

Settlement of Power Station Structures In the Latrobe Valley, Victoria

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SUMMARY: A review is made of predicted and observed settlement at four power stations in the Latrobe Valley. The methods of settlement analysis are compared with those used to predict settlement at the new Loy Yang Power Station. Ground instrumentation installed to monitor both regional subsidence and net settlement of structures at Loy Yang is described. It is concluded that one-dimensional analysis is the most rational method of analysis for large structures underlain by a multi-layered soil profile.

1 INTRODUCTION

The Latrobe Valley contains one of the world's largest deposits of brown coal and forms the basis for power generation in the State of Victoria. There are at present four major power stations with a total generating capacity of some 3000 MW which is to be augmented in the 1980s by the Loy Yang Power Station of 4000 MW capacity.

The brown coal deposits occur in three major seams and have been recovered by open cut methods since the early 1920s. The location of the open cuts and their associated power stations is shown on Figure 1. The general stratigraphy and structural geology of the Latrobe Valley has been described by Glee (1976).

The development of the Morwell Open Cut in the 1960s made it necessary to depressurise aquifers within and below the Morwell coal seams. This

prevented hydrostatic pressures causing heave in the floor of the open cut. The dewatering of the extensive M1 and M2 aquifers has resulted in the regional subsidence shown on Figure 1. The effects of ground movements resulting from open cut development are discussed by Hutchings et al (1977).

In reviewing the settlement of large power station structures in the Latrobe Valley, previous methods of analysis will be compared with that adopted for Loy Yang A Power Station.

2 EFFECTS OF SETTLEMENT ON STRUCTURES

It is generally accepted by the Commission that differential settlements of 1.0 to 0.3% between structural columns can be absorbed without concern. There is greater concern for the effects of settlement on plant and machinery. Some notable exceptions are the central lift towers and the cooling towers. The lift towers are usually the

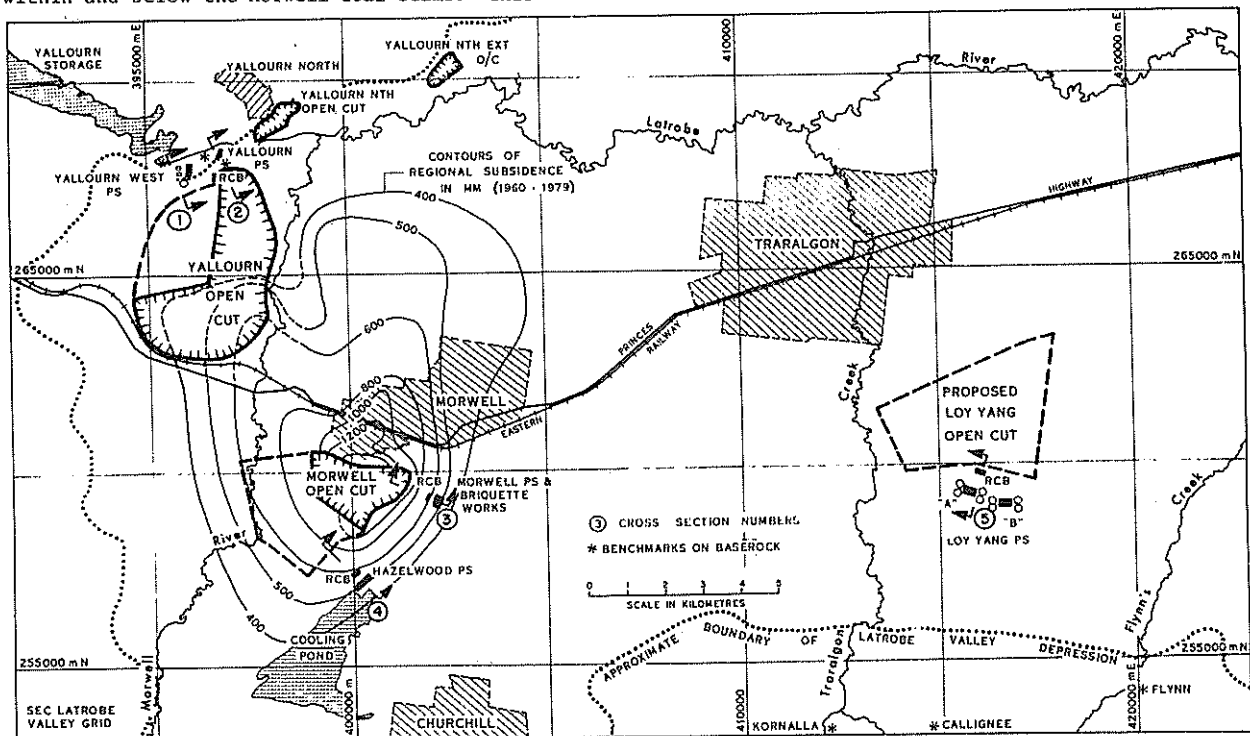


Figure 1 - Location of Power Stations and Open Cuts, Latrobe Valley, Victoria, Australia

TABLE I

Summary of Observed and Predicted Settlements for Power Station Structures

Power Stations & Structure	Date foundation completed	Foundation dimensions (metres)	Sustained Net. Press. (kPa)	Predicted Net. Settlof (mm)	Observed Net. Settlof (mm)	Regional Settlement (mm)	Max. Tilt. & direction (%)	Remarks on settlement analysis & soil conditions
VALLOURN (D) 470 MW								
-Boiler foundations	1954	55 × 15	188	6-20	25-30	38	0.05 SE	Elastic analysis based on plate load tests. E=275MPa Turbine founds, all an CO. Remainder $\frac{1}{4}$ on CO, $\frac{3}{4}$ on CLSA. Base rock at 300m* GWL at 9m (perched). See Section ①
-Boiler columns	"	73 × 4.3	188	5-20	12-28	"	"	
-Turbine foundations	"	26 × 6	140	6-10	15	"	"	
-Total Found. Area	"	100 × 60*	35*	20	33 max.	"	"	
VALLOURN WEST STAGE 1 700MW								
-Boiler foundations	7/68-2/69	30 × 30*	160*	25-45	20	36	0.02 S	I-D oedometer method using average m_v and $\mu=0.3$. Elastic ignored. CLSI & CLSA with up to 3m of compacted fill on E-side of boiler founds. Base rock at 5-25m, GWL at 8m. CT2 analysis based on plate load tests. E=125MPa (CT1: Rock at 3-10m, GWL at 10m. CT2: $\frac{1}{2}$ on CO $\frac{1}{2}$ on CLSI. Rock at 10-25m. GWL 13-20m.
-Boiler columns	7/68-2/69	8 × 8	170-255	20-40	20	36	"	
-Bunkerbay columns	2/68-6/69	7 × 8	200-240	30-40	10	36	"	
-Turbine foundations	2/68-6/69	44 × 14	122	18-19	0-10	30	0.014 S	
-Turbine columns	9/68-6/69	5 × 4	70-115	20	0-15	30	0.012 S	
-Total Found. Area	1970	130 × 105*	72*	56	20	36	0.015 S	
-Chimney No. 1	3/70	30 ϕ (168h)	100.	25	11	50	0.02 S	
-Cooling Tower 1	3/70	90 ϕ × 2.5 w	125	10	14	18	0.01 SE	
-Cooling Tower 2	4/71	90 ϕ × 2.5 w	125	10	34	35	0.085 SSW	
Stage 2 750 MW								
-Boiler foundations	6/76-6/77	50 ϕ *	150*	120	60+	20	0.01 SE	I-D oedometer method using m_v varying with applied press. and $\mu=0.3$. Elastic component added. Based on E=80MPa to 10m & E=150 MPa below. 5-10m of compacted fill. $\frac{2}{3}$ on site underlain by CO remainder CLSI & CLSA. Baseroack at 60-120m. GWL at 9m (perched). RCB Baseroack 300mm See Section ②
-Boiler columns	1976-77	8 × 5	220	120	60+	20	"	
-Bunkerbay columns	4/76-12/76	33 × 12	260	130	70+	16	"	
-Turbine foundations	4/76-3/77	42 × 14	131	81-95	28+	12	"	
-Elect. Annexe cols.	3/77	8 × 6	200	125	25+	16	"	
-Total Found. Area	1976-79	130 × 110*	77*	130	70+	110 (p) 20	0.01 SE	
-Chimney No. 2	6/77	30 ϕ (168h)	130	85	21+	22	0.007 SE	
-Cooling Tower 3	8/76	103 ϕ × 3 w	100	16	23+	30	0.007 SE	
Raw Coal Bunker (RCB)	11/75	120 × 45	180	120	67+	150 (p) 55	0.004 S	
MORWELL (240 MW) & BRIQUETTE WORKS								
-Boiler foundations	6/55	100 × 92	115	NA	15	490	0.03 W	German design predictions N.A. Mainly mat. foundations. R.C.B. cellular raft. Interbedded SACL & CLSA Baseroack 300+m. GWL 12-15m (perched). See Section ③
-Turbine foundations	9/57	6 × 15.2	120	"	9	480	0.04 W	
-Turbine columns	9/57	3 × 5	115	"	6	480	0.055 W	
-Chimneys × 4	9/57	20 ϕ (94h)	115	"	3	490	0.11 N	
Briquette Factories	1957-58	113 × 30	122-134	"	6	480	0.01 W	
Raw Coal Bunker	1957-58	70 × 23	128	"	15	600	0.05 W	
HAZELWOOD 1600 MW								
-Boiler foundations	1962-68	30 × 14	188	12	15	380-400	0.02 N	I-D oedometer method using average m_v . Elastic ignored. Interbedded CLSA & SACL. Baseroack at 300+m. GWL at 10m (perched). Site cut on East side. Fill on West side. See Section ④
-Boiler columns	"	7 × 7	260	18	15	"	"	
-Bunkerbay columns	"	3 × 3	260	5	15	"	"	
-Turbine foundations	"	28 × 10	160	0	18	"	"	
-Total Found. Area	1961-68	83 × 91(x4)	83	18	25	"	"	
-Site Cut & Fill	1959-60	760 × 360	$\begin{cases} -300 \\ +150 \end{cases}$	$\begin{cases} -245 \\ +150 \end{cases}$	$\begin{cases} -120** \\ +15 \end{cases}$	$\begin{cases} 425 \\ 350 \end{cases}$	0.03 E**	
-Chimneys (×8)	1963-68	22 ϕ (137h)	140	0	0	390-410	0.02 N	
Raw Coal Bunker	4/62-8/64	(116 × 10) × 4	160	160	140	425	0.09	
LOY YANG 'A' Station 2000 MW								
-Boiler foundations	1979-82m	48 × 48*	153*	75-105	NA	85 (p)	0.10 N(p)	I-D oedometer method using CR ₁ for unload-reload & CR ₂ for net loading. Elastic ignored. Post construction assumed $\frac{1}{3}$ of oedometer. SACL underlain by interbedded SISA & CLSI Baseroack at 130-220m GWL at 75m See Section ⑤
-Boiler columns	"	10.5 × 10.5	163	80	"	"	"	
-Turbine foundations	"	42 × 20	85	70	"	"	"	
-Turbine columns	"	4 × 6	50	25-35	"	"	"	
-Total Found. Area	1979-83	140 × 150(x2)	70*	105	"	"	"	
-Boiler Excavation	1978	50 × 120	60	-20	-27	"	"	
-Chimneys (×2)	1979-80	40 ϕ (260h)	185	50	NA	100(p)	"	
-Chimney Excavation	1979	50 ϕ	200	-40	-48	"	"	
-Cooling Towers (×4)	1979-83	103 ϕ × 3.2 w	100	25-30	NA	85 (p)	"	
Raw Coal Bunker	1979-80	166 × 68	190	150	"	330 (p)	0.20 N (p)	
-Bunker Excavation	1978	166 × 68	60	-20	-18	"	"	

NOTES: * Indicates foundation dimensions and net pressures are based upon averages.

** Measurements started 12 months after construction complete.

Soil Type; SA-sand SI-silt CL-clay CO-coal ie. SISA-silty sand.

NA-Not available (p) predicted w-width h-height ϕ -diameter

first structures erected in the centre of the power station block, usually between the boilers and adjacent to the bunker bay. Once erected these 100 m high concrete structures are subjected to tilt caused by subsequent construction. This produces connection problems with steelwork and floors at higher levels.

The thin shell hyperbolic cooling towers are constructed on a continuous strip footing at low bearing pressures to minimise differential settlements. To date, the maximum observed planar tilt has been 0.085% under Cooling Tower 2 at Yallourn West. It is noted that Ciesielski et al (1977) has reported values of planar tilt in the order of 0.10% and differential settlements between adjacent columns around the perimeter footing of 0.17%.

The major items of plant which are affected by settlements include the turbine house crane rail, the bunker bay shuttle rail, the boiler off-take ducts and turbo-generators. Provided that post-construction adjustments can be made to the supports for these items, the effects of settlement can be accommodated.

3 SETTLEMENT OF EXISTING STRUCTURES

The earliest power station for which survey records on settlements are available is located at Yallourn. The later "D" and "E" sections of this station were constructed after 1954. Morwell Power Station and Briquette Works were completed between 1955 and 1958, while Hazelwood and Yallourn West were constructed between 1962-68 and 1968-80 respectively. A summary of the observed settlements at these stations is presented in Table I. The stratigraphy beneath these stations is indicated on the cross-sections, Figure 2.

3.1 Yallourn D

Observed settlements at Yallourn D Power Station are approximately 50% higher than predicted. The difference may be attributed to the method of analysis which used the elastic modulus from plate load tests to determine an assumed elastic settle-

ment. The method did not take into account the size of the loaded area or the time-dependent nature of settlement on coal. However, settlements have been relatively small and no structural distress has occurred.

3.2 Morwell

The Morwell Power Station and Briquette Works were designed in Germany in the early 1950s and no settlement estimates are available. The foundations are monolithic rafts on a site which had significant excavation prior to construction. Net settlements are small while regional settlements are the largest experienced in the Latrobe Valley. These settlements have not caused distress in the structures.

3.3 Hazelwood

Settlement predictions at Hazelwood were made using an average coefficient of compressibility m_v from laboratory oedometer tests and a large scale load test described by Green (1972). An allowance was made for site cut and fill in the choice of m_v values. No elastic settlement was considered.

3.4 Yallourn West

Stage 1 of Yallourn West Power Station was completed in 1971. Observations indicate that settlement of the structures is substantially complete with additional settlement due only to regional effects and construction of the Stage 2 structure. As shown in Figure 2, the base rock is much shallower under the Stage 1 structure and settlements are correspondingly lower than Stage 2 which is nearing completion. The method of analysis used in settlement prediction for Stage 1 adopted a one-dimensional (1-D) approach using average m_v values directly from laboratory consolidation curves. A correction factor $\mu = 0.3$ was then applied to the oedometer settlement ρ_{oed} thus calculated to obtain the estimated total settlement ρ_t ie $\rho_t = \mu \rho_{oed}$. This factor had its origin in the experience gained from settlement of structures at Hazelwood and was thought at the time to be related to Skempton and Bjerrum's correction factor μ quoted in Burland et

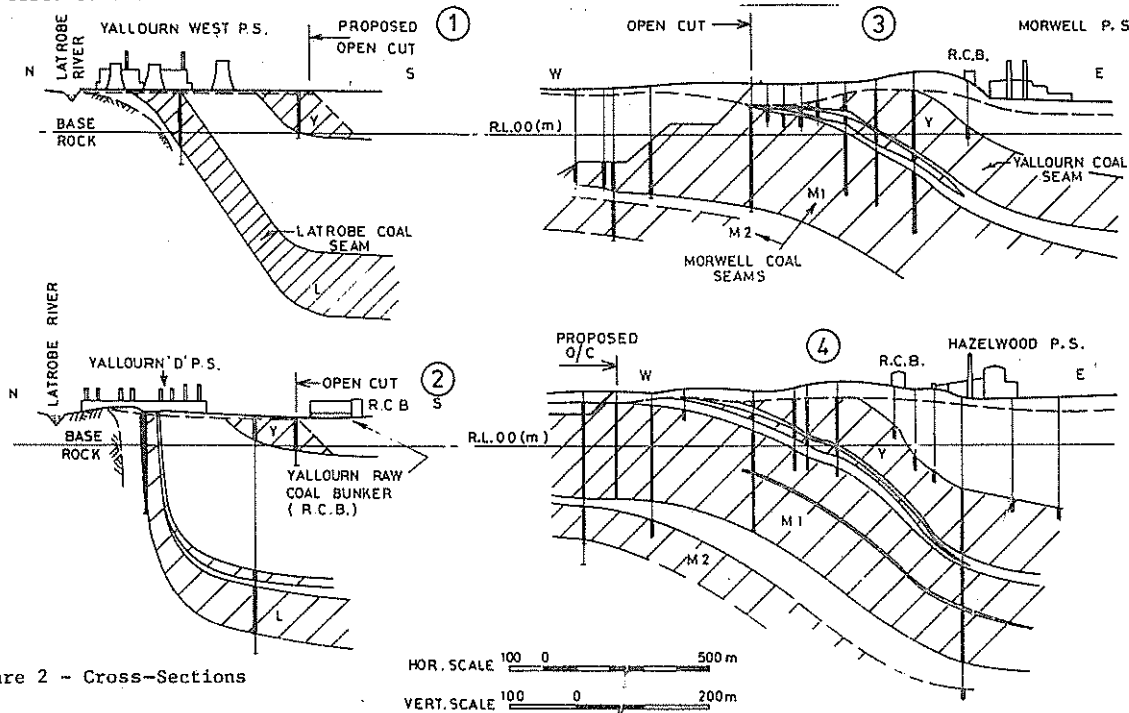


Figure 2 - Cross-Sections

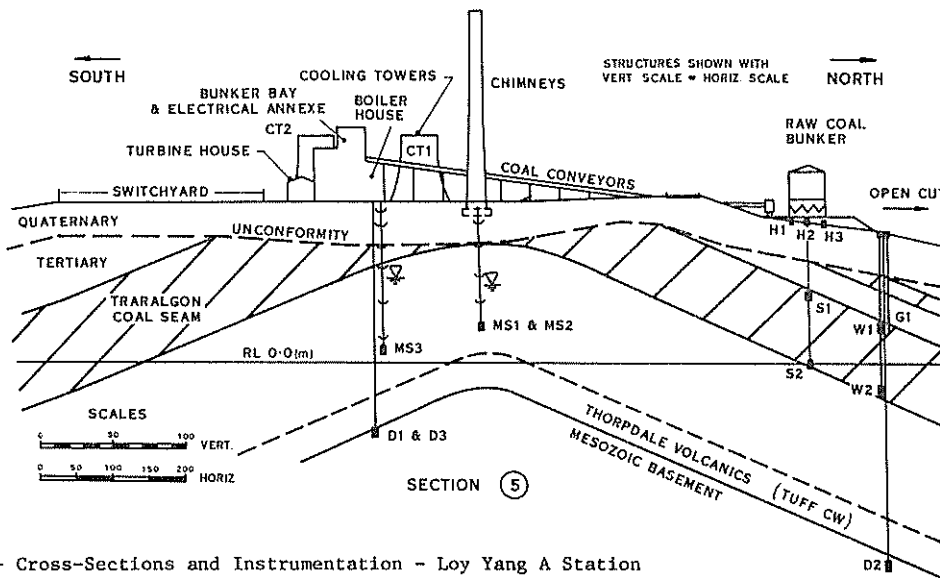


Figure 3 - Cross-Sections and Instrumentation - Loy Yang A Station

al (1977). No additional allowance was made for immediate elastic (lateral yield) settlement. Comparison of the predicted and measured settlement in Table I indicates a reasonable agreement in the Stage 1 power station block itself. The Stage 2 analysis used a variable m_v from laboratory curves and added an elastic component ρ_i after applying a factor $\mu = 0.3$ to the oedometer settlement $\rho_t = \rho_i + \mu \rho_{oed}$. The rate of settlement of Stage 2 foundations is being observed at present. Elastic settlement is predicted to be approximately 70% of total net settlement. By mid 1979 approximately 75% of the load had been applied resulting in some 50% of the predicted settlement occurring.

4 LOY YANG POWER STATION

The Loy Yang Power Station site lies across an anti-clinal dome structure on the southern flank of the proposed open cut. Two 2000 MW stations, A and B, are presently under construction on adjacent sites. The subsurface profile is shown in Section 5, Figure 3.

4.1 Soil Properties

At A Station a total of 28 distinct soil layers were identified in the upper 130 m of the soil profile. Study of the laboratory consolidation characteristics of these soils, shown idealised in Figure 4, indicates that the coefficient of compressibility m_v should not be used directly from the curve. Significant sample disturbance is shown to occur in the working range of P_0 to P_c where the immediate strain component $\Delta \epsilon_i$ reaches its peak. This made it necessary to reconstruct the undisturbed consolidation curve by adopting a compression ratio CR_2 based on the rebound curve CR_2^I or CR_2^{II} over a similar pressure ordinate range. A similar recycle from P_0 gave a compression ratio CR_1 which was adopted for calculation of heave or reload. The virgin curve and preconsolidation pressure were determined by the Schmertmann method and the slope identified by the compression ratio CR_3 . In general, the value of CR_2 was found to be about 10% of CR_3 and four times CR_1 .

As the soil profile in Figure 5 shows, the apparent preconsolidation pressure decreases through the upper Quaternary materials due to desiccation of the upper clays. In the Tertiary materials there

is an increase in the over-consolidation ratio which becomes more distinct in the coal seams. This additional apparent preconsolidation is the result of high secondary consolidation in the organic coal. This manifests itself in a high undrained strength compared with clays at a similar depth. Near the base of the Tertiary materials there is a formation known as the Thorpdale Volcanics consisting mainly of a completely weathered tuff. The deeper samples taken in this material showed a tendency to collapse at lower preconsolidation pressures. A rapid rise in preconsolidation results once the Mesozoic basement is encountered.

In the applied stress range these over-consolidated soils show little evidence of a Terzaghi type primary consolidation time curve. A typical curve tends to exhibit an initial immediate strain and

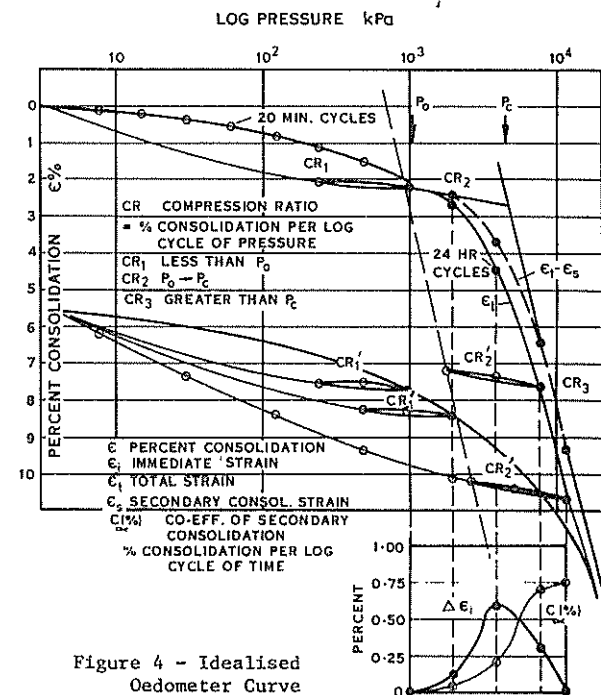


Figure 4 - Idealised Oedometer Curve