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THE STABILITY AND CONTAMINATION OF SOME TIPS AND TAILINGS DAMS IN NORTHERN ENGLAND

R. A. Forth

University of Newcastle. Department of Civil Engineering
Drummond Building
Newcastle upon Tyne NE1 7RU, United Kingdom
Phone: + 44 191 2226888, Fax: + 44 191 2226613
e-mail: C.M.Earle-Story@newcastle.ac.uk

ABSTRACT

Research into the stability of colliery spoil in the UK was triggered by the Aberfan tragedy in 1966 when a spoil tip liquefied and engulfed the village of Aberfan and in particular the school. 144 people lost their lives, including 112 children. As a result today there are very few colliery spoil tips to be seen and those remaining have been graded and landscaped.

Where possible the coarse colliery spoil has been used as general fill, whilst the fine material was generally discarded into lagoons where they remain. This paper focuses on the coarse discard and specifically an examination of the contamination of the spoil at sites in the Northumberland and Durham coalfield where some of the earliest mining in Britain occurred. There are currently no deep mines in operation in this coalfield and considerable effort is being made to reclaim waste land associated with the mining, including the spoil tips.

Also present in Northern England, notably in the Pennines hills, are the remnants of a once thriving lead mining industry. The legacy of this industry in the Nent Valley of Cumbria is to be seen in the presence of large tailings dams which are close to the River Nent. Destabilisation of the slopes due to undercutting of the banks of the River Nent has resulted in high concentrations of lead and particularly zinc in the river.

The stability and contamination of the tailings dams and the heavy metal pollution of both the tips and rivers is assessed in this paper.

INTRODUCTION

The failure of a tailings dam in Spain, discussed elsewhere in this Conference, has dramatically brought into focus the importance of the design, construction and continual monitoring of the stability of these structures. Elsewhere in the world communities are only too aware of the potential hazards of tailings dams, and some of these have been studied and published. It is worth reviewing the literature to learn from these failures.

One of the most dramatic and devastating failures was the collapse of fluospar tailings dams at the Prestavel mine in Stava di Tesero in Trentino region of northern Italy, in July 1985. About 190,000 m^3 of liquefied tailings swept down the valley engulfing the villages of Stava and Tesero, some 3.5 km from the mine; 268 people perished in this disaster (Berti *et al.*, 1988).

The tailings dams which collapsed were founded on fluvio glacial deposits of gravels and cobbles in a fine matrix on land sloping at 12º-16º towards the River Stava. A fault ran under the site and the ground was reported to be "soft with many springs". The first tailings dam was completed in 1969. The dam itself was constructed of sandy material and the silty fines pumped into the lagoon. The final dam height was about 26 metres with a sloping face at an angle of 32º.

The second tailings dam above the first lagoon was constructed commencing in 1969, but no ground improvement was undertaken, unlike the first one where wooden stakes has been hammered into the ground providing a sort of reinforcement perhaps equivalent to the modern form of soil nailing. By 1998 this second tailings dam was raised up to a height of 25 metres with a sloping face of 39º. The mine shut down for two years but working continued from 1980 to a final height of 29.5 m before the final collapse in 1985.

During the life of the dams surplus water was decanted by pipes from the top dam to the lower dam. Damage to the decant pipes, due to freezing, caused sinkholes and minor slipping to occur, and an emergency decant pipe was installed. During this repair work the water level was dropped and when completed the water level rapidly raised. Four days later the upper dam collapsed and triggered collapse of the lower dam and the subsequent tragedy.

Genevois and Tecca (1993) reviewed the data and concluded that the upper dam was of marginal stability with factors of safety ranging from 0.9 to 1.13 depending on the position of the phreatic surface. Chandler and Tosatti (1995) also attributed the failure to poor repairs of the blocked descent pipe as being a major contributing factor to the failure.

Another disastrous failure of a tailings dam occurred in 1974 in Bafokeng platinum mine in South Africa. Slimes Dam No.1 constructed of loose, silty fine sands failed, firstly as a minor breach and later in the year as a catastrophic failure as a result of piping followed by overtopping. The failure sent some 3 million m^3 of tailings in a path some 800 m wide, destroying a mine shaft on the way killing 12 people.

The tailings dam covered an area of 900 m by 900 m with a height of 20 m. It was constructed of silty fine sands with a friction angle of 35º. Immediately before the failure witnesses reported a jet of water issuing from the tailings dam, suggesting a piping failure followed by an initial breach some 5 m deep and 20 m wide, which developed to a final breach the full height of the dam over a width of 800 m. Jennings (1979) considered that the failure could have been initiated by burrowing animals and compounded by the layering of the dyke walls, concentrating water flow. Analysis by Blight (1997) showed that the tailings at large moisture content could behave with "Bingham" plastic flow, i.e. it exhibits viscosity with a threshold shear strength.

UK LEGISLATION AND PRACTICE

These well documented cases, and others, encouraged local authorities, owners and agencies to impose stricter legislative requirements. In Great Britain the impetus was a result of the disastrous Aberfan coal tip failure. The term "Classified Tip" in the UK means a tip to which Part 1 of the Mines and Quarries (Tips) 1969 Act applies. In the context of tailings dams this encompasses:

- a tip exceeding 4 m in height above the level of any part of the neighbouring land within 50 metres of its perimeter; or
- a tip with a volume exceeding 10,000 m^3.

The Mines and Quarries (Tips) Regulation 1971 requires that a Classified Tip is to be inspected by a "competent person" every two years if active, and every 5 years if liquid, i.e. a tailings dam. Tips are also to be inspected after every "dangerous occurrence". A consultation document issued in 1998 by the Health and Safety Commission seeks to define the competent person as a "geotechnical specialist" and expects a high quality geotechnical report in line with Regulations and accepted Codes of Practice. The appointment of a "geotechnical specialist" in all cases is currently receiving some criticism from industry and it is likely that the requirement will be limited to the more critical situations. The present proposals also seek to widen the definition of a "tip" to include, for example, mounds of materials for backfilling excavations and landscaping sites, stockpiles for later processing or sale, soil bunds etc.

PENNINE LEAD MINING - TAILINGS DAMS

In the context of the above a contract is presently underway to remediate three large tailings dams in the Nenthead area of Cumbria, UK. These tailings dams are a relic of a once thriving lead/zinc mining industry. The earliest mining probably took place in Roman times, but became significant in the Middle Ages when there was a demand for lead for roofing and drainage purposes for monasteries. The mineral rights were owned by the monks, but on the dissolution of the monasteries by King Henry VIII the mineral rights were sold off and numerous private mining ventures started. In the remote Nent valley of the northern Pennine hills the London Lead Company became the backbone of the local economy. Towards the end of the 19th century zinc, found in association with lead, became the more profitable mineral, as Britain was flooded with cheaper imports of lead from Spain. The area remained commercially viable until 1921 and, after years of neglect, sprang to life again during the Second World War as a source of zinc for the war effort. In fact it was reworking of the original tailings dams that created the three large tailings dams seen today. The largest of these is some 23 m high, 200 m long and 130 m wide (Figure 1).

Figure 1. Tailings Dam above River Nent.

TAILINGS DAMS - STABILITY

The tailings dams are now over 50 years old and have been subject to both river erosion at the toe and sub-ariel erosion, compounded by rabbits burrowing into the banks. As a result there are obvious signs of deterioration as illustrated by the collapse of a gabion wall at the toe of one of the dams. There is this obvious concern that a major failure of the dams could cause massive pollution of the River Nent, a tributary of the much larger River Tyne which passes through Newcastle on the way to the North Sea at Tynemouth.

Comprehensive studies of the stability of the tailings dams were carried out using conventional site investigation techniques. Standard Penetration Tests (SPT) confirmed the low relative density of the sandy material corresponding to a friction angle of around 30º. Since some of the slopes exceeded this angle and there were obvious signs of distress it was obvious that slope regrading was necessary to provide an adequate factor of safety.

TAILINGS DAMS - CONTAMINATION

In the UK the allowable concentration of contaminants depends on the end use of the site and is determined by guidelines produced in the 1980s by the Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL). The ICRCL values are often compared with the Dutch ABC values, recently superseded by the so-called trigger and action values. The Dutch values are more comprehensive than the ICRCL values and also cover groundwater. The approach to contamination has changed recently in the UK towards a risk-based method.

A previous study of heavy metal contamination in the area of Nenthead was carried out in 1985. Testing of samples from the tailings dams revealed average concentrations of 2,686 mg/kg lead, 34.8 mg/kg cadmium and 12,126 mg/kg zinc, values that, apart from the zinc, which is high, agree very closely with those from recent tests (Table 1).

Comparison of the results of the contamination tests of the tailings dams material at Nenthead (Table 1) against recommended threshold trigger levels for parks, playing fields and open spaces prove the soils to be contaminated with heavy metals. Cadmium threshold levels are exceeded in all three dams, with values in excess of up to four times the recommended level in Dam C. Lead levels are marginal and only exceed threshold trigger values in Dam B.

Zinc is by far the most proliferant of the contaminants exceeding threshold trigger levels by as much as 18 times. The ICRCL 70/90 recommends that a maximum value of 1,000 mg/kg of zinc should not be surpassed in order to avoid the possibility of phytotoxicity in agricultural crops. The results clearly show this value to be exceeded by up to five times. It is not surprising that re-vegetation programs in the past have resulted in failure.

Dam B appears to have higher lead and copper levels than the other two but it also has lower zinc concentrations.

Heavy metal leachate concentrations from soil samples taken from the dams are reported in Table 2. Surprisingly the zinc leachate only exceeded the value of 1.3 mg/l considered to be toxic to living organisms in Dam B. This is unusual because Dam B has a lower level of zinc concentrations in solid form but a pH of 8 comparable with the other tailings dams. The acceptable level for salmonid mortality is 0.3 mg/l (DoE 1994). The level of zinc leachate is higher than this value in all three of the dams on the site. This leachate draining into the river is eventually going to cause problems of contamination. The weight of metal in solution is probably so little due to the alkaline pH of the soil (pH≈8). An alkaline pH reduces the solubility of acid metals in the soil.

	Tailings Dam		
Determinand	**A**	**B**	**C**
pH	7.9	7.9	8.58
Arsenic	104	96	-
Cadmium	15.99	39	67.8
Chromium	8.9	19	16.9
Copper	170	188	104
Iron	4.6	3.7	4.53
Lead	1342	3842	1716
Manganese	4604	2067	3276
Mercury	-	1.184	0.31
Zinc	5527	2916	5353

Table 1. Concentration values of contaminants found in tailings dams expressed as mg/kg (1997 values).

	Tailings Dam		
Determinand	**A**	**B**	**C**
pH	8.1	7.85	<0.01
Arsenic	<0.01	<0.01	<0.05
Cadmium	<0.01	<0.05	<0.1
Chromium	<0.1	<0.01	<0.1
Copper	<0.1	<0.01	0.8
Iron	<0.1	0.482	<0.1
Lead	<0.1	<0.01	1.38
Manganese	2.12	0.29	<0.01
Mercury	<0.001	<0.01	<0.1
Zinc	0.45	2.87	0.536

Table 2. Concentration of leachate found in tailings dams expressed as mg/l.

The area between Dam B and the River Nent, and on the opposite side of the river to Wellgate, have also been tested for contamination. This ground has remarkably high proportions of zinc and lead contamination, with values of 8,000 mg/kg of zinc, and lead values up to 9,000 mg/kg not unusual.

Water quality samples were taken from four places along the river Nent (Table 3). A difference in values of over 2 mg/kg can be noted from Table 3. At Dam A the total level of zinc has been diluted slightly to 1.43 mg/kg by the cleaner water entering at the confluence of the Nent with Guddamgill (1.02 mg/kg).

Determinand	Location			
	Nent Bridge	Footbridge by Dam C	North of Dam A	Guddhamgill
pH	8.1	8.1	8.0	8.1
Arsenic	<0.01	<0.01	<0.01	<0.01
Cadmium	<0.005	<0.005	<0.005	<0.005
Chromium	<0.01	<0.01	<0.01	<0.01
Copper	<0.01	<0.01	<0.01	<0.01
Iron	0.12	0.01	0.11	0.02
Lead	<0.01	<0.01	0.02	<0.01
Manganese	1.11	0.15	0.07	0.04
Mercury	<0.001	<0.001	<0.01	<0.001
Zinc	0.09	2.11	1.43	1.02

Table 3. Concentration of contaminants in the River Nent, expressed as mg/l.

CONTAMINATION - SUMMARY

Cadmium and lead levels of contamination in the three large tailings dams on the site all marginally exceed threshold trigger levels for parks and playing fields. Zinc contamination of the tailings dams in massive, exceeding both ICRCL threshold trigger values and the C group values from the Dutch system.

The lack of vegetation on the tailings dams is caused by phototoxicity induced by the high zinc levels. The loose fine sandy material is subject to physical erosion by winds in periods of dry weather. Wind blown erosion is deposited in local gardens allowing a gradual build-up of heavy metal to a potentially hazardous level.

River pollution by heavy metals results from leachate from the dams and made ground, water erosion of the flanks of the dams dumping the sediments in the river, and the erosion of the made ground through which the river flows.

There is noticeable rise in zinc contamination between the Nenthead bridge and the footbridge. This will be as a result mainly of the erosion of the made ground through which the river flows and the dumping of fluvially eroded tailings dam debris.

COLLIERY SPOIL TIPS - STABILITY AND CONTAMINATION

Since the Aberfan disaster in 1966, when 144 people were killed as a result of the failure and liquefaction of a colliery spoil tip, considerable effort has gone into the stability of tips and most have been removed or stabilised and landscaped. There are few, if any, high risk colliery spoil tips left in the UK although failures are occasionally reported (Forth, Beaumont and Hughes, 1995).

The main interest in colliery spoil nowadays is in finding uses for the material as general fill or hardcore for highway embankments and house foundations. In the latter case a number of problems have arisen in recent years due to the solubility of sulphates present in shale from spoil tips. These sulphates attack concrete unless sulphate resistant cement is used in the mix. The concrete base slabs of houses are cracked and brickwork displaced.

In respect of contaminated colliery spoil its use is regulated by the Environment Agency and governed ultimately by EEC Directives, notably Directive 76/464/EEC. One of the main problems is the presence of the oxidation of iron pyrites, and at pHs less than 4, aluminium, copper, manganese and zinc become soluble. This creates potentially toxic conditions within the tip. The leachate this forms has the potential to enter water courses and possibly aquifers causing severe contamination. It is common practice to encapsulate tip material with inclusions of limestone to control the pH. Indeed the most significant remediation technique for tips is to reduce the pH and hence the solubility of potential toxic compounds.

Another localised source of contamination is due to the proximity of some tips to the coastline of north-east England. It is thought that sea spray is responsible for the high levels of cadmium in some tips, and high levels of boron, zinc and arsenic exist on some tips. Interestingly, the arsenic levels in the leachate and the tips often show no correlation because of the low solubility of arsenic.

Another feature of colliery spoil is the tendency for self-combustion or ignition due to the dumping of hot ashes on the tips. Some tips have been known to burn for years with temperatures exceeding 450°C. Burnt colliery spoil has been found to be a more stable and homogeneous material than the unburnt spoil, and it has a lower tendency to produce leachate.

The Road Research Laboratory carried out extensive testing of burnt colliery shale and concluded that if the sulphate content of a 1:1 shale-water extract exceeded 2g/l (as SO_3) it could have an adverse effect on cementitious material. Their studies concluded that sulphate resistant cement should be used in concrete structures placed close to burnt colliery spoil (Sherwood and Riley, 1979).

Problems also arose in the compaction of colliery spoil due to the variable grading arising from the source rock. The material was also found to be susceptible to frost heave which could be controlled by the addition of about 5% cement (Road Research Laboratory, 1967).

CONCLUSIONS

Mining has taken place in northern England for many centuries leaving a legacy of contaminated land. The very different properties of the tailings from the metalliferous ore mining in the Pennines to the coal tips of the coal fields require careful assessment and appropriate remediation.

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REFERENCES

Berti, G, F. Villa, D. Dovera, R. Genvois and J. Brauns, 1988. The disaster of Stava, northern Italy. Proceedings of American Society of Civil Engineers Geotechnical Engineering Division Speciality Conference, Fort Collins, 492-510.

Blight, G.E., 1997. Destructive mud-flows as a consequence of tailings dyke failures. Proceedings of Institution of Civil Engineers, Geotechnical Engineering, 125, 9-18.

Chandler, R.J. and G. Tosatti, 1995. The Stava tailings dams failure, Italy. Proc. Instn. Civ. Engrs. Geotech. Engng., 113, April, 67-79.

Forth, R.A., D. Beaumont and D.B. Hughes, 1997. Investigation of a landslide in County Durham, UK. In Proceedings of Conference on Engineering Geology and the Environment, Athens, 641-645.

Genevois, R. and P.C. Tecca, 1993. The tailings dams of Stava (Northern Italy): an analysis of the disaster. Proc. Inst. Conf. Environmental Management, Geo Water and Engineering Aspects, Wollongong, Australia, 23-26.

Jennings, J.E. 1979. The failure of a slimes dam at Bafokeng. Mechanisms of failure and associated design considerations. Civ. Engr. S. Afr., 21, No.6, 135-141.

Road Research Laboratory, 1967. A laboratory investigation of the physical and chemical properties of burnt colliery shale (authors C. K. Fraser and J. R. Lake). RRL Report LR125.

Sherwood, P.T. and M.D. Ryley, 1970. Sulphates in colliery shales: effect on cemented materials. Surveyor.