

Earth dams in Victoria : a historical study

by

Lee and Speedie.

# Earth Dams in Victoria

## A Historical Review

BY

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*Summary.*—More than forty Victorian storage dams are referred to by type and date of construction and points of particular historical interest are quoted. Brief statements are also given of the development of investigation, design and construction practices.

### EARLY DAMS

Although a small settlement had been established at Portland a year or two earlier, the settlement of Victoria can be said to date from 1835 when Batman founded the "village" of Melbourne.

And it was in connection with Melbourne and its water supply that 18 years later the first earthen embankment in the State was commenced—the Yan Yean Reservoir near Whittlesea—3234 ft. long and 31 ft. high. Commenced in 1853 it was completed and brought into service in December, 1857.

The inner and outer slopes were 3 to 1 and 2 to 1, respectively, with a central puddle clay core.

A paper on the work by the Engineer in charge—Mr. M. B. Jackson, M.I.C.E.<sup>(1)</sup>—makes interesting reading. The puddle core was made unusually thick for, as Mr. Jackson states, he considered "it would be difficult to secure good and honest work in the Colony, and he feels certain that he will be acquitted of having acted injudiciously in this respect, especially when the frightful consequences that would attend the failure of such a reservoir are taken into account".

The specification was based on that of Mr. James Leslie, M.I.C.E., of Edinburgh, and appears to set out very sound practice.

For example, the foundations were to be "stripped of all loose earth, mould or vegetable matter so that the embankment may come into close contact with, and rest upon, rock, clay or other solid material, and the surface is to be always newly scraped and picked as the embankment is brought up".

The bank was to be formed in regular layers, not exceeding 6 inches in thickness and sloping down to the centre from the sides at an inclination of 1 in 12. The most clayey and earthy part of the "stuff" was to be used in the heart of the embankment, more especially for the inner side. Every layer was to be pressed or trodden down, solid, by having the carts or barrows carrying the stuff to pass over it without using rails or planks, and if necessary to ensure solidity there was also either to be a heavy roller passed sufficiently often over each layer, or it was to be well

pounded by beaters. In dry weather the stuff was to be moistened by having water poured over each layer.

The puddle clay core was similarly described in detail. With little quantitative additions such as number of passes, moisture content, etc., the specification could well be adapted to present-day methods.

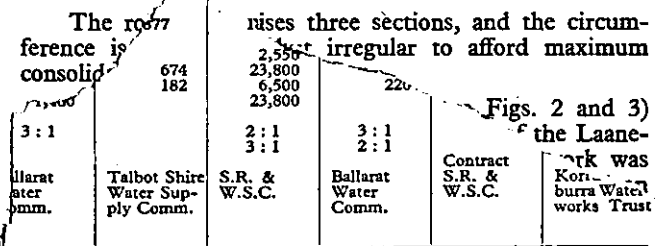
With the discovery of gold in Victoria at this same period, Ballarat and other mining towns flourished and not unnaturally the next earth dams recorded were constructed for the Ballarat goldfield Water Supply<sup>(2)</sup>.

These comprised Kirk's (1862), Beale's (1863), Pincotts (1867) and Gong Gong (1877). These were conventional earth banks with puddle clay cores of height from 16 ft. to 82 ft. For the smaller structures the upstream slope was 2½ to 1, and 2 to 1 downstream. For the larger Gong Gong Reservoir the upstream slope was 3 to 1. This had also been used in Malmsbury dam,<sup>(20)</sup> built in a similar manner 1866-70 to control the Coliban River for the water supply of Bendigo.

The Upper Stoney Creek Dam (1867) built for the Geelong Water Supply was 84 ft. high and was regarded as one of the high embankments of the world, being mentioned by Wegmann in his classical work on dams. It is recorded that the bank had settled 4½ feet by 1871 and that a subsidence occurred in 1872, after which the embankment and spillway were lowered 8 and 27 ft., respectively, and the upstream face flattened to 4 to 1. Subsequently the spillway was raised 12 ft. in 1882 to an intermediate level.

An interesting sidelight on the means of consolidation used on one of the earlier dams—probably Pincotts—was the discovery of a stone roller at the Prospect Dam (Sydney).

This dam was constructed in 1888 and old records reveal that the stone roller was drawn by a team of at least 10 horses driven by a Mr. George Pincott and his brother Tom. It was also ascertained that the roller originated at Ballarat where it was earlier used on dam construction—this is confirmed by the type of stone in its construction, which is similar to the Ballarat stone.



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Another method of consolidation used was to drive flocks of sheep across the fresh fill—surely the original “sheepsfoot” rollers! All the reservoirs so far described followed the pattern of the time—homogeneous earth fill with puddle clay cores.

However, in Ballarat's Gong Gong Reservoir (1877) the importance of downstream drainage was apparently realized for the downstream zone of the fill comprised alternate 6-in. layers of crushed granite rock and granitic soil.

Wilson's Dam, Ballarat (1891) again showed that the importance of stony high shear value fill was being realized, as clayey material was provided each side of the puddle core with stony material in both the upstream and downstream outer zones.

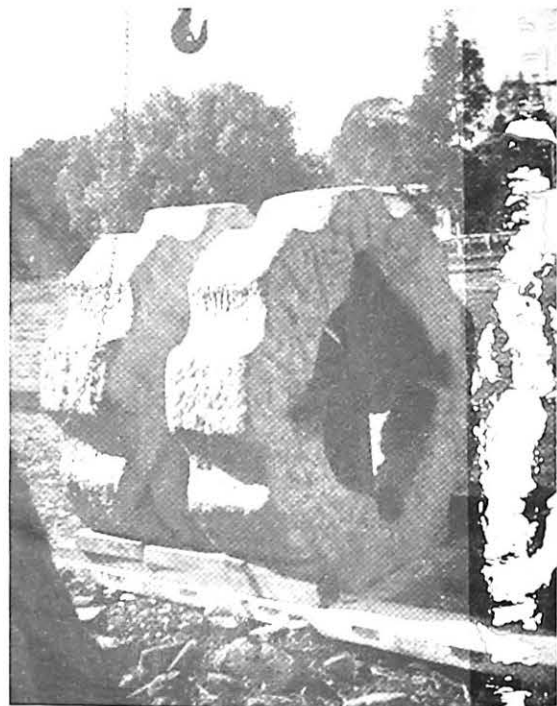
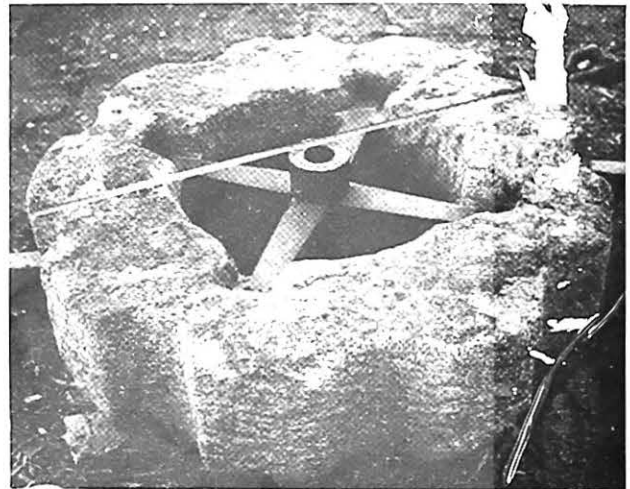
An unusual form of construction was used at Wartook Dam<sup>(30)</sup> in the Grampian Mountains (1882-7). This low embankment was constructed of fine sand with an upstream slope of 2 to 1 and a downstream slope of 3 to 1, the unusual slopes being used to flatten the hydraulic grade line through the structure. A puddle clay blanket was subsequently placed beneath the beaching, but the embankment has continued to leak a small fraction of a cusec.

- During the early stages of construction two American wheel scoops—“lever” and “windmill” types—were imported and tested, with the result that four of the “lever” type were recommended for use in construction. This was probably the first use of the well-known “monkey-tail” scoop which was to become so common on earth constructions in the early twentieth century.

Laanecoore Dam on the Loddon River (1888-91) conformed to the usual puddle clay core wall type but was breached by flood overtopping in August, 1909. After reinstatement with increased spillway provision it has served satisfactorily, and in 1935 the embankment was raised a further 3 ft. to provide additional flood protection. The original contract for construction provided some interesting legal arguments regarding extra costs, which resulted in the contractor preparing a petition to parliament in an appeal against the arbitration decision of the Chief Engineer, an appeal to a court not being possible under the contract.



Other dams with puddle clay cores supported on both sides with earth fill were constructed to serve the great Wimmera-Mallee area. These included Lake Lonsdale (1902) which was raised 18 inches in 1931 by which time it appeared to have settled at least 15 inches, Fyans Lake (1915), Taylors Lake (1917), Pine Lake (1921), Dock Lake (1932), and Green Lake (1932). The general procedure in this puddle clay construction was to strip the borrow area, plough the clay, flood with water and then load the clay by hand into back-tipping 1-cu. yd. horse-drawn drays. The pug was dumped on the bank and worked and compacted by horses ridden by boys. Delivery horses were preferred to draught horses on account of their higher foot loading intensity.



Figs. 2 and 3.—Roller made from Maldon Granodiorite. The original roller had four rings and was probably drawn by eight horses. Reported to be used on road work and Laanecoore Dam 1880-1890.

The Waranga Basin embankment was described<sup>(4)</sup> as one of the largest projects of its kind in the world as completed in 1907. It had a length of 22,539 ft. (4.27 miles) which was greater than the total of all other dams built in the State to that date. Its height was 29 ft. but this was increased to 40 ft. in 1915-26.

The original embankment had a central puddle clay core wall and was constructed as described in the Appendix. The enlargement was executed by uncovering the puddle clay and continuing it horizontally a distance of 19.5 ft. with a thickness of 4 ft. and then vertically again, at the same time widening the embankment to support the core. Difficulty was encountered with erosion of the beaching (1906) and with piping—several holes up to 5-in.

diameter (1921)<sup>(4)</sup>. The former was corrected by placing and grouting heavier stones and it is interesting to note that the freeboard assessment not only considered the water level rise that would result from flood rains, wave height and wave run up but also "heaping" due to wind. A recommendation was made that water level indicators be installed at the embankment and the opposite end of the fetch to observe heaping and wave action, unfortunately this suggested research did not come to fruition and such studies had to wait many years to receive the attention they deserved.

The piping troubles could not be accounted for by any theory of defective workmanship or supervision, or careless or improper procedure, nor could it be attributed to any

SCHEDULE OF VICTORIAN EARTH DAMS

CONSTRUCTED 1857-1870

Details	Units used	Yan Yean	Kirks	Beales	Pincotts	Spring Gully	Upper Stony	Barkers Creek	Malmsbury
Stream Name		Whittlesea	Yarrowee Ck. Ballarat	Ballarat	Ballarat	Spring Ck. Bendigo	Stony Ck. Geelong	Barkers Ck. Castlemaine	Coliban R. Kyneton
Area of Watershed	sq. miles	43					5.4		112
Type of Dam		Earth bank, puddle wall	Earth bank, puddle wall	Earth bank, puddle wall	Earth bank, puddle wall	Earth bank	Earth bank, clay core	Earth bank	Earth bank, clay core
Full Supply Level	ft.	604	1,675	1,916	1,814		1,175		1,477
Maximum Height above Lowest Foundation	ft.					79	95	43	80
Maximum Height above Ground Level or River Bed	ft.	30	42	21	24	71	82	42	61
Length of Dam at Crest	ft.	3,234	876	1,379	538	1,680	1,325	2,240	2,098
Maximum Width of Base of Dam	ft.	170	16	10	10		460		201
Width of Top of Dam	ft.	20					15		7
Volume of Material in Dam	cu. yd.	269,000							
Commenced (Original and Extension)		1853					1866		1866, 1939
Completed (Original and Extension)		1857	1862, 1867	1863	1867	1868, 1929	1868	1869	1870, 1940
Cost	£	337,047					75,670		198,000
Lake Area at Full Supply Level	acres	1,360	17	63	25		132		760
Total Storage Capacity	ac. ft.	27,000	320	330	166	2,007	2,770	2,180	14,400
Useful Storage above Outlets	mill. gal.	7,230	87	90	45	560	754	590	3,920
Embankment Slopes:	ac. ft.	24,600					2,770		14,400
Upstream		3 : 1	2½ : 1	2½ : 1	2½ : 1		4 : 1		
Downstream		2 : 1	1½ : 1	2½ : 1	2 : 1		2 : 1		
Contract Authority		Contract M.M.B.W.	Ballarat Water Comm.	Ballarat Water Comm.	Ballarat Water Comm.	S.R. & W.S.C.	Geelong Waterworks & Sewerage Trust	S.R. & W.S.C.	S.R. & W.S.C.
Reference to Description of Works									

CONSTRUCTED 1871-1899

Details	Units used	Newlyn	Crusoe	Gong Gong	Talbot	Wartook	Wilson's	Laanecoorie	Korrum-burra
Stream Name		Bullarook Ck. Daylesford	Bendigo	Fellmongers Ck. Ballarat	Mary-borough	McKenzie R. Stawell	Ballarat	Loddon R.	Coalition Ck.
Area of Watershed	sq. miles			9.8		29	9.8	1,590	
Type of Dam		Earth bank	Earth bank	Earth bank, clay core	Earth bank	Sand fill, clay and stone beaching	Earth bank, puddle wall	Earth bank, masonry spillway	Earth bank, concrete core
Full Supply Level	ft.			1,689		1,451	1,996	527	
Maximum Height above Lowest Foundation	ft.	38	39	98	49	36		71	50
Maximum Height above Ground Level or River Bed	ft.	36		78	47	36	32	55	42
Length of Dam at Crest	ft.	2,240	2,046	913	591	4,646	1,135	1,308	682
Maximum Width of Dam at Base	ft.			418		197		200	
Width of Top of Dam	ft.			16		12		10	
Volume of Material in Dam	cu. yd.			220,000					
Commenced (Original and Extension)				1874		1883		1889	
Completed (Original and Extension)		1871, 1961	1873	1877	1877	1887	1891	1891, 1935	1895, 1924
Cost	£			92,000				155,000	
Lake Area at Full Supply Level	acres			72		2,556	90	1,186	
Total Storage Capacity	ac. ft.	2,700	1,240	1,520	674	23,800	815	6,300	110
Useful Storage above Outlets	mill. gal.	730	336	410	182	6,500	220	1,720	30
Embankment Slopes:	ac. ft.			1,480		23,800		6,300	
Upstream				3 : 1		2 : 1	3 : 1		3 : 1
Downstream						3 : 1	2 : 1		2 : 1, 1½ : 1
Contract Authority		S.R. & W.S.C.	S.R. & W.S.C.	Ballarat Water Comm.	Talbot Shire Water Supply Comm.	S.R. & W.S.C.	Ballarat Water Comm.	Contract S.R. & W.S.C.	Korrum-burra Waterworks Trust
Reference to Description of Works									

## CONSTRUCTED 1900-1919

Details	Units used	Upper Coliban	Korweinguborra	Wetanga	Lance Creek	Pykes Creek	Moorabool	Melton	Beaconsfield
Stream		Coliban R.	E. Moorabool R.		Lance Ck.	Pykes & Myers Cks.	W. Moorabool R.	Werribee R.	
Nearest Town		Kyneton	Ballarat	Rushworth	Wonthaggi	Ballarat	Ballarat	Werribee	Melbourne
Area of Watershed	sq. miles	74				50	11.7	430	
Type of Dam		Earth bank, clay core, concrete cut-off	Earth bank, puddle core, concrete cut-off	Earth bank, clay core	Earth bank	Earth bank, clay core, part concrete cut-off	Earth bank, clay & R.C. core	Rockfill, clay & concrete core	Earth bank
Full Supply Level	ft.	1,652		398		1,306	1,985	273	340
Maximum Height above Lowest Foundation	ft.	93	40	40	57	128	58	116	80
Maximum Height above Ground Level or River Bed	ft.	84	40	40	57	111	50	88	72
Length of Dam at Crest	ft.	1,334	2,044	22,970	630	1,452	2,440	939	553
Maximum Width of Dam at Base	ft.	460		210		493	267	447	
Width of Top of Dam	ft.	15		10		28	8	10	
Volume of Material in Dam	cu. yd.	238,000						216,000	
Commenced (Original and Extension)		1900, 1915, 1924				1908, 1928	1914	1913, 1937	
Completed (Original and Extension)		1903, 1917, 1925	1910	1910, 1926	1911	1911, 1930	1915	1916, 1938	1918
Cost	£	114,000		963,650		143,000	30,920	100,000	
Lake Area at Full Supply Level	acres	830		14,450		501	392	628	
Total Storage Capacity	ac. ft.	25,700	1,700	333,400	1,550	19,400	5,430	15,500	732
Useful Storage above Outlets	mill. gal.	7,000	460	90,600	420	5,280	1,478	4,220	197
Embarkment Slopes:	ac. ft.	25,700		333,400		19,400	5,430	15,500	
Upstream		2 : 1		2 : 1		2 : 1, 3 : 1	2½ : 1, 3 : 1	2 : 1	2 : 1
Downstream		2 : 1, berm		2 : 1, berm		1.8 : 1	2 : 1	2 : 1	2 : 1
Contract or Day Labour		Contract S.R. & W.S.C.		Day Labour S.R. & W.S.C.	S.R. & W.S.C.	Contract S.R. & W.S.C.	Ballarat Water Comm.	Contract S.R. & W.S.C.	S.R. & W.S.C.
Construction Authority		Trans. Vic. Inst. Surveyors, 1919, S. Murray.	Geelong Waterworks & Sewerage Trust						
Reference to Description of Works									

## CONSTRUCTED 1920-1933

Details	Units used	Frankston	Eildon (Original)	Korrumburra	Leongatha	O'Shannassy	Pine Lake	Tylden	Silvan
Stream		Sweatwater Ck.	Goulburn R.	Ness Gully	Ruby Ck.	O'Shannassy R.		Little Coliban R.	Stoneyford Ck.
Nearest Town		Frankston	Alexandra	Korrumburra	Leongatha	Warburton	Horsham	Kyneton	Melbourne
Area of Watershed	sq. miles		1,500			47			3.5
Type of Dam		Earth bank	Rockfill, clay and concrete core wall	Earth bank, concrete core puddle u/s core	Earth bank	Rockfill & earth, R.C. & clay core	Earth bank	Earth bank	Earth bank, R.C. core
Full Supply Level	ft.		823			1,211	475		810
Maximum Height above Lowest Foundation	ft.	63	157	37	44		31	47	
Maximum Height above Ground Level or River Bed	ft.	63		36	38	113	30	44	142
Length of Dam at Crest	ft.	880	3,259	322	240	740	11,022	591	2,114
Maximum Width of Dam at Base	ft.		575			673			720
Width of Top of Dam	ft.		15			20			20
Volume of Filling in Dam	cu. yd.		2,000,000			307,300			1,679,000
Commenced (Original and Extension)			1915, 1929			1923			1927
Completed (Original and Extension)		1920	1927, 1935	1928	1928	1928	1928	1930	1932
Cost	£		1,895,000			318,314			803,786
Lake Area at Full Supply Level	acres		8,000			74			822
Total Storage Capacity	ac. ft.	560	306,000	85	110	3,440	52,000	674	32,520
Useful Storage above Outlets	mill. gal.	151	83,300	23	30	930	14,000	182	8,850
Embarkment Slopes:	ac. ft.		306,000			3,440	32,300		32,440
Upstream			1.45 : 1		2½ : 1				
Downstream			1.6 : 1		2 : 1, berm				
Contract or Day Labour		S.R. & W.S.C.	Day Labour S.R. & W.S.C.	Korrumburra Waterworks Trust	Leongatha Waterworks Trust	Day Labour M.M.B.W.	S.R. & W.S.C.	Kyneton Waterworks Trust	Day Labour M.M.B.W.
Construction Authority			Jour. I.C.E. Mar. 1938 R.G. Knight						Trans. I.E. Aust. 1930 E. Ritchie
Reference to Description of Works									

cracks or fissures, but there were strong grounds for the presumption that the leaks had most probably been caused by burrowing creatures—at least in their initial stages. There was no evidence brought forward to negative such a conclusion and the Board was unable to point to any other cause.

Yabbies (*parachaerape bicarinatus*) or water rats were suspected but it is doubted that the failure could have been caused in this way. A concrete core wall was constructed near the downstream toe and raised to a level about seven

feet below top water level. This was backed up by additional earth fill and reduced the hydraulic gradient through the bank as well as giving protection against burrowing creatures. Scoops loading drays and side-tipping rail trucks through a "chinaman" were used in this work.

That these dams composed of earth and clay were well constructed is shown by the fact that in very few cases are there records of failure by shear (slip-circle) although several have been washed out by being overtopped through inadequate spillway provision.

CONCRETE CORE WALL ERA

About the turn of the century the use of concrete gained favour, and in the Korumburra No. 1 (1895), Upper Coliban Dam (1903), Korweinguboora (1909), Moorabool

Dam (1915), Ness' Gully Dam (1928), Ruby Creek (1928), Bellview Creek (1956) and Ruby Creek 3 (under construction), we find the clay core reinforced by a central concrete core wall extending into the foundations and through the

SCHEDULE OF VICTORIAN EARTH DAMS (Contd.)

CONSTRUCTED 1934-1954

Details	Units used	Lysterfield	Hume	Tank Hill	Yarrowonga Weir	Ryans Ck.	Romsey	White Swan	Bostock
Stream		Eumemmering Ck. Melbourne	Murray R. Albury	Warrnambool	Murray R. Yarrowonga	Ryans Ck. Benalla	Bolinda Ck. Romsey	Gong Gong Ck. Ballarat	E. Moorabool R. Ballarat
Nearest Town									
Area of Watershed	sq. miles		6,000					4.3	
Type of Dam		Earth bank	Earth bank, R.C. core	Earth bank	Earth bank, clay core	Earth bank	Earth bank	Earth & rockfill, conc. cut-off	Earth & rockfill, conc. cut-off
Full Supply Level	ft.	221	636		412				
Maximum Height above Lowest Foundation	ft.	46	204	62	39	70	37	135 (Main bank)	88 (Main bank)
Maximum Height above Ground Level or River Bed	ft.	41	142	40		53	34	126	80
Length of Dam at Crest	ft.	1,400	5,300	720	1,125	534	475	1,570	880
Maximum Width of Base of Dam	ft.		762		197			680	
Width of Top of Dam	ft.		32		26			20	
Volume of Material in Dam	cu. yd.		4,919,000		164,000			1,149,000	155,000
Commenced (Original and Extension)			1917		1934			1947	
Completed (Original and Extension)		1934	1936, 1961	1938	1939	1940	1949	1951	1954
Cost	£		5,658,000					1,250,000	312,000
Lake Area at Full Supply Level	acres		54,100		11,200			310	
Total Storage Capacity	ac. ft.	3,400	2,500,000	550	95,100	522	100	12,000	5,500
Useful Storage above Outlets	mill. gal.	920	675,000	149	25,900	140	27	3,274	1,500
Embankment Slopes:									
Upstream		2:1	2:1, 3:1					2:1, 4:1	2:1, 1:1, berm
Downstream		2:1	2.07:1, 2:1					2:1, 2½:1	2:1, 1:1, berm
Contract or Day Labour		S.R. & W.S.C.	Day Labour S.R. & W.S.C., P.W.D. (N.S.W.)	S.R. & W.S.C.	Day Labour S.R. & W.S.C.	Benalla Waterworks Trust	Romsey Waterworks Trust	Day Labour Ballarat Water Comm.	Contract Geelong Waterworks & Sewerage Trust
Construction Authority									
Reference to Description of Works			Short history of the R. Murray Wks. J. Eaton		Comm. Engineer. Jan. 1938 E. D. Shaw				

CONSTRUCTED 1955-1962

Details	Units used	Eildon	Cairn Curran	Korumburra	Upper Yarra	Rocky Valley	Tullaroop	Castlemaine	Moondarra
Stream		Goulburn R.	Loddon R.	Bellview Ck.	Yarra R.	East Kiewa R. Bright	Tullaroop Ck. Maryborough	Green Ck.	Tyers R.
Nearest Town		Alexandra	Maryborough	Korumburra	Warburton			Castlemaine	Moe
Area of Watershed	sq. miles	1,500	600		120		287		106
Type of Dam		Earth and rockfill	Earth and rockfill	Earth fill conc. cut-off	Earth and rockfill	Earth and rockfill	Earth and rockfill	Earth and rockfill	Earth and rockfill, sloping core
Full Supply Level	ft.	950	684.5		1,220	5,338	733	1,340	546
Maximum Height above Lowest Foundation	ft.	260	144	54			135	97	
Maximum Height above Ground Level or River Bed	ft.	259	104	53	293	100	96	82	135
Length of Dam at Crest	ft.	3,225	2,151	340	2,000	1,750	1,560	1,100	1,020
Maximum Width of Dam at Base	ft.	1,050	580		1,600		520		
Width of Top of Dam	ft.	30	20		30		35		
Volume of Material in Dam	cu. yd.	13,613,000	1,060,000		7,430,000	600,000	1,030,000	222,000	650,000
Commenced (Original and Extension)		1951	1947		1947	1950	1958		
Completed (Original and Extension)		1955	1956	1956	1957	1959	1959	1960	1962
Cost	£	28,500,000	3,618,000		14,100,000				
Lake Area at Full Supply Level	acres	34,200	4,740		1,837		1,785		
Total Storage Capacity	ac. ft.	2,748,400	120,600	330	167,000	23,000	59,700	1,100	25,000
Useful Storage above Outlets	mill. gal.	748,000	32,800	90	45,400	6,250	16,200	300	6,800
Embankment Slopes:									
Upstream		2.5:1	2.75:1	3:1, 6:1	3:1, 2½:1, 2:1	2:1, 3.5:1	2:1, 2.36:1, 2.5:1, berm	3:1, 2:1, 1.5:1	2:1
Downstream		1.9:1, berm	2.5:1, 2:1	2½:1, 3:1, berm	3:1, 2½:1, 2:1	2:1	2:1, 2.42:1, 2.92:1, 3:1, berm	2:1, 1.5:1, 3:1	1.4:1
Contract or Day Labour		Contract	Contract & Day Labour S.R. & W.S.C.	Korumburra Waterworks Trust	Day Labour	Day Labour	Day Labour	Day Labour	Contract
Construction Authority		S.R. & W.S.C.			M.M.B.W.	S.E.C.	S.R. & W.S.C.	S.R. & W.S.C.	Latrobe Valley Water & Sewerage Board
Reference to Description of Works		Jour. I.E. Aust. Mar. 1953 R.G. Knight & E.D. Shaw	Comm. Eng. July 1950		Proc. I.E. Aust. Conference 1953 H. Caine	Jour. I.E. Aust. Sept. 1961 A. Rufenschacht			

EARTH DAMS IN VICTORIA—Lee & Speidie.  
 SCHEDULE OF VICTORIAN EARTH DAMS (Contd.)  
 CONSTRUCTED 1963-

Details	Units used	Eppalock	West Barwon					
Stream		Campaspe R.	W. Barwon R.					
Nearest Town		Bendigo	Forrest					
Area of Watershed	sq. miles							
Type of Dam		Earth and rockfill	Earth and rockfill, sloping core					
Full Supply Level	ft.	637.0						
Maximum Height above Lowest Foundation	ft.	149	145					
Maximum Height above Ground Level or River Bed	ft.	139	108					
Length of Dam at Crest	ft.	3,500	1,000					
Maximum Width of Dam at Base	ft.							
Width of Top of Dam	ft.							
Volume of Material in Dam Commenced (Original and Extension)	cu. yd.	1,018,000	910,000					
Completed (Original and Extension)		1963	Incomplete					
Cost	£							
Lake Area at Full Supply Level	ac. ft.	250,000	18,000					
Total Storage Capacity	mill. gal.	68,000	4,900					
Useful Storage above Outlets	ac. ft.							
Embankment Slopes :								
Upstream		1.3 : 1, 1.8 : 1	1.75 : 1, 2.5 : 1					
Downstream		1.3 : 1, berm	1.3 : 1 1.4 : 1					
Contract or Day Labour		Day Labour	Contract					
Construction Authority		S.R. & W.S.C.	Geelong Waterworks & Sewerage Trust					
Reference to Description of Works								

full or lower section of the embankment. At Coliban it extended for a height of 25 ft. (height of dam now 93 ft.) while in Moorabool the core extended for 41 ft. of the 51 ft. total height.

Pykes Creek (1911) also has a clay puddle core, with a concrete key wall built into the foundations. It was raised 10 ft. in 1927-30.

A new form of construction was adopted for Melton Dam (1916) where a central concrete core wall extending the full height of the embankment (98 ft.) had a narrow clay zone immediately upstream of it with rock fill forming the remainder of the bank<sup>(5)</sup>. The outer embankment slopes were 2 to 1, on both sides. The same type of design was adopted for the original Eildon Dam (1915-35) except that the rock fill had average upstream and downstream slopes of 1.45 and 1.6 to 1, respectively, and was founded on clay instead of rock. An extensive subsidence<sup>(6)</sup> of the upstream portion of the Eildon embankment occurred in 1929 following filling and draw-down and was at first thought<sup>(7)</sup> to result from pressure from the clay zone but was subsequently shown<sup>(8)</sup> to have been caused by the foundation clay. The core wall deflected a maximum of nearly 10 feet.

Hume Dam (1919-36) had a clay embankment with a full height concrete core wall from rock and concrete slab protection against waves on the upstream face. A subsidence in the lower half of the upstream slope extending over nearly 1500 lineal feet of embankment occurred in 1939 and was stabilized by adding a rock-fill zone to the upstream face. The dam was subsequently raised (1960).

In the original construction of Hume Dam the clay was loaded by 1½-2½-cu. yd. steam shovels into side-tipping rail trucks and hauled to the embankment by locos. Three-horse wheel scoops were used for subsequent transport and spreading and this traffic provided the compaction. 2½-cu. yd. rock shovels, back-tip motor trucks and bottom-dump barges were used for the upstream addition of rock fill.

The lack of adequate consolidation has resulted in subsequent settlement and was a big factor contributing to the subsidence referred to above. Consolidation of the filling is causing pressure between the concrete slabs.

#### EARLY SOIL MECHANICS

O'Shannassy (1919-1927) showed a further development in design, the full height concrete core wall being flanked by a puddle clay core upstream and a crushed stone zone against the downstream face of the core wall with discharge drains out through the downstream toe. In this dam also a large rock zone was placed at the downstream toe.

It was on this project that the Resident Engineer—the late A. E. Kelso—initiated crude soil tests that are now recognized<sup>(10)</sup> as the forerunner of modern Soil Mechanics—preceding even those of Proctor in California.

Although quantitative results were not recorded, a careful moisture control was maintained, consolidation being by the steel rims of wheel scoops, together with the horses' feet. The soil, a red clay from decomposed dacite, was an excellent fill material. Some 35 years after construction a shaft was sunk through the downstream embankment and *in situ* tests averaged 94% of maximum density. Moisture averaged 2 to 5% above optimum which would be close to the figure at time of placing. The optimum for the material is quite high—about 35%.

Silvan (1927-1931),<sup>(24)</sup> rolled earth fill 142 ft. high, was one of the first fully mechanized constructions. Steam excavators, locomotives and truck and tractor-drawn scoops placed the fill in 6-in. layers. Steam rollers with grooved wheels consolidated the fill and the soil tests started at O'Shannassy were further advanced on this project<sup>(11)</sup>.

These tests established the principle of optimum moisture for maximum density and regular field tests were carried out to confirm that this maximum density was being obtained.

Another interesting test carried out on this project was that relating to percolation. A miniature dam was constructed of the material under test in a small gully and the storage filled with water. A line of vertical auger holes was drilled across the bank and regular observations taken of the hydraulic grade line through the material. Some material in a section of the borrow pits was rejected on the result of these tests.

Other features of Silvan were:—no puddle clay core and no downstream drainage, this being incorporated in a cellular core wall which intercepted any leakage from upstream.

The Depression years, followed by the Second World War put an end to dam construction for some years, and the White Swan Reservoir in Ballarat was one of the first completed earth dams after the War. Soil Mechanics had shown a great advance during the war years, on air-field and road construction work and at White Swan latest soil control methods were fully utilised. This dam, 135 ft. high, comprised a large central impervious zone composed of rolled decomposed Ordovician sediments, flanked by rock-fill zones. It is of interest that the rock fill—to the extent of nearly 400,000 cu. yd.—was transported from old mining dumps in Ballarat and district. Compaction of the rolled fill was by sheepsfoot rollers.

#### ROCK-FILL ERA

The construction of high dams necessitated the use of the earth rock-fill type and two world-class dams with low concrete cutoffs, impervious cores, filter and rock-fill zones, were erected at Eildon<sup>(8, 9)</sup>—260 ft. high (1955), and Upper Yarra—293 ft. (1957)<sup>(18, 23, 26)</sup>. Each at the time of completion was the highest in Australia but have both been exceeded by Eucumbene Dam in the Snowy Mountains Area. Both were fully mechanized with full earth placing control and some development of new design and control practices. The former was constructed by contract and the latter by day-labour. An interesting feature of the consolidation of Upper Yarra Dam was the use of grooved rollers, which had been developed on the Silvan Dam (1927-1932).

In lieu of the more common method of up to 12 passes of the sheepsfoot roller, at Upper Yarra about half this number of sheepsfoot passes were made followed by 4 or more passes of the grooved roller. The chief advantages claimed for this method were:

- (a) A greater depth of loose material could be uniformly consolidated throughout the depth of layer, and
- (b) The surface, finished with grooved roller, would shed water, instead of absorbing water in the case of the loose sheepsfoot finish. In the high rainfall locality this permitted work to proceed shortly after rain had ceased.

Other dams of this type have followed, viz. Bostock (1955), Cairn Curran (1956), Tullaroop (1959), Rocky Valley (1959)<sup>(12)</sup> on the Bogong High Plains, Castlemaine (1950), and Eppalock (1963). Cairn Curran utilized locally available river gravels instead of rock fill and the others, except Rocky Valley, relatively weak Silurian and Ordovician shales and sand stones subject to breakdown by weathering or exposure. The weathering action occurs only near the outside of the filling and does not extend more than 30 inches from the surface.

Dams composed mainly of rock fill have been built on account of a shortage of earth and/or the comparatively low present-day cost of rock fill. Modern quarrying methods make it almost as cheap as earth per cubic yard and when

its higher shear value and stability are considered it is the least costly dam building material available today.

The first "Nantahala" or thin sloping earth membrane dam in the State was Moondara (1962) which is 1020 ft. long and 135 ft. high. It is the first dam in the State where large-scale sluicing of rock fill was adopted and is notable for the portable sluicing rigs devised. It has been followed by a slightly higher (145 ft.) dam of the same type—West Barwon—at present under construction.

#### INVESTIGATION DEVELOPMENT

The investigation of dam sites has been developed considerably in the past twenty-four years<sup>(28)</sup>. Previously, hand boring, diamond drilling and shaft sinking, with power boring in some instances, were used, and material tests consisted of examination of hand samples and the carrying out of indicative non-quantitative tests. In connection with Hume Dam 5-in. dia. undisturbed sampling from bore holes up to nearly 80 ft. deep was undertaken in 1939, and shear, permeability, Atterberg, mechanical analysis and qualitative classification tests carried out. At Upper Yarra Dam 6-inch dia. direct double shear tests were made in 1941 but were discontinued in favour of 4-inch dia. triaxial testing in 1943<sup>(13)</sup>. Four-inch dia. direct shear tests were made on the Kiewa Project in 1941, and similar but further developed machines have been used with improved testing technique and interpretation<sup>(14, 15)</sup> for the testing of materials in connection with the extensive dam building programme of the State Rivers and Water Supply Commission and other bodies since 1944.

Pore pressure measurements were first attempted at Hume Dam where two types of equipment were installed in 1941<sup>(18)</sup> and improved equipment and methods in the old Eildon Dam (1944)<sup>(17)</sup>. Settlement and pore pressure measurements have since been taken in White Swan, Upper Yarra, new Eildon and other dams with worthwhile results<sup>(18, 19, 25)</sup>.

Weathering tests on rock were carried out in connection with the new Eildon, Upper Yarra and other dam projects and examination of the behaviour of rock in the old Eildon dam provided valuable information for the subsequent programme.

Geophysical studies were made at the Cobbleicks Ford dam site with disappointing results in 1940. Recently, further work of this nature has proved helpful on current projects.

A notable advance in the past twenty years has resulted from the increased use of geologists in both dam-site investigations and the recording of geological information exposed during construction.

#### DESIGN DEVELOPMENT

Design practice prior to the Second World War lacked quantitative calculations for stability but these and flow net plotting to determine pore pressure distribution were made in 1939 for Hume dam and all subsequent projects. In general, slip circle stability calculations are preferred although wedge theory has been used<sup>(18)</sup>, and several improvements have been developed in the procedures. However, stress distribution in foundations and embankments has sometimes been computed by established practices based on elastic theory<sup>(6)</sup>.

An arithmetical step-by-step method of computing the relief of pore pressure during draw-down was developed by the second mentioned author about 1945 and this was



followed by modified procedures for determining pore pressure and selecting shear values for design from a mass of test data<sup>(20, 27)</sup>. The latter is a subject that, surprisingly, had been neglected in the technical press.

Quite recently a computer programme was prepared for stability calculations by slip circles, the programme taking into account all factors including pore pressures and providing for repetition of calculations on other circles until the critical circle is located and the results analysed.

The first use of American moisture control practices developed by Proctor and the Bureau of Reclamation on Australian Dam construction was in a small 20-ft. high supplementary embankment associated with the Lauriston mass concrete dam in 1941<sup>(21)</sup>. Trial embankments were constructed at Upper Yarra, Cairn Curran and Eildon Dams and control procedures developed. The novel and useful drop test, suggested by J. MacN. Turnbull<sup>(22)</sup>, has been used on most recent projects.

Undisturbed samples are normally cut from materials compacted in embankments to determine by test the properties of the dam materials for comparison with the design assumptions. Pressures exerted on, and resulting strains in the reinforced concrete outlet culvert of Tullaroop Dam, are regularly measured to provide much needed design data for similar future projects.

The latest research developments are in self spillway rock-fill dams which have been under investigation in Tasmania, by the University of Melbourne and the State Rivers and Water Supply Commission, and as a result substantial cost savings have already been achieved in connection with flood diversion costs during dam constructions in Papua and Queensland.

#### CONCLUSION

It is interesting to note a very distinct pattern of change of practice extending over a little more than a century of earth dam construction in the State of Victoria. In this the following steps are readily recognised.—

1. Earth-fill embankments with a central puddle clay core.
2. As for (1) but with stony material added to the outer zones.
3. The addition of a low concrete cutoff wall within the lower levels of the puddle clay.
4. Development of the concrete cutoff into a core wall extending throughout the whole or a major part of the embankment height, with or without a puddle clay or other special clay zone.
5. Following its era of popularity the concrete core wall was again reduced to a low cutoff. Concurrently earth-rock-fill construction was used for high dams. These accompanied the introduction of soil mechanics principles in design and construction and the mechanization of field operations.
6. Concrete cutoff walls are now showing a tendency to disappear and rock-fill construction with a thin impervious membrane is developing.

Following the application of moisture control to earth dam construction in Victoria and the development overseas of the principles of soil mechanics in the late twenties and thirties of this century, these principles were applied in Victoria to dam site investigations, design and construction, before the commencement of the Second World War.

Advantage was taken of the pause in dam construction during that war to further develop and apply these practices and, although the best American procedures were usually selected, local worthwhile modifications and developments were made.

Many advantages have resulted from the application of soil mechanics principles, these include :

- (a) the increase in the possible height of earthen dams from the previously generally accepted limit of 100 feet to several times this figure;
- (b) the elimination of the very costly concrete and puddle clay core walls;
- (c) an appreciation of the need for adequate density in earth fill and the provision of a means of controlling the density obtained;
- (d) moisture and density control have made it possible to use materials previously considered unsuitable and the thickness of the impervious zone can now be reduced; and
- (e) an appreciation of the advantages of the higher shear value of rock filling is leading to big economies as a result of the greater use of rock fill in designs.

The mechanization of construction has made practicable the construction of very large dams at acceptable costs.

#### ACKNOWLEDGMENTS

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#### APPENDIX

*Abstract from "Works at Waranga Storage Reservoir" by Stuart Murray.*

#### REPORT OF WARANGA RESERVOIR INQUIRY COMMITTEE, 1907.

"The excavation for the puddle trench, or core wall, ... was carried down to, and into, the rock of silurian, sandstones and shale, from about 35 to about 65 chains on the section. On each side of this portion the rock is no longer within reach, at warrantable depth; but is succeeded by a bed of compact stiff clay generally at no more than about 10 feet from the surface. The trench was carried down into this stratum, a further depth of not less than 2 feet, and succeeded by a bonding chase, 2 feet wide by 6 inches deep. The chase and trench were then filled, to the surface of the ground, with clean tough clay, of homogeneous texture, thoroughly rammed with narrow faced iron-shod rammers, so as to make it perfectly compact, and to fill all interstices. It was further consolidated by having heavy draught horses parade over the surface of each layer of clay.

"The bulk of the clay was obtained from the ground forming the bed of the reservoir; the unsuitable surface material being stripped and laid aside, and the excavation being discontinued, so soon as the ground began to assume the character of loam or to contain a sensible mixture of sand.

"From the surface of the ground the core wall was carried up with like material, deposited and consolidated in like manner; the surface of the clay wall being at all times slightly above that of the adjacent earthwork of the bank. The head of the clay wall as built is practically identical with the full supply level of water in the basin.

"In general, the clay, whether in that portion of the core wall below ground or in that above ground, was put into the work direct from the pit. It was sufficiently plastic to consolidate under the rammers, or under traffic, without wetting; but where clay had been in place so long as to become dry on the surface, it was scarified and wetted before the imposition of the next layer.

"The clay wall, above ground, was enclosed in a mass of specially selected material; of thickness equal to that of the clay, on each side thereof. This material was of clean clayey loam, of such texture as to bind freely under the pressure of traffic, and to form a compact mass but slightly permeable by moisture.

"Outside the selected material, the body of the embankment, both up and down stream, was built of clean free binding earth, in layers not exceeding 6 inches thick, uniformly intermixed with not less than 15 per cent. of gravel or rough sandstone, from the quarries near the work. The gritty material is intended to give the earth work of the embankment greater stability, by increasing its natural angle of repose. It is spread out uniformly between the layers of earth, and broken up so as to amalgamate with it. By the terms of the specification, the maximum dimension of stones is to be 1-10th of a cubic foot in the inner, and  $\frac{1}{4}$  in the outer portion of the bank respectively. As a matter of fact they are broken with hammers to a much smaller size. The layers of earth, both of the selected and of the general material, are worked with a slope inwards of about 1 in 12.

"Except in wet weather, the surface of the layers was kept moist, during the process of building, by sprinkling with water pumped through piping and distributed by means of a hose.

"The inspectors, supervising the building of the embankment, were provided with light handy trestles and planks; which they were enjoined to shift continually, as each portion of a layer was filled in; so that the whole of each layer might be equally subjected to the compressing influence of the traffic. A roller, as provided by the specification, was on the works, and was used occasionally; but as a rule the consolidation was solely the result of the traffic. The solidity of the mass was such that rolling made no perceptible impression on it."

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# Measurement of Earth Pressures on a Sheet Pile Breastwork

By C. F. MEAD, B.E., A.M.N.Z.I.E.\*

**Synopsis.**—During the construction of Freyberg Wharf, Auckland, a steel sheet pile breastwork was driven into sandstone and backfilled with scoria. Earth pressure cells were installed to measure the pressures against the sheet piling. This paper describes the installation of the cells and reports the results obtained.

## INTRODUCTION

During the construction of Freyberg Wharf, Auckland, a steel sheet pile breastwork was driven into sandstone and backfilled with scoria. This work was carried out by contract for the Auckland Harbour Board. Officers of the Soil Mechanics Section of the Department of Scientific and Industrial Research worked in co-operation with the Board's Engineers to install instruments to measure the load on the tie rods and the earth pressures against the wall. No useful information was obtained from the strain gauges on the tie rods due to infiltration of moisture, but the earth pressure cells behaved in a satisfactory manner and the results are reported herein.

A section of the sheet pile breastwork in the locality of the cells is shown in Fig. 2. The piling was driven to retain the filling at the approach to the wharf. The apron slab provides access from the reclaimed ground to the wharf deck.

The purpose of these investigations into soil pressures was primarily to determine whether the design assumptions of soil behaviour were reasonable. Sheet pile design calculations can produce a wide range of answers depending upon what design procedure is followed. Considerable information is available on the results of model measurements, but not a great many field test results have been published.

## PRESSURE CELLS

Ten Goldbeck Cells<sup>(1)</sup> obtained from the Soil Bureau, D.S.I.R., Wellington were used in this investigation. The cells were checked, calibrated and adjusted by officers of the Soil Mechanics Section, D.S.I.R., Auckland. The construction of the cells is shown in Fig. 1. A load piston is set in a substantial brass surround and carries the earth pressure on its face. Air pressure is introduced slowly to the underside of the piston until, with a movement of less

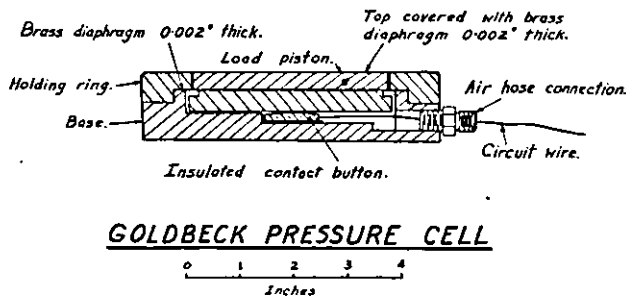


Fig. 1.

\*Auckland Harbour Board.

than one thousandth of one inch, an electrical contact is broken. It is assumed that this movement is not sufficient to mobilize any passive pressure and thus the applied air pressure is equal to the active earth pressure.

The cells were calibrated under hydrostatic loading obtained by placing them inside a pressure tank filled with water. After minor adjustments had been made a correction factor of unity was obtained in all cases.

Tests were then carried out with the cells enclosed in a latex rubber bag full of sand. Both wet and dry sand was used without significant variation in results. The rubber bag was subjected to hydrostatic pressure by placing it within the pressure tanks and, at the same time, a range of pressures could be applied to the water inside the bag (to simulate pore water pressure). The calibration factor for sand pressure was found to be practically independent of this direct water (i.e., pore) pressure. It was found important that the piston be in contact with the bottom when the sand was placed in the bag, otherwise low readings were obtained. It was also found that the air pressure introduced into the cell for obtaining the readings must not be increased beyond that required to break the contact, otherwise a further source of low reading errors was introduced. The ratio of cell air pressure required to sand pressure impressed varied between 1.25 and 1.45. By most careful and painstaking work in the laboratory, a confidence was built up that the cells would prove reliable under service conditions. Individual pressure measurements were repeatable within an overall variation of 15 per cent.

## PLACING OF CELLS

After the sheet pile wall had been driven and tie rods placed, the pressure cells were supported from the tie rods at varying depths 3 ft. from the inside face of the breastwork. The cells were set to measure the horizontal pressure and were free to move bodily sideways with any shifting of the fill material, but they were held firmly in a vertical direction. Fig. 2 shows the arrangement of the cells in the filling and

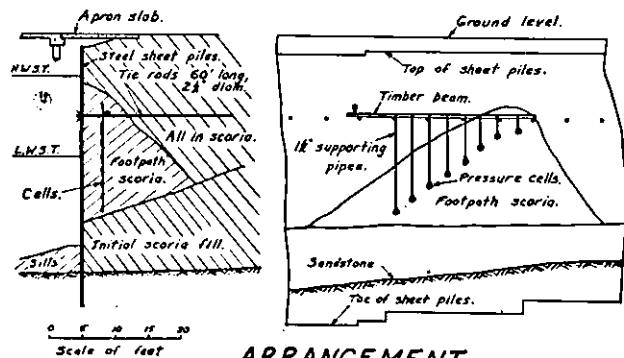


Fig. 2.