MONITORING OF EARTH AND ROCK DAMS

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Electricity Commission of N.S.W.

MONITORING ELECTRICITY COMMISSION OF NEW SOUTH WALES' DAMS

1. INTRODUCTION

The Electricity Commission of New South Wales owns and operates eleven dams. The purpose and some salient details of these structures and the instruments installed to monitor performance are given in Table 1A and 1B.

It is standard Commission practice for the dam designers to be responsible for obtaining and interpreting performance data during the construction and contract maintenance periods. At the end of the maintenance periods, responsibility for this work is transferred to the Power Development Division and it is this phase of the work which is covered in this paper.

Each dam is inspected at least once a year and a formal inspection report prepared. Depending upon conditions of the structures and their past performances, additional inspections are made at more frequent intervals of those features of a dam which may be causing concern.

With the exception of Tallawarra No. 1 Ash Dam, Wangi Ash Dam and Ulan Water Supply Dam, each dam has been instrumented to some extent with ground water level observation pipes, piezometers, settlement cross arm installations, as well as survey monuments to observe horizontal and vertical movements and weirs to measure seepage rates. The numbers and types of instruments installed have been determined having regard for the size, importance and condition of the structure, and to some extent the consequences of failure.

Immediately after construction, surveys to determine settlements and deformations are usually made at three monthly intervals, but this is reduced progressively to six monthly and yearly intervals once the reservoir has been filled and the pattern of movements has been established.

In the case of the critical section of Tallawarra No.2 Ash Dam (See Section 3 below), surveys were taken as frequently as once weekly during the period near the end of construction and immediately thereafter and, for this structure, the time intervals between surveys are now still assessed having regard for the previous results.

Ground water levels, piezometers and seepage flows are usually observed at monthly intervals during filling periods and this is reduced to three or six monthly intervals after seepage conditions have stabilised or when the observations show that changes are occurring slowly.

Piezometer, ground water level and seepage observations are made by a Technical Officer working under the supervision of a senior engineer. The Technical Officer is also responsible for plotting and recording results. He has developed some expertise in the field and now makes the annual routine inspections of the minor structures.

Surveys to determine horizontal and vertical movements are made by officers from the Commission's Survey Branch.

Interpretation and assessment of the observations are made by senior engineers. This usually amounts to an examination of the trends in the rates of change of seepage, settlement, horizontal movement and pore pressures. The piezometer and ground water level readings are checked for high pore pressures in areas protected by filters and near the downstream toes. For recently constructed dams the piezometer readings are further examined to check whether steady state seepage conditions are being reached and to ensure that filters are effective.

To illustrate this work, further details are given hereunder of the Liddell Cooling Pond Dam and Tallawarra No.2 Ash Dam. These two examples represent extreme cases of our experience. The cooling pond dam is the largest structure monitored. Its performance has been satisfactory and the major monitoring difficulty has been the establishment of survey procedures to measure settlement and deformation. By comparison, the Tallawarra ash dam is a relatively low structure which has been deliberately built to a low factor of safety. In this case, the performance observations have been used to assess the limits of safe construction and operating levels, and thus the need for augmentation.

2. LIDDELL COOLING POND DAM

Liddell Cooling Pond Dam is shown in plan on Figure 1 and cross section on Figure 3. Details of the structure have been published previously in Reference 1 and some behaviour data in Reference 2.

A total of sixty-eight hydraulic piezometers were installed in the dam at the two sections shown on Figure 1. Twenty-nine ground water observation holes were installed in abutments and downstream of the dam. Four cross arm settlement installations were installed near the piezometer installations. A total of twenty three survey monuments were installed on the dam crest and on the downstream face of the dam to check settlement and horizontal movements.

The drainage system from the inclined drain and filter under the downstream part of the dam is collected at a point adjacent to the original creek and is measured with a weir. A number of weep holes in the diversion tunnel downstream of the plug have discharged a considerable quantity of water and provision has been made for fitting a temporary weir in the drainage channel in the floor of the tunnel to measure this flow. The coal seam which outcrops within the storage near the left abutment has been worked and the tunnels extend to within about 10 chains of the reservoir. Seepage into these tunnels flows to the current working sections of Liddell Colliery. The tunnels are inspected annually and seepage rates estimated.

Details of the survey net and procedures warrant special mention because of the difficulties which have been experienced in obtaining satisfactory results. The control stations and observation points are shown on Figure 1.

It was originally planned to observe the settlement and deformation points on the crest and downstream slope of the dam from survey stations located on the dam abutments. The stations were established but it was found that relationships between them were not being maintained. Four additional key control stations were therefore established downstream of the dam at the locations shown on Figure 1. Selection of the sites for these stations was made having regard for underground coal mining operations downstream of the dam and possible earth movements caused by subsidence. The sites were finally located on mining barriers where the effects of subsidence could be expected to be minimal.

There has been a history of instability with survey reference marks in the Liddell area. Measurements on 1 cubic foot concrete survey monuments have shown vertical movements of up to 0.1 feet and horizontal displacements of 0.03 feet. In order to limit such movements the key control stations were constructed of 8 cubic yard blocks of concrete cast in place below ground level.

Special precautions have been taken to ensure that the survey net provided by the key control stations is secure and that the net can be re-established even after the loss of two stations. The net has been defined by high accuracy distance measurements using an electro-optical machine combined with high precision triangulation. Instruments and targets are fixed with position locating pins cast into the blocks.

Refraction problems generally require that surveys be carried out at night.

At the start of each settlement and deflection survey, the levels of the corners of the key control stations are levelled to ensure that tilting has not occurred. It has been found that the large reference marks have tilted up to 0.01 feet. The control net is then surveyed to ensure that the interrelationship between marks has been maintained. The positions of the observing survey stations on the dam abutments are observed and these stations are then used to fix settlement point positions. Adjustments of the triangulation nets and determination of the correct settlement point positions are calculated using a computer. The program also determines the error probability of the position fix.

In the absence of changes in the position of the key control stations, it is estimated that the positions of the settlement points are defined to an accuracy of about 0.01 feet in the transverse direction and to about 0.02 feet in the longitudinal direction.

Difficulties have been experienced in providing a secure base for level measurements and a station remote from the dam is used for this purpose. The relative levels between the reference station and settlement points is determined to an accuracy of $\pm$ 0.005 feet but the absolute level accuracy is probably of the order of $\pm$ 0.02 feet.

Surveys are taken annually and the results of the recent survey are shown on Figure 2. Post-construction settlements and movements have been small and give no rise for concern for the stability of the structure.

The pore pressures measured at cross section chainage 11 + 72 are shown on Figure 3. Examination of these show that as of March, 1972, construction pore pressures have not completely dissipated and that steady state seepage conditions have not been reached. The piezometer readings upstream and downstream of the chimney drain indicate that it is working effectively and piezometer readings in the foundation under the downstream slope indicate that the blanket drainage facilities are performing satisfactorily.

Since the dam was filled in 1969, seepage from the dam drainage system and from the diversion tunnel has remained sensibly constant at about 0.1 and 0.2 cusecs respectively.

High ground water levels have developed in the left abutment near the zone of high seepage into the diversion tunnel. The ground water levels in this area increased at a rate corresponding to the pond water level. There has been no noticeable increase in seepage into the coal mine since the pond was filled.

3. TALLAWARRA NO.2 ASH DAM

The Tallawarra ash dams are ring dams as shown on Figure 4. The dams have a maximum height of about 30 feet, and average about 20 feet. No.1 pond, of approximately 400 acre feet storage, was filled in 1961. No.2 pond has a capacity of about 2,400 acre feet of which about 1,800 acre feet has been filled by mid 1972.

Between chainages 1200 and 4400, the No.2 dam is founded on soft marine clays up to 60 feet thick, which have given difficult foundation conditions. Elsewhere, the dam is founded on stiff residual soils which have given satisfactory foundations.

The deepest section of soft foundation material is located between chainages 2800 to 4400 and the remainder of this discussion will be concerned with this part of the dam.

The section of the dam of interest was built in stages as shown on Figure 5. The stages of construction were:

1st Stage:	November, 1961	To R.L. 12 with 90 feet crest width
2nd Stage:	Early 1963	To R.L. 20 with 15 feet crest width
3rd Stage:	Feb.-May, 1965	To R.L. 30 with 20 feet crest width

The factor of safety for the third stage of construction was assessed to be unity when constructed to R.L. 30. Consideration was given (in 1965) to constructing the dam to a safer lower level but there were a number of impelling reasons for building the dam as high as possible at that time. To achieve this, it was decided to use lightweight fly ash fill (85 lb./cu.ft. bulk density compared with 130 lb./cu.ft. for the alternative clay fill available), to measure settlements and horizontal movements of reference marks installed on the downstream side of the dam and to assess from the deformation observations when an unsafe condition was being reached so that construction could be stopped. The layout of the reference marks is shown on Figure 6. Observation survey stations were located on the stable sections of the dam at chainages 2850 and 4000 and these are checked against key reference survey stations located away from the dam.

Figure 5 also shows the settlement and deformation observations obtained during the construction period (ending May, 1965) and through to the end of 1966.

The fill was placed in about 2 foot lifts during discrete time intervals and each period of fill placement was followed by a rest period of about a week. It was found that the addition of fill caused the settlement points on the lower berm and at the toe of the dam to rise (see Figure 5 - settlement point 12 and pipe). During the rest period, the level of these marks fell. Figure 5 clearly shows three periods of fill placement followed by rest periods. It was planned during construction, that if the reference marks did not fall during any rest period to cut down the previously placed lift and to finish off the dam at the lower level. This did not occur and the dam was finished off at the target level of R.L. 30.

Figure 6 shows the total settlements and lateral movements recorded between 1965 and 1972. Settlements have been reasonably uniform. There is a rapid increase in settlement (0 to 2 feet) over the 200 feet length of dam between settlement points 25 and 24 and this severe deformation has caused the dam to crack transversely at the location shown on Figure 6. The differential settlements in this area are caused by steeply dipping base-rock surface and a corresponding rapid change in the thickness of the compressible clay layer.

Horizontal movements have been much less uniform along the length of the dam shown on Figure 6. These range from 0.05 feet on survey mark No. 27 to 0.7 feet on mark No. 16. The small displacements at the bend in the dam are probably related to the spread (three dimensional) support provided at corner and also by the reduced thickness of soft material in this area. The effect of differences in thickness of the soft stratum has not been reflected in settlements at this stage of consolidation.

To the east of the corner (settlement point No. 27) the dam has moved generally about 0.6 feet laterally and the movements have been reasonably uniform throughout the cross section. To the west of the corner the transverse horizontal movements have been greater at the toe of the dam than at the centreline.

Approximately one half of the total recorded horizontal movements occurred within two years of completing Stage 3. The movements are still continuing at a slow rate.

A total of 31 piezometers (stand pipe type) have been installed in the soft clay foundations. Figure 7 shows typical piezometer records plotted against height of dam, ponding level and tailwater level. Piezometer tip No. 18 was located at chainage 3450 near the centre of the clay stratum and approximately under the centre line of the 2nd Stage west. Piezometer tip No. 33B2 is located in the same relative position at chainage 3350. The example shown is typical of our experience with these instruments. It has been found that the standpipes are readily damaged despite all reasonable precautions taken to protect them, and if replaced by new instruments located at virtually identical positions, the two records are often inconsistent.

As shown on Figure 7, pore pressures are still high in the centre of the clay layer but they have fallen in the upper and lower parts of the clay stratum. The increase in pore pressure reading observed by tip No. 33B2 from 1968 to 1972 is undoubtedly related to the increase in pond level. However, the relatively rapid increase during 1970 cannot be explained with any certainty.

The factor of safety of the structure against a slip circle failure has been estimated recently using soil strength data and a pore pressure field based on the piezometer observations. The computed values ranged from 0.7 to 1.3 depending upon the method of analysis used. The wide range in values appears to be typical of this situation where the angle subtended by the critical slip circle is large and foundation pore pressures are high.

The future stability of the structure depends on the rate of pore pressure dissipation and the rate of increase in storage level with further ponding of ash. It is considered that calculated factors of safety are not precise and cannot be used for deciding whether the overall stability of the structure is improving or deteriorating. In this situation, recourse must continue to be made to the procedure which has been evolved for observing trends in settlements and movements in order to decide when stability is deteriorating and if left unchecked would lead to failure. When it is considered that such a situation has been reached, construction will be started on the fourth stage embankment located on the ash deposits upstream of the existing dam.

4. DISCUSSIONS

The case histories which have been briefly described above highlight the different approaches which have been taken to monitor and assess the performance of two widely different types of structures. The Liddell cooling pond dam is a major structure which has been designed and built to high standards. Failure of this structure would have far-reaching consequences and all precautions must be taken to ensure that its future operation is satisfactory. The Tallawarra ash dam on the other hand is a relatively minor structure which has deliberately been built to a low factor of safety. This has been done having regard for the purpose of the structure (which ponds ash and not water against the weak section of the embankment), the minimal consequences of a slip and the real incentives for making best use of the storage provided at the site.

It has been our experience that it is not possible to have standard instrumentation systems and procedures for monitoring the performance of dams. Each structure must be treated differently according to its particular features. Having obtained the field data, the engineer responsible for the safety of the structure has to decide on the criteria he will adopt to assess whether a structure is safe, unsafe, or whether he should defer a decision to implement maintenance works until further performance data is available. The decision is often difficult and must be made having regard for all the performance data available, the large sums of money which may be involved in strengthening a structure and the consequences which would occur if failure took place. The literature is of little value in this work as there are few fully documented cases of dam or embankment performance immediately prior to failure, and what is available is usually only relevant to the situations described.

In our work, considerable emphasis has been placed on the measurement of seepage flows and the settlements and movements of reference marks because it is considered that the best indication of deteriorating conditions will show up by increased seepage or as accelerating movements. As the criteria are based on changes or trends, it is most important that the measurements be taken accurately so as to ensure that slow changes are not marked by errors in the observations.

References

1. Martin G.F. & Bacon G.A. "Main Cooling Water Dam for Liddell Power Station, N.S.W." Ancold Bulletin Issue No. 25 February 1968.

2. Bacon S.A. "Observation Behaviour of Dam Embankments Instrumented by the Snowy Mountains Authority" Ancold Bulletin Issue No. 29 October 1969.

Acknowledgements

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TABLE 1A

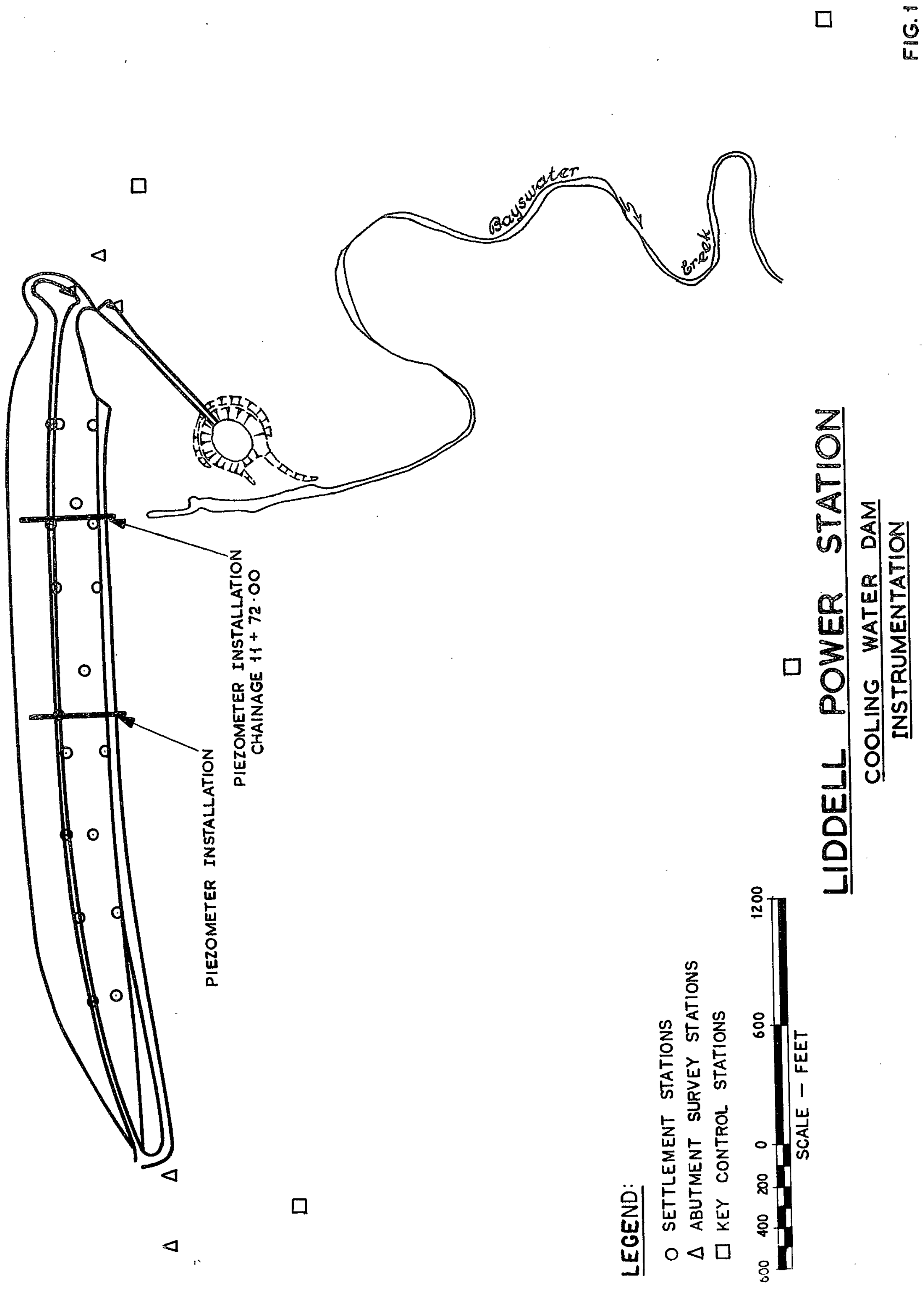
ELECTRICITY COMMISSION OF N.S.W. DAMS - SALIENT FEATURES

Dam	Type	When Constructed	Max. Height (Feet)	Crest Length (Feet)	Capacity (Acre Feet)	Catchment (Square Miles)
Bega Hydro Dam	Earthfill	1958	94	1,200	2,500	13.6
Liddell P.S. Cooling Pond Dam	Earthfill	1967/8	145	4,250	120,000	27.0
Liddell P.S. Water Supply Dam	Earthfill	1969	105	1,350	3,700	0.78
Liddell P.S. Ash Dam	Earthfill	1971	108	2,830	11,200	4.0
Munmorah P.S. Ash Dam	Earthfill	1966	20	6,200	4,000	3.0
Tallawarra No. 1 Ash Dam	Earthfill	1953	20	5,000	400	0
Tallawarra No. 2 Ash Dam	Earthfill Staged Construction	1961 1963 1965	12 20 30	10,500	2,400	0
Ulan P.S. Water Supply Dam	Rockfill and Concrete Gravity	1957	34	600	135	45.0
Wallerawang P.S. Ash Dam	Earthfill	1967	30	3,600	270	0.5
Wangi P.S. Ash Dam	Earth and Ashfill Staged Construction	1955 1960 1967	10 20 30	2,500	2,500	1.5
Vales Pt. P.S. Ash Dam	Earthfill	1963	40	3,000	7,000	9.0

TABLE 1B

ELECTRICITY COMMISSION OF N.S.W. DAMS – INSTRUMENTATION DETAILS

Dam	Piezometers		Ground Water Holes		Settlement Surveys		Horizontal Movement Surveys		Seepage Weirs	
	No.	Read	No.	Read	No. of Stations	Read	No. of Stations	Read	No.	Read
Bega Hydro Dam	11	Monthly	–	–	13	Yearly	13	Yearly	2	Weekly
Liddell P.S. Cooling Pond Dam	68	6–Monthly	29	6–Monthly	4 sets of cross arms & 27	6–Monthly	23	Yearly	2	6–Monthly
Liddell P.S. Water Supply Dam	20	6–Monthly	9	6–Monthly	19	6–Monthly	9	Yearly	1	6–Monthly
Liddell P.S. Ash Dam	27	3–Monthly	13	3–Monthly	32	6–Monthly	32	Yearly	1	3–Monthly
Munmorah P.S. Ash Dam	–	–	19	6–Monthly	24	Yearly	–	–	–	–
Tallawarra No. 1 Ash Dam	–	–	–	–	–	–	–	–	–	–
Tallawarra No. 2 Ash Dam	44	3–Monthly	6	3–Monthly	15	Variable (6–Monthly)	15	Variable (6–Monthly)	–	–
Ulan P.S. Water Supply Dam	–	–	–	–	–	–	–	–	–	–
Wallerawang P.S. Ash Dam	–	–	11	6–Monthly	–	–	–	–	1	6–Monthly
Wangi P.S. Ash Dam	–	–	–	–	–	–	–	–	–	–
Vales Pt. P.S. Ash Dam	16	6–Monthly	–	–	9	Yearly	9	Yearly	–	–



LIDDELL POWER STATION
COOLING WATER DAM
INSTRUMENTATION
FIG. 1
Bayswater Creek
PIEZOMETER INSTALLATION
CHAINAGE 11 + 72·00
PIEZOMETER INSTALLATION
LEGEND:
○ SETTLEMENT STATIONS
△ ABUTMENT SURVEY STATIONS
□ KEY CONTROL STATIONS
600 400 200 0 600 1200
SCALE – FEET

Figure 1

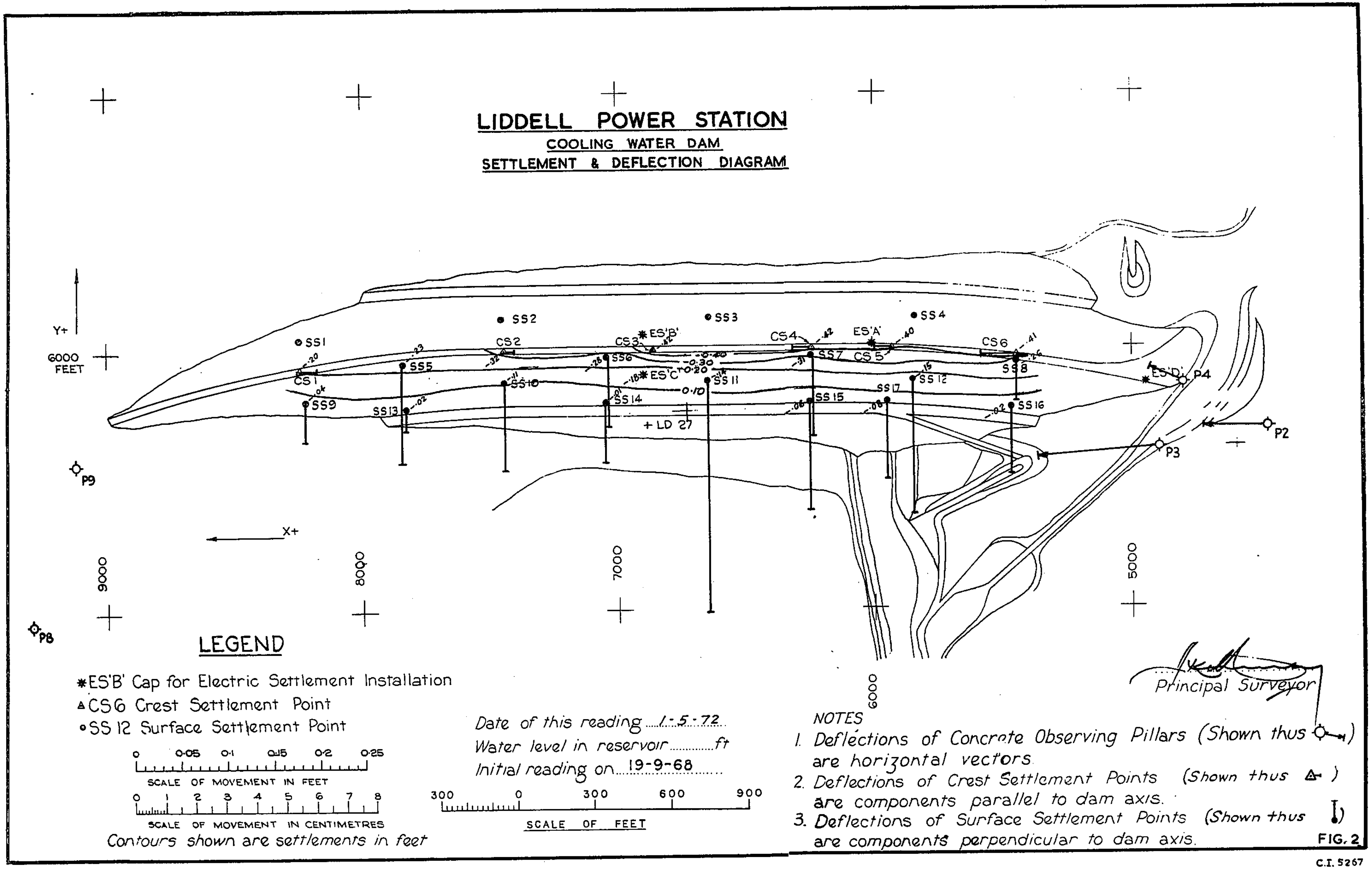

LIDDELL POWER STATION
COOLING WATER DAM
SETTLEMENT & DEFLECTION DIAGRAM
SS1
SS2
SS3
SS4
CS1
CS2
CS3
CS4
CS5
CS6
ES'A'
ES'B'
ES'C'
ES'D'
SS5
SS6
SS7
SS8
SS9
SS10
SS11
SS12
SS13
SS14
SS15
SS16
SS17
+ LD 27
P2
P3
P4
P8
P9
Y+
X+
6000 FEET
9000
8000
7000
6000
5000
LEGEND
*ES'B' Cap for Electric Settlement Installation
▵CS6 Crest Settlement Point
∘SS 12 Surface Settlement Point
0 0·05 0·1 0·15 0·2 0·25
SCALE OF MOVEMENT IN FEET
0 1 2 3 4 5 6 7 8
SCALE OF MOVEMENT IN CENTIMETRES
Contours shown are settlements in feet
Date of this reading 1-5-72
Water level in reservoir ft
Initial reading on 19-9-68
300 0 300 600 900
SCALE OF FEET
NOTES
1. Deflections of Concrete Observing Pillars (Shown thus) are horizontal vectors.
2. Deflections of Crest Settlement Points (Shown thus) are components parallel to dam axis.
3. Deflections of Surface Settlement Points (Shown thus) are components perpendicular to dam axis.
Principal Surveyor
FIG. 2
C.I. 5267

Figure 2

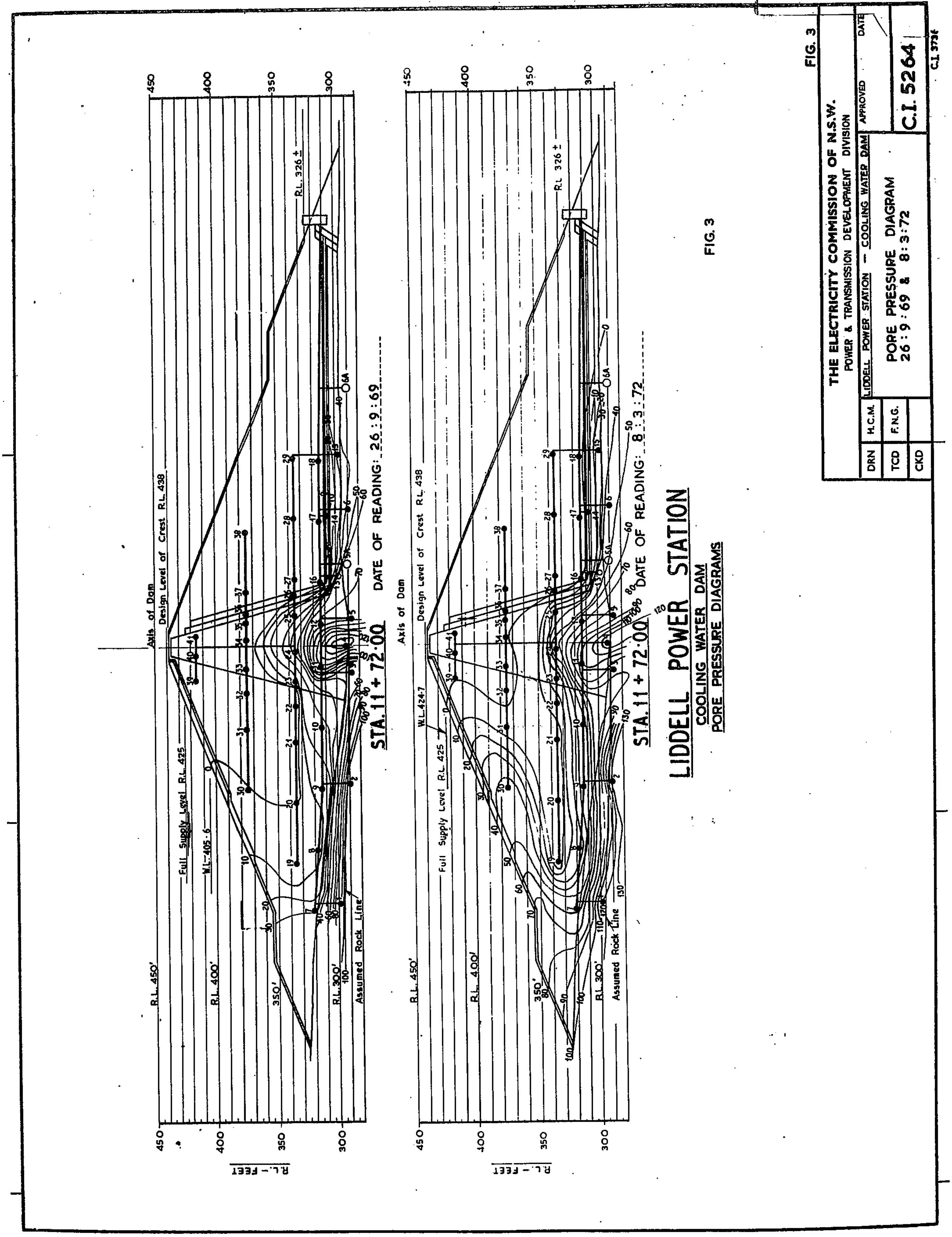


FIG. 3
THE ELECTRICITY COMMISSION OF N.S.W.
POWER & TRANSMISSION DEVELOPMENT DIVISION
LIDDELL POWER STATION — COOLING WATER DAM
PORE PRESSURE DIAGRAM
26 : 9 : 69 & 8 : 3 : 72
C.I. 5264
DRN H.C.M.
TCD F.N.G.
CKD
APPROVED
DATE
LIDDELL POWER STATION
COOLING WATER DAM
PORE PRESSURE DIAGRAMS
STA. 11 + 72·00
DATE OF READING: 26 : 9 : 69
STA. 11 + 72·00
DATE OF READING: 8 : 3 : 72
Axis of Dam
Design Level of Crest R.L. 438
Full Supply Level R.L. 425
W.L. 405·6
W.L. 424·7
R.L. 326 ±
Assumed Rock Line
R.L. 450'
R.L. 400'
R.L. 300'
350'
R.L. - FEET

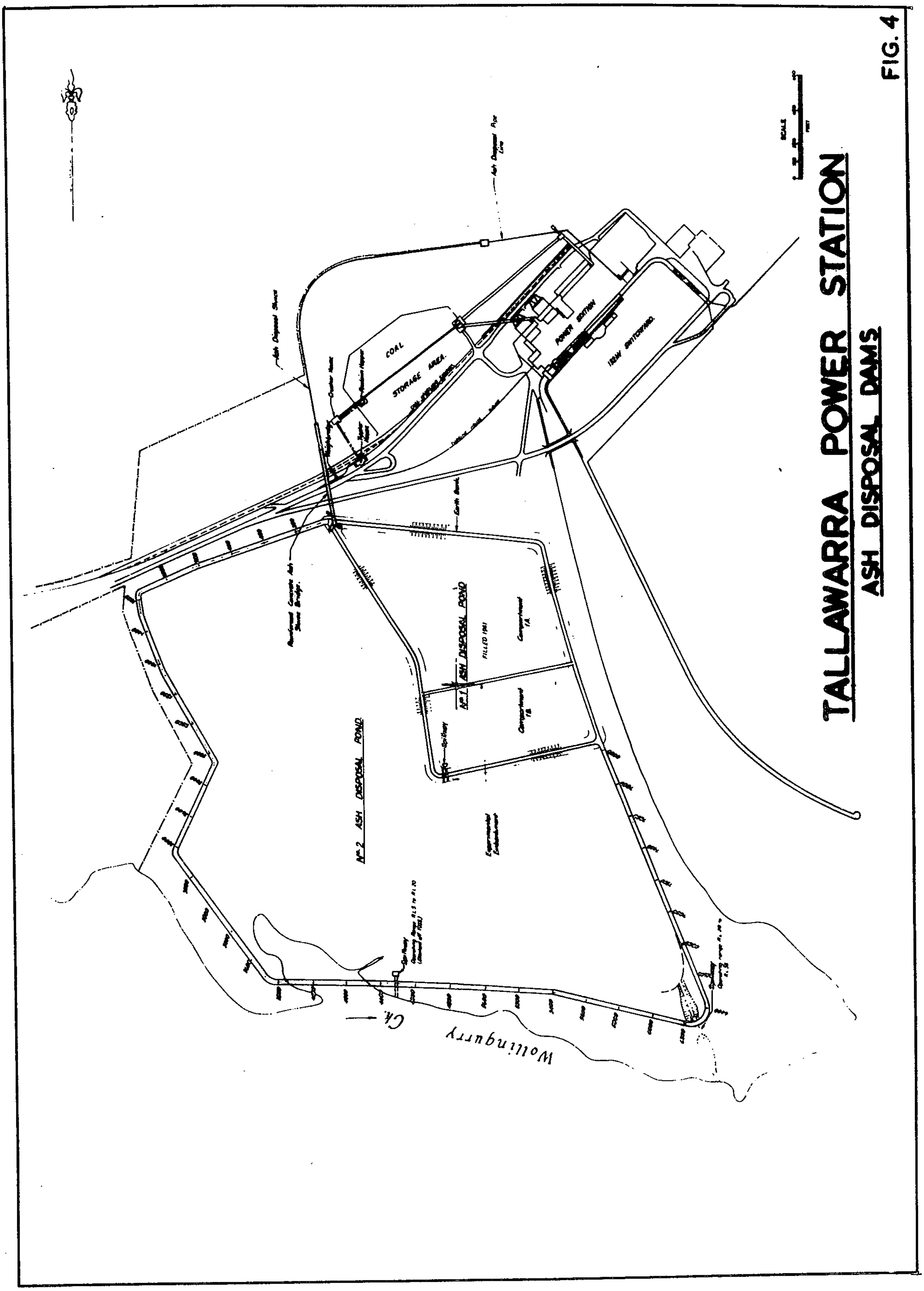
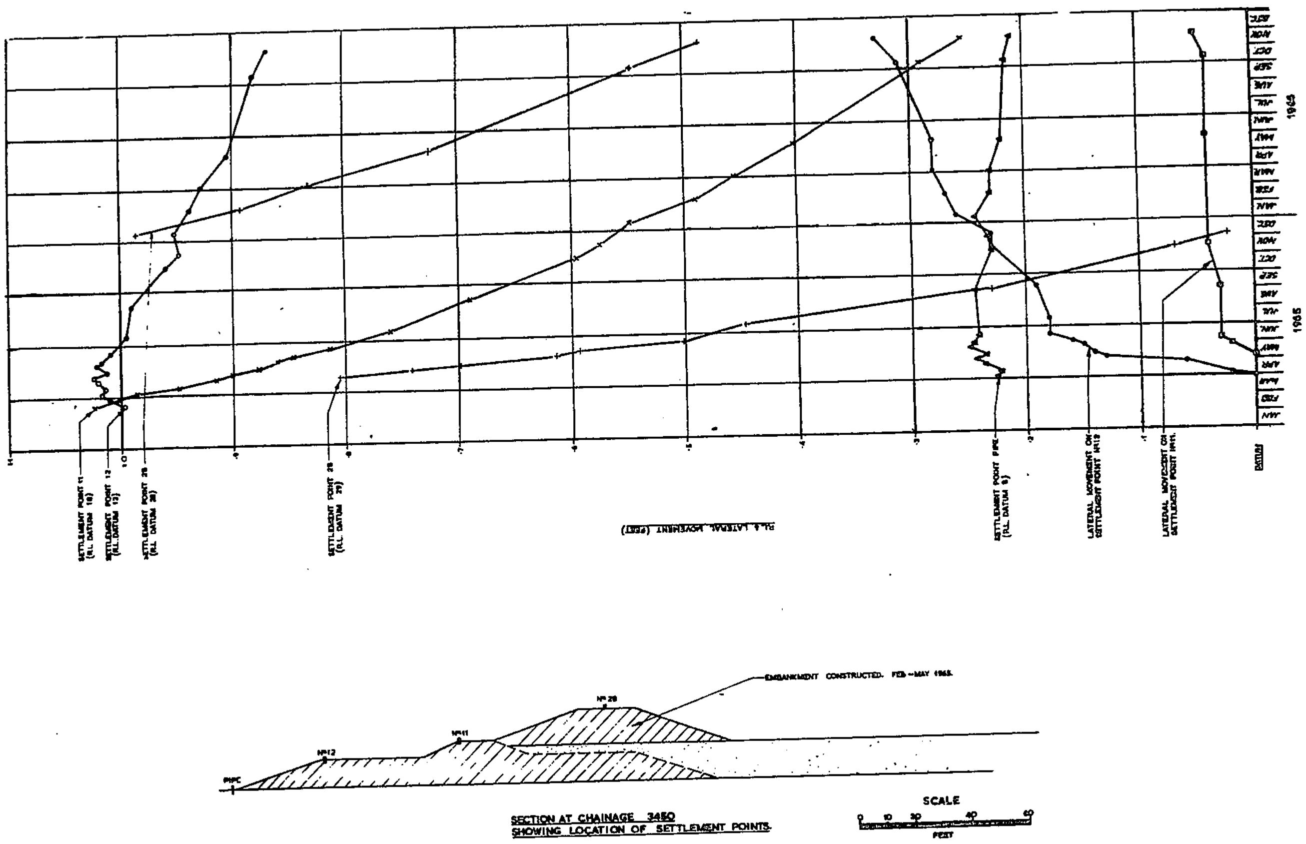

TALLAWARRA POWER STATION
ASH DISPOSAL DAMS
FIG. 4
COAL
STORAGE AREA.
POWER STATION
132kV SWITCHYARD
No.1 ASH DISPOSAL POND
No.2 ASH DISPOSAL POND
Wollingurry Ck.

Figure 4



TALLAWARRA No 2 ASH DAM

SETTLEMENTS & MOVEMENTS AT CHAINAGE 3450

FIG. 5

Figure 5

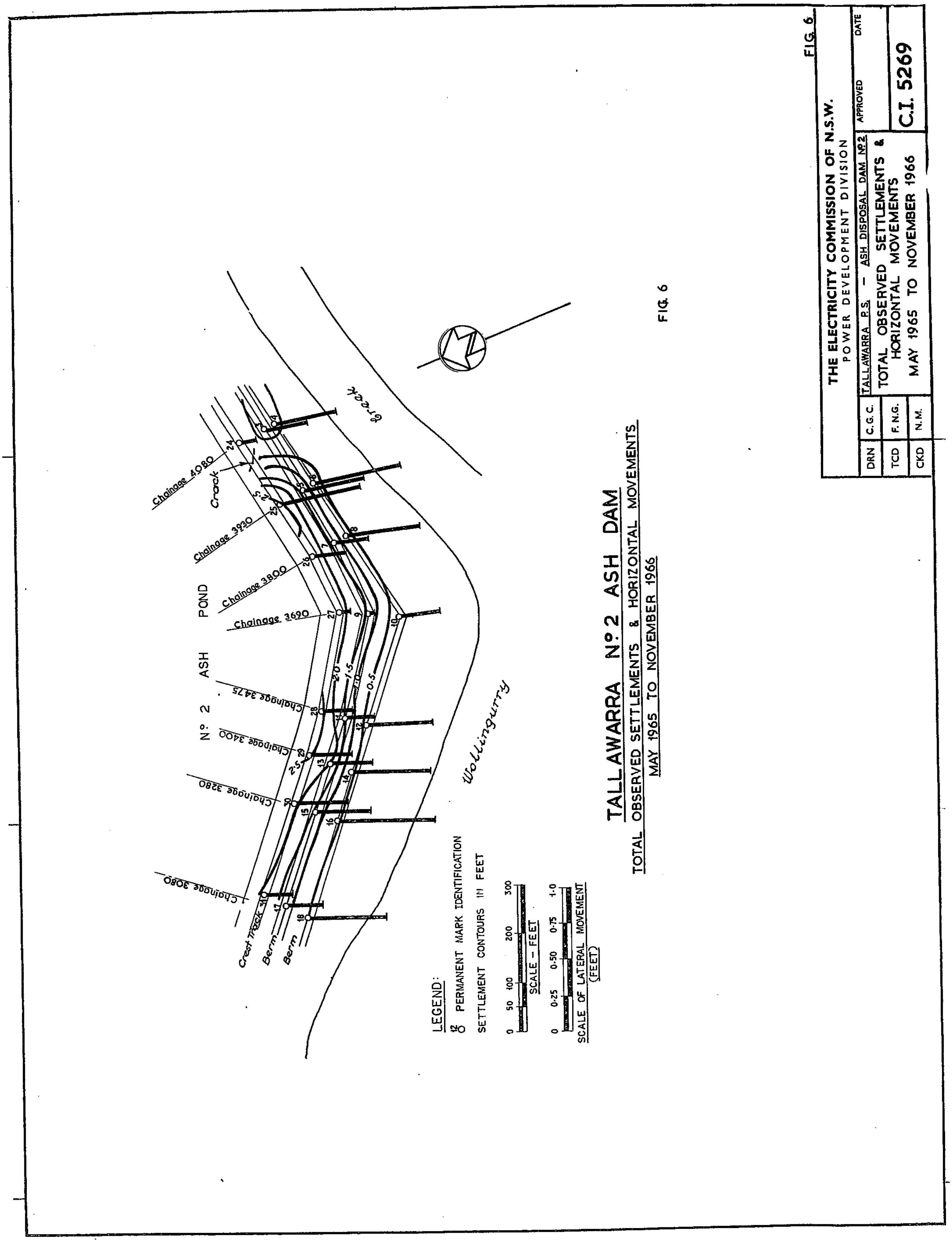
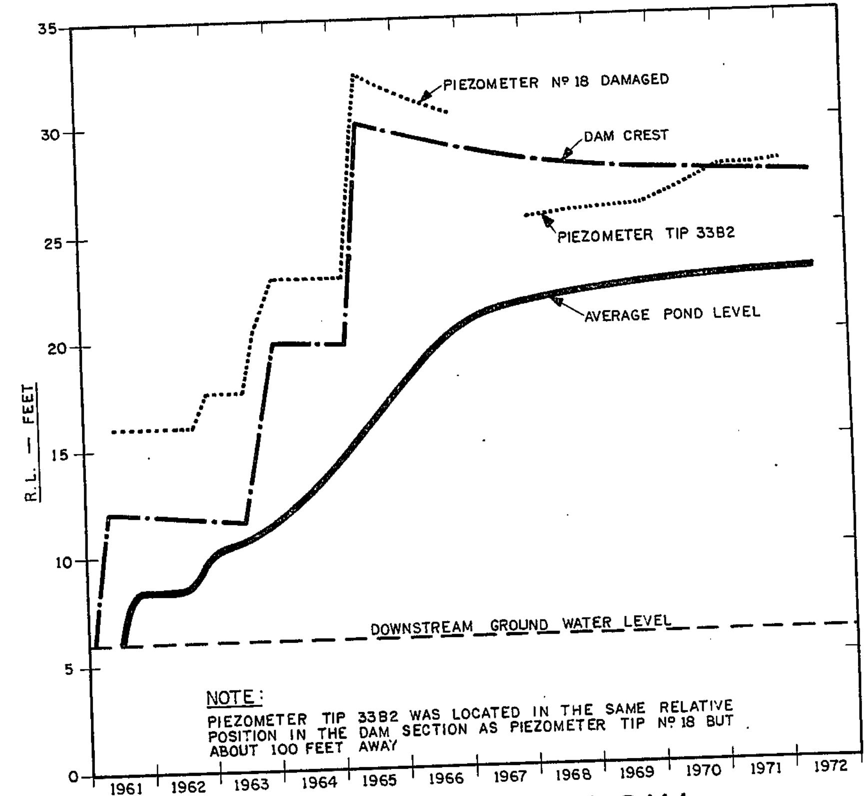


FIG 6
THE ELECTRICITY COMMISSION OF N.S.W.
POWER DEVELOPMENT DIVISION
TALLAWARRA P.S. — ASH DISPOSAL DAM No 2
TOTAL OBSERVED SETTLEMENTS & HORIZONTAL MOVEMENTS
MAY 1965 TO NOVEMBER 1966
DRN C.G.C.
TCD F.N.G.
CKD N.M.
APPROVED
DATE
C.I. 5269
FIG 6
TALLAWARRA No 2 ASH DAM
TOTAL OBSERVED SETTLEMENTS & HORIZONTAL MOVEMENTS
MAY 1965 TO NOVEMBER 1966
No 2 ASH POND
Creek
Wollingurry
Chainage 4080
Crack
Chainage 3930
Chainage 3800
Chainage 3690
Chainage 3475
Chainage 3400
Chainage 3280
Chainage 3080
Crest Track
Berm
Berm
LEGEND:
PERMANENT MARK IDENTIFICATION
SETTLEMENT CONTOURS 1" FEET
SCALE - FEET
SCALE OF LATERAL MOVEMENT (FEET)

Figure 6



TALLAWARRA Nº2 ASH DAM

DAM HEIGHT, POND LEVEL & PIEZOMETER READING AT CHAINAGE 3300

FIG. 7

FIG. 7

THE ELECTRICITY COMMISSION OF N.S.W. POWER DEVELOPMENT DIVISION				
DRN	C.G.C.	TALLAWARRA P.S. — ASH DISPOSAL DAM Nº2	APPROVED	DATE
TCD	F.N.G.	DAM HEIGHT, POND LEVEL & PIEZOMETER READINGS AT CHAINAGE 3300	C.I. 5266	
CKD				