A Benchmark on In-Pit Tailings Disposal

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ABSTRACT

In response to the environmental challenges inherent in conventional tailings storage practices, different solutions are swiftly rising to prominence on a global scale. In-pit tailings disposal emerges as a compelling alternative, gaining traction across diverse geographical regions.

The article provides a comprehensive overview of in-pit tailings disposal, emphasizing the need for a thorough assessment of potential challenges and risks. Through a technical and environmental evaluation, it compares in-pit tailings disposal with conventional tailings storage, highlighting key considerations related to failure modes. Key findings include the reduced need for embankment dams in in-pit storage facilities, mitigating risks to physical stability. Challenges such as groundwater contamination and complex underdrainage systems are noted. Additionally, repurposing already impacted areas and leveraging the operational history of pits are identified as significant advantages, while acknowledging the ongoing management of liabilities associated with open pits. These features show that, beyond mitigating environmental impacts, this method heralds a significant paradigm shift in tailings management strategies.

The investigation extends to the assessment of 41 in-pit tailings storage facilities, providing insights into some of their features. While the dataset may not guarantee global representativeness, it offers significant insights into the suitability of in-pit disposal methodologies across diverse geological and environmental contexts. Despite potential information biases stemming from variations in data disclosure among countries, the gathered information encompasses crucial aspects such as location, geometric attributes, tailings composition, and disposal techniques. This dataset represents ongoing research aimed at laying the foundation for a globally representative database. These cases underscore the versatility of the methodology in diverse settings and reveal nuances in discharge strategies and water recovery practices.

It is essential to recognize that in-pit tailings disposal is an integral component of the broader mining operation framework. Rather than being viewed as a standalone solution, this methodology should be considered a highly recommended best practice from the outset of any mining project. By embracing in-pit tailings disposal as a fundamental component of mining operations, stakeholders can effectively address environmental concerns while optimizing operational efficiency and safety standards.

INTRODUCTION

The mining industry faces increasing pressure to adopt sustainable and environmentally responsible practices in tailings management. Conventional tailings storage methods, such as surface impoundments and embankment dams, have raised concerns due to their potential for catastrophic failures and long-term environmental impacts. In response, alternative approaches, such as in-pit tailings disposal, have emerged amongst viable solutions.

In-pit storage involves filling abandoned open pit surface mines with tailings or other waste materials, offering several differences compared to conventional storage methods. It is a methodology that has been practiced in countries like Australia ever since the first half of the 20th century, being initially conceived as a fill post-mining in closure stages of the project, this means pits would be filled with waste rock and other waste materials (ACG, 2005). In Canada, in-pit tailings disposal would begin in the second half of the 20th century, with the renowned cases of Key Lake and Rabbit Lake (MEND, 2015). In South America, in-pit tailings disposal emerges as a relevant methodology within the framework of sustainable development and the circular economy.

This article aims to provide a comprehensive analysis of in-pit tailings disposal to identify potential risks and challenges from a technical perspective. The study explores the advantages and disadvantages of in-pit disposal, examine the characteristics of 41 in-pit tailings storage facilities globally, and evaluate some parameters that include the general characteristics of the pit, the type of processed mineral, location, size, tailings disposal methodology, amongst others.

TECHNICAL OVERVIEW

In addressing the features of in-pit tailings disposal, it is necessary to adopt a comprehensive approach that identifies potential challenges and risks. This section conducts a technical and environmental assessment, comparing the features of in-pit disposal against conventional tailings storage. The objective is to compare both methodologies within a framework familiar to the industry, encompassing specific considerations related to the failure modes of each type of facility:

- In most cases, in-pit tailings storage facilities reduce the need for building an embankment dam. This not only benefits the operational process but also mitigates risks linked to the physical stability of the deposit. Although slope failures of the pits are feasible, they are not linked to an uncontrolled release of tailings into the environment. Yet, they could still have relevant consequences related to operational processes and workers safety.
- Regarding other failure modes associated with conventional tailings dams, failures originated by water are limited to groundwater contamination for in-pit facilities. The potential for overtopping and internal erosion is minimal. Overtopping in open pits, while feasible, poses a limited risk of contaminant release upon reaching capacity, primarily involving a confined quantity of contact water. Moreover, internal erosion within pit walls, is unlikely to pose a risk associated to an uncontrolled release of tailings.

- In considering other benefits of in-pit tailings disposal, repurposing already impacted areas stands out as a significant advantage. This approach avoids intervention in pristine regions, reducing the environmental impact associated with tailings disposal.
- The extended operational history of the pit provides valuable precedents that may support or simplify feasibility assessments, providing useful information for high levels of engineering calculations. The anticipation of minimal deviations in operational performance based on historical pit behavior is a reasonable expectation.
- A significant challenge associated with in-pit tailings disposal is the potential for groundwater contamination. This poses a notable environmental risk that must be carefully assessed and managed. Additionally, the implementation of complex underdrainage systems may be necessary to control seepage, adding complexity to the engineering considerations.
- Considering water recovery is fundamental in mining operations, in-pit water recovery systems may be more limited and complex than for a conventional tailings facility.
- Another challenge is that the original purpose of the open pit differs from the current scenario of tailings disposal. This variation introduces distinct design criteria, acceptability criteria and objectives, outlining specific risks associated with in-pit disposal.
- Regardless of its utilization for tailings disposal, an open pit remains a liability that demands diligent management. Even when repurposed for in-pit tailings storage, the pit retains inherent risks and environmental considerations that necessitate ongoing attention and mitigation efforts. Proactive monitoring and maintenance protocols are essential to ensure the safety of workers, surrounding communities, and the integrity of the ecosystem.
- In-pit disposal is subject to the availability of open-pits, which will normally be in lesser quantity than the generated tailings. Factors such as the addition of water and swelling make it highly unlikely that a pit can solely store all the tailings from a mining operation.

DATABASE

This section provides an overview of the dataset comprising 41 in-pit tailings storage facilities situated globally. The distribution of facilities across different regions, their geometric characteristics, tailings composition, disposal techniques, and water recovery systems are analyzed to identify trends and patterns in in-pit disposal practices.

The selection of cases was conducted based on information provided by public technical reports, international data bases, external sources, and Ausenco's expertise in in-pit tailings disposal. The database may not necessarily be globally representative; instead, it primarily considers the availability of publicly accessible information collected from online sources. This information is anticipated to serve as an initial foundation for the construction of a globally representative database. The presence of information biases is not ruled out, as certain countries tend to have more easily accessible public information on their mining operations compared to others. Consequently, numerous cases from other countries might not be considered due to limitations in publicly available information.

Figure 1 shows the start year of in-pit tailings disposal related to the maximum depth of the pit for some of the studied mining projects. Note that not all depths were publicly available, hence some operations are displayed at ground level, such are the cases of Whistle, Key Lake, Granites, Central Norseman, Bulong, Kanowna Belle, Jundee and Nikolayesvky mines. The characteristics studied in each operation include geometrical features of the open pit, location, main commodity, years of operation, average solids content by weight, tailings discharge disposal method, state of deposit and water recovery systems.

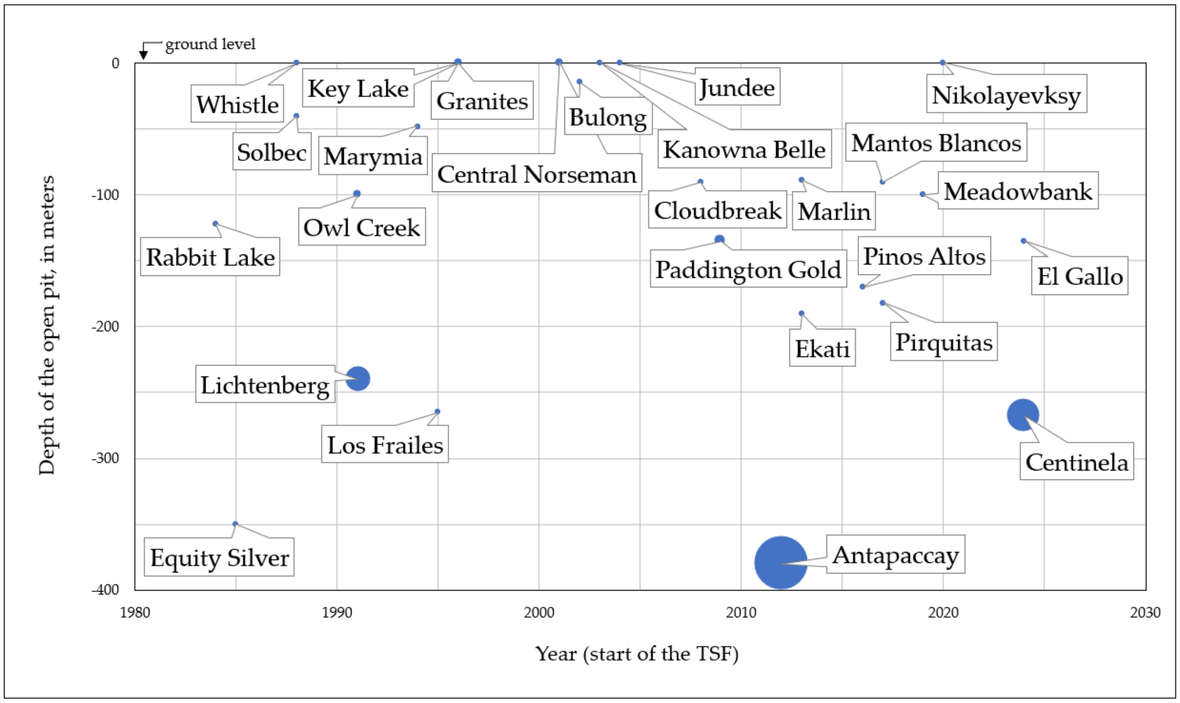

Figure 1 Start Dates of In-pit Tailings Disposal Related to the Depth of the Pit for Different Evaluated Mines.

Figure 2 displays the distribution of the studied in-pit facilities across the world. The distribution of in-pit tailings disposal operation reveals a concentration of evaluated cases in Australia (13) and Canada (12), with increasing representation in Spain (2), Chile (2), Mexico (2) and Guyana (2). A lower presence is observed in several other countries, including Peru, Argentina, Finland, Guatemala, Germany, Namibia, the Philippines, and Russia, each contributing one case.

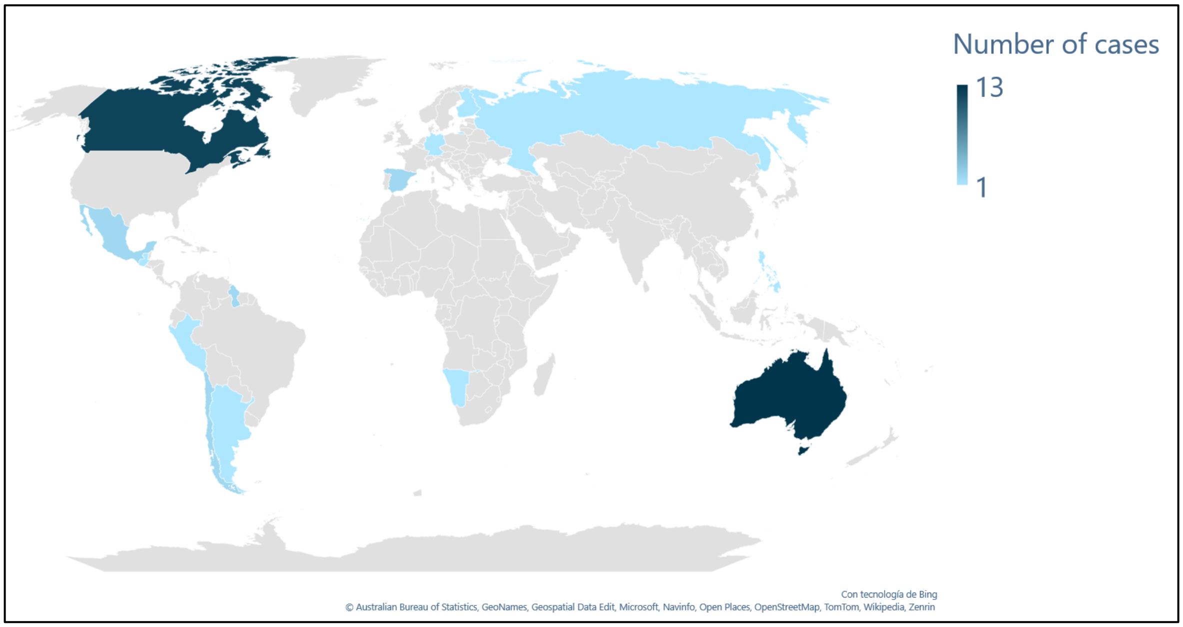

Figure 2 Location of the Considered In-pit Tailings Storage Facilities

General features of each studied case are shown in Table 1. Analyzing the pit characteristics, the predominant pit depth range among the cases is 200 to 380 meters, accounting for the highest frequency with nine cases. Following this, depths of 40 to 80 meters and 80 to 120 meters each comprise five cases. Notably, no instances exceeding 380 meters in depth are evident in the dataset. Regarding pit area, 23 cases are observed within the 0 to 50-hectare range, signifying a prevalence of relatively compact pit areas. Four cases fall within the 50 to 100-hectare range, while single instances are noted in the 150 to 200-hectare and 300 to 500-hectare categories.

It was observed that many of the Australian open pits have relatively low depth and area, generally ranging between 40 to 130 meters deep. Additionally, some mining projects in Australia and Canada have several pits, so some pits become 'empty' and available for filling. Other projects had a deep continuous orebody but start open pit and then shift underground. When shifting underground, pit disposal becomes an option. Considering the giant porphyries of South America, all the evaluated open pits in this study had a considerable depth, all cases over 100 meters. Because of the deposits nature, there could generally be less opportunity to fill the large pits, as an open pit cannot be filled while it is being mined.

Table 1 Evaluated Cases of Study

TSF name - Mine	Country	Commodities	Number of discharge points	Maximum pit depth [m]	Approximate Area [Ha]
San Miguel – Pirquitas	Argentina	Zinc, Silver	1	182	19
Criterion - Bulong	Australia	Nickel	-	14.5	5.5
Cloudbreak and Christmas Creek	Australia	Iron	>5	90	Variable
Venture – Central Norseman	Australia	Gold	>5	-	48
GTD04 – Granites	Australia	Gold	2	<50	14
GTD02 – Granites	Australia	Gold	-	-	10
GTD05 – Granites	Australia	Gold	-	-	26
Fisher – Jundee	Australia	Gold	>5	-	14.5
Panglo – Kanowna Belle	Australia	Gold	>5	-	21
Agneus – Lawlers	Australia	Gold	>5	-	16
K1SE – Marymia	Australia	Gold	>5	48	0.1
K1 – Marymia	Australia	Gold	>5	-	9.3

TSF name - Mine	Country	Commodities	Number of discharge points	Maximum pit depth [m]	Approximate Area [Ha]
ITSF – New Acland	Australia	Coal	-	-	29
Main Pit – Paddington	Australia	Gold	>2	135	66
Beartooth – Akati	Canada	Diamond	>5	190	14
Waterline – Equity Silver	Canada	Silver, Gold, Copper	-	43	4
Main Zone – Equity Silver	Canada	Silver, Gold, Copper	-	350	22
South Tail – Equity Silver	Canada	Silver, Gold, Copper	-	-	2.5
Key Lake – Key Lake	Canada	Uranium	-	-	52
Goose – Meadowbank	Canada	Gold	-	100	17
Portage A – Meadowbank	Canada	Gold	-	75	20
Portage E – Meadow bank	Canada	Gold	-	75	22
Owl Creek	Canada	Gold	-	100	46
Rabbit Lake	Canada	Uranium	-	122	16
Solbec	Canada	Copper, Zinc, Lead	-	40	1.43

TSF name - Mine	Country	Commodities	Number of discharge points	Maximum pit depth [m]	Approximate Area [Ha]
Whistle	Canada	Nickel, Copper	-	-	9.7
Tesoro Central - Centinela	Chile	Copper	-	267	210
FTD – Mantos Blancos	Chile	Copper	1	100	30
Kittila	Finland	Gold	-	-	-
Lichtenberg	Germany	Uranium	-	240	160
Marlin	Guatemala	Gold, Silver	N/A	89	17
Wenot – Omai	Guyana	Gold	1	215	80
Fennel – Omai	Guyana	Gold	1	260	50
Samaniego – El Gallo	Mexico	Gold	-	135	8
Oberón de Weber – Pinos Altos	Mexico	Gold, Silver	N/A	170	17
TSF3 – Larger Heinrich	Namibia	Uranium	-	300	37
Tintaya – Antapaccay	Peru	Copper	>3	380	350
Tapian – Marcopper	Philippines	Copper	-	-	58
Nikolayevsky	Russia	Coal	-	-	-

TSF name - Mine	Country	Commodities	Number of discharge points	Maximum pit depth [m]	Approximate Area [Ha]
Aznalcollar – Los Frailes	Spain	Zinc	-	275	35
Los Frailes Pit – Los Frailes	Spain	Zinc	-	265	24

Majority of the studied cases have shown to use several discharge points for tailings discharge and have implemented water recovery systems. Using several discharge points have considerable advantages. It provides more control for the location of the supernatant pond, which facilitates the design and operation of the surface water recovery system. Using several discharge points may also facilitate tailings beach formations, favoring consolidation processes for increasing lifespan of the tailings storage facility and reducing closure and post-closure consolidation (McDonald et al., 2010). Information regarding groundwater management systems was scarce and it was not included in this study.

Regarding the concentration of weight in solids, it is observed that the majority of the studied cases exhibit a Cp with an average 55% in weight. However, some deposits, such as Marlin and Pinos Altos, stand out due to the use of filtered tailings (Cp > 78%) for fill. In the context of disposing filtered tailings, a noteworthy advantage relies in the reduction of the need for water recovery, as water recovery systems may be more complex for in-pit facilities.

DISCUSSION

This article provided a comprehensive analysis of in-pit tailings disposal, highlighting its advantages, disadvantages, and challenges. The findings underscore the importance of adopting a systematic approach to identify and mitigate potential risks and ensure the effectiveness of in-pit disposal projects.

In-pit tailings disposal offers significant advantages, including the repurposing of impacted areas to minimize environmental impact and the reduction of embankment dams, mitigating risks associated to the uncontrolled release of tailings. Additionally, the extended operational history of pits may provide valuable precedents for feasibility assessments, although challenges such as groundwater contamination and complex underdrainage systems must be carefully managed. While in-pit disposal greatly reduces the consequences of failure modes associated with conventional tailings dams, it introduces distinct design criteria and risks, requiring diligent management throughout the mining operation lifecycle. Furthermore, the limited availability of open pits and the voluminous requirement for storing the entirety of tailings production underscore the necessity for in-pit tailings storage to function as a complementary rather than standalone solution. Despite these challenges, in-pit tailings disposal represents a promising approach for sustainable mining practices, underscoring the need for strategic planning and multidisciplinary collaboration in tailings management.

The analysis of 41 in-pit tailings disposal projects spanning diverse countries reveals a significant concentration in Australia and Canada, suggesting a widespread embrace of this approach in these regions. This dataset is ongoing research envisioned as a preliminary step towards establishing a globally representative database.

General trends of the studied characteristic underscore the method's adaptability and effectiveness within varying geological and operational landscapes. Particularly in mining operations featuring multiple open pits, in-pit disposal emerges as a particularly advantageous solution, as these pits may swiftly become available for filling as mining progresses. Chilean mining projects, predominantly defined by vast copper porphyries, present unique challenges due to the expansive size of their deposits, suggesting prolonged operational lifespans before mines reach decommissioning stage and are prepared for filling. This needs a long-term perspective and strategic tailings management approaches to ensure effective planning and implementation. Moreover, the cultural and historical context of the Chilean mining industry has been deeply entrenched in traditional approaches for open pit and tailings management. The introduction of the concept of in-pit disposal represents a significant departure from established practices, requiring a paradigm shift that is still in the process of being fully adopted by the Chilean industry.

Finally, it is worth remarking that while the pit serves as an alternative for tailings disposal, it cannot be the sole solution. Proactive planning and predesigning are necessary, and it could even lead the transformation of the open pit into a conventional tailings storage facility once it has been filled. This adds an intriguing dimension. If this approach were adopted, it prompts the question of how adjustments in the initial design and operational strategies of the pit would be warranted.

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