

FEASIBILITY STUDY OF GEO-ENGINEERING INVESTIGATIONS OF MINE TAILINGS CONDITIONS

A. A. Gilyarova, A. I. Kalashnik, O. V. Smirnova

Mining Institute of the Kola Science Centre of the Russian Academy of Sciences,
24, Fersman st., Murmansk region, Apatity, 184209 Russia

Abstract

The paper presents a short review of investigations on conditions of tailings from the mining industry. The preliminary feasibility study was carried out of expenditures for performing integrated research of a tailing's conditions as a whole, and for principal types of field and laboratory works. The studies performed have shown that among the main work research groups the most costly are engineering-geodetic operations which carrying out is almost in one and a half time more expensive than carrying out of engineering-geological works. Laboratory works, including processing, analysis and generalization of all the test results as well as drawing up of a technical report require one third of all expenses. For the purpose to optimize and partially decrease the total amount of financial maintenance of works and increase information content and efficiency of the results received the authors offer to integrate modern innovative methods and means such as georadar subsurface and surface sounding, satellite and air photos, satellite georadar surveys and GPS measurements into integrated research of state of a tailing, and to apply more largely automated methods and technologies during laboratory processing of field measurement results.

Key words: tailing, studies of state, feasibility study, optimization

1. INTRODUCTION

Hydrotechnical facilities of mining enterprises are potentially hazardous facilities of the 1st and 2nd class and must be exploited in strict adherence to industrial safety requirements regulated by the Federal Law of the Russian Federation "On safety of hydrotechnical facilities", the Construction Standards and Regulations of the Russian Federation "Hydrotechnical facilities. Fundamental principles" and the Safety rules. Disturbance in filtration and functionality and instability of such hydrotechnical facilities can lead to an accident and significant social-economic damage to population, civil and industrial buildings, roads, utilities systems and financial losses such as lost profit due to an enterprise's laying off, additional expenditures for repair operations, accident management, pollution charges and ecological damage (Gal'perin, 2001; Kalashnik et al., 2015 a, b; Kiebasiewicz, 1984).

World expertise in exploiting hydrotechnical facilities contains multiple cases of extremal situations and accidents; the most known of which are (Gal'perin, 2001; Grimalt et al., 1999; Jhle, 1995; Martin et al., 2002; Ritcey, 1989; Salgueiro et al. 2008; Vanden Berghe et al. 2011): Kachkanarskiy GOK (Russia), El Cobre mine (Chile), Karamkenskiiy GMK (Russia), coal-dressing plant in Buffalo Creek (the USA), Prestavel mine (Italy), a sludge dump of the MAL Hungarian Aluminum plant (Hungary), Talvivaara mine (Finland) and other. Analysis of the accidents indicates that the principal cause of emergencies was a local or total destruction of embankment dams caused by invisible filtration-deformation zones generating in the dam's body, processes of soils dilution and erosion, suffusion processes, formation of "hydraulic" fissures and their further transformation into water supply canals and further intensive washing-out of a lower slope.

2. RESEARCH PURPOSE AND METHOD

In accordance with normative requirements on providing industrial and ecological safety of hydrotechnical facilities of tailings enterprise-owner's services or contracting organizations perform annual investigations of a hydrotechnical facility's conditions. The investigations involve standard integrated field engineering-geological and survey works, laboratory treatment, analysis and summary

of data received and a technical report as a result (Gal'perin, 2001; Kalashnik et al., 2015 a). The value of very costly operations is determined in accordance with Reference books (Kalashnik et al., 2015 b). At that seasonality and volumes of field works are of significant importance as well as state of reference points and control and measurement instrumentation. The work given is aimed at systematization and analysis of structure of expenditures for performing systemic research of a tailing's conditions as a whole, and for principal types of field and laboratory works. A formal-logical method (analysis + synthesis) has been chosen as the main research method.

3. EXPENDITURE STRUCTURE ANALYSIS TO RESEARCH STATE OF HYDROTECHNICAL FACILITY

Experience of integrated investigations of hydrotechnical facilities at dressing plants from mining enterprises located at the North-West of Russia (Gal'perin, 2001; Kalashnik et al., 2015a, b) has allowed defining a total image of forming a generalized economic structure of annual expenditures for the operations (Fig. 1). As it is seen from the figure expenditures for field works are 2/3 of the total cost, at that value of engineering-geological works is less than one and a half than this of engineering-geodetic works. Expenditures for laboratory treatment are approximately one third of the total value of works.

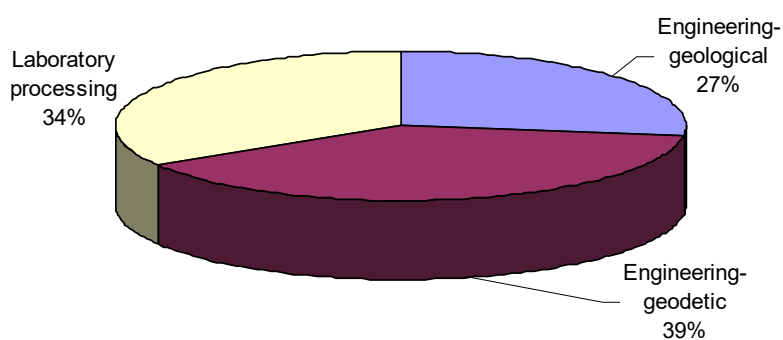


Fig 1. Enlarged structure of annual expenditures to investigate state of tailing's hydrotechnical system

For the further analysis and understanding of labor-intensiveness it is necessary to select principal work types: engineering-geological, engineering-geodetic and laboratory works.

Principal engineering-geodetic works are sampling of soils and deposits, laboratory determination of their physical-mechanical characteristics, measurements of a tailing pond's depth, hydrogeological measurements on reference points of embankment facilities. The sampling is realized through a special method along lines of axial observations with horizontal and vertical positioning of sampling points. The samples are weighed on-site and placed into hermetic containers; this allows keeping their natural humidity. Then in laboratory conditions standard methods are used to determine their principal physical-mechanical properties.

Measurements of the tailing pond's depth are performed through a measuring stick and submergence of a metal disk or a weight at grid of 150*150 m with horizontal positioning of tachymeter measurement points. This allows determining as the depth of water properly, so the summary depth of water and bottom deposits. Measurements in equipped reference points (piezometers and hydrogeological boreholes) are performed on embankment dams.

Besides, it should be noted that hydrogeological works can be performed with applying modern high informative and low-cost subsurface georadar measurements (Kalashnik et al., 2013; Kalashnik et al., 2014; Reicherter et al., 2001; Tamura et al., 2008). The generalized structure of expenditures for

engineering-geological works is seen on Fig. 2. As it is shown, more than 44% belong to expenditures for determining physical-mechanical properties of tailing sediment samples. Expenditures for sampling and the tailing pond's depth measurement are approximately the same (about 20%). Piezometer measurements occupy a little more than 10% because of their discreteness.

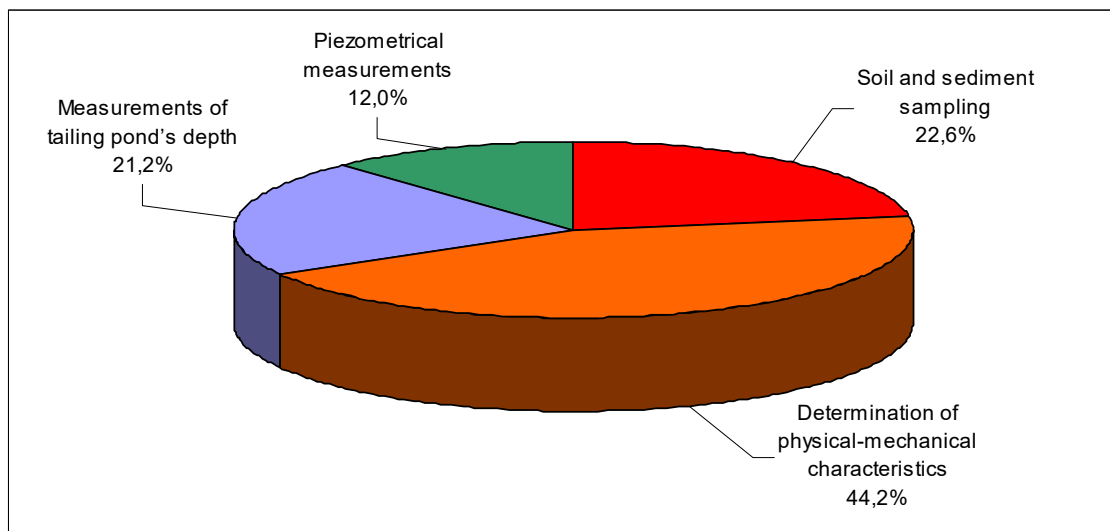


Fig 2. Expenditures for engineering-geological works

Engineering-geodetic works are as follows: traversing of I rank polygonometric course for surveying the tailing's hydrotechnical system, including existing reference points; a survey properly; III rank leveling by reference points; technical leveling by crests of embankment facilities; horizontal and vertical planning of sampling points and measurements of the tailing pond's depth.

The works are performed by geodetic methods with using standard equipment (tachometer, reflectors, leveling, and leveling poles). Such conventional approach makes them rather labor-intensive and highly discrete (one-two measurement cycle per year). At the same time the advanced technologies on the world survey practice are GPS-measurements and satellite georadar surveys which allow considerably increasing productivity and information capacity of data received with discreteness up to 10-15 days and less (Kalashnik, 2005; Melnikov et al., 2015; Panzhin, Panzhina, 2012). The summarized structure of expenditures for engineering-geodetic works is given in Fig. 3. The most costly works are those of topographic survey and diversion dams and alluvion dams leveling (cumulatively up to 75%). Traversing of polygonometric course and leveling in reference points have approximately equal values (10-13 %). Expenditures for conducting reconnaissance of initial points of a hydrotechnical facility and for works on horizontal and vertical planning of sampling points and measurements of the tailing pond's depth are negligible (don't exceed 2.5% cumulatively).

Laboratory works include treatment of in-situ engineering-geological and geodetic measurements data, results of laboratory identifications of physical-mechanical characteristics of soil and sediment samples, drawing up of registers, plans, profiles, analysis of results and drawing up of a technical report. In order to get this the calculations are made of polygonometric courses, III rank leveling by reference points, technical leveling by crests of embankment dams, topographic survey of the tailing's hydrotechnical facilities, measurements of the tailing pond's depth and piezometrical observations. Then horizontal and vertical planning of observation points is calculated as well as their relative changes for observation cycles, deformation characteristics by reference points, volume of water in the tailing pond (total, conditionally clean, volume of bottom sediments), areas of hydrotechnical facilities and a pond and etc. These data are basis for designing a topographic plan of the hydrotechnical facility, longitudinal and transversal profiles of embankment dams with identifying depression curves

and drawings of horizontal and vertical deformations.

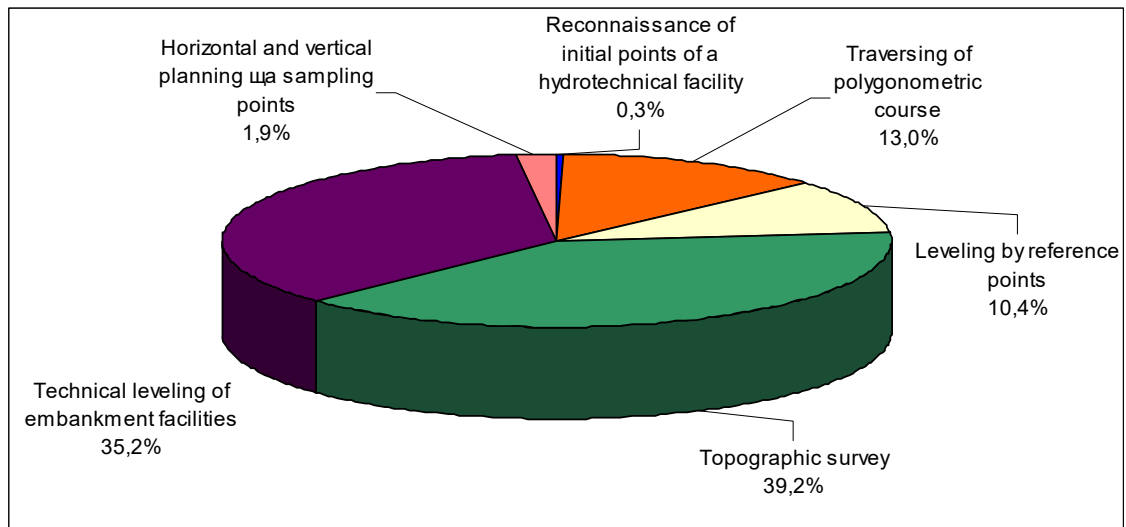


Fig 3. Structure of expenditures for engineering-geodetic works

The most significant and important operations are those of analyzing, systematizing and summing the results obtained as well as drawing up the technical report based on summarizing the results of the integrated investigations performed. It should be noted that considerable temporal and costly profit is provided by applying automated data processing systems, inquiry and communications systems and decision support systems (Melnikov et al., 2015).

The summarized structure of expenditures by laboratory works types is presented on Fig. 4. As it is seen, specific distribution of expenditures is rather equal (from 7% to 15%), but however processing of leveling data and topographic survey exceeds cumulatively 40%. It is reasonable that analysis of all the results obtained and drawing up of the report is expensive as well.

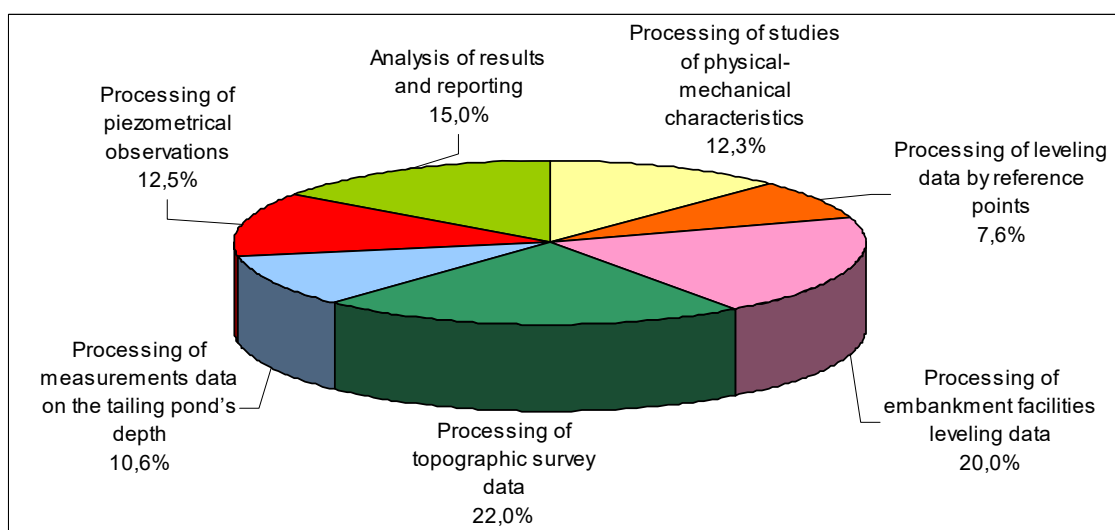


Fig 4. Structure of expenditures for laboratory works

Since expenditures for individual types of field and laboratory works are determined with their scales

(area of a hydrotechnical facility, length of embankment facilities, number of soil and water sampling point, number of reference observation points and etc.), the further analysis of these expenditures was performed specifically per a corresponding measurement unit. For engineering-geological works the unit is a quantity of samples taken, number of piezometers and depth measurement points. For engineering-geodetic works analysis of specific expenditures was performed in reliance on an area unit (ha), length unit (1 km) and number of reference points and points of tools installation. Hence, Fig. 5 presents a summarized structure of specific expenditures for principal field works and laboratory processing. As it is seen, specific expenditures for one sample will be about 14%; at the same time expenditures for the laboratory determination of its physical-mechanical properties will require more 28%, i.e., twice as much. Measurement of the tailing pond's depth doesn't exceed 3% specifically; one piezometrical measurement is a little more 5%.

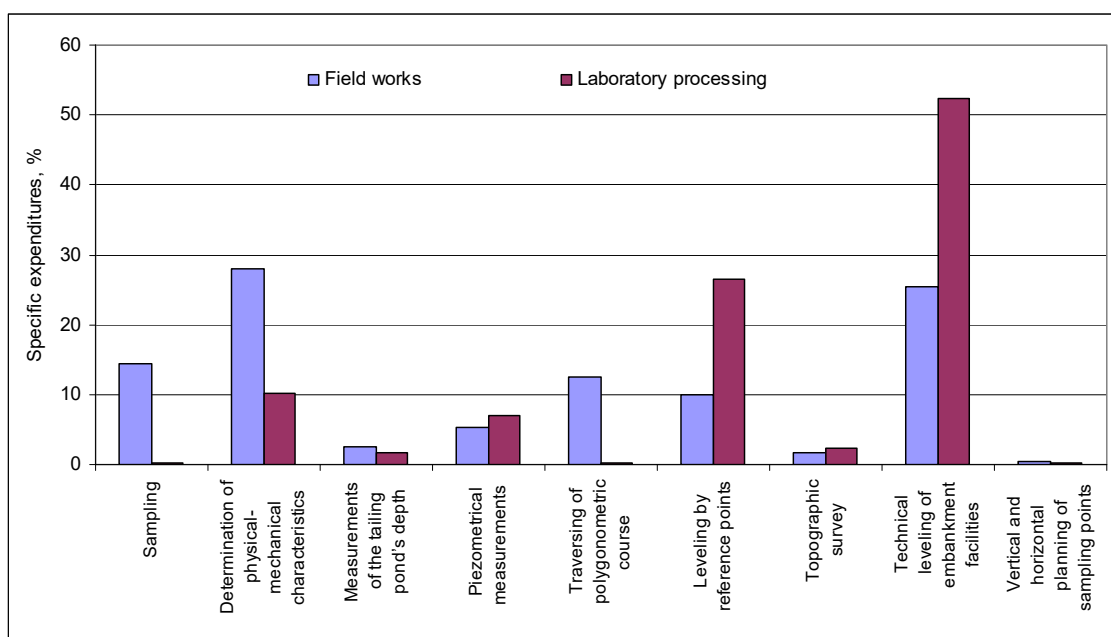


Fig 5. Specific expenditures per a unit of principal field works and laboratory processing

Engineering-geodetic works will occupy specifically from 1% (horizontal and vertical planning of one sampling point) to 26% (technical leveling of embankment facilities of 1km). Leveling works in reliance on one reference point will occupy approximately 10%, traversing of 1km of polygonometric courses – about 10%, and topographic survey of 1 ha will take 1%.

Specific laboratory expenditures are rather unbalanced: leveling takes 25-52%, determination of physical-mechanical properties – 10%, and piezometrical measurements – 6%. For other works specific laboratory expenditures amount 1-2%.

4. APPLICATION OF RESULTS

To the authors' opinion, optimization and partial decrease of the total financial support of complex investigations of a mining tailing's hydrotechnical facilities and increase of information capacity and efficiency of the results obtained can be achieved due to integrating into standard observation systems such modern innovative methods and technologies as georadar subsurface and surface sounding, satellite georadar surveys and GPS-measurements, and applying automated methods and technologies when performing laboratory processing of field measurement results.

The Mining Institute KSC RAS develops a systematic structure of integrated investigations of tailings' hydrotechnical facilities which takes into account geological-geophysical particularities of the region and includes modern complexes of in-situ measurements of potentially hazard zones, forecast calculations and computer modeling, expert assessments of natural and technogenic impacts of hydrotechnical facilities with the aim to forecast and discover features of occurrence of hazardous filtration-deformation processes at early stages and to solve managerial decisions and prevention measures. For integrated investigations of tailings' hydrotechnical facilities the authors propose to use as conventional engineering-geological and engineering-geodetic methods, so a georadar subsurface and surface sounding which made a good showing when monitoring mining-engineering systems. To determine displacements and deformations of embankment facilities the authors offer integrating satellite GPS measurements and georadar area survey into the conventional (leveling and polygonometry) geodetic system. Performance of complex studies of hydrotechnical facilities state with additional (or replacing for some operations) application of the modern methods and technologies mentioned above will allow receiving more quickly information detailed on the facility's state in less labour expenditures. At that, the data obtained automatically will be integrated into the computer base of data and parameters which will considerably accelerate and facilitate their logical treatment and comparison with normative and threshold values. Based on it the expert assessment of current and forecast state of hydrotechnical facilities should be performed in automated regime and managerial decisions will be taken, including development decisions; if necessary, preventive and protective measures will be performed.

5. CONCLUSION

1. The feasibility study has been performed of geotechnical investigations of a mining tailing. It has been revealed that engineering-geodetic works take the maximum volume (up to 40%), exceeding engineering-geological works in one and a half. Laboratory works require approximately the one third part of the total financial support of works, including an annual technical report.
2. Optimization and partial decrease of the total financial support of works and increase of information capacity and efficiency of the results obtained can be achieved due to integrating into complex studies such modern innovative methods and means as georadar subsurface and surface sounding, satellite georadar surveys and GPS-measurements, and applying automated methods and technologies when performing laboratory processing of field measurement results.

REFERENCES

- Gal'perin, AM, Ferster, V & Shef, Kh-Yu 2001, *Mining-made rock massifs and environment protection*, MGGU, Moscow.
- Grimalt, JO, Ferrer, M, & Macpherson, E 1999, 'The mine tailing accident in Aznalcollar', *The Science of the Total Environment*, no. 242, pp. 3-11.
- Jhle, F 1995, 'Untersuchungen zur Auswertung von Drucksondierungen', *Geotechnik*, 2.
- Kalashnik, AI 2005, 'Methodology of the information technologies application in the Kola Peninsula mineral resources development', *Science and education. 10 years together*, Apatity, KSC RAS Printing house, pp. 132-139
- Kalashnik, AI, Gilayrova, AA, Kalashnik, NA & Smirnova, OV 2015a, 'Studies of mining tailings from the Kola regional mining enterprises: expenditure structure analysis', *North and market: formation of economic order*, no. 2 (45), pp. 31-39.
- Kalashnik, AI, Gilayrova, AA, Kalashnik, NA & Smirnova, OV 2015b, 'Structure of expenditures for studies of hydrotechnical facilities of liquid mining waste facilities in the Kola region', *Arctic: ecology and economics*, no. 4 (20), pp. 96-103.

Kalashnik, AI, Kalashnik, NA & Zaporozhets, DV 2014, 'Study of state of a bulk hydrotechnical facility on the moraine foundation', *PetrSU proceedings. Series: Natural and technical sciences*, no. 6 (143), pp. 92-98.

Kalashnik, AI, Zaporozhets, DV & Kalashnik, NA 2013, 'Definition of filtration-deformation processes in the body of the tailing's protective dam', *Vestnik KSC*, no. 2, pp. 13-17.

Kiebasiewicz, W 1984, 'Ocena przydatnosci wierzchowiny zwalowiska do zabudowy ze wzgledu na deformacje', *Ochr. teren. gorn.*, no. 67, p. 18.

Martin, TE, Davies, MP, Rice, S, Higgs, T & Lighthall, PC 2002, 'Stewardship of tailings facilities', *Mining, Minerals and Sustainable Development*, no. 20, <<http://pubs.iied.org/pdfs/G01027.pdf>>.

Melnikov, NN, Kalashnik, AI, Kasparian, EV & Kalashnik NA 2015, 'Concept of geodynamic monitoring of oil-gas recovery in the Barents sea area', *Geoecology*, no. 2, pp. 166-175.

Panzhin, AA, &Panzhina, NA 2012, 'On particularities of geodynamic monitoring during the Ural mineral deposits development with using satellite geodesy complexes', *Physical-technical issues in minerals mining*, no. 6, pp. 46-55.

Reicherter, KR, & Reiss S 2001, 'The Carboneras Fault Zone (southeastern Spain) revisited with Ground Penetrating Radar – Quaternary structural styles from high-resolution images Netherlands Journal of Geosciences', *Geologie en Mijnbouw*, no. 80 (3-4), pp. 129–138.

Ritcey, GM 1989, *Tailings managemant*. Elsevier – Amsterdam – Oxford – New-York – Tokyo.

Salgueiro, A-R, Pereira, H-G, Rico, M-T., Benito, G & Díez-Herreo, A 2008, 'Application of Correspondence Analysis in the Assessment of Mine Tailings Dam Breakage Risk in the Mediterranean Region', *Risk Analysis*, vol. 28, no. 1, <<http://cerena.ist.utl.pt/hgp/artigos/Risk%20Analysis.pdf>>.

Tamura, T, Murakami, F, Nanayama, F, Watanabe, K & Saito, Y 2008, 'Ground-penetrating radar profiles of Holocene raised-beach deposits in the Kujukuri strand plain, Pacific coast of eastern Japan', *Marine Geology*, no. 248, pp. 11–27.

Vanden Berghe, J-F, Ballard, J-C, Pirson, M, & Reh, U 2011, Risks of Tailings Dams Failure, <http://vzb.baw.de/e-medien/geotechnical-safety-and-risk-2011/PDF/3%20Risk%20and%20Reliability%20in%20Geotechnical%20Engineering/3_03.pdf>.