PAPER NO. 7.

PROBLEMS ENCOUNTERED IN THE USE OF THIRD ORDER LEVELLING FOR THE NATIONAL LEVELLING GRID.

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The following notes have been prepared for the Colloquim on Control for Mapping to be held at the University of New South Wales in May 1967.

Control Levelling Activities in Australia.

Control Levelling in this paper is understood to be Levelling of High Precision, Precision Levelling and Third Order Levelling as defined by the National Mapping Council. Its purpose is to provide a framework of levelling traverses along roads, railways and tracks with permanent bench marks placed at certain intervals. The heights of these marks are obtained by means of geometric (differential) Levelling in reference to a datum mark which is usually related to mean sea level of a certain period at the main tidal gauging station of the State.

Before 1956 some 3,000 miles of control levelling had been completed in three States of the Commonwealth. Between 1956 and 1960 an additional 10,000 miles were levelled and by the end of 1966 the total amount of control levelling had reached 80,000 miles covering the continent and Tasmania. An adjustment of the levelling survey is planned for 1970 by which time over 100,000 miles of control levelling will be completed. (See diagram)

The Levelling Survey of Australia forms loops of between 300 to 1,000 miles in circumference. Its main purpose is to provide control heights for topographical mapping. Within loops lower order levelling or other survey methods are being employed to provide vertical control for photogrammetric stereo models. (Other methods : Trigonometric heighting, barometric methods, Automatic Profile Recording, Levelling with Johnson Elevation Meter.)

The decision to observe the major part of the levelling net to third order standards was made by Commonwealth Authorities who were faced with an urgent requirement for levelled heights in connection with mapping and gravity surveys.

The levelling net is going to provide heights sufficiently accurate for all practical purposes. An analysis of the misclosure of 112 loops with an average length of 320 miles yields a standard error of $\pm$ 0.036 feet for 1 mile of levelling. On this basis it should be possible to determine the height of a bench mark in the centre of this continent with a standard error of $\pm$ 1.2 feet.

The National Mapping Council of Australia has laid down accuracy requirements (1) for the following classes of levelling:-

1. Special High Precision Levelling.
2. Precision Levelling.
3. Third Order Levelling.

Accuracy requirements for 1 and 2 are as specified by the International Association of Geodesy. For field observations certain check conditions apply. These refer to the allowable difference of the forward and backward runs of a section between permanent bench marks which are M miles apart as well as to the allowable misclosure of circuits of M miles in Circumference. (In both cases M is measured along the levelling route.)

These requirements are:

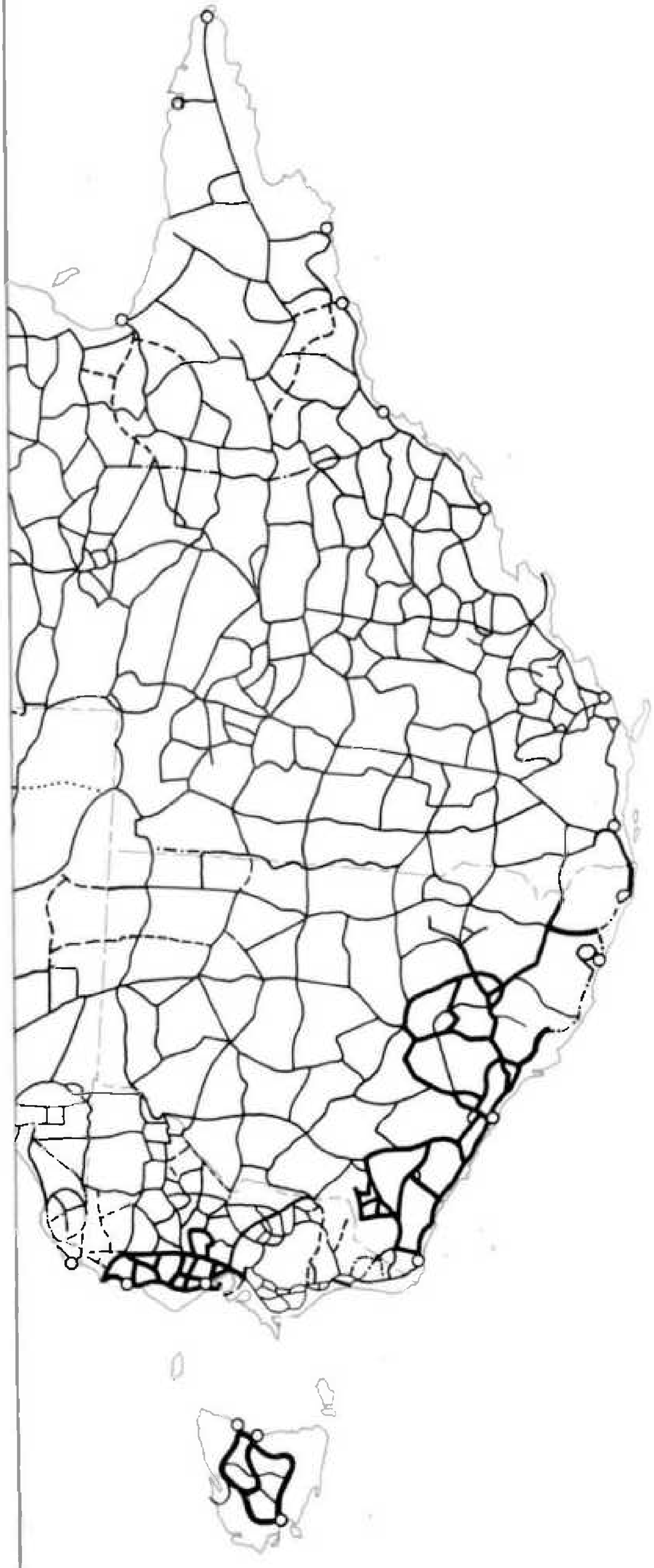
Special High Precision	0.017 $\sqrt{M}$ feet
Precision	.035 $\sqrt{M}$ "
Third Order	.05 $\sqrt{M}$ "

AUSTRALIA

NATIONAL LEVELLING SURVEY

AS AT MARCH 1967

- First Order Levelling completed or in hand
- Second Order Levelling completed or in hand
- Third Order Levelling completed or in hand
- Third Order bench marking completed or in hand
- Third Order proposed 1st priority
- Third Order proposed 2nd priority
- Tide Gauges



To the end of 1966 progress in the 3 classes of control levelling in Australia was as follows:

Special High Precision and Precision		
by State Lands Department and Statutory		Miles
Authorities		5,500 miles 6.7 °/o
Third Order Levelling		
by Lands Departments	16,100)	
by private Surveyors for Department	)	51.7 °/o
of National Development	26,300)	
One Way Third Order Levelling		
with dual faced staves by		
Department of Interior for the		
Bureau of Mineral Resources	34,100	41.6 °/o
Total	82,000	

Here are some of our problems associated with third order levelling as the title of these notes suggests

Levelling Instruments

All third order levelling in Australia is observed with automatic levels. In the early sixties rather large section misclosures in two way levelling and loop misclosures in one way levelling occurred before the influence of a systematic error in the compensating mechanism of automatic levels had been recognized.

I refer to the error caused by an imperfect rectification of the line of sight also known as "oblique horizon". This error occurs only when the circular buble of an automatic level is not in perfect adjustment which unfortunately it never is. The effect of the oblique horizon can be rendered ineffective over two consecutive setups if the circular bubble is in good adjustment and by using the "unsystematic procedure of levelling" with equal sighting distances. The oblique horizon of the compensator of an automatic level is not constant. It changes with a change of the residual adjustment error of the circular bubble and with a factory adjustment of the c factor of the compensator.

Other systematic errors are feared to cause misclosures just outside the allowable limit in sections of 50 miles and more in length. Hysteresis in compensators as described by D.F. Schellens (2) and M. Drodofsky (3) may occur in automatic levels and especially in those which have the compensator mounted away from the centre of rotation of the telescope, mostly near the ocular lens.

Hysteresis in the compensator can be compared with "Black Lash" in micrometers or the "Lag Error" in a spirit level.

The effect of hysteresis depends on the direction from which the compensator moves to its rest position. This is either from the stop on the eyepiece side of the compensator or from the stop on the opposite side, the objective side.

In all automatic levels which do not have the compensator mounted in the centre of rotation of the instrument the compensator will deflect away from this centre when the instrument is rotated. This is caused by centrifugal force.

After every rotation the compensator returns to its rest position from the same direction, provided of course the instrument had been levelled up before hand.

The effect of hysteresis on readings preceded by a rotary motion of the instrument is equivalent to a constant collimation error.

In our system of levelling (unsystematic procedure) one out of every four readings is not preceded by a rotation of the telescope. There is an equal chance that the compensator moves from either stop to its rest position at this one out of four readings. That means that over four instrument set ups with 8 readings one reading will occur (a back sight reading) at which the compensator moves to its rest position from a direction opposite to that of the other 7 readings. It is this reading we are concerned about.

If the telescope is rotated after the instrument has been levelled then every reading of the 8 readings in 4 set ups is preceded by a rotation and the effect of hysteresis is equivalent to a constant collimation error.

A constant collimation error of any reasonably magnitude is eliminated provided equal sighting distances are taken or the sum of the backsight distances balance the sum of the foresight distances in a section.

It could be argued that not all automatic levels are subject to hysteresis especially not the telescopic type ones. This may be so, however, it is thought that the little work involved in rotating the telescope of any type of automatic level to and fro is justified in order to establish a strict observing routine.

An additional benefit of this routine is that a sticky compensator is dislodged before every reading.

The National Mapping Council has adopted a recommendation which lays down a strict observing procedure designed to minimise the effect of compensator errors.

The problem is how to make sure that surveyors engaged in the levelling survey stick to the recommended practices. It is a matter of education and I think that the Universities can play an important part here.

Levelling Staves

Wooden levelling staves of the folding type manufactured by Wild and Watts are mainly used in third order levelling. Interior uses the telescopic type dual faced staff and in Western Australia some aluminium staves are used.

For levelling contracts folding staves calibrated in the capital of the State they are to be used in are issued to contract surveyors and on completion of the contract are recalibrated. The calibration consists of comparing a number of staff intervals with a standard. The scale factor of the staff

$$c = \frac{\text{Sum of Actual Lengths of Intervals}}{\text{Sum of Nominal Lengths of Intervals}}$$

is obtained. From the standard deviation of the observations and from the estimated setting accuracy of the measuring scale the random graduation error of the staff is computed. This gives us a measure of the quality of the staff.

E.G. Thwaite of the Standards Laboratory C.S.I.R.O. (4) has described a staff calibration procedure based on the comparison of random staff intervals. He recommends that the random staff graduation error should not exceed $\pm$ .001 ft. for 3rd order staves. All of the Wild and Watts staves checked by National Mapping so far have a smaller random graduation error.

Prior to the National Levelling adjustment it is intended to correct differences in elevation by multiplication with the combined scale factor of the pair of staves which have been used in the observation.

Although we require the recording of dry temperatures during the 3rd order levelling observations a temperature correction will not be applied to the observed quantities. The coefficient of thermal expansion of European Red Pine (Wild staves) is about 2×10^{-6} per degree Fahrenheit. A difference in elevation of 100 feet levelled at a temperature of 100°F with wooden staves calibrated at 70°F will be measured too short by 0.006 ft. We are prepared to ignore this.

We do not attempt to determine the changes of moisture content in wooden staves, although these are likely to occur inspite of protective coats of paint and varnish. Staves are withdrawn from control levelling activities after two or three field seasons or before when badly chipped.

Short term variation in humidity are believed to have only a small effect on the moisture content of wood and even less on painted or varnished wood.

The change in length of wood whose fibres run longitudinally due to a change of 1 $^{o}/o$ of moisture contents is about 0.007$^{o}/o$. Moisture contents of wood when unseasoned is about $30^{o}/o$, when kiln dried it may approach $0^{o}/o$. According to investigations carried out by the Lands Department of Queensland the annual average moisture content of wood in Brisbane is $14^{o}/o$ that in the western Queensland about $8^{o}/o$.

As stated before the change in moisture content is a slow process especially in painted wood. Its effect on the length of a staff can be taken care of to a great extent by recalibration of the staff within a short time after its return from the field.

<u>Marking and photo identification</u>

In stable ground the conventional type of marks are placed at intervals varying from 1 to 4 miles according to the practice of the survey authority.

In unstable ground deep bench marks are emplaced. They may consist of 3/8" brass rod or galvanised iron pipes of up to 12 feet in length set in concrete at the bottom of a hole 4 to 6 inches in diameter. The remainder of the hole is filled with loose gravel or sand. At ground level a concrete collar is slipped over the rod or pipe. This type of mark is used extensively in South Australia and the eastern parts of Western Australia. Clusters of 3 bench marks 200 to 300 feet apart at intervals of 50 to 100 miles or on the edges of large areas of unstable ground are being placed in Queensland and the Northern Territory. In South Australia it is the practice to place clusters of 3 marks at intervals of 12 miles.

In general we have very little trouble with damage or loss of marks attributed to natural causes. It is people seeming to enjoy destruction who are responsible for almost all the damage or disappearance of marks.

Control level bench marks in South Australia are identified on air-photos. Most of them have been premarked on the ground often rather permanently and later on photographed with a RC 8 camera on special sorties. All bench marks levelled by the Department of Interior are identified on existing aerial photographs by pin pricking. Bench marks placed in the eastern part of Western Australia and in the Northern Territory for third order contract levelling will be premarked on the ground at the time they are placed. This marking consists of a ring of stones 12 feet in diameter painted white or a circular trench of the same diameter. Special flights will be organised in order to photograph these marks. In the office the position of the bench marks will then be transferred to the mapping photography with the aid of a differential stereoscope.

One of the jobs of the recently established Levelling Section in National Mapping will be to connect trig and traverse stations of the National Geodetic Survey to the levelling net at intervals of about 100 miles. This will be done systematically by 250,000 sheet areas and while in the area levelling parties will photo identify all bench marks in this area which had not been identified before.

Tide Gauges.

As part of Australia's 10 year mapping programme the Division of National Mapping on behalf of the National Mapping Council and with the help of various State and other Authorities is organising a programme of tidal readings at 33 tide gauge stations around the coastline of Australia, (see diagram).

The aim of this programme is to obtain simultaneous recordings at all stations on a continuous basis for a period of one year in order to compute mean sea level at these stations pertaining to the same epoch.

The processing and analysing of the tide record charts is being undertaken by the Horace Lamb Centre for Oceanographic Research of the Flinders University in Adelaide. Hourly values are read from the charts to the nearest 0.1 ft. and punched onto cards. All records are digitised in Universal Time. There is a card per day for each station with 24 tide readings on the hour (UT).

During the first twelve months of the programme which started on 1st January 1966 twenty-four stations have supplied their records for digitising. The programme is to continue for at least one more year in order to get records from as many stations as possible for the same period of 12 months.

National mapping is sending a survey team to visit each tide gauge. The team's job will be to calibrate the tide gauge recorder against a standard instrument to establish additional permanent marks so that there are at least 3 near every tide gauge and to level the difference in height between the staff gauge and the permanent marks as well as to take photographs of all important fixtures of the tide station.

Adjustment of the National Levelling Survey.

An adjustment of selected loops of the continental net is to take place in 1970. Observed orthometric differences based on theoretical gravity will no doubt be used.

The biggest problem will be to obtain the necessary abstracts of the levelling which is to be included in the adjustment showing all pertinent information free from clerical errors. National Mapping is working on the design of an appropriate data sheet which provides for all necessary information. It is to be filled in by the survey authority which holds the field level books. Certain columns of the form are spaced in the fashion of computer data sheets and information in these columns is meant for punching on cards without further transcription.

The method of adjustment has not been determined yet. However it seems pretty certain that the levelling net will have to be split in more than 2 parts whatever method will be used. There are several ways of dealing with the mean sea level data of the tidal stations in the adjustment. I will mention just two. (A) We can hold all msl values at zero and adjust the whole net to them. This method would be based on the theory that mean sea level is an equipotential surface coinciding with the geoid. It is not hard to define such a datum surface, it is a different matter to accurately determine this surface at the tidal stations.

Oceanographers have long ago come to the conclusion that many of the forces which have a bearing on the height of tides are not periodic in nature. Winds, barometric pressure variations, ocean currents, variations in the density of the sea water and under-water topography near stations give reasons to believe that mean sea level determined at widely separated stations from the hourly readings of the same period does not represent the same equipotential surface. This gives weight to the following approach. (B) We can hold one arbitrary datum point fixed somewhere in the centre of Australia and adjust the whole net disregarding mean sea level at the tide gauges. There will be differences at the tide gauges between the arbitrarily adjusted values and the theoretical zero values of mean sea level. A block shift can now be applied to the whole net the amount of which can be determined by least squares with the condition that the sum of the squares of the remaining differences be a minimum. Either solution may be acceptable and may lead to the determination of a National Height Datum.

Levelling traverses not included in the adjustment will be tied to adjusted B.M.'s. Finally all trig heights along traverses and chains of triangulation of the Australian Geodetic Survey will be re-adjusted in terms of the National Height Datum.

Bibliography

(1) National Mapping Council of Australia : "Standard Specification and Recommended Practices for Horizontal and Vertical Control Surveys". Prepared on behalf of the National Mapping Council of Australia by the Director of National Mapping, Division of National Mapping, Department of National Development, Canberra, A.C.T., April 1967.

(2) D.F. Schellens : "Design and application of automatic levels." Canadian Surveyor Vol.XIX, June 1965, No. 2.

(3) M. Drodofsky : "Consistently positive closing errors in first order levelling." Zeiss Information No. 56.

(4) E.G. Thwaite : "Calibration of precise levelling staffs by a procedure involving a random selection of intervals." National Standards Laboratory, Division of Metrology M.I.R. 1960, April 1958.
E.G. Thwaite: "Accuracy of staff calibrations to meet National Mapping requirements. "National Standards Laboratory, Division of Applied Physics, M.I.R. 1130, September 1962.