SILTATION OF AUSTRALIAN RESERVOIRS : SOME OBSERVATIONS AND DAM SAFETY IMPLICATIONS

H. CHANSON and D.P. JAMES

Department of Civil Engineering, The University of Queensland, Brisbane QLD 4072, Australia
Fax: (61 7) 33 65 45 99 - Email: h.chanson@mailbox.uq.edu.au

ABSTRACT

The Australian continent can experience extreme sedimentation rates which affect water supply systems. The study documents complete reservoir siltation events. Sedimentation problems were observed predominantly with small to medium size reservoirs (catchment area less than 100 km^2). The effects of reservoir siltation are analysed in terms of dam safety. In several cases, the sediment load associated with major flood events would create high loads on the dam wall, especially in the cases of thin concrete structures. For such situations, the tested concrete strength could be less than twice the load, and the safety of the dam becomes questionable.

Keywords: reservoir siltation, Australian reservoirs, extreme sedimentation, hydrology, dam safety

INTRODUCTION

Reservoir siltation affects the safety of old reservoirs in several ways. The reservoir sediment increases the load on the dam wall. The reduction of reservoir storage capacity reduces the attenuation of the flood and it may increase the outflow, hence the head above crest, for a given reservoir inflow. Often the original hydrological study of ancient reservoirs relied on a small sample of data, and the estimated inflow underestimated the 'real' probable maximum flood (PMF) of the catchment-reservoir system. Altogether the sediment weight and larger head above crest create higher pressures on the dam wall (fig. 1).

In this paper, the writers review extreme siltation cases of Australian reservoirs. Then they discuss the implications in terms of dam safety, with practical examples.

RESERVOIR SILTATION IN AUSTRALIA

Several Australian dams failed slowly because of reservoir siltation, although the authorities do no acknowledge it. The writers investigated reservoir siltation cases (e.g. CHANSON and JAMES 1998a,b). Between 1890 and 1960, numerous dams became fully-silted, mostly in New South Wales (Table 1, Fig. 2, 3, 4 and 5). De Burgh dam (Fig. 2) was disused in 1929 after the dismantlement of the railway line. It is the oldest reinforced concrete thin arch in Australia. Koorawatha dam (Fig. 3) was the second arch dam built at the same site. Both structures became fully-silted by bed-load material. The siltation of Cunningham Creek dam (Fig. 4) was well-documented by HELLSTRÖM (1941) (suspension sedimentation predominantly). Illalong Creek (Fig. 5) was completed two years after and it is located less than 30-km from Cunningham Creek.

Some reservoirs became fully-silted in less than 20 years, and their failure affected the local economy. The list (Table 1) includes town water supply reservoirs (e.g.

Moore Creek dam), railway dams (e.g. Gap weir) and mining reservoirs (e.g. Junction Reefs).

Comparison between Australian and overseas siltation rates

Table 2 summarises (well-documented) extreme siltation events in Australia. The analysis suggests that sedimentation rates in Australia were high. The siltation of Quipolly reservoir between 1941-1943 was an extraordinary event. The Korrumbyn Creek dam sedimentation was very rapid : i.e., less than 7 years ! The site selection was improper (CHANSON and JAMES 1998a). Overall sedimentation problems were experienced mostly with small to medium size reservoirs : i.e., catchment area less than 100 km^2 typically. In contrast large reservoirs have not been sedimenting rapidly at the exception of Melton, Eppalock and Eildon reservoirs, all in Victoria. Heavy siltation at Eildon was experienced in 1940 during torrential rainfalls, following bushfires which destroyed more than 50% of the catchment forest (JOSEPH 1953). At Eppalock, the catchment was affected by extensive gold mining, tree clearing and hydraulic mining during the period 1851-1890, and rabbit infestation was another problem (DAVIES 1996).

Since the 1950s, lower siltation rates have been experienced on the Australia continent. The decrease in reservoir sedimentation is related to the introduction of new farming techniques, new land conservation practices and an awareness of soil erosion problems. The trend is characteristic in New South Wales, Victoria, South Australia and Queensland.

Note that most extreme (recorded) siltation rates were observed during short duration studies (1 to 10 years) and there is no information on long-term siltation (over 70 years).

Figure 1 - Effects of reservoir siltation on dam wall pressure

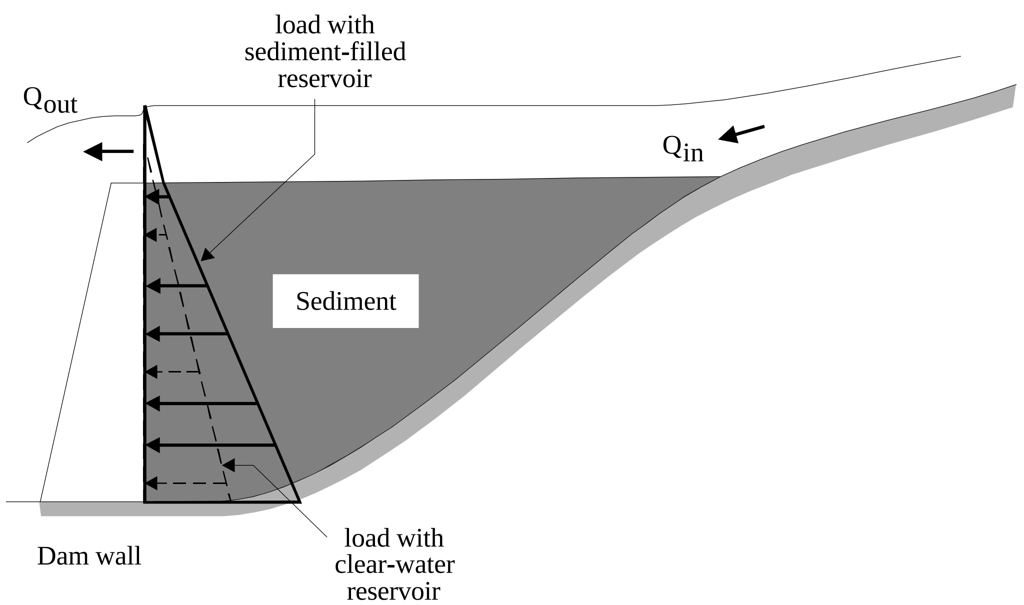


Fig. 2 - De Burgh dam, Baren Jack NSW, 1908 (Photograph in July 1998)
H = 5 m - Fully-silted railway reservoir

Sediment flushing devices

Surprisingly most Australian dams have been inadequately equipped with flushing devices. Some did not have scour pipe (e.g. Gap weir 1902). Most reservoirs were equipped with a small scour outlet (∅ = 0.3 to 0.5 m) inadequate to desilt a reservoir. For example, DARLEY (1900) recommended a "24-inch" diameter outlet. Only few dams were equipped with two or more flushing systems : e.g., the Illalong Creek dam (1914, Binalong NSW) completed in 1914 and now fully-silted (Fig. 5) !

Table 1 - Examples of major siltation of Australia dams

Reservoir (1)	Location (2)	Completion date (3)	End of use (4)	Purpose (5)
Sheba dams	Nundle NSW	1888	-- (*****)	Mining. Two dams.
Corona	Broken Hill NSW	1890	1910 (*****)	Irrigation.
Laanecoorie	Maryborough VIC	1891	Still in use	Irrigation.
Stephens Creek	Broken Hill NSW	1892	Still in use	Town water supply.
Junction Reefs	Lyndhurst NSW	1896	1930? (*****)	Hydropower for mining activities.
Moore Creek	Tamworth NSW	1898	1924 (*****)	Town water supply.
Koorawatha No. 1	Cowra NSW	1901	1911 (*****)	Railway supply. Replaced by 2nd dam.
Gap	Werris Creek	1902	1924 (*****)	Railway supply.
Pekina Creek	Orroroo SA	1907	1984	Irrigation and town water supply.
de Burgh dam	Barren Jack NSW	1908	1929 (*****)	Railway and town water supply.
Koorawatha No. 2	Cowra NSW	1911	-- (*****)	Railway supply.
Pykes Creek	Ballan VIC	1911	Still in use	Irrigation and water supply.
Pekina Creek	Orroroo SA	1910s	1930s (*****)	Town water supply.

Cunningham Creek	Harden NSW	1912	1929 (*)	Railway supply.
Illalong Creek	Binalong NSW	1914	1985? (*)	Railway supply.
Umberumberka	Broken Hill NSW	1915	Still in use	Town water supply.
Melton	Werribee VIC	1916	Still in use	Irrigation.
Korrumbyn Creek	Murwillumbah NSW	1918	1924? (*)	Town water supply.
Borenore Creek	Orange NSW	1928	Still in use	Railway supply. Town water supply today.
Eppalock	Central Victoria	1932	Still in use	Irrigation and water supply
Quipolly	Werris Creek NSW	1932	1955 (*)	Railway supply.
Inverell	Inverell NSW	1939	1982 (*)	Town water supply.
Arrona Gorge dam	Leigh Creek Town SA	1950	--	Mining and town water supply.

Reference : Present study, CHANSON and JAMES (1998a,b).
Note : (*) : reservoir fully-silted today; (--) : information not available.

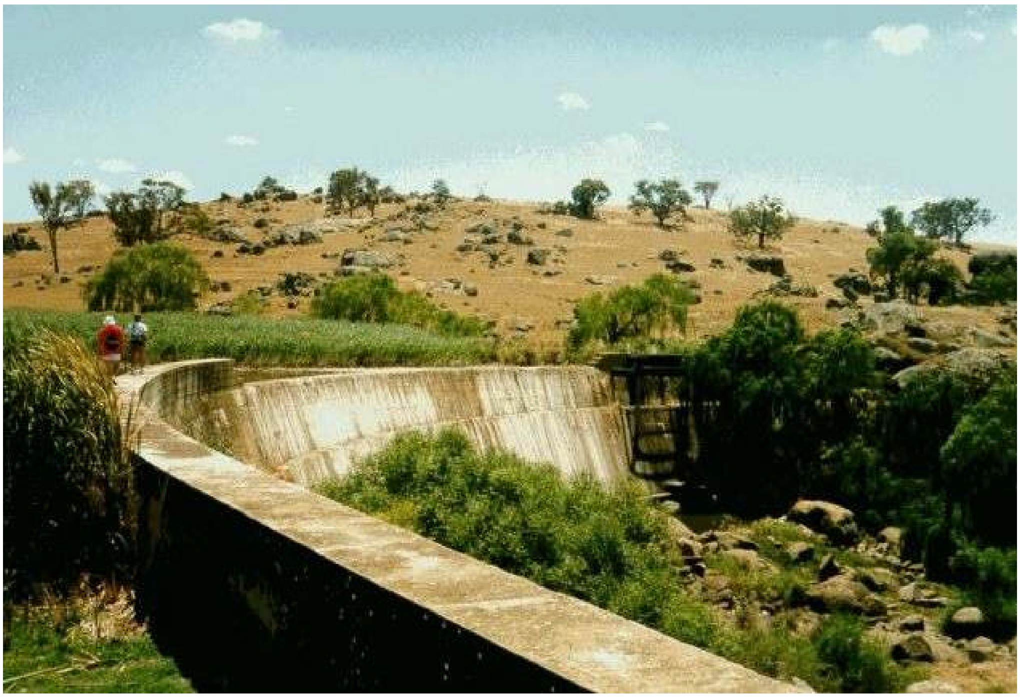
FLOOD HYDROLOGY AND DAM SAFETY

Reservoir siltation affects the safety of old reservoirs : by reducing the flood attenuation and by increasing the wall pressure. The author re-analysed the storm hydrograph of several Australian reservoirs affected by siltation (e.g. Moore Creek 1898, Korrumbyn Creek 1918, Quipolly No. 1 1932). The study shows that, in most cases, the storage capacity was very-small. The reservoir became full before the storm peak flow and it did not attenuate the flood (e.g. 1910 flood at Moore Creek). Once the reservoir was full, the outflow would almost equals the inflow (i.e. no translation) and the additional storage capacity was negligible compared to the inflow volume.

At Moore Creek, a concrete thin arch dam, the spillway was designed to pass 100 m^3/s before dam overtopping, corresponding to a 1-in-40 year flood event. But the designers allowed for a 0.6-m [2-ft] dam crest surcharge (WADE 1909), corresponding to a 270 m^3/s overflow. For that surcharge, the wall compression stress was about 2.2 MPa (clear-water reservoir). A recent re-analysis of the catchment hydrology argued that the PMF inflow would be about 1500 m^3/s. For the 1500 m^3/s peak inflow, the head above spillway crest would be about 4 metres, leading to a compression stress of the concrete arch of about 2.5 MPa at base for a water-filled reservoir and about 4.5 MPa for a fully-silted reservoir !

Fig. 3 - Koorawatha dam (No. 2), Koorawatha NSW, 1911 (Photograph on 28 December 1997)H = 9.1 m - Fully-silted railway reservoir

Fig. 4 - Cunningham Creek dam, Harden NSW, 1912 (Photograph on 28 December 1997)
H = 16 m (?), e = 0.93 m - Fully-silted railway reservoir since the 1930s



These values must be compared with the concrete resistance. During the 19th century, the strength of concrete was lower than today. Typically, concrete strengths (at 6 months) ranged from 2 to 15 MPa (CHANSON and JAMES 1998b). DARLEY (1900) who designed Moore Creek dam performed concrete tests : "the average crushing strength of a large number of specimen, [...] six months old, has been ascertained by testing to vary from about 70 to 145 tons per square foot - 80 tons may be taken as a safe average" (p. 53) {1 ton/ft^2 ≈ 0.1073 MPa}.

For a fully-silted concrete arch wall (e.g. Moore Creek), the effect of reservoir siltation and a more accurate estimate of the PMF indicate that the arch wall stress could be larger than half of the original concrete stre
ngth. The resulting safety factor is very low (i.e. less than 2) although most concrete structures were designed with a safety factor of 5 (DARLEY 1900, WADE 1909).

There are concerns for the safety of old concrete dams and several fully-silted reservoirs have low safety records : Moore Creek, Cunningham Creek, Korrumbyn Creek, Quipolly No. 1.

DISCUSSION

With good quality concrete, the concrete strength is expected to increase with age. At the Barossa dam (1902), the measured compressive strength was 19.5 MPa at 90 day and 43.5 MPa 80 years later (DOHERTY and SCHMITT 1987). But, in some cases (e.g. Victoria dam WA, Lithgow No. 2 dam, NSW), concrete deterioration occurred and diminished the wall resistance. Proper in-situ tests of concrete strengths are required for fully-silted concrete dams.

The above calculations are optimistic because they do not take into account the presence of trees and bush at the dam crest. In several cases (e.g. Moore Creek, de Burgh, Korrumbyn Creek), a forest occupies the reservoir and trees sit on the dam crest. The obstruction caused by the trees would cause a backwater effect associated with an additional wall surcharge (e.g. Fig. 2) !

SUMMARY AND CONCLUSION

The study demonstrates that reservoir sedimentation has been a serious problem in Australia. Several reservoirs (Table 1) became fully-silted because the designers did not take into account correctly the soil erosion and sediment transport processes, and no soil conservation practice was introduced.

Fully-silted reservoirs stand as a source of embarrassment for the scientists and the public. They are also a potential hazards. During a large flood event (e.g. PMF), the sediment weight adds to the wall compression stress and the safety factor (ratio of concrete strength to load) could become less than two ! With concrete structures, the properties of the wall must be tested in-situ. Further a proper analysis of the reservoir catchment and dam wall should be conducted for each individual structure.

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Table 2 - Extreme reservoir siltation rates in Australia

Reservoir (1)	Sedimentation. rate (**Fehler!**) (2)	Study period (3)	Catchment area (km^2) (4)	Annual rainfall (mm) (5)
<u>AUSTRALIA</u>				
Quipolly (*)	1,143	1941-43	70	686
Pykes Creek	465	1911-45	125	--
Umberumberka	407	1961-64	420	220
Corona (*)	400	1890-1910	15	--
Eildon	381	1939-40	3,885	--
Umberumberka	330	1915-41	420	220
Stephens Creek	238	1892-1907	510	--
Quipolly (*)	222	1943-52	70	686
Pykes Creek	215	1945-60	127	
Quipolly (*)	206	1932-41	70	686
Umberumberka	195	1941-44	420	220
Quipolly (*)	186	1952-85 (?)	70	
Moore Creek (*)	174	1911-24	51	674
Pekina Creek (*)	174	1911-44	136	340 to 450
Melton	141	1916-45	1,098	470 to 1040
Tenterfield Creek	138	1930-51	38	--
Eppalock	130	1962-68	2,000	--
Stephens Creek	129	1944-58	510	--
Borenore Creek	129	1928-81	22	--
Moore Creek (*)	128	1898-1911	51	674
Eppalock	124	1968-76	1,850	
Korrumbyn Creek (*)	1,400 (?)	1918-1924 (?)	3	1,699

References : Present study, CHANSON and JAMES (1998a,b), ORTH (1934), ROWAN et al. (1995).
Notes : (*) fully-silted reservoir; (?) uncertain data; (--) Data not available.

Fig.5 - Illalong Creek dam, Binalong NSW, 1914 (Photograph on 28 December 1997)
H = 11.3 m, L = 170 m, R = 91.4 m - Fully-silted railway reservoir, despite two scour outlets