.

The requirements for instruments also show the need for highly refined field procedures and observational techniques.

There are various methods of detecting or monitoring movements or deformations. These are by geodetic, photogrammetric and physical methods. The method to be used depends on the type of move-

ments being monitored and the magnitude and direction of the movements.

For the present purpose, monitoring of vertical movements, vertical controls are important. Validity of detected movements being real depends on the stability of the vertical controls used as reference points. The controls must be stable or assumed stable throughout the period of observations. The vertical controls used in this project are U4, BMA, BMB and BMC.

Lachapelle (1979) had noted that "studies related to vertical movement require precise levelling measurements carried out at different epochs with optimal accuracy".

The adjustment of the levelling network was carried out using the method of Least Squares. This is because it allows a better statistical evaluation of the accuracy of the network and also gives the most probable values.

The difference between the adjusted elevations of monitoring stations in April and August will be the movements that have occurred during the period.

To summarise, chapter one deals with introduction, two with literature review, three with methods and equipment and four is the conclusion.

1.1 Objective of Study

The objective of this project will be discussed under (i) Justification and (ii) Exact aims of the project.

(i) Justification

The justification of this type of project can be identified from three examples given below.

(a) A landslide noticed in Akko Local Government Area of Bauchi State buried four teenagers alive, prompting the state government to declare the area a "danger zone". If periodic observations were taken in such area, the impending landslide would have shown a trend well inadvance, to warrant safety measures being taken before that disaster.

(b) A part of the A7 Block of Suleiman Hall, Ahmadu Bello University, Zaria is sinking. If survey marks had been affixed to the building and precise observations carried out periodic -

ally, the movement would have been revealed. If this subsidence exceeds a certain limit, cement injection can be applied to the foundation to stop the movement.

(c) Ajakaiye (1974) and Hou (1979) gave lists of dams that have failed in various countries, resulting in loss of life and property damage.

All the examples above justify the need to set up a monitoring program to detect movements of the A.B.U. Dam.

(ii) Exact Aims of the Project

The aims of the study are twofold:-

(a) Determination of vertical movement due to accumulation or increase in water level during the period April - August.

(b) Evolving a monitoring program for vertical movement of A.B.U. Dam considering the fact that none has been in existence. This involves the adoption of precise levelling methods and adapting it to suit the prevailing situation, taking into consideration

personnel factor, as much as we can.

1.2 Limitations of Study

The limitations are:-

(i) Time constraint - this becomes very significant when a differentiation is to be made between harmless and destructive movements since enough information cannot be obtained from observations carried out between April and August.

(ii) The absence of reliable controls around the dam leading to extra work to provide heights for points to be used as control reference stations.

CHAPTER 2

LITERATURE REVIEW OF CURRENT MONITORING TECHNIQUES

2.1 Methods of Deformation Monitoring

Structural deformations result in changes of shape and or sizes of structures. These deformations can be in both horizontal and vertical directions.

A number of factors responsible for structural movements are crustal movements, effect of force of gravity, weather changes (e.g. temperature, wind, rainfall), differences in geological formation, etc.

Richardus (1974) stated that all movements are three - dimensional; there are several ways of measuring them. The methods are generally classified into three groups: (A) Geodetic, (B) Physical and (C) Photogrammetric.

Definitions

Relative or Differential movements are movements within the structure causing permanent and elastic deformations. The points of a structure can be observed from refernce stations in the vicinity but outside the moving region. The deformation pattern depends on the type of structure and external contributing factors.

Absolute movements are those exerted by the structure as a rigid body on the ground on which it

stands. The movement commence as soon as the foundations are being laid with the weight increasing until the construction is completed.

Regional movements are those taken place in the regions adjacent to the structure and are the results of absolute movements.

(A) Geodetic Methods

These methods give relative as well as absolute movements. Points on the structure can be observed from reference stations in the vicinity but outside the moving region. They are classified into two:

(i) Methods of determining horizontal movements which are:

(a) Alignment method;

(b) Triangulation;

(c) Traversing;

(d) Trilateration and

(ii) Methods of determining vertical movements

(a) Precise levelling

(b) Trigonometric levelling.

Since this project is concerned with vertical movement, only brief explanation will be given on the methods of horizontal movement monitoring.

The alignment method involves bringing a target into alignment with a straight line established between two stations which are assumed stable. A theodolite is used. The difference in the instantaneous positions determined over a period indicates the amount of movement recorded with a micrometer.

In triangulation, angular observation measurements are used to connect targets set up at the site of the movement to a number of control stations outside the moving region. The instantaneous position of targets are then established either by intersection (observations of direction at the reference points only), resection (observations carried out at the moving points) or by a combination of both.

The method of traversing requires that points being monitored be included in a traverse connecting two terminal control stations. This type of traverse has a disadvantage of having short sides which affect the precision of angular measurements.

The method of trilateration involves only distance measurements. The advent of EDM or eletronic distancers e.g. Mekometer ME3000 have advanced their use in these studies. Nyland (1977) stated that "The fundamental limitation of trilateration appears now not to be instrumental but meterological".

Hou (1979) reported the use of triangulation and trilateration method to detect deformations of the Axis Earthdam, East of Carnation, Washington. It was observed that though the two methods are of comparable accuracies, the trilateration method was faster during field measurements and much simpler in computation and adjustment.

The vertical component of the deformation are measured using precise levelling and trigonometrical levelling.

Bomford (1971) lists a number of aims and associated requirements for precise levelling. Two classifications can be noted:

(i) Scientific investigations and

(ii) Engineering and mapping requirements.

Only (i) is of relevance to this project. These investigations impose the need for highest possible accuracy. Various work carried out using precise levelling methods are well documented, see (Anderson, 1979; Berry, 1976; Ebong, 1984; Ellingwood, 1972; Lachapelle, 1979; Linton, 1974; Mitchel, 1972; Nyland, 1977; Savage, 1971; Wong, 1976).

Berry (1976) made a distinction between geodetic and precise levelling, contending that in geodetic levelling, all known imperfections in the instrument system are compensated by application of computed

corrections while in precise levelling, attempts or efforts are made to reduce the magnitude of observational errors to tolerable limits by careful and frequent adjustment and calibration of instrument system, a process which minimises or totally eliminates systematic corrections.

In precise levelling, a precise level, invar staves, struts, umbrella, etc. are always used.

The observational procedures are well documented in Clark (1973). Also, see Garner et al (1976).

The level instrument is generally fitted with a center hair and two stadia hairs (upper and lower). There seems to be two reasons for using the upper and lower stadia readings. One, they serve as a check against gross errors in the reading of the center hair and two, to check equality of backsight and foresight distances at each instrument set up.

In this project, the upper and lower stadia readings were not recorded since the sight lengths were pre-marked. The readings of the two sets of graduations were taken on the staff hence obtaining two independent elevation differences at a single instrument set-up using a single staff.

The advantages of the precedure used in this project are:

(i) One set of elevation difference from the

left set of graduations acts as a check on the other obtained from the right.

(ii) The ordinary levelling fieldbook could be used for recording field observations.

(iii) Ammount of writing and attendant mistakes are reduced since only four readings are taken at a set up of instrument as against a minimum six in the conventional method using two staves.

(iv) It does not require an even number of instrument set-ups like conventional method.

(v) Only one staff man and a surveyor are needed thus reducing personnel requirement.

(vi) Since the same turning points are used for each instrument set-up, ΔH_L and ΔH_R could be averaged as they will be sufficently close together (ΔH_L and ΔH_R means elevation difference for left and right staff graduation readings respectively).

The field techniques are designed to eliminate as much as possible levelling errors. For example, gross errors or blunders which may be caused by the observer and assistants were avoided by carefulness and provision of check measurements. Systematic errors due to refraction was avoided by setting level instrument at equal distances from the back and forward stations and also using short sight lengths. Systematic

errors due to the instrument e.g. collimation error were avoided by observing the rules stated above. Also grazing rays of light were avoided by not taking readings less than 0.5000m on the staff.

The field observations are reduced using the "Rise and fall" method. A check on the arithmetical computation was also carried out as follows:-

$$\Sigma B.S. - \Sigma F.S = \Sigma Rises - \Sigma Falls = Last\ R.L - First\ R.L.$$

where $\Sigma B.S.$ = summation of backsights

$\Sigma F.S.$ = summation of foresights

R.L. = Reduced level.

A rise occurs when B.S - F.S is positive.

A fall occurs when B.S - F.S is negative.

R.L of a station = R.L of preceeding station + Rise (or - Fall).

The sources of errors in levelling are listed in (Clark, 1973; Clendinning; 1962; Garner et al, 1976), and the various techniques of avoiding them were stated.

The adjustment is based on the principle of least square /method B (by correlates). Only round-off problems using are encountered in all direct computations and the way to avoid this is to follow the rules guiding rounding-off problems given by Barry (1966). The difference between the adjusted elevation of monitoring stations give the size and sign of the movement

during the period of observation.

Trigonometric levelling determines elevation using observed vertical angles. The formular for computing height is given in Garner et al (1976). Blachut et al (1979) observed that simultaneous reciprocal observations of vertical angles should be used since the coefficient of refraction varies greatly at tripod heights. Richardus (1974) stated that this method yields the same precision as in precise levelling using short sight lengths. In the adjustment of trigonometrical levelling, Hirvonen (1971) says "it is more usual to take the height differences as measured quantities, not the vertical angles".

Ashkenazi and Howard (1984) stated that this method could be used when precise levelling is impracticable, e.g. in rough terrain, and reported its use in Nottingham University.

(B) Physical Methods

This methods involve the use of strain guages, special thermomoters, tilt meters, etc., in monitoring or detecting movements. Only relative movements can be observed using this method. The observation station are either attached to or built into the structure.

These methods involve the use of strainmeters, tiltmeters, special thermometres etc, in monitoring or detecting movements.

The operating principle of strainwater consists of connecting two distinctly moving points with a wire in order to record the distance variation between them as a function of time. If both points moved, relative movements are determined, whereas if one point is fixed, absolute information is obtained.

The variation in length can be determined indirectly by means of a spring attached between the wire and the fixture, or directly by a linear scale. Precision of the results is affected by temperature effects, wind loads, and additional loads due to water and ice acting on the wire according to Schlemmer (1982). High accuracy is achieved by choosing an adequate location of the strainwater and by avoiding open spaces.

The advantages are:-

(i) they do not need any long and complex measurement campaigns

(ii) they are easy to use, reliable and therefore do not require a special operative quality in measurement operations

(iii) the information can be read, recorded, filed and transmitted under numerical or digital form, by means of automatic systems

Disadvantages are:

(i) each measurement is autonomous and so is not framed into

A general homogenous system

(ii) the number of points under control is generally small and for each point the displacement in the preferential direction and not "the displacement vector" is determined.

(iii) the measurements can be set up only if particular structural situations are present.

(C) PHOTOGRAMMETRIC METHOD

This method is advantageously applied in cases where a large number of points must be determined to describe the behaviour of a structure and also when the area is less accessible.

It involves the remote sensing of points on the structure, coordinate measurements and analysis with reference to ground control points. The test points could be photographed from the air (aerial photos) or from ground stations (terrestial). In both, expensive geodetically determined control points tied to first order survey pillars are used. A minimum number of control points are required to appear on a single photograph taken from one camera station. The coordinates and heights of the points in the control network are determined by precise instruments. The most probable coordinates and heights of all control points are obtained from a rigorous least squares adjustment.

The test points which should be clearly labelled symmetrical crosses with arms 1.5 times the diameter of the floating mark of the steroplotter or comparator (Atkinson, 1980) are marked

carefully on a contrasting brickground of the structure before photography.

The X, Y and Z coordinates of each point are read from the X, Y, Z counters after model formation and setting of floating mark precisely on each point. Final check of coordinate measurements of any single stereomodel is achieved by comparing coordinate values by conventional engineering survey techniques with those obtained photogrammetrically.

Comparing the coordinate values of the test points obtained from two or more series of photography, movements on the structure are determined. The field coordinate values of the control points are regarded as error free to obtain the standard deviation of each coordinate.

Terrestial photography have been used and reports given by (Borchers, 1968; Danphin and Torlegard, 1970; Scott, 1978). Use of aerial photographs have been reported by Bradanberger and Erez (1972) and Lo (1978).

The advantages are:-

(i) it is quick and can yield reliable and accurate results.

(ii) the number of points used for analysis can be increased or decreased at wish without going to the field.

Disadvantages are:-

(i) it is costly

(ii) involves use of expensive plotting instruments, camera calibration, etc. for model formation and data extraction

(iii) depends on size of project area

Photogrammetric method is an indirect measuring method as opposed to conventional surveying methods of direct field measurements in the natural space. In photogrammetric methods, measurements are carried out on models of natural space. The photographs, however, depend on controls supplied by ground methods. The terrestrial photographs are taken with terrestrial cameras e.g. wild p32.

Finally, an economic comparison between geodetic and photogrammetric method of deformation measurements has been attempted and the conclusion is that the total time for each method is comparable.

2.2 Relative Merits of Methods

The physical methods require no need on assuming stable control points because the observation stations are built into or attached to the structure. Accurate and up-to-date information of the trend of relative movement can be easily collected. The use of the method is seriously affected by non-availability of the instruments.

The photogrammetric methods have a great advantage in the number of pints that can be used for precise

measurements and analysis. They do not require any physical contact with the structure after the targets have been fixed (this is particularly useful in earthquake prone areas). The biggest disadvantage is the cost of procurring photographs. Identification problems should not be overlooked. The method depends on ground controls provided by ground survey methods and hence cannot be expected to be more accurate than deformation measurements carried out by conventional methods (this is particularly a problem with height determination). It can only measure relative movements.

The geodetic methods are used to determine both horizontal and vertical movements. The merits lie in the accuracy achievable in detection and monitoring of movements. The demerits lie in the personnel requirement, laborious field procedures and uncertainty of reliability of control points (where they are available). In fact, Wong (1976) observed that "although there are geotechnical (physical) methods which can be used to detect small ground movements, field survey techniques remain to be the most practical and economical". Geodetic methods have the advantage of giving immediate results. It is for this reason that they are still employed especially for measuring deformations in dam. The equipment

(precise levels, theodolite, EDM instruments) are costly but not too expensive and does not have to be permanently positioned.

2.3 Instruments Used in Practice

The instruments used in practice are:

(i) Theodolites - for angular measurements e.g. Wild T3 or T2, Kern DKM3, etc.

(ii) Levels - for measuring elevation differences e.g. Wild N3, Ni-2, etc.

(iii) EDM instruments - for distance measurements e.g. Mekometer ME3000, etc.

2.4 Purpose/Advantages of Adjustment

When there are more observations or measured quantities than required for the determination of some quantities, an adjustment is required. These redundant observations are always needed since a blunder in a small number of measurements can be disastrous. The adjustment is not carried out to remedy errors but to minimise their effect on a network.

Barry (1978) noted that "whenever measurements are made, errors are made - the single exception being when the measurement is a discrete count (e.g. the number of people in a room)". This observation justifies the need for an adjustment, taking advantage of compensatory possibilities of unavoidable small

errors (random errors).

Hirvonen (1971) stated that "a net of spirit levelling is usually adjusted by method B (by correlates)" and this was applied to the adjustment of the net of precise levelling for this project.

Only the Least Squares (L.S) method meet the requirement of a homogeneous and consistent precision needed in deformation monitoring. In levelling, the weight has always been applied inversely as the length but Clendinning (1962) noted that where the lengths are short, this system of weighting may not be valid and other factors have to be put into consideration, such factors may be the number of times a line was measured and Barry (1966) says that "when conditions are identical except that one quantity is measured more times than another, weights are reasonably assigned in proportion to the number of measurements". Of significance is that the L.S. adjustment allows a better statistical evaluation of the accuracy of the network.

CHAPTER 3

METHODS AND EQUIPMENT

3.1 Preliminary Information Available

They are:-

(i) Benchmarks located around the dam. They are identified as U4, BMA, BMB, and BMC.

(ii) The elevation of U4 as given in Isa (1979) is 646•29600m. The origin of reference was however, not stated and the heights of the other benchmarks were not given.

(iii) Instruments available in the store of Department of Surveying which include Wild N3, Invar staff.

(iv) Monitoring stations already established on the dam.

(v) Plan of dam area drawn by Isa (1979).

3.1.1 Choice of Method and Instrument

After a review of all the methods available for monitoring and detecting deformations, it was found that only geodetic methods were applicable to this particular project.

Since the project is concerned with vertical movements, methods of horizontal deformation measurements are obviously not applicable. This, consequently, restricted the choice of method to two: precise and

trigonometric levelling.

The main problem with trigonometric levelling is the effect of refraction at tripod heights. This can be avoided by reciprocal observations but the difficulty lies in setting up the theodolite over the monitoring stations. Also, not all the stations are visible from the control points. These two factors led to the abandonment of trigonometric levelling method. Thus, only the precise levelling method was applicable.

The precise levelling method is a highly accurate one with all the field procedures, computational techniques, highly refined and precise instruments used.

The instruments chosen were:- precise level, invar staff, triangular footplates, survey umbrella, tapes. The Wild N3 level was used. The level can take staff readings to 0.1mm with the aid of parallel plate micrometer built into the level. The Wild GPL3 staff was also chosen since it maintains graduations on it accurately.

3.1.2 Calibration of Instrument

The instrument used for staff calibration, a travelling microscope, is not available in the department. However, a simple method was deviced to detect the deviation of the displacement of staff

readings from the nominal value of 301.55cm. This was carried out by taking left and right graduations of the staff placed at different positions. The results are shown in Table 3.1. The mean value was 301.552 which is 0.002cm or 0.02mm higher than nominal value. We could attribute this to estimation error which is still less than 0.05mm normally given for staff estimation.

Left Readings (CM)	Right readings (CM	Difference (cm)
149.329	450.874	301.545
160.369	461.915	301.546
173.655	475.201	301.546
137.880	439.421	301.541
140.640	441.202	301.562
142.252	443.785	301.533
160.574	462.136	301.562
142.857	444.435	301.578
	Mean	= 301.552

Table 3.1 Staff Calibration Test.

The Wild N3 level was calibrated in the field using the two-peg test. The records of the calibration are contained in Table 3.2.

B.S (cm)	F.S (cm)	
443.461 (S_1)	473.543 (S_2)	FIRST INSTRUMENT POSITION
441.043(S_3)	410.965(S_4)	SECOND INSTRUMENT POSITION

Table 3.2 Collimation Error Test

Collimation error (e) $=(S_1-S_2) - (S_4-S_3)$

$= - 30.082 - (-30.078)$

$= - 0.004$cm per 60m

$= - 00^{o}00' \ 0.14"$

The result suggest that the level is still in adjustment.

3.1.3 Location/Description of Benchmarks and Monitoring Stations

The benchmarks are U4, BMA, BMB and BMC. The monitoring stations are CP1, CP2, CP3 and CP4.

The first and perhaps the most important stage in any field survey work is the reconnaissance (recce). The area was visited and suitable stations were chosen. The benchmarks' descriptions and locations can be found in appendix A. Figure 1 is a recce diagram (not drawn to scale) of the area.

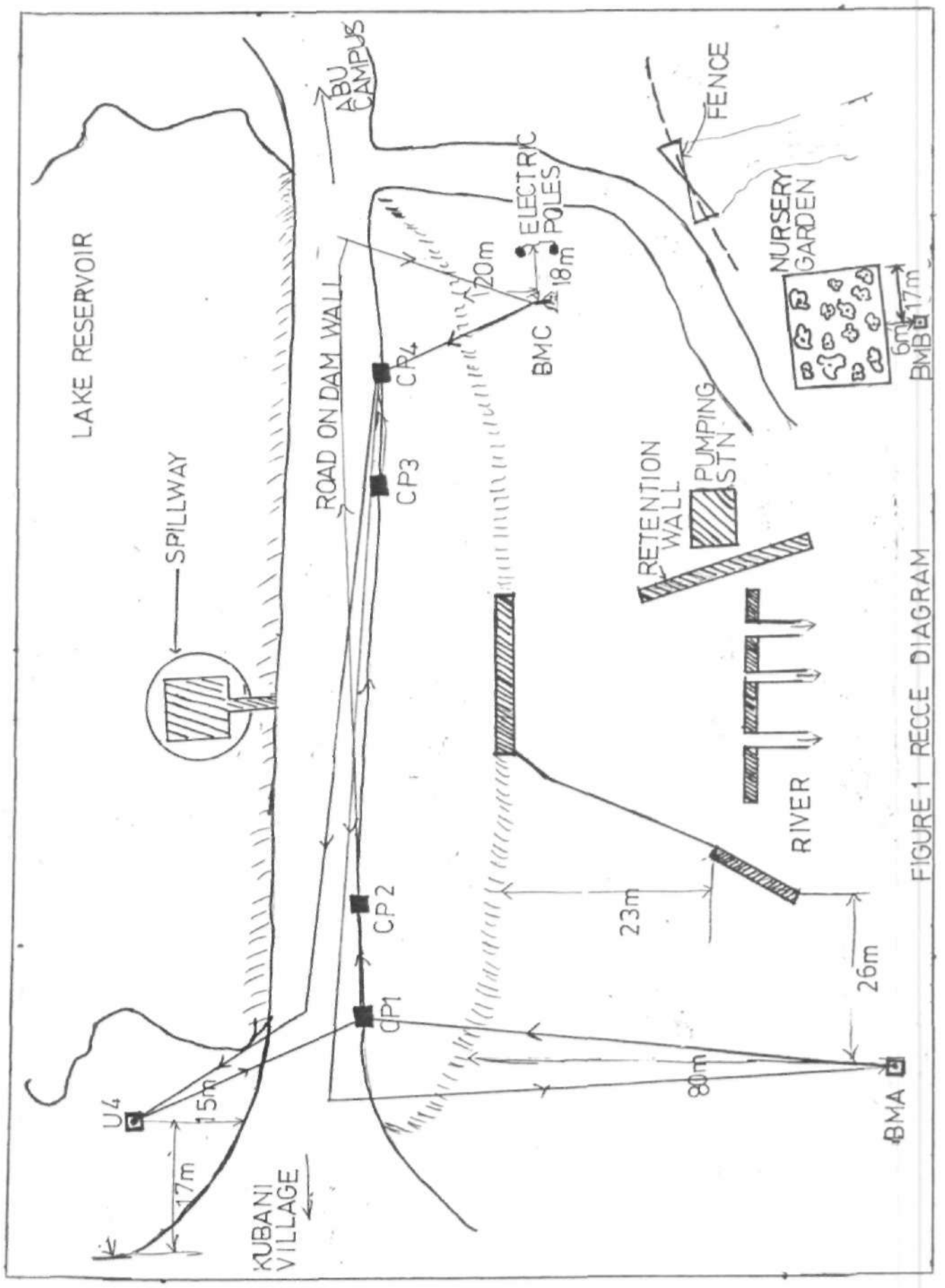


FIGURE 1 RECCE DIAGRAM

The dam is accessible through a motorable but untarred road from A.B.U. staff school to central stores. The road is tarred from central stores to and passes over the dam. The road leads to Kubani Village after the dam. On approaching the dam from central stores, the Kufena Hill becomes very visible. It takes about 5 minutes' drive from the staff school to the dam.

(i) Benchmarks Location/Description

U4, BMA and BMB are pre-cast concrete pillars with a nail showing the center as shown in Figure 2.

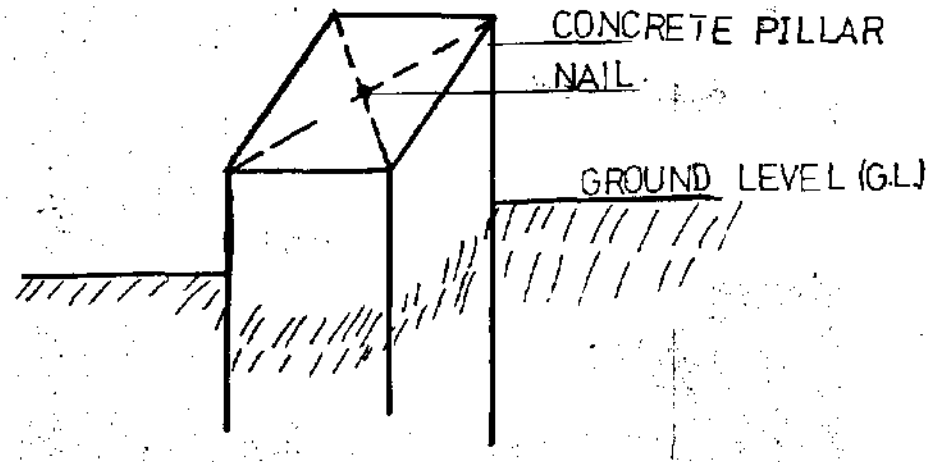


Figure 2 Shape of Benchmarks.

BMC is an iron rod driven into the ground and supported by a wound of concrete as shown in Figure 3.

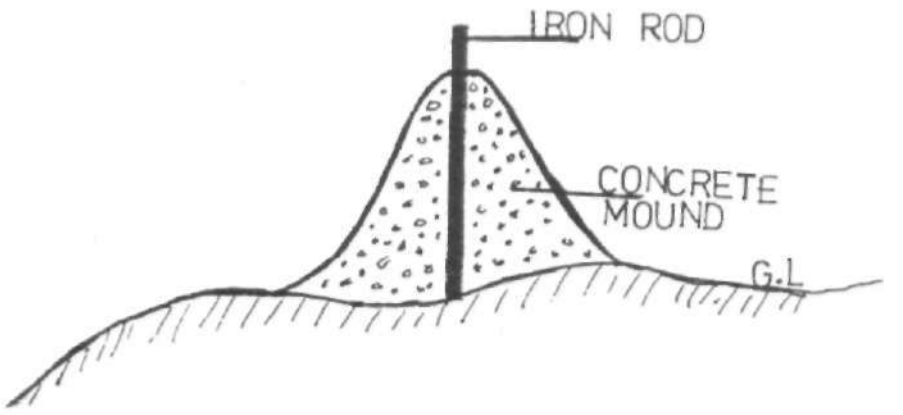


Figure 3 Shape of BMC.

Using prismatic compass and a linen tape, measurements were taken to permanent features to locate the positions of the benchmarks. See appendix A.

(ii) CPs' Description/Locations

The choice of monitoring stations is a technical problem. The approach adopted was to choose locations where none of the monitoring stations will lie directly above any concrete (e.g. the spillway outlet). Concrete is believed to have the ability of absorbing and concealing movements. The monitoring stations are all made of pre-cast concrete pillars buried on the left edge of the road over the dam when approaching the spillway from the central stores and facing the Kufena Hill. These CP's

have been buried presumably for the purpose of observations to monitor and detect movements of the dam. From the junction of the untarred road to the pumping station and tarred road over the dam, a tape was set out and distances were measured to locate the positions of the monitoring stations. See appendix B.

3.1.4 Preliminary Levelling

This became necessary when only the height of U4 is known. An arbitrary height could be given to the other benchmarks but since a uniform reference plane is desired for the control points, it became imperative to run a preliminary levelling starting from U4, passing through BMA, BMB and BMC and closing back on U4. The Wild N3 level and invar staff was used. The loop misclosure was distributed according to the number of instrument stations. The arithmetical mean of the R.L of a station as given by left and right staff readings were computed and accepted as the height of the BMs. The results are shown in Table 3.3.

Station	Height (m)
U4	646.29600
BMA	638.18249
BMB	637.94456
BMC	644.40783

Table 3.3 Height of BMS

3.2 Data Acquisition

The survey techniques adopted in the fieldwork was designed to minimise time spent and personnel requirement to an observer and an assistant while maintaining accuracy by eliminating instrument - observer error contributions.

Precise levelling was carried out over the monitoring stations. The levelling circuit commenced on any of the four benchmarks, passed through the monitoring stations and closed back on the starting point. See Figure 4. The arrows indicate the direction of levelling. I, II, III and IV are used to mean circuit I, etc. respectively.

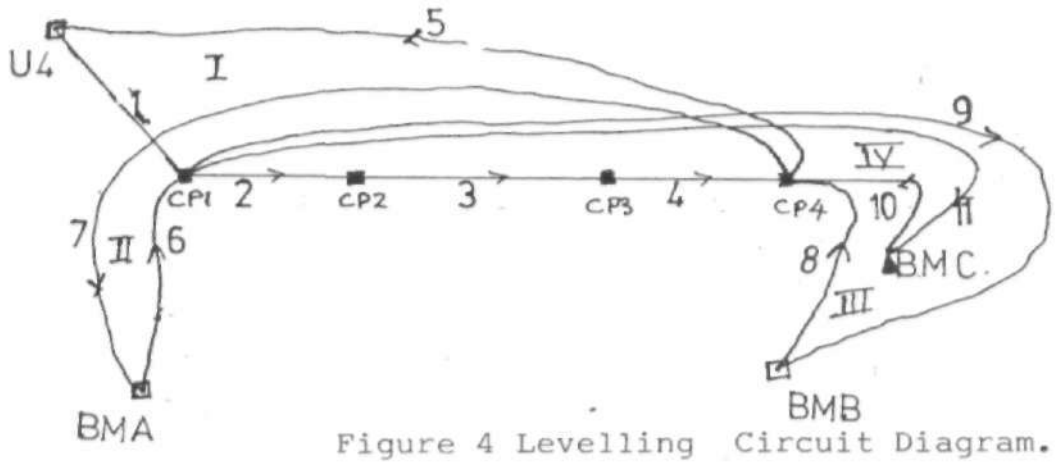


Figure 4 Levelling Circuit Diagram.

3.2.1 Instruments

The instruments used during the fieldwork were:-

(i) Wild N3 Precise Level Nr 96766 which with the aid of a parallel plate micrometer built into the instrument can measure

elevation difference to 0.1mm

(ii) Invar staff - Wild GPL3, which has two sets of graduation marks, was used. This use of invar staff has been seen to contribute to good results in precise levelling. The invar staff maintains constant graduations on it.

(iii) Change plates or triangular foot plates are used at turning points to ensure stability of such points.

Brief description of each of these instruments follow.

(i) Wild N3 Precese Level

For precise and geodetic work, N3 level equipment with parallel plate micrometer is used. The level employs the tilting principle in which the telescope is not rigidly fixed to the standing axis or vertical spindle, but capable of a slight movement in the vertical plane about a pivot placed immediately below the telescope. Tilting levels are noted for their robustness and high accuracy. The N3 level is light enough for comfortable transportation during field operations and is rugged.

The tilting screw controls the level bubble and three foot-screws used in preliminary approximate levelling of the instrument for which a circular level is fitted. See Figure 5.

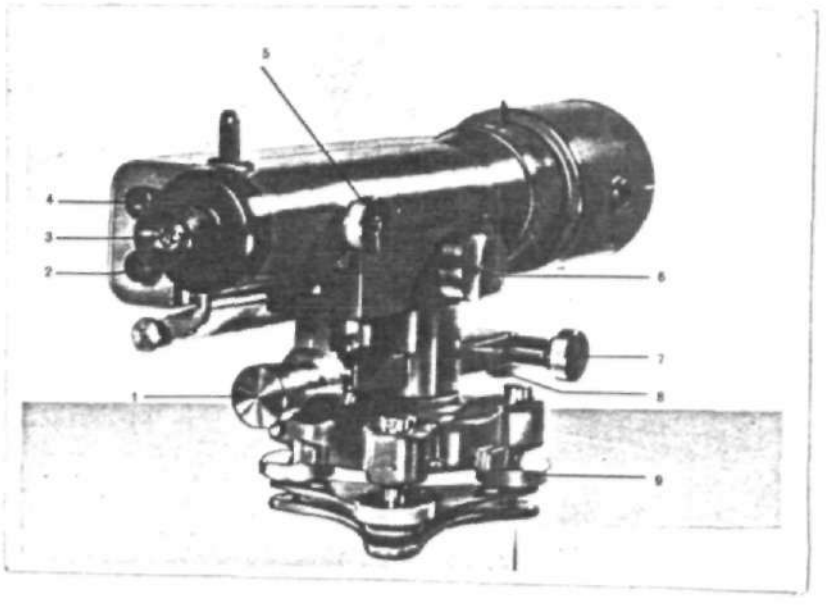


Figure 5 Wild N3 Precise Level.

The technical data of Wild N3 level are given below:-

Telescope magnification	42X
Clear objective diameter	50mm
Stadia multiplication constant	100
Shortest focussing distance	2m
Standard deviation for 1km double run levelling	±0.25mm
Length of Telescope	30cm
Weight of Level	3.5kg.

(ii) Invar Staff

The Wild levelling staff GPL3 was used. It has two sets of metric graduations side by side on the staff but one displaced by a constant 301.55cm from the other. The graduations on each side is at 1cm interval. For preeise work, the invar staff must be used. At one instrument set-up, two independent readings are obtained. See Figure 6.

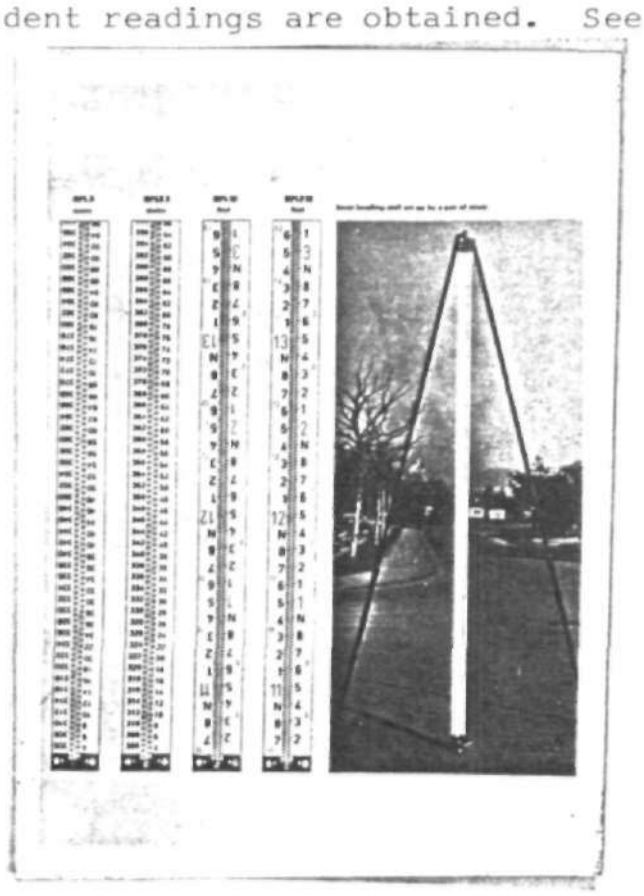


Figure 6 Invar staff.

(iii) Triangular Footplates

These are desirable to ensure that the heights of turning points are unaltered

during observations.

They have hemispherical heads on which the staff was placed. They are made of heavy triangular iron supported at the bottom by three pointed legs. The pointed legs ensured that the footplate was stably and firmly set on the ground. See Figure 7.

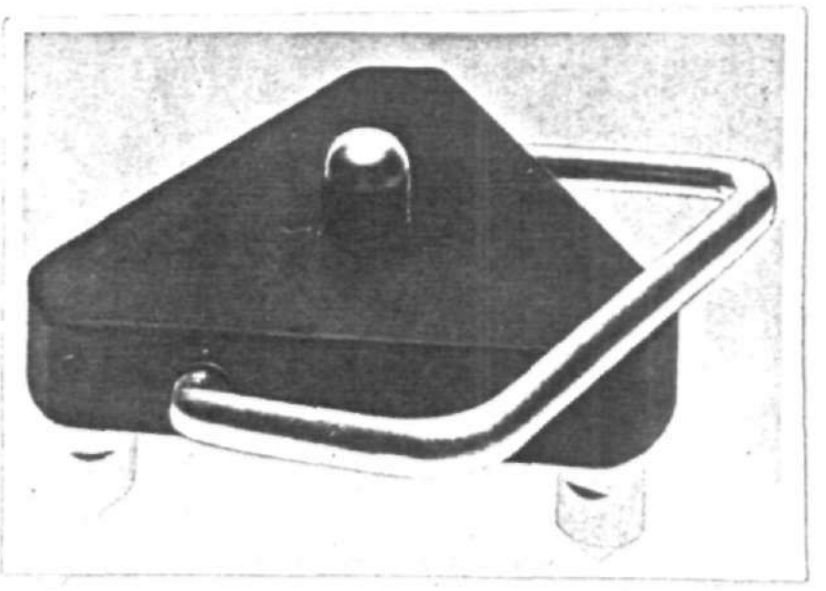


Figure 7 Triangular Footplate.

3.2.2 Procedures

The procedures shall be discussed under

(i) Observational procedure

(ii) Reading/recording procedure

(iii) Precautions.

(i) Observational Procedure

(a) At the instrument's marked positions, the level was set up with the tripod

head approximately levelled.

(b) The N3 was levelled using the three foot-screws.

(c) The telescope and cross hairs were focussed to remove parallax.

(d) The triangular foot-plate was put into its marked position, if not a benchmark or monitoring station, and a vertical staff placed upon it. The verticality of the staff was ensured by a bubble attached to the back of the staff. This was backsight reading position.

(e) The V-shaped reticule was straddled on a graduation mark and the tubular bubble set to coincide. The reading was recorded after reading the fractional part on the micrometer scale. Only the center hair readings were observed.

(f) The staff was placed at the forward position and step (e) was repeated.

(g) To avoid gross errors, $(\Delta H_L - \Delta H_R)$ was checked and kept below $\pm$ 1mm, using a calculator. The instrument was moved only when the above condition was met.

(h) The instrument was moved to the next station and levelled up. The last

foresight station became the new back-sight station for instrument position and center hair readings were taken for both left and right graduation on staff.

(i) Step (f) was repeated.

(j) The above procedures was followed until the levelling closed back onto the starting point (of known elevation).

(k) Distances between back and forward stations were recorded to check the compliance with the maximum allowable misclosures of the levelling.

(ii) Reading/Recording Procedure

(a) The V-shaped reticule was accurately placed on the individual staff graduation (for both left and right side).

(b) The micrometer bubble was made coincident and micrometer readings were made directly to the nearest 0.05mm.

(c) Readings taken on back stations were recorded as backsights in the fieldbook and readings to forward stations were put under the foresight column. See appendix C for field observations. See Figure 8 for reading system.

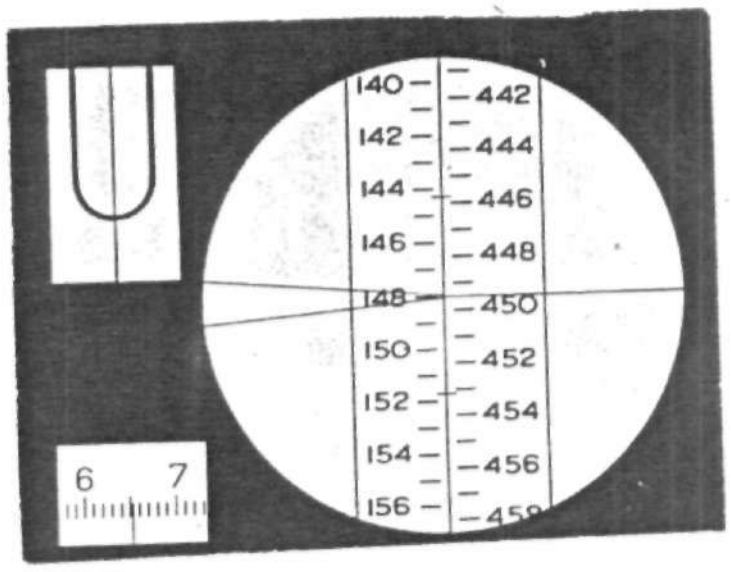


Figure 8 Reading System.

The distances measured were used to compute the circuit misclosure from formular $\pm$ 4mm$\sqrt{K}$ where k is distance in kilometers. Table 3.4 gives a comparison between maximum allowable and observed misclosures (mm) of each circuit.

Circuit	Month	Observed misclosure	loop length (k)	Allowable misclosure
I	A	-2.24	1.1408	4.27
II	P	-4.11	1.5820	5.03
III	R	-3.12	2.2020	5.94
IV	I L	-1.56	1.3320	4.60
I	A U	-2.42	1.1520	4.29
II	G	-1.16	1.6000	5.06
III	U S	+4.06	2.2660	6.01
IV	T	-3.58	1.4110	4.75

Table 3.4 Misclosures

(iii) Precautions

The general procedure of levelling is similar to that of ordinary levelling, but staff and instrument positions were set out in advance of observations. The following are precautions taken:-

(a) Maintainance of equality of backsight and foresight distances is preferred to applying curvature and refraction correction.

(b) Curvature and refraction errors were eliminated using short sight lengths. No sight length was more than 30m.

(c) Triangular footplates were used at turning points to ensure stability. This is felt to contribute to improved quality of work.

(d) Levelling was carried out only during favorable weather conditions. Strong winds were avoided or working in the rain.

(e) Readings were taken as fast as possible to avoid sinking of instrument between observations.

(f) Soft and sloping ground were avoided as much as possible.

(g) Readings less than 0.5000m on the staff were avoided to reduce extreme contributions to differential refraction caused by sighting near the ground surface.

(h) Instrument (level) was shielded to prevent the effect of unequal contraction and expansion of the level.

(i) $(\Delta H_L - \Delta H_R)$ were checked before the level was moved.

(j) Foresight and backsight distances were kept equal to within $\pm$0.50m.

The observation of the precautions and the use of precise instruments, it is our belief, will improve the quality of the work done and remove or reduce to the barest minimum the contribution of the instrument-observer combination to errors.

3.3 Data Processing

3.3.1 Level Reduction

A 10-digit scientific calculator CASIO FX-140 was used.

The level reduction of field observations was carried out using the "Rise and Fall" method. All the checks for detecting arithmetical mistakes were applied.

3.3.2 Adjustments

The adjustments are divided into (i) procedure and

(ii) results and (iii) statistical analysis.

Generally, in levelling, the elevation differences are the quantities being adjusted and the method of adjustment was by condition equation method using correlates.

The levelling network consisted four closed circuits. Around each circuit, the sum of the measured elevation differences should be = 0; but in practice a small misclosure appeared. The elevation differences were entered into the appropriate condition equation it belonged. When an elevation difference was measured more than once, the arithmetical mean was the value entered into the condition equations (e.g. in the case of lines CP1-CP2, CP2-CP3, CP3-CP4 which were measured four times each). The weights used were taken as being directly proportional to the number of times a line was measured.

(i) Procedure

(a) Condition equations were formed for each levelling circuit. This means there are four condition equations.

(b) The reduced condition equations were formed by writing the conditions in terms of corrections.

(c) Formation of combined corrections by introducing the correlates.

(d) The weighted correlative normals were formed. A sum check column was also included.

(e) The weighted correlative normals were decomposed using Choleski's method. A sum check column was also included. Rounding-off errors were also checked.

(f) A back solution was carried out to obtain the values of the correlates

(g) The corrections which are functions of the correlates were determined.

(h) These corrections were applied to the respective observed values to get adjusted elevation differences.

(i) The adjusted elevation of CP1, CP2, CP3, and CP4 were obtained through U4, the starting point.

(j) The precision of the adjustment was computed. So also, the precision of adjusted quantities.

Mathematically, a condition equation can be written in matrix form as AV =b were A is an (nxm) matrix of known coefficients, n is the number of unknowns, m is the number of measurements; V is (mx1) matrix of (unknown) corrections and b is an (nx1) matrix of constant terms.

The L.S. solution was obtained by minimising WV^2 (V^TWV) which is the same thing as minimising $V^TWV - 2(AV-b)^TK$ where K is (mx1) matrix of correlates. This leads to $V = W^{-1}A^TK$ where K was obtained from correlative normals $(AW^{-1}A^T)K = b$ and W is weight matrix of size (mxm). Thus

$$V = W^{-1}A^T (AW^{-1}A^T)^{-1}b.$$

The solution for $V_1, V_2 \ldots\ldots, V_{11}$ enabled the most probable values (X_1, X_2, ..., X_{11}) of the elevation differences to be found from $X_i = M_i + V_i$ where M_i is the observed elevation difference and i = 1, 2, ..., 11 being line number.

(ii) *Results*

The results of the adjusted elevation of CP1, CP2, CP3 and CP4, the monitoring stations are given in Table 3.5.

Station	August (H_F)	April (H_A)
CP1	646.45785	646.46319
CP2	646.40255	646.39855
CP3	646.50047	646.49584
CP4	646.36196	646.35881

Table 3.5 Adjusted Elevation (m).

The precision of the adjustments (σ) and adjusted difference in height (σ^1) is given by

$$\sigma = \sqrt{\frac{WV^2}{n_c}} \quad \text{and} \quad \sigma^1 = \sigma\sqrt{\frac{m-n}{m}} \quad \text{where} \quad n_c \text{ is the}$$

number of conditions,

σ is standard deviation per unit weight of an observed height defference.

σ' is standard deviation of an adjusted height difference.

Table 3.6 contains the Precision Estimates.

Period	Inst.	Observer	σ(mm)	σ^1(mm)
April '86	Wild N3	Oluyori P.D	2.03	1.62
Aug. '86	"	"	1.55	1.24

Table 3.6 Precision Estimates.

The movements (mm) during the period of April to August (ΔH) = $H_F - H_B$. The results are shown in Table 3.7.

Station	ΔH(mm)
CP1	-5.34
CP2	+4.00
CP3	+4.63
CP4	+3.15

Table 3.7 Movements.

(iii) Statistical Analysis

To determine whether the survey is acceptable (i.e. to test if the mathematical model and accuracy estimation used are correct), a Chi-Square test (X^2) at 95% probability level

was performed.

For X^2 distribution, the confidence interval is given by

$$\left[\frac{n\sigma^2}{X^2P_2} \leqslant \sigma_0^2 \leqslant \frac{n\sigma^2}{X^2P_1}\right] \quad (A)$$

where n is the number of redundant observations

σ_0 is a priori standard deviation

X^2P_2 and X^2P_1 are found from statistical tables for Chi-square distribution by interpolation.

For April and August observations, n = 7,

$X^2_{P_2}$ = 15.95, $X^2_{P_1}$ = 1.71.

σ = 2.03 in April

σ = 1.55 in August.

From the formular (A) above, we've for April,

$$\frac{7 \times 2.03^2}{15.95} \leqslant \sigma_o^2 \leqslant \frac{7 \times 2.03^2}{1.71}$$

which gives

$$1.80 \leqslant \sigma_o^2 \leqslant 16.87$$

and for August,

$$\frac{7 \times 1.55^2}{15.95} \leqslant \sigma_o^2 \leqslant \frac{7 \times 1.55^2}{1.71}$$

which gives

$$1.05 \leqslant \sigma_o^2 \leqslant 9.83.$$

The test shows there is 95% probability that the mathematical model and accuracy estimation measurements are correct and therefore the survey is acceptable.

Because of the very small number of redundant observations, the certainty attached to the estimated σ^2 is small.

To be noted, however, is the fact that the application of statistical tests to the network analysis is not very meaningful since the number of redundant observations is less than 30.

DEFORMATION ANALYSIS

The Karlsrue procedure of deformation analysis as described by Ninkov and Vojin (1985) has been applied. This involves the adjustment of each epoch of measurements separately, joint or simultaneous adjustment of the observations and the testing of the stability of the network points.

It has been noted by Chrzanowski et al (1982) that dynamic analysis is performed when the loading and the response are changeable with time and it is of interest to find the frequency and amplitude of the changes. This could be achieved by repeated deformation surveys as done in this project.

In the null hypothesis it is supposed that H_o: d = 0 and in the alternative H_a: d = 0. The test value T is calculated from $T = \frac{(\Omega_2 - \Omega_0)/f_1}{\Omega_0/b}$ And must be smaller than

the value of F distribution calculated for F/f_1, b, $1-\alpha$/. If this condition is satisfied, the presupposed stable points remain stable. If not, there is 95% probability that the displacement of the points occurred.

$\Omega_o = \Omega_1 r_1 + \Omega_2 r_2$

$\Omega_1 = \sum WV^2$ in 1st epoch (April)

$\Omega_2 = \sum WV^2$ in 2nd epoch (August)

r_1, r_2 = relationship between weights in 1st and 2nd epoch

f_1 = $(K - 1)n.P_o - d$

K = no. of epochs at the joint adjustment

n = dimension of the network which is (n - 1) for leveling.

P_o = no. of geodetic network points

d = 0 for networks with datum

b = $\sum_{i=1}^{K} b_i$ - degree of freedom of i - epoch

Separate adjustment of both epoch of measurements yield the following on table 3.8

	(April) 1st	(Aug.) 2nd
std. dev. of unit weight	2.89052×10^{-5}	1.67208×10^{-5}
m - no. of measurements	11	11
m - no. of unknowns	4	4
(m-n) no. of degrees of freedom	7	7

Table 3.8

Joint Adjustment

It is supposed that U4, BMA, BMB, and BMC will be stable. Their stability will be controlled (confirmed) by means of the test value T, defined for one-dimensional network.

$\Omega_1 = 2.89052 \times 10^{-5}$

$\Omega_2 = 1.67208 \times 10^{-5}$,

$\Omega_0 = 4.56260 \times 10^{-5}$

$b = b_1 + b_2 = 14$

on the ground of joint adjustment, the following results have been obtained

$\Omega_Z = 4.60445 \times 10^{-5}$

b_Z = 19 - *no. of degrees of freedom of joint adjustment*

$f_1 = /2\text{-}1/./4\text{-}1/ = 3$

The test wanted is $T = \frac{(\Omega_Z - \Omega_0)/f_1}{\Omega_0/b_Z} = 0.058085631$

$F/3, 19, 0.95/ = 0.115074798$

As $T < F/3,19,0.95/$, the null hypothesis could be accepted with a 95% probability that the points did not move.

After the confirmation of the network stability, the work started on the analysis of the points on the structure. To be noted is the fact that the numerical indicators of the movement could be shown as in Fig. 9 but they have no visual effect as in the case of plain or horizontal networks.

Analysis of deformation (movement) deals usually with very small deformation quantities which may be at the margin of measuring errors. This, therefore, necessitates a very careful accuracy analysis and statistical testing of the results

to be able to accept detected movements.

Also, since emphasis is given towards attainment of high precision which is an index of accuracy, the following could be said:

(a) the bench marks used as monitoring stations are assumed to have achieved total settlement (ie stable)

(b) this method which combines a carefully designed and constructed set of instruments, with proper observing routine and used by a competent observer and applying rigorous adjustment and analytical methods will give a highly accurate work.

(c) the movement type is dynamic since the loading (causative effect) and response are changeable with time.

(d) stability of reference stations is highly desired for proper analysis of movements of a structure.

The above lead to the analysis and conclusions reached in chapter 4.

CHAPTER 4

CONCLUSIONS

4.1 Difficulties Encountered

The following difficulties were met in the course of this project:-

(i) Additional levelling had to be carried out to provide heights for BMA, BMB and BMC.

(ii) Period of observation had to come before farmcrops grow to disturb our program and aviod damages.

(iii) There were transportation and personnel problems.

(iv) In fact, time constraint was the most important difficulty that can affect this type of work.

4.2 Data Interpretation (Analysis)

It happens frequently that when a comparison of levellings at different periods are made, apparent elevation changes are interpreted as real movements. Unless efforts are made to remove systematic errors and allow adjustment techniques (L.S) treat the random errors, such changes may often not be real movements. Errors generated by the instrument - observer combination should be removed by employing precise instruments in the fieldwork, adoption of refined field techniques, having many redundant

observations, testing for collimation error, provision of check measurements, etc. It is then possible to interprete the difference in elevation of monitoring stations as movements that occurred during the period of observation.

If observations are frequently taken using precise equipment, it is possible to deferentiate between seasonal and progressive movements if a movement versus time graph is drawn.

Interpretation of the data requires that a few assumptions be made. These are:-

(i) that the circuit misclosure was solely due to random errors.

(ii) that there was a fixed element within the levelling network: U4 was held fixed.

The data in Table 3.7 can be interpreted as follows:-

(a) There was vertical movement on the dam between April and August.

(b) The movements were in the same direction for CP2, CP3 and CP4 since they all have positive sign and opposite direction for CP1 with negiative sign.

(c) The movement could be attributed to accumulation of water during the period of observation causing sudden load on the dam.

(d) The movements could also be as a result of change in moisture conditions in the soil which lead to volume changes and forced the dam to move vertically.

(e) The dam was not moving at the same rate since the magnitude of the movements are not the same i.e. the dam was unstable.

(f) Since the vehicular flow over the road on dam wall is thin or minute and no heavy-duty vehicle was noted using the road during observations, it means these movements are solely due to increase in volume of water and consequent effect on the soil: and hence the dam movement.

(g) The dam was sinking towards CP1 and rising towards or relative to CP2, CP3 and CP4. as shown in Figure 9.

4.3 Implication of Results

The vertical movements that occurred during the April - August observations reveal the need for periodic measurements to decide whether any detected movements are significant,

The signs of the movements also imply that the dam is sinking (although, we cannot conclusively say, at the same rate) for CP1 and rising for CP2, CP3 and CP4.

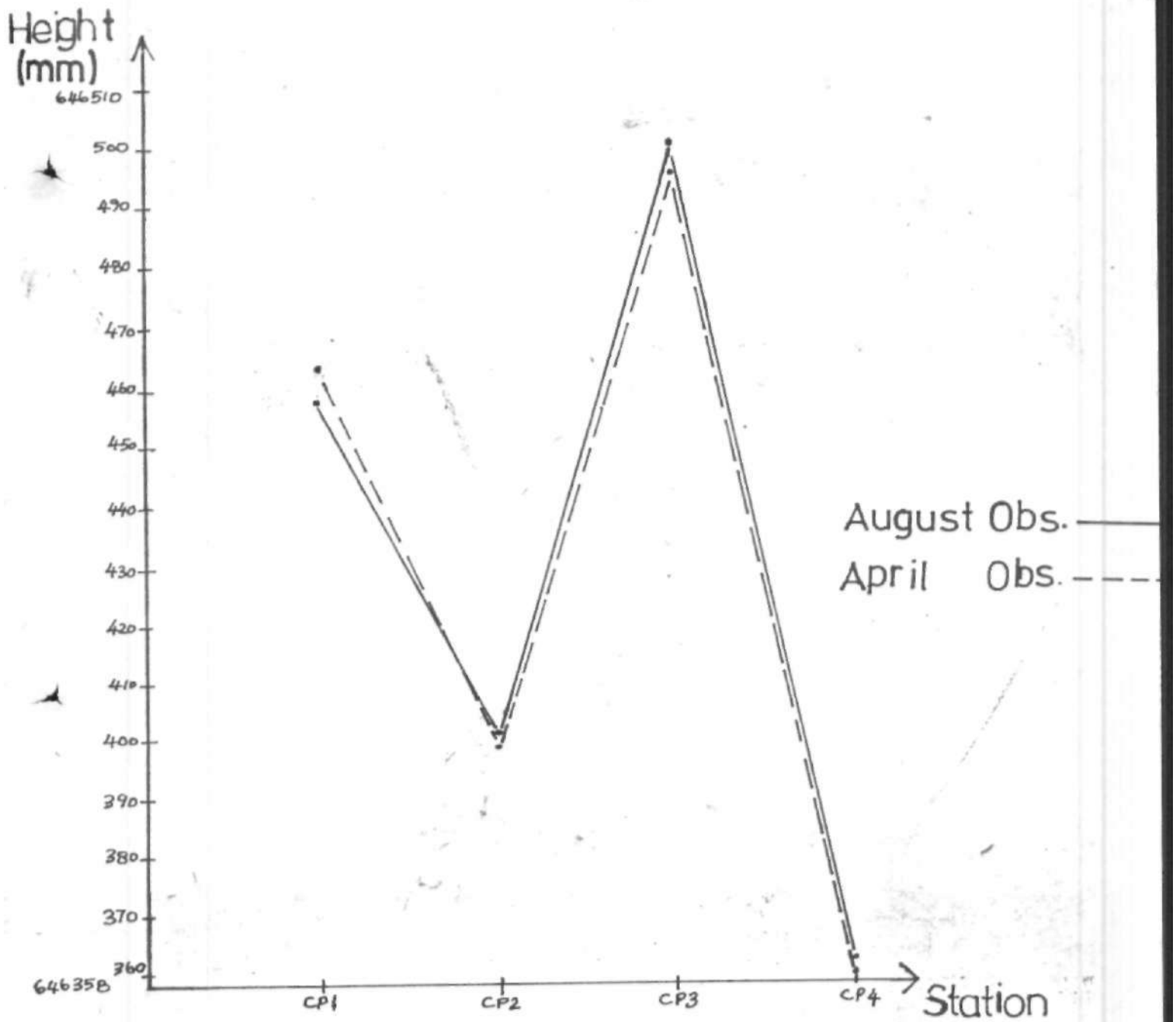


Figure 9. Height of Monitoring Stations

The results also point out the fact that more measurements are needed to defferentiate seasonal from progressive movements. Progressive movements are destructive.

4.4 Discussion

With reference to Table 3.6, the precision of the adjusted elevation differences was 1.62 and 1.24mm respectively for April and August. These precisions are fairly comparable and indicate that no significant variations was introduced in the field observations.

Although the heights of BMA, BMB and BMC were determined, it was solely to put them on the reference plane as U4. Only U4 was fixed.

4.5 Conclusions

The following are the conclusions reached:-

(1) There were vertical movements on the dam.

(2) The absence of any appreciable rainfall during the months of April, May and June does not allow any fair comments on the rates of movement.

(3) The precisions of the adjusted height differences are nearly the same.

(4) The objective of the project has been achieved by the designed geometry of the

levelling network, field observational and reading techniques using minimum personnel (one assistant) and equipment.

(5) Since the desired results are changes in elevation (future work may involve the determination of rates of changes), the absolute position is not of importance and hence, these needs have been met by observation of elevation differences using this method.

(6) The significance or otherwise of the detected movements is not up to the surveyors to determine. The decision becomes the builder's problem.

4.6 Recommendations

The following are recommended.

(1) Precise levellings to be carried out following the procedure outlined in this project during the April to August period.

(2) A movement versus time plot is necessary so as to differentiate the seasonal movements from the continuous or progressive movements.

(3) More monitoring stations should be added to the four presently used so that a full view of the movements and their trends can be obtained.

(4) Although outside the scope of this project,

only trilalateration method looks applicable to monitoring horizontal movements of the dam. This was noted during the fieldwork.

(5) The Department of Surveying should assign the fieldwork to the technicians (in fact one of them participated fully and throughout the field observations for this study) supervised by a lecturer. The adjustment of the field observations could be carried out or assigned to any lecturer who teaches optimisation and adjustment in the department.

(6) Further periodic surveys are recommended to follow up those carried out by this author.

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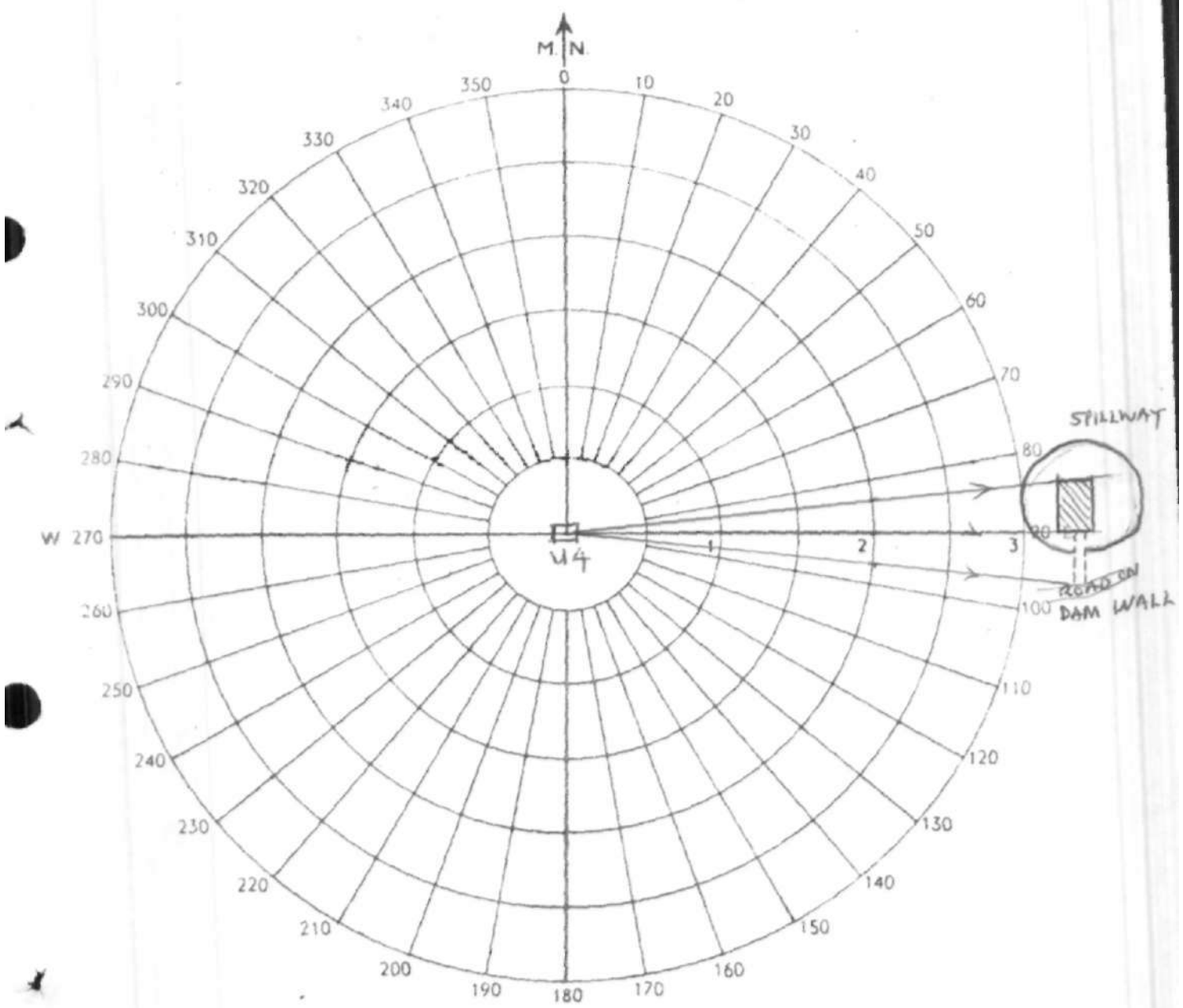
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APPENDIX A

Station Description/Location

Ref. Point	Bearing	Distance	Ref. Point	Bearing	Distance
Spillway	84°				
11	90°				
Road	96°				



Scale..... .....

Signature.....

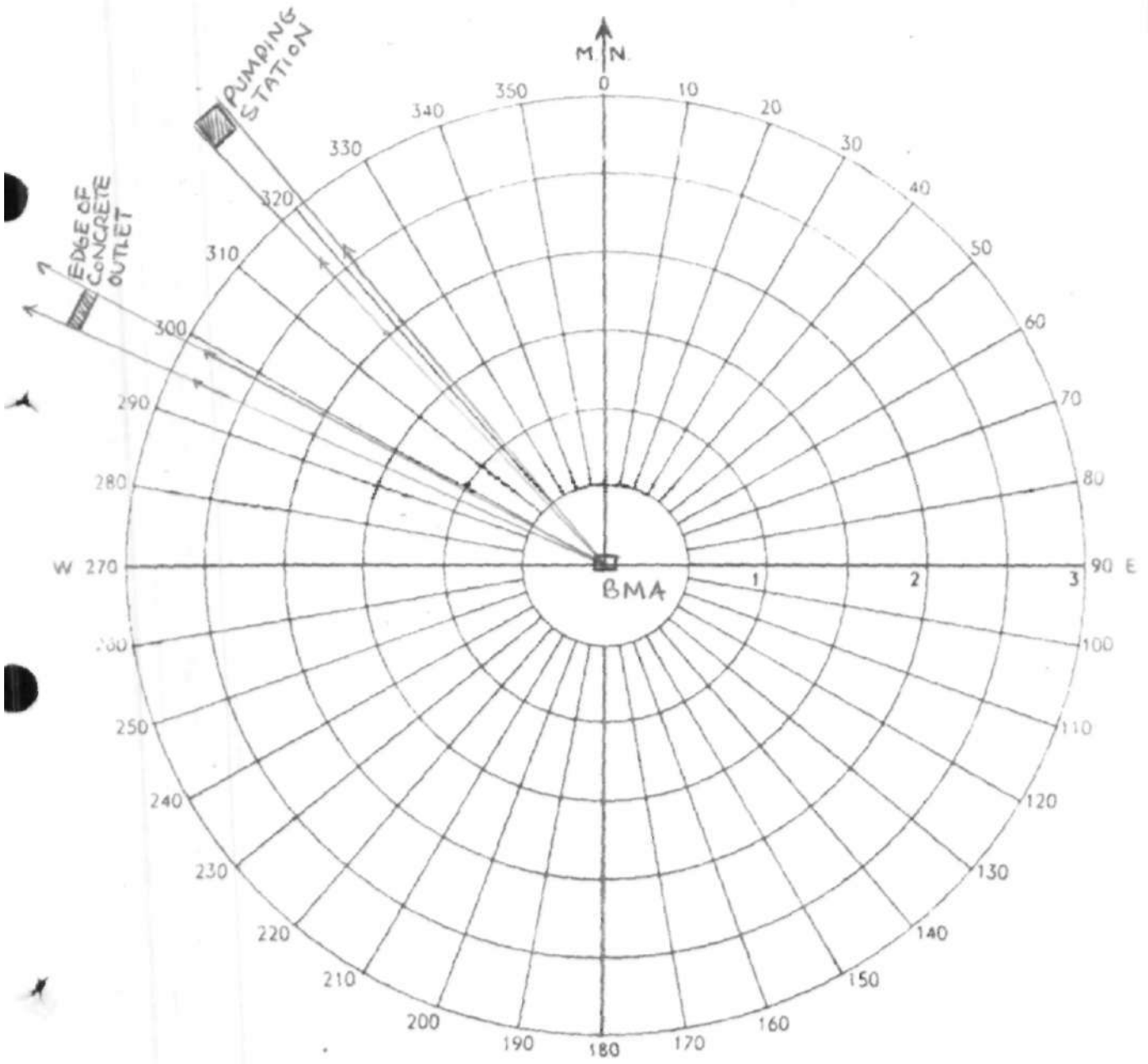
*DELETE ONE.

Date.....

HEIGHT.....

Description of surface mark. BMA (precast concrete bill ar... with a nails at the center)

Ref. Point	Bearing	Distance	Ref. Point	Bearing	Distance
Pumping station	317°		Edge of Concrete outlet 2	299° 30'	
4	321°				
Edge of Concrete outlet	294°				



Scale..... .....

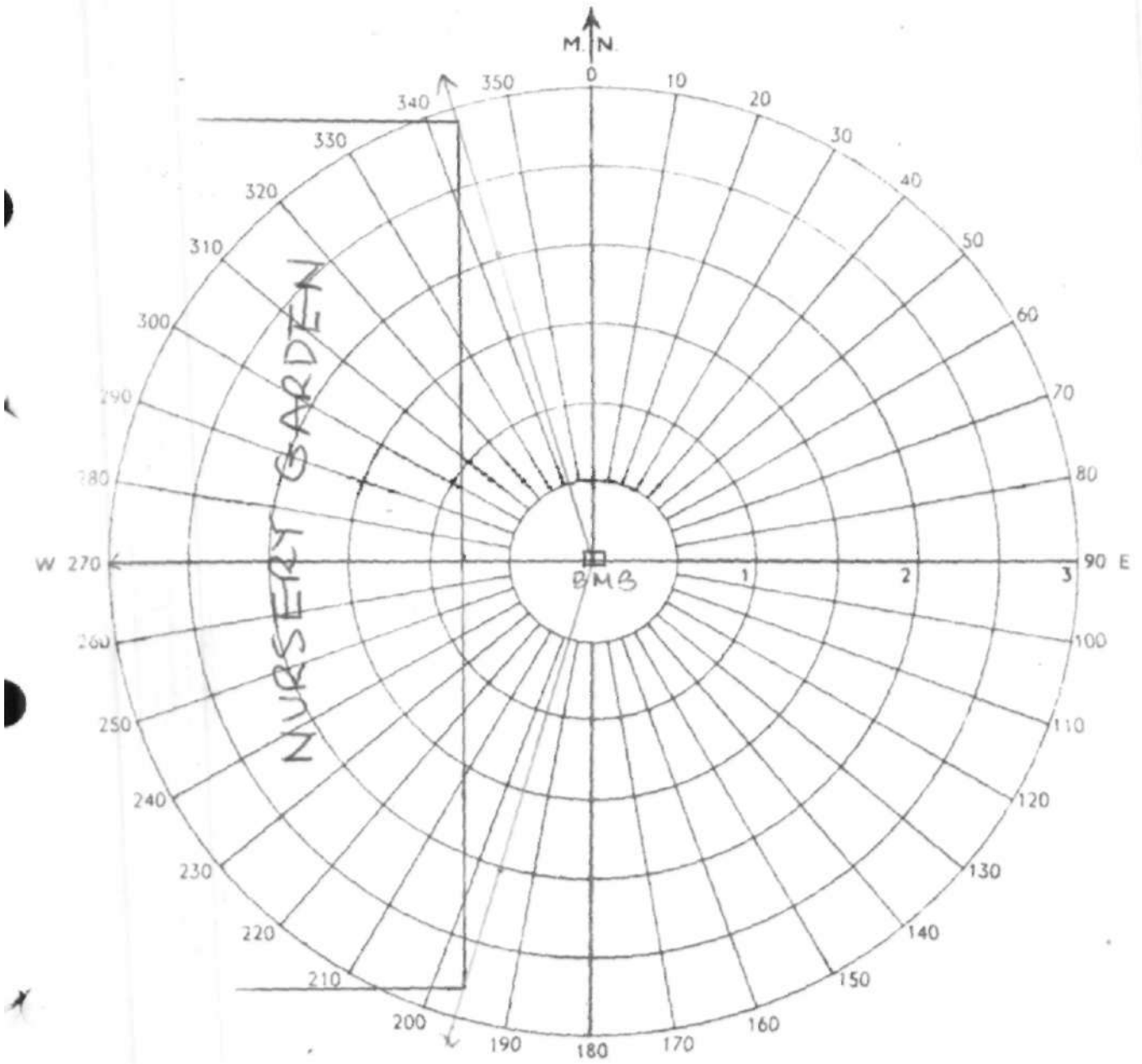
Signature.....

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Date.....

Description of surface mark. BMB (Pre-cast concrete pillar with nails at the center)

Ref. Point	Bearing	Distance	Ref. Point	Bearing	Distance
Edge of Nursery Garden	196°				
"	343°				
Perpendicular offset to fence	270°	6m			



Scale 1:300

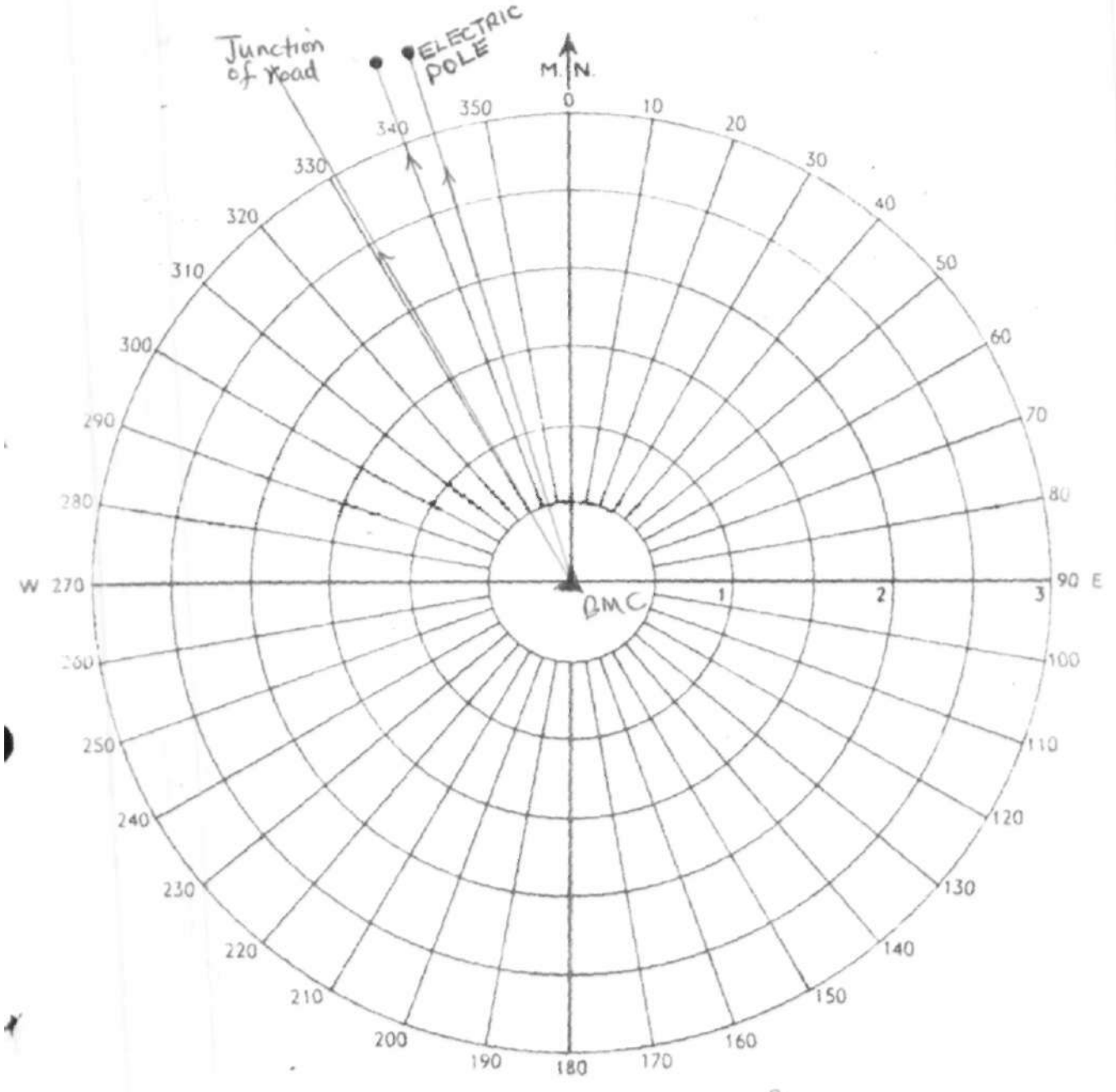
Signature.....

*DELETE ONE.

Date.....

Description of surface mark. BMC Iron rod with concrete mound

Ref. Point	Bearing	Distance	Ref. Point	Bearing	Distance
Electric Pole	340°		Junction gumtree road and Tarmac	331°	
"	343° 31				
Perpendicular offset to pole	~~23m~~	23			



Scale.....

Signature.....

*DELETE ONE.

Date.....

APPENDIX B

Plan of Dam

APPENDIX C
Field Observations

Levelling From U4 to U4

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
76·608				646·29600	50	U4
94·423	185·131		108·523	645·21077	"	Pt 1
78·366	218·059		123·636	643·97441	"	2
76·330	200·509		122·143	642·75298	"	3
41·703	237·321		160·991	641·14307	"	4
93·601	261·354		219·651	638·94656	"	5
118·416	169·962		76·361	638·18295	38·76	BMA
53·392	178·455		60·039	637·58256	50	Pt 6
59·030	175·685		122·293	636·35963	"	7
233·248	16·601	42·429		636·78392	40	8
139·178	88·860	144·388		638·22780	50	9
125·310	158·503		19·325	638·03455	"	10
117·792	134·048		8·738	637·94717	"	11
173·507	162·260		44·468	637·50249	"	12
178·756	129·292	44·215		637·94464	44	BMB
245·878	63·690	115·066		639·09530	50	Pt 13
263·363	64·675	181·203		640·90733	"	14
152·968	130·296	133·067		642·23800	"	15
278·030	107·256	45·712		642·69512	"	16
89·402	126·138	151·892		644·21404	"	17
139·192	153·865		64·463	643·56941	"	18
151·227	187·982		48·790	643·08151	"	19
168·023	134·522	16·705		643·24856	"	20
137·792	52·061	115·962		644·40818	27·60	BMC
202·371	75·913	61·879		645·02697	50	Pt 21
198·978	102·744	99·627		646·02324	"	22
140·563	153·869	45·109		646·47433	"	23
147·228	150·789		10·226	646·37207	"	24
138·807	137·610	9·618		646·46825	"	25
141·390	150·829		12·032	646·34793	"	26
152·260	134·800	6·590		646·41383	"	27
146·410	136·351	15·909		646·57292	"	28
145·287	150·775		4·365	646·52927	"	29
148·353	154·141		8·854	646·44073	"	30
138·674	136·836	11·517		646·55590	"	31
137·554	152·432		13·758	646·41832	"	32
141·712	138·422		0·868	646·40964	"	33
160·398	154·627		12·915	646·28049	"	34
147·133	131·529	28·869		646·56918	"	35

Date 12/3/86 LEFT

Levelling From U1 to U4 CONTINUES

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
139.253	141.742	5.391		646.62309	50	36
59.018	146.982		7.729	646.54580	50	37
	83.636		24.618	646.29962	48	U4
Sum (Σ)	Sum	Sum	Sum			
5770.924	5770.562	1275.148	1274.786			
ΣB.S − ΣF.S = 0.362						
ΣRise − ΣFall = 0.362						

Date 12/3/86 RIGHT.

Levelling From U4 to U4 Page 3

BACK SIGHT (m)	FORE SIGHT (m)	RISE (m)	FALL (m)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
378·180				646·27600		U4
395·968	486·699		108·519	645·21081	50	Pt 1
379·949	519·613		123·645	643·97436	"	2
377·882	502·077		122·128	642·75308	"	3
343·262	538·877		160·995	641·14313	"	4
395·165	562·933		219·671	638·94642	"	5
419·985	471·500		76·335	638·18307	38·76	BM A
354·953	480·013		60·028	637·58279	50	Pt 6
360·575	477·240		122·287	636·35992	"	7
534·802	318·172	42·403		636·78395	40	8
441·503	390·437	144·365		638·22760	50	9
426·880	460·823		19·320	638·03440	"	10
419·367	435·597		8·717	637·94723	"	11
475·063	463·810		44·443	637·50280	"	12
480·344	430·850	44·213		637·94493	44	BM B
547·489	365·292	115·052		639·09545	50	Pt 13
564·950	366·270	181·219		640·90764	"	14
454·531	431·871	133·079		642·23843	"	15
579·588	408·823	45·708		642·69551	"	16
390·942	427·721	151·867		644·21418	"	17
439·783	455·435		64·493	643·56925	"	18
452·770	488·592		48·809	643·08116	"	19
469·580	436·100	16·670		643·24786	"	20
439·367	353·591	115·989		644·40775	27·60	BM C
503·918	377·486	61·881		645·02656	50	Pt 21
500·561	404·310	99·608		646·02264	"	22
442·130	455·432	45·129		646·47393	"	23
448·759	452·365		10·235	646·37158	"	24
440·337	439·160	9·599		646·46757	"	25
442·940	452·394		12·057	646·34700	"	26
453·807	436·370	6·570		646·41270	"	27
447·971	437·896	15·911		646·57181	"	28
446·849	452·310		4·339	646·52842	"	29
449·700	455·703		8·854	646·43988	"	30
440·256	438·401	11·499		646·55487	"	31
439·083	453·998		13·742	646·41745	"	32
443·267	439·971		0·888	646·40857	"	33
461·970	456·155		12·888	646·27969	"	34
448·697	433·088	28·882		646·56851	"	35

Date 12/3/86 RIGHT

Levelling From U4 to U4 CONTINUES Page 4

BACK SIGHT	FORE SIGHT	RISE	FALL	REDUCED LEVEL	DISTANCE	REMARKS
440·815	443·318	5·379		646·62230	50	36
360·587	448·550		7·735	646·54495	"	37
	385·218		24·631	646·29864	48	U4
Σ	Σ	Σ	Σ			
18134·725	18134·461	1275·023	1274·759			
Σ B·S − Σ F·S = 0·264						
Σ Rise − Σ Fall = 0·264						

Date 25/3/86 LEFT

Levelling From U4 to U4

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL m	DISTANCE (m)	REMARKS
83.802				646.29600		U4
161.338	72.590	11.212		646.40812	50	Pt 1
143.483	145.170	16.168		646.56980	"	2
142.502	144.117		0.634	646.56346	"	3
153.510	167.119		24.617	646.31729	"	4
140.460	139.175	14.335		646.46064	39	CP 1
139.624	146.481		6.021	646.40043	28	CP 2
151.633	134.680	4.944		646.44987	50	Pt 5
145.718	149.341	2.292		646.47279	"	6
146.253	143.040	2.678		646.49957	23.80	CP 3
149.500	144.425	1.828		646.51785	50	Pt 7
141.275	140.758	8.742		646.60527	"	8
137.655	156.043		14.768	646.45759	"	9
152.014	146.951		9.296	646.36463	36	CP 4
161.828	135.922	16.092		646.52555	50	Pt 10
141.121	159.912	1.916		646.54471	"	11
139.157	142.560		1.439	646.53032	"	12
148.291	140.722		1.565	646.51467	"	13
134.219	139.728	8.563		646.60030	"	14
144.839	146.860		12.641	646.47389	"	15
140.568	142.730	2.109		646.49498	"	16
150.538	135.604	4.964		646.54462	"	17
151.751	153.509		2.971	646.51491	"	18
71.609	143.110	8.641		646.60132	"	19
153.360	169.172		97.563	645.62569	"	20
	86.148	67.212		646.29781	14	U4
Σ	Σ	Σ	Σ			
3526.048	3525.867	171.696	171.515			
ΣB.S − ΣF.S = 0.181						
ΣRise − ΣFall = 0.181						

Date 25/3/86 RIGHT.

Levelling From U4 to U4

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
385·376				646·29600		U4
462·948	374·175	11·201		646·40801	50	Pt1
445·011	446·711	16·237		646·57038	〃	2
444·065	445·680		0·669	646·56369	〃	3
455·089	468·684		24·619	646·31750	〃	4
442·070	440·616	14·473		646·46223	39	CP1
441·252	448·069		5·999	646·40224	28	CP2
453·199	436·278	4·974		646·45198	50	Pt5
447·255	450·879	2·320		646·47518	〃	6
447·827	444·609	2·646		646·50164	23·80	CP3
451·072	446·001	1·826		646·51990	50	Pt7
442·819	442·304	8·768		646·60758	〃	8
439·218	457·560		14·741	646·46017	〃	9
453·544	448·509		9·291	646·36726	36	CP4
463·376	437·460	16·084		646·52810	50	Pt10
442·670	461·482	1·894		646·54704	〃	11
440·700	444·117		1·447	646·53257	〃	12
449·821	447·304		1·604	646·51653	〃	13
435·756	441·290	8·531		646·60184	〃	14
446·385	448·370		12·614	646·47570	〃	15
442·101	444·303	2·082		646·49652	〃	16
452·119	437·180	4·821		646·54473	〃	17
453·302	455·080		2·961	646·51512	〃	18
373·206	444·642	8·660		646·60172	〃	19
454·920	470·717		97·511	645·62661	〃	20
	387·713	67·207		646·29868	14	U4
Σ	Σ	Σ	Σ			
11065·101	11064·833	171·724	171·456			
ΣBS − ΣFS = 0·268						
ΣRise − ΣFall = 0·268						

Date 9/4/86 LEFT.

Levelling From BMC to BMC

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
132·813				644·40783		BMC
197·494	71·240	61·573		645·02356	50	Pt 1
193·369	97·473	100·021		646·02377	"	2
138·761	147·979	45·390		646·47767	"	3
146·994	150·517		11·756	646·36011	"	4
137·588	135·922	11·072		646·47083	"	5
143·811	149·460		11·872	646·35211	"	6
145·572	142·192	1·619		646·36830	32	CP 4
154·225	133·383	12·189		646·49019	50	Pt 7
140·250	146·681	7·544		646·56563	"	8
140·248	145·345		5·095	646·51468	"	9
142·270	141·371		1·123	646·50345	38	CP 3
136·467	139·170	3·100		646·53445	50	Pt 10
144·402	155·860		19·393	646·34052	"	11
145·399	137·800	6·602		646·40654	24	CP 2
143·830	139·400	5·999		646·46653	30	CP 1
145·467	140·285	3·545		646·50198	50	Pt 12
145·650	141·730	3·737		646·53935	"	13
146·759	148·306		2·656	646·51279	"	14
140·900	141·835	4·924		646·56203	"	15
121·588	116·989	23·911		646·80114	"	16
133·590	154·089		32·501	646·47613	"	17
142·603	137·350		3·760	646·43853	"	18
131·717	138·020	4·583		646·48436	"	19
139·378	139·070		7·353	646·41083	"	20
156·927	139·020	0·358		646·41441	"	21
98·930	198·260		41·333	646·00108	"	22
72·260	202·203		103·273	644·96835	"	23
	128·117		55·857	644·40978	48	BMC
Σ	Σ	Σ	Σ			
3959·262	3959·067	296·167	235·972			
ΣBS − ΣFS = 0·195						
ΣRise − ΣFall = 0·195						

Date 9/4/86 RIGHT

Levelling From BMC to BMC

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
434·378				644·40783		BMC
499·033	372·813	61·565		645·02348	50	Pt 1
494·900	399·038	99·995		646·02343	"	2
440·320	449·560	45·340		646·47683	"	3
448·540	452·089		11·769	646·35914	"	4
439·143	437·461	11·079		646·46993	"	5
445·373	451·040		11·897	646·35096	"	6
447·135	443·732	1·641		646·36737	32	CP 4
455·760	434·931	12·204		646·48941	50	Pt 7
441·825	448·205	7·555		646·56496	"	8
441·777	446·881		5·056	646·51440	"	9
443·808	442·918		1·141	646·50299	38	CP 3
438·030	440·721	3·087		646·53386	50	Pt 10
445·938	457·427		19·397	646·33989	"	11
446·940	439·359	6·579		646·40568	24	CP 2
445·343	440·940	6·000		646·46568	30	CP 1
447·030	441·770	3·573		646·50141	50	Pt 12
446·178	443·278	3·752		646·53893	"	13
448·300	448·839		2·661	646·51232	"	14
442·460	443·408	4·892		646·56124	"	15
423·118	418·584	23·876		646·80000	"	16
435·149	455·624		32·506	646·47494	"	17
444·147	438·886		3·737	646·43757	"	18
433·250	439·543	4·604		646·48361	"	19
440·903	440·620		7·370	646·40991	"	20
458·453	440·555	0·348		646·41339	"	21
400·489	499·789		41·336	646·00003	"	22
373·777	503·719		103·230	644·96773	"	23
	429·649		55·872	644·40901	48	BMC
Σ	Σ	Σ	Σ			
12401·497	12401·379	296·030	295·972			
Σ B·S − Σ F·S = 0·118						
Σ Rise − Σ Fall = 0·118						

Date 19/4/86 LEFT

Levelling From BMB To BMB

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
181·972				637·94456		BMB
234·539	65·560	116·412		639·10868	50	Pt 1
264·848	55·419	179·120		640·89988	"	2
147·965	131·210	133·638		642·23626	"	3
278·520	101·633	46·332		642·69958	"	4
91·662	126·572	151·948		644·21906	"	5
135·279	156·577		64·915	643·56991	"	6
153·292	186·150		50·871	643·06120	"	7
188·310	128·503	24·789		643·30909	"	8
205·644	76·492	111·818		644·42727	"	9
182·150	87·906	117·738		645·60465	"	10
130·730	88·660	93·490		646·53955	"	11
132·989	141·429		10·699	646·43256	"	12
148·102	135·618		2·629	646·40627	"	13
142·219	149·431		1·329	646·39298	"	14
149·383	145·430		3·211	646·36087	54	CP4
152·265	133·022	16·361		646·52448	50	Pt 15
141·168	147·365	4·900		646·57348	"	16
140·467	149·012		7·844	646·49504	"	17
144·852	139·808	0·659		646·50163	30	CP3
135·914	142·692	2·160		646·52323	50	Pt 18
148·272	156·590		20·676	646·31647	"	19
147·555	139·507	8·765		646·40412	22	CP2
146·196	141·510	6·045		646·46457	32	CP1
144·719	142·055	4·141		646·50598	50	Pt 20
136·785	135·868	8·851		646·59449	"	21
143·938	147·279		10·494	646·48955	"	22
142·253	140·516	3·422		646·52377	"	23
155·106	137·932	4·321		646·56698	"	24
132·751	159·768		4·662	646·52036	"	25
147·801	149·845		17·094	646·34942	"	26
145·830	138·641	9·160		646·44102	"	27
140·980	149·713		3·883	646·40219	"	28
149·498	145·628		4·648	646·35571	"	29
85·225	130·504	18·994		646·54565	"	30
97·376	192·579		107·354	645·47211	"	31
64·480	192·287		94·911	644·52300	"	32
118·552	183·378		118·898	643·33402	"	33
125·228	134·602		16·050	643·17352	"	34

Date 19/4/86 LEFT

Levelling From BMB To BMB

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (M)	DISTANCE (M)	REMARKS
182·646	105·349	19·879		643·37231	50	Pt 35
114·170	106·150	76·496		644·13727	"	36
87·240	240·688		126·518	642·87209	"	37
167·266	187·191		99·951	641·87258	"	38
66·149	233·204		65·938	641·21320	"	39
78·141	226·379		160·230	639·61090	"	40
80·357	155·910		77·769	638·83321	"	41
	168·830		88·473	637·94848	34	BMB
Σ	Σ	Σ	Σ			
6630·784	6630·392	1159·439	1159·047			
ΣB·S − ΣF·S = 0·392						
ΣRise − ΣFall = 0·392						

Date 19/4/86 RIGHT

Levelling From BMB To BMB

BACK SIGHT (m)	FORE SIGHT (m)	RISE (m)	FALL (m)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
483·564				637·94456		BMB
536·081	367·116	116·448		639·10904	50	Pt 1
566·416	356·971	179·110		640·90014	"	2
449·498	432·772	133·644		642·23658	"	3
580·082	403·163	46·335		642·69993	"	4
393·191	428·131	151·951		644·21944	"	5
436·816	458·124		64·933	643·57011	"	6
454·818	487·678		50·862	643·06149	"	7
489·820	430·033	24·785		643·30934	"	8
507·200	377·992	111·828		644·42762	"	9
483·680	389·450	117·750		645·60512	"	10
432·283	390·210	93·470		646·53982	"	11
434·555	442·960		10·677	646·43305	"	12
449·664	437·169		2·614	646·40691	"	13
443·750	450·976		1·312	646·39379	"	14
450·974	446·971		3·221	646·36158	54	CP4
453·780	434·590	16·384		646·52542	50	Pt 15
442·681	448·910	4·870		646·57412	"	16
441·994	450·560		7·879	646·49533	"	17
446·400	441·380	0·614		646·50147	30	CP3
437·465	444·255	2·145		646·52292	50	Pt 18
449·788	458·180		20·715	646·31577	"	P 19
449·119	441·053	8·735		646·40312	22	CP2
447·711	443·119	6·000		646·46312	32	CP1
446·280	443·569	4·142		646·50454	50	Pt 20
438·330	437·401	8·879		646·59333	"	21
445·496	448·792		10·462	646·48871	"	22
443·792	442·080	3·416		646·52287	"	23
456·623	439·480	4·312		646·56599	"	24
434·340	461·304		4·681	646·51918	"	25
449·330	451·414		17·074	646·34844	"	26
447·360	440·201	9·129		646·43973	"	27
442·537	451·260		3·900	646·40073	"	28
451·024	447·221		4·684	646·35389	"	29
386·730	432·050	18·974		646·54363	"	30
398·903	494·130		107·400	645·46963	"	31
366·035	493·811		94·908	644·52055	"	32
420·100	484·910		118·875	643·33180	"	33
426·161	436·170		16·070	643·17110	"	34

Date 19/4/86 RIGHT

Levelling From BMB to BMB

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
484·200	406·882	19·879		643·36989	50	Pt 35
415·700	407·685	76·515		644·13504	"	36
388·900	542·247		126·547	642·86957	"	37
468·817	488·749		99·949	641·87008	"	38
367·784	534·737		65·920	641·21088	"	39
379·685	527·918		160·134	639·60954	"	40
381·889	457·450		77·765	638·83189	"	41
	470·389		88·500	637·94689	34	BMB
Σ	Σ	Σ	Σ			
20501·846	20501·613	1159·315	1159·082			
ΣB·S − ΣF·S = 0·233						
ΣRise − ΣFall = 0·233						

Date 22/4/86 LEFT

Levelling From BMA To BMA

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
179·078				638·18249		BMA
266·311	76·412	102·666		639·20915	50	Pt 1
226·980	62·043	204·268		641·25183	"	2
292·930	122·108	104·872		642·30055	"	3
262·440	145·526	147·404		643·77459	"	4
275·709	129·919	132·521		645·09980	"	5
147·567	132·218	143·491		646·53471	"	6
147·779	147·089	0·478		646·53949	"	7
127·470	154·890		7·111	646·46838	"	8
147·500	137·087		9·617	646·37221	"	9
138·550	138·886	8·614		646·45835	12	CP1
140·619	144·582		6·032	646·39803	32	CP2
154·435	135·629	4·990		646·44793	50	Pt10
144·562	151·951	2·484		646·47277	"	11
146·801	142·099	2·463		646·49740	24	CP3
150·401	144·970	1·831		646·51571	50.	Pt12
141·728	142·549	7·852		646·59423	"	13
137·900	156·522		14·794	646·44629	"	14
152·235	146·970		9·070	646·35559	24	CP4
158·711	135·214	17·021		646·52580	50	Pt15
144·470	156·630	2·081		646·54661	"	16
142·711	148·818		4·348	646·50313	"	17
149·919	142·900		0·189	646·50124	"	18
138·437	145·329	4·590		646·54714	"	19
136·100	140·534		2·097	646·52617	"	20
140·296.	135·130	0·970		646·53587	"	21
144·728	132·645	7·651		646·61238	"	22
147·027	148·970		4·242	646·56996	"	23
83·410	143·182	3·845		646·60841	"	24
68·389	190·947		107·537	645·53304	"	25
73·610	207·731		139·342	644·13962	40	26
75·761	197·175		123·565	642·90397	50	27
60·367	237·170		161·409	641·28988	"	28
74·648	273·680		213·313	639·15675	"	29
	171·678		97·030	638·18645	"	BMA
Σ	Σ	Σ	Σ			
5119·579	5119·183	900·092	899·696			
ΣBS - ΣFS = 0·396						
ΣR.L - ΣFall = 0·396						

Date 22/4/86 RIGHT

Levelling From BMA To BMA

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
480·593				638·18249		BMA
567·859	377·928	102·665		639·20914	50	Pt1
528·535	363·567	204·292		641·25206	〃	2
594·493	423·641	104·894		642·30100	〃	3
563·963	447·069	147·424		643·77524	〃	4
577·260	431·463	132·500		645·10024	〃	5
449·130	433·728	143·532		646·53556	〃	6
449·328	448·604	0·526		646·54082	〃	7
428·994	456·487		7·159	646·46923	〃	8
449·034	438·583		9·589	646·37334	〃	9
440·077	440·439	8·595		646·45929	12	CP1
442·169	446·141		6·064	646·39865	32	CP2
455·953	437·175	4·994		646·44859	50	Pt10
446·114	453·509	2·444		646·47303	〃	11
448·328	443·656	2·458		646·49761	24	CP3
451·960	446·505	1·823		646·51584	50	Pt12
443·264	444·090	7·870		646·59454	〃	13
439·435	458·081		14·817	646·44637	〃	14
453·784	448·514		9·079	646·35558	24	CP4
460·282	436·739	17·045		646·52603	50	Pt15
446·030	458·181	2·101		646·54704	〃	16
444·271	450·391		4·361	646·50343	〃	17
451·478	444·465		0·194	646·50149	〃	18
439·988	446·872	4·606		646·54755	〃	19
437·632	442·078		2·090	646·52665	〃	20
441·859	436·680	0·952		646·53617	〃	21
446·293	434·184	7·675		646·61292	〃	22
448·590	450·530		4·237	646·57055	〃	23
384·970	444·736	3·854		646·60909	〃	24
369·888	492·473		107·503	645·53406	〃	25
375·121	509·280		139·392	644·14014	40	26
377·329	498·704		123·582	642·90432	50	27
361·920	538·715		161·386	641·29046	〃	28
376·200	575·231		213·311	639·15735	〃	29
	473·260		97·060	638·18675	〃	BM4
Σ	Σ	Σ	Σ			
15372·125	15371·699	900·250	899·824			
ΣB.S − ΣF.S = 0·426						
ΣRise − ΣFall = 0·426						

Date 21/8/86 LEFT

Levelling From BMC To BMC

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
121·413				644·40783		BMC
181·560	50·326	71·087		645·11870	50	Pt 1
262·827	95·380	86·180		645·98050	"	2
139·513	197·397	65·430		646·63480	"	3
137·938	158·741		19·228	646·44252	"	4
138·709	140·449		2·511	646·41741	"	5
133·113	131·402	7·307		646·49048	"	6
142·937	146·679		13·566	646·35482	"	7
150·552	141·931	1·006		646·36488	28	CP4
153·332	133·570	16·982		646·53470	"	Pt 8
140·540	151·418	1·914		646·55384	"	9
135·696	145·064		4·524	646·50860	"	10
141·418	136·195		0·499	646·50361	32	CP3
129·729	137·462	3·956		646·54317	50	Pt 11
138·891	148·150		18·421	646·35896	"	12
143·050	134·090	4·801		646·40697	24	CP2
140·930	137·021	6·029		646·46726	32	CP1
135·753	136·420	4·510		646·51236	50	Pt 13
140·041	130·406	5·347		646·56583	"	14
138·704	144·109		4·068	646·52515	"	15
140·972	138·547	0·157		646·52672	"	16
136·720	127·481	13·491		646·66163	"	17
138·228	155·921		19·201	646·46962	"	18
141·292	140·510		2·282	646·44680	"	19
135·978	135·784	5·508		646·50188	"	20
131·821	144·529		8·551	646·41637	"	21
164·558	144·379		12·558	646·29079	"	22
160·113	138·320	26·238		646·55317	"	23
89·517	234·514		74·401	645·80916	"	24
122·419	200·054		110·537	644·70379	"	25
	151·679		29·260	644·41119	45	BMC
Σ	Σ	Σ	Σ			
4308·264	4307·928	319·943	319·607			
ΣB·S − ΣF·S = 0·336						
ΣRise − ΣFall = 0·336						

Date 21/8/86 RIGHT

Levelling From BMC To BMC

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
422·939				644·40783		BMC
483·115	351·858	71·081		645·11864	50	Pt 1
564·377	396·931	86·184		645·98048	"	2
441·040	498·940	65·437		646·63485	"	3
439·491	460·291		19·251	646·44234	"	4
440·259	442·035		2·544	646·41690	"	5
434·668	432·941	7·318		646·49008	"	6
444·490	448·247		13·579	646·35429	"	7
452·098	443·456	1·034		646·36463	28	CP4
454·893	435·143	16·955		646·53418	50	Pt 8
442·079	452·945	1·948		646·55366	"	9
437·250	446·586		4·507	646·50859	"	10
442·952	437·728		0·478	646·50381	32	CP3
431·263	439·011	3·941		646·54322	50	Pt 11
440·461	449·679		18·416	646·35906	"	12
444·591	435·634	4·827		646·40733	24	CP2
442·467	438·602	5·989		646·46722	32	CP1
437·370	437·921	4·546		646·51268	50	Pt 13
441·580	431·979	5·391		646·56659	"	14
440·280	445·612		4·032	646·52627	"	15
442·549	440·098	0·182		646·52809	"	16
438·267	429·065	13·484		646·66293	"	17
439·765	457·468		19·201	646·47092	"	18
442·833	442·067		2·302	646·44790	"	19
437·530	437·350	5·483		646·50273	"	20
433·353	446·080		8·550	646·41723	"	21
466·103	445·928		12·575	646·29148	"	22
461·670	439·874	26·229		646·55377	"	23
391·049	536·090		74·420	645·80957	"	24
423·970	501·583		110·534	644·70423	"	25
	453·230		29·260	644·41163	45	BMC
Σ	Σ	Σ	Σ			
13354·752	13354·372	320·029	319·649			
ΣB.S − ΣF.S = 0·380						
ΣRise − ΣFall = 0·380						

Date 25/8/86 — LEFT

Levelling From BMB To BMB

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
179·831				637·94456		BMB
232·133	89·212	90·619		638·85075	50	Pt 1
287·548	70·570	161·563		640·46638	"	2
160·612	107·805	179·743		642·26381	"	3
234·846	121·503	39·109		642·65490	"	4
190·802	140·292	94·554		643·60044	"	5
110·420	146·848	43·954		644·03998	"	6
146·469	161·690		51·270	643·52728	"	7
166·267	132·093	14·376		643·67104	"	8
174·513	118·134	48·133		644·15237	"	9
191·464	104·062	70·451		644·85688	"	10
238·348	91·571	99·893		645·85581	"	11
123·120	152·585	85·763		646·71344	"	12
127·664	148·423		25·303	646·46041	"	13
145·350	131·973		4·309	646·41732	"	14
137·062	142·229	3·121		646·44853	"	15
143·040	148·436		11.374	646·33479	"	16
151·258	139·860	3·180		646·36659	14	CP4
152·287	136·830	14·428		646·51087	50	Pt 17
136·395	145·060	7·227		646·58314	"	18
136·554	143·759		7.364	646·50950	"	19
138·424	136·948		0·394	646·50556	36	CP3
129·286	135·481	2·943		646·53499	50	Pt 20
141·620	147·255		17·969	646·35530	"	21
140·492	136·402	5·218		646·40748	24	CP2
141·871	134·549	5·943		646·46691	32	CP1
140·920	137·458	4·413		646·51104	50	Pt 22
140·369	135·517	5·403		646·56507	"	23
140·790	145·400		5·031	646·51476	"	24
139·600	139·626	1·164		646·52640	"	25
140·835	126·862	12·738		646·65378	"	26
134·020	158·619		17·784	646·47594	"	27
144·389	144·328		10·308	646·37286	"	28
140·821	136·422	7·967		646·45253	"	29
138·549	145·298		4·477	646·40776	"	30
144·062	130·761	7·788		646·48564	"	31
166·569	139·404	4·658		646·53222	"	32
98·570	245·290		78·721	645·74501	"	33
108·098	194·148		95·578	644·78923	"	34

Date 23/8/86 . LEFT.

Levelling From BMB To BMB

BACK SIGHT (CM)	FORE SIGHT (CM)	RISE (CM)	FALL (CM)	REDUCED LEVEL (M)	DISTANCE (M)	REMARKS
126·240	177·506		69·408	644·09515	50	Pt 35
145·660	178·184		51·944	643·57571	"	36
163·320	152·488		6·828	643·50743	"	37
147·224	99·540	63·780		644·14523	"	38
76·359	284·223		136·999	642·77524	"	39
140·302	136·184		59·825	642·17699	"	40
53·810	246·121		105·819	641·11880	"	41
96·341	264·540		210·730	639·01150	"	42
	203·437		107·096	637·94054	60	BMB
Σ	Σ	Σ	Σ			
6984·524	6984·926	1078·129	1078·531			
$\Sigma B.S - \Sigma F.S = -0.402$						
$\Sigma Rise - \Sigma Fall = -0.402$						

Data 23/8/86 RIGHT

Levelling From BMB To BMB

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
481·392				637·94456		BMB
533·659	390·743	90·649		638·85105	50	Pt 1
589·129	372·128	161·531		640·46636	"	2
462·187	409·364	179·765		642·26401	"	3
536·387	423·054	39·133		642·65534	"	4
492·351	441·826	94·561		643·60095	"	5
411·949	448·405	43·946		644·04041	"	6
447·989	463·240		51·291	643·52750	"	7
467·832	433·625	14·364		643·67114	"	8
476·072	419·670	48·162		644·15276	"	9
492·981	405·598	70·474		644·85750	"	10
539·863	393·102	99·879		645·85629	"	11
424·679	454·082	85·781		646·71410	"	12
429·212	449·981		25·302	646·46108	"	13
446·908	433·493		4·281	646·41827	"	14
438·612	443·770	3·138		646·44965	"	15
444·588	449·956		11·344	646·33621	"	16
452·820	441·400	3·188		646·36809	14	CP4
453·812	438·380	14·440		646·51249	50	Pt 17
437·914	446·570	7·242		646·58491	"	18
438·088	445·289		7·375	646·51116	"	19
439·980	439·465		0·377	646·50739	36	CP3
430·816	437·022	2·958		646·53697	50	Pt 20
443·146	448·816		18·000	646·35697	"	21
442·039	437·937	5·209		646·40906	24	CP2
443·428	436·113	5·926		646·46832	32	CP1
442·495	438·980	4·448		646·51280	50	Pt 22
441·937	437·113	5·382		646·56662	"	23
442·338	446·940		5·003	646·51659	"	24
441·140	441·184	1·154		646·52813	"	25
442·400	428·425	12·715		646·65528	"	26
435·563	460·183		17·783	646·47745	"	27
445·918	445·688		10·325	646·37420	"	28
442·349	437·985	7·933		646·45353	"	29
440·090	446·865		4·516	646·40837	"	30
445·594	432·310	7·780		646·48617	"	31
468·110	440·951	4·643		646·53260	"	32
400·126	546·822		78·712	645·74548	"	33
409·650	495·683		95·557	644·78991	"	34

Date 23/8/86 RIGHT

Levelling From BMB To BMB

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
427.769	479.061		69.411	644.09580	50	pt 35
447.211	479.733		51.964	643.57616	"	36
464.850	454.064		6.853	643.50763	"	37
448.752	401.088	63.762		644.14525	"	38
377.901	585.750		136.998	642.77527	"	39
441.822	437.737		59.836	642.17691	"	40
355.366	547.662		105.840	641.11851	"	41
397.871	566.081		210.715	639.01136	"	42
	504.961		107.090	637.94046	60	BMB
Σ	Σ	Σ	Σ			
21157.085	21157.495	1078.163	1078.573			
ΣB.S − ΣF.S = −0.410						
ΣRise − ΣFall = −0.410						

Date 25/8/86 LEFT

Levelling From BMA To BMA

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
146·765				638·18249		BMA
266·321	58·451	88·314		639·06563	50	Pt1
203·212	53·730	212·591		641·19154	"	2
261·811	108·465	94·747		642·13901	"	3
188·132	66·588	195·223		644·09124	"	4
279·202	83·600	104·532		645·13656	"	5
150·335	141·296	137·906		646·51562	"	6
143·806	145·859	4·476		646·56038	"	7
136·567	160·200		16·394	646·39644	"	8
138·990	130·570	5·997		646·45641	52	CP1
140·581	144·919		5·929	646·39712	30	CP2
149·795	134·990	5·591		646·45303	50	Pt9
141·626	147·042	2·753		646·48056	"	10
144·552	140·147	1·479		646·49535	24	CP3
146·120	140·650	3·902		646·53437	50	Pt11
139·130	139·519	6·601		646·60038	"	12
136·470	153·415		14·285	646·45753	"	13
153·312	146·377		9·907	646·35846	34	CP4
134·510	112·554	40·758		646·76604	50	Pt14
139·877	157·272		22·762	646·53842	"	15
136·632	141·071		1·194	646·52648	"	16
143·020	138·575		1·943	646·50705	"	17
134·259	131·800	11·220		646·61925	"	18
149·228	149·526		15·267	646·46658	"	19
140·731	150·564		1·336	646·45322	"	20
151·609	134·270	6·461		646·51783	"	21
146·185	152·888		1·279	646·50504	"	22
129·913	141·503	4·682		646·55186	"	23
76·265	208·621		78·708	645·76478	"	24
99·588	209·815		133·550	644·42928	38	25
59·057	195·181		95·593	643·47335	50	26
100·771	232·702		173·645	641·73690	40	27
56·500	233·858		133·087	640·40603	46	28
125·384	246·660		190·160	638·50443	46	29
	157·440		32·056	638·18387	40	BMA
Σ	Σ	Σ	Σ			
4990·256	4990·118	927·233	927·095			
ΣBS−ΣFS = 0·138						
ΣRise − ΣFall =		0·138				

Date 25/8/86 RIGHT

Levelling From BMA To BMA

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
448·300				638·18249		BMA
567·880	359·982	88·318		639·06567	50	Pt 1
504·760	355·284	212·596		641·19163	"	2
563·352	410·042	94·718		642·13881	"	3
489·668	368·144	195·208		644·09089	"	4
580·730	385·159	104·509		645·13598	"	5
451·851	442·829	137·901		646·51499	"	6
445·358	447·411	4·440		646·55939	"	7
438·115	461·733		16·375	646·39564	"	8
440·510	432·123	5·992		646·45556	52	CP1
442·120	446·451		5·941	646·39615	30	CP2
451·331	436·530	5·590		646·45205	50	Pt 9
443·179	448·583	2·748		646·47953	"	10
446·102	441·677	1·502		646·49455	24	CP3
447·635	442·218	3·884		646·53339	50	Pt 11
440·683	441·059	6·576		646·59915	"	12
438·011	454·938		14·255	646·45660	"	13
454·852	447·930		9·919	646·35741	34	CP4
436·080	414·106	40·746		646·76487	50	Pt 14
441·421	458·813		22·733	646·53754	"	15
438·193	442·615		1·194	646·52560	"	16
444·580	440·138		1·945	646·50615	"	17
435·823	433·341	11·239		646·61854	"	18
450·772	451·109		15·286	646·46568	"	19
442·285	452·130		1·358	646·45210	"	20
453·180	435·806	6·479		646·51689	"	21
447·749	454·439		1·259	646·50430	"	22
431·449	443·061	4·688		646·55118	"	23
377·800	510·170		78·721	645·76397	"	24
401·151	511·367		133·567	644·42830	38	25
360·590	496·708		95·557	643·47273	50	26
402·340	534·250		173·660	641·73613	40	27
358·063	535·421		133·081	640·40532	46	28
426·939	548·205		190·142	638·50390	46	29
	458·987		32·048	638·18342	40	BMA
Σ	Σ	Σ	Σ			
15242·852	15242·759	977·134	927·041			
ΣB.S - ΣF.S = 0·093						
ΣRise - ΣFall = 0·093						

Date 27/8/86 LEFT

Levelling From U4 To U4 Page 23

BACK SIGHT (cm)	FORE SIGHT (cm)	RISE (cm)	FALL (cm)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
76·052				646·29600		U4
159·658	64·530	11·522		646·41122	50	Pt1
145·028	142·545	17·113		646·58235	"	2
136·869	146·455		1·427	646·56808	"	3
154·912	165·751		28·882	646·27926	"	4
141·270	136·942	17·770		646·45896	38	CP1
136·150	147·208		5·938	646·39958	30	CP2
153·265	130·658	5·492		646·45450	50	Pt5
141·837	151·099	2·166		646·47616	"	6
142·038	139·933	1·904		646·49520	22	CP3
144·813	137·851	4·187		646·53707	50	Pt7
139·513	137·206	7·607		646·61314	"	8
136·737	154·261		14·748	646·46566	"	9
154·110	147·148		10·411	646·36155	32	CP4
161·562	137·280	16·830		646·52985	50	Pt10
143·570	159·380	2·182		646·55167	"	11
141·230	145·249		1·679	646·53488	"	12
145·464	143·181		1·951	646·51537	"	13
138·972	136·247	9·217		646·60754	"	14
151·271	151·965		12·993	646·47761	"	15
138·885	151·280		0·009	646·47752	"	16
151·961	133·074	5·811		646·53562	"	17
144·681	152·748		0·787	646·52776	"	18
127·048	140·285	4·396		646·57172	"	19
142·764	223·076		96·028	645·61144	"	20
	73·962	68·802		646·29946	30	U4
Σ	Σ	Σ	Σ			
3549·660	3549·314	175·199	174·853			
ΣB.S - Σ F.S = 0.346						
ΣRise - ΣFall = 0.346						

Levelling From U4 To U4

BACK SIGHT (m)	FORE SIGHT (m)	RISE (m)	FALL (m)	REDUCED LEVEL (m)	DISTANCE (m)	REMARKS
377·580		-		646·29600	50	U4
461·187	366·080	11·500		646·41100	50	Pt 1
446·553	444·093	17·094		646·58194	11	2
438·415	447·998		1·445	646·56749	11	3
456·451	467·281		28·866	646·27883	11	4
442·816	438·500	17·951		646·45834	38	CP1
437·711	448·752		5·936	646·39898	30	CP2
454·773	432·260	5·451		646·45349	50	Pt 5
443·360	452·636	2·137		646·47486	11	6
443·563	441·490	1·870		646·49356	22	CP3
446·360	439·415	4·148		646·53504	50	Pt 7
441·065	438·751	7·609		646·61113	11	8
438·291	455·822		14·757	646·46356	11	9
455·656	448·717		10·426	646·35930	32	CP4
463·098	438·825	16·831		646·52761	50	Pt 10
445·115	460·931	2·167		646·54928	11	11
442·746	446·802		1·687	646·53241	11	12
447·035	444·720		1·974	646·51267	11	13
440·530	437·800	9·235		646·60502	11	14
452·809	453·501		12·971	646·47531	11	15
440·421	452·828		0·019	646·47512	11	16
453·504	434·600	5·821		646·53333	11	17
446·232	454·295		0·791	646·52542	11	18
428·578	441·824	4·408		646·56950	11	19
444·307	524·589		96·011	645·60939	11	20
	375·508	68·799		646·29738	30	44
Σ	Σ	Σ	Σ			
11088·156	11088·018	175·021	174·883			
ΣB.S − ΣF.S = 0.138						
ΣRise − ΣFall = 0.138						