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The Vale Brazilian Dam Collapse: An Ethical and Engineering Disaster

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ABSTRACT: *Vale S.A. is the largest iron ore mining company in the world. On January 25, 2019, Dam1 of Vale's Corrego do Feijao iron-ore mine in Brazil collapsed. The dam was built upstream on a mountain in order to contain mining waste or tailings, which are made up of dirt, rocks and bits of ore that are dumped into a dam reservoir. The mining waste was estimated to be travelling as fast as 50 miles an hour downhill toward the city of Brumadinho. The mining waste killed 270 people within minutes, and it is the deadliest mining disaster of its type in more than 50 years. Mine sediment from the dam was found as far away as 119 miles from the dam.*
There were several causes for the dam's failure including: the use of cheap materials, Vale's managers ignoring warnings of structural problems, and monitoring equipment that was no longer working. Both Vale and its safety inspector TUV SUD are under criminal investigations for their actions leading up to the dam collapse.
Keywords: *Brazilian mining industry, collapsing dam, Vale S.A. TUV SUD.*

I. INTRODUCTION

Without warning, on January 25, 2019, the area surrounding the town of Brumadinho, Brazil would, within minutes, be inundated with a muddy mixture of dirt, rock and ore. The Dam1 in Vale's Corrego do Feijao mine had collapsed. As the thick mud moved downhill, there were no warning sirens to inform the people of the town to evaluate. The collapse occurred at lunchtime so many Vale employees died instantly as the mud destroyed the cafeteria on the way down the mountain. Vale responded to the disaster by stating that, "The dam had a safety factor in accordance with the world's best practices… (and that it could) attest to the physical and hydraulic safety of the dam."

There were several causes for the dam's failure, which included the use of cheap materials, management ignoring warnings of structural problems, and some monitoring equipment that was no longer working. The dam had been inactive for almost three years and it was certified as stable in September 2018. In response to the criticism that it did not warn the people of the collapse, Vale did not have enough time to sound the warning system (Darlington et al, 2019).

II. THE MINING PROCESS AND TAILINGS

Tailings are the byproduct of the mining process of extracting valuable metals from raw ore. There is a four-step process which takes place for the tailings to end up in a dam reservoir. The first step is the iron ore being mined from the earth and then finely ground through a milling process. The second step is the addition of water and sometimes chemicals to the milled rock in order to separate the metal from the ore. The third step occurs after the metal is extracted. The byproduct of the process is called the tailings and is a very thick mud like texture called slurry. The last step is pumping the slurry into a reservoir in a dam, which is designed to last for centuries(Kowsmann et al, 2019).

III. DANGERS OF TAILING DAM RISKS

A tailing dam is built by taking the tailings and using them as a wall of the dam. The mud like tailings are dried and then used to create the dam wall. As the tailings increase within the dam reservoir, the mining company adds new layers to the wall using the tailings. As a result, there is no structural foundation for the dam other than the dried tailings. There are no steel or wood reinforcements for the wall. As a result, this type of dam is considered to be extremely dangerous since the integrity of the dam wall can be easily compromised. An upstream tailings dam refers to the location of the dam in a mountain location. Upstream means that the dam is above the ground and, therefore,

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would threaten everyone who lives downstream at the bottom of the mountain. In mountainous countries in South America, upstream dams are very common with towns located at the base of the mountain.

There are four major risks when maintaining the safety of a tailings dam. The four risks are: water, weak foundation, rate of rise, and height and angle.

3.1 Water

Water is the most dangerous risk of any tailings dam. If water leaks into the dam, it saturates the dam walls and/or the tailings beneath an upstream dam. If enough water enters the dam area, the whole structure can liquefy and can create a mud slide which will pick up speed as it moves downhill.

3.2 Weak Foundation

A weak foundation of the tailings dam will destroy the integrity of the dam. If an undetected layer of clay or silt moves beneath the tailings dam, the foundation is weakened, in addition, clay and silt drain very poorly which allows water to accumulate within the dam.

3.3 Rate of Rise

The tailing dams increase in height by adding layer upon layer of tailings to the existing dam structure. For upstream tailing dams, this increase in height should occur slowly in order to allow the solid tailings time to dry in order to support the new higher level of the dam. This is critical since this new layer must withstand the immense pressure for the material inside the dam. Mining companies must have the patience to let the new layer "set" before releasing more material.

3.4 Height and Angle

The dam's height and angle are critical since the taller the dam, the greater the disaster if the dam fails. Therefore, the steeper the angle of the dam, the higher the risk of failure. For upstream tailings dams, engineers recommend a moderate 25 percent gradient which is flat enough to walk up.

The rise of collapses of upstream tailings dams has increased due to the general decline of the amount of ore that is discovered globally. As the supply of ore decreases, the mining companies must dig up more dirt and rock which leads to more tailings. This increase in tailings has been drastic since 2000. In 2000, mining companies produced 4 billion metric tons of tailings annually which increased to 7.4 billion metric tons in 2010 and 8.5 billion metric tons in 2017. This increase in tailings results in constantly increasing the height of the tailings dam to accommodate the increased volume of tailings.

Upstream tailing dams are a popular choice since they are cheaper than other designs; an upstream dam is between one-half to one-quarter as expensive as much safer downstream dams. Upstream dams are cheaper since they do not require the same amount of digging as must occur for a downstream dam. A downstream dam is built outward from the tailings reservoir and has a bulkier design. While upstream dams are banned in Chile due to potential earthquakes, there are 12,000 tailing dams in China in which 95 percent are upstream. Climate change is also a factor since the original belief was that tailings dams were built to last for centuries. However, due to changes in weather patterns, including more common intense rainfalls, this cascade of rainwater converts the tailings into a liquefied mud that results in the collapse of the dam (Patterson, 2019).

IV. THE BRUMADINHO DAM

The Brumadinho Dam was 280 feet in height and did not have a separate concrete or metal wall to retain the mud. The dam was made of mud which had to remain solid for the tailings mud to be contained. The Brumadinho Dam was created using compact material that acted like a dyke for the tailings mud. As the mining process continues, new dykes were built upstream on top of the solidified mud tailings. The building of new dykes can result in the "landfill" of mud reaching the water table which would result in high water pressure.

This high water pressure could potentially breach the dam and create the liquefaction of the mud. When liquefaction occurs, the solid mud becomes a liquid and the increased pressure results in the dam breaching and the mud flowing downhill and burying everything in its path. However, other factors such as heavy rains or poor management of the dam can also create enough internal pressure to liquefy the mud. When the Brumadinho Dam collapsed, it sent 11.7 million cubic meters of mining waste downhill toward the town. That was enough waste to fill almost 5,000 Olympic swimming pools (Darlington et al, 2019).

V. BRAZIL'S REGULATORY PROCESS OF MINING DAMS

Brazil's National Mining Agency employs 34 field inspectors of which 20 specialize in dams. Those 30 inspectors are responsible for evaluating approximately 770 mine dams in Brazil (Kowsmann et al, 2019)

In Brazil, there are 87 upstream mining dams of which 83 have been rated by the Brazilian government as vulnerable to collapse. In addition, at least 27 of those dams are located directly uphill from cities or towns which have a population of more than 100,000.

Due to the shortage of government inspectors, mining companies in Brazil are allowed to self-regulate and hire independent auditors to verify the safety of a dam through regular inspections and the analysis of written records provided by the firm. This creates a potential of conflict for interest since the firm is paying the auditor to do an evaluation in which the firm expects to receive a clean audit without any concerns (Darlington et al, 2019).

The power of the mining industry in Brazil allows mining companies to determine, in part what information the companies make available to various stakeholders including the government, employees, suppliers and local communities. This lack of transparency can encourage the managers of the mining companies to ignore complaints and take unethical and potentially illegal shortcuts in its operations. The net result is an industry that makes decisions without the constant monitoring of its stakeholders.

VI. THE ROLE OF TUV SUD

TUV SUD was founded in 1866 and has 800 locations globally, working in industries such as mining, telecommunications, nuclear power, railways and healthcare. Its trademark can be found in numerous consumer and industrial products across Germany representing safety and quality in the testing of its products.

Employees of TUV SUD are both safety inspectors and consultants for Vale which presents an inherent conflict of interest. In another example of the close relationship between TUV SUD and Vale, TUV SUD employees have also co-authored research reports with Vale and spoke at conferences with Vale. In Brazil, it is customary for companies such as TUV SUD to act in the roles of both safety inspector and consultant for its client. Gavin Mudd, an environmental engineering professor at Australia's RMIT University, stated, "The expertise is too connected with those controlling the money – and nowhere near enough emphasis on protecting public interest." (Knowsmann and MacDonald, 2019).

TUV SUD had warned Vale in a 128-page report in September 2018 that faulty water drainage and inoperative monitoring systems increased the potential risk that the Brumadinho dam would collapse. A report by the inspectors presented to Vale stated that flaws in monitoring crucial water concentrations and drainage made it difficult for TUV SUD and Vale to fully evaluate the stability of the dam. The report discussed damage to the draining systems in certain parts of the dam including the water-drainage tubes and channels. These channels are grooves that are cut into the dam in order to allow water to flow and be drained from the dam reservoir. Some of the drainage damage was due to the trampling of large animals such as cows and the drainage tubes were clogged by vegetation causing water to build up inside the dam. The report stated that "Not all drains had siphons to prevent air entry…In some cases, even though there were siphons, they were installed upside down." In some lower levels of the dam, there was no drainage at all, and pockets of water were forming on the surface of the dam reservoir. Furthermore, the dam collapse could be triggered by an external event such as a small earthquake, nearby explosion or the presence of heavy machinery. The vibrations from these activities could threaten the integrity of the dam. Yet, Vale did not have a seismic monitor to measure ground activity in the immediate area around the Brumadinho Dam. TUV SUD had recommended that Vale should install one.

Built in 1976, Vale had bought the dam in 2001 from ThyssenKrupp. When purchased, Vale had few details of the history of the dam. The TUV SUD report stated that "Little data about the dam's foundation and the reservoir was found." The net result was that TUV SUD or any other inspector could only rely on current information pertaining to the dam and, therefore, had to make conclusions based on incomplete data. Eduardo Marques, an engineering and geology professor at the Federal University of Vicosa in Brazil, commented, "The structure was not well known…There is a great lack of information about the real situation of the dam from the geometric, geotechnical and hydrological point of view." Even though the dam was over 40 years old, information related to the process of adding layers to the dam in the past was not available. Despite these warnings, TUV SUD had certified that the dam was stable. *The Wall*

Street Journal asked two independent mining experts to review the report and concluded that, in their opinion, the dam was not stable (Knowsmann and Patterson, 2019).

Makoto Namba, who was a senior engineering inspector for TUV SUD, along with other inspectors found evidence of risk conditions that the dam that was holding back 11 million cubic meters of mine waste. After the May 2018 inspection of the dam, Namba wrote that "Everything suggests (the dam) won't pass." Nambe felt pressured by Vale to sign the safety certification since Vale needed the certification in order to continue operations. The operations at the mine associated with the dam yielded $1 million of iron ore daily for Vale. Namba and the other inspectors were also concerned that Vale would stop working with TUV SUD in retaliation for not certifying the dam as safe. Namba also thought his own career at TUV SUD would be jeopardized since TUV SUD had contracts for safety audits at 30 other Vale dams located in Brazil.

In September 2018, Makoto Nambe signed off another certification that concluded that the Brumadinho Dam was stable. Namba had won an award from a local trade organization for a research project he had co-authored with Vale including its geotechnical risk manager. The project focused on analyzing a new Vale methodology that was being used to detect and measure risk at its tailing dams including Brumadinho Dam. The conclusion of the report, in part, was that the Brumadinho Dam had a low probability of failure (Knowsmann and MacDonald, 2019).

In reaction to the disaster, a Vale spokeswomen stated the Vale trusts the conduct of the contractors it hires and the employees of the contractors "Vale is committed to the safety of its structures and has a structured system to manage the dams that includes several technical and governance actions." (Kowsmann et al, 2019).

VII. THE CONSEQUENCES OF THE DISASTER

On February 15, 2019, the Brazilian police arrested eight employees on suspicion of first-degree murder for their role in the Brumadinho Dam disaster. In the arrest warrant, Judge Rodrigo Heleno Chaves stated the eight people were "fully aware of the instable situation of the day." The judge also stated that Vale had found a "drastic variation" in its monitoring instruments just before the dam collapse and that Vale management should have ordered an immediate evacuation of the people downhill from the dam.

The police also carried out search and seizure warrants of the Brazilian subsidiary of TUV SUD. Emails that were included in the arrest report stated that the TUV SUD engineer, Makoto Namba, who was part of the inspection, saw indicators that the dam was at risk of liquefaction in which the solid tailings would become a murky liquid. Namba stated that despite his concerns, "…as always, Vale is going to push us to the wall." (Darlington, 2019)

On March 4, 2019, Vale's CEO, Fabio Schvartsman, and eight other top executives agreed to temporarily step aside as prosecutors investigated whether there was criminal negligence as part of the dam collapse. Vale barred the top officials from firm facilities and forced them to cease all business operations. In response to the dam collapse, Schvartsman stated that "I'm absolutely convinced that my personal conduct and that of the members of our leadership, who are now being asked to step down, was absolutely adequate, correct and, chiefly in keeping with our nonnegotiable commitment to security in the company's operations."

Brazilian prosecutors had alleged that the contractors hired by Vale to monitor safety standards were a conflict of interest since Vale paid these contractors and the contractors wanted to continue to work for Vale. To demonstrate Vale's level of power in this relationship, Vale no longer hired a safety auditor that raised warning signs about the dam. When Vale hired another auditor, it got a clean safety audit (Londono et al, 2019)

On July 10, 2019, a judge in Brazil ruled that Vale was financially liable for the damages that were created because of the dam collapse. The judge ruled that the damages are "not limited to the deaths that resulted from the event, since it also affects the environment locally and regionally, as well as the economic activity of surrounding communities." (Londono, 2019).

In October 2019, the Brazilian police completed a report from investigations of criminal actions by Vale and TUV SUD. The Brazilian police believe that top level executives and managers at Vale deliberately shielded themselves from information pertaining to the dangers of the dam collapsing in order to avoid legal liability. Up to a year before the collapse, Vale's own consultants conducted studies that warned that the structure of the dam was fragile and would eventually collapse. The police report stated that "The top bosses of Vale continued to…boast about the falsely

impressive quality of their structures…They closed their eyes to studies commissioned by the company itself, preferring to remain ignorant so that, in a moment like this, they could allege ignorance as their defense." The report also stated that Vale and TUV SUD ignored the warnings of its safety factor. The safety factor is a standard metric used to assess the safety and stability of the dam. The minimal safety level for Vale is 1.3 (the larger the number, the safer the dam). TUV SUD calculated the safety factor for the Brumadinho Dam at 1.09. As a result, TUV SUD had to develop a methodology to justify why it still considered the dam stable despite a safety number below Vale's acceptable level (Pearson and Magalhaes, 2019)

On November 15, 2019, the International Council of Mining & Metals published a draft proposal for strict new global standards to monitor how firms build and operate the type of tailings dam like the one that collapsed in Brumadinho. The new rules would require mining firms to design and monitor its dams based on tougher benchmarks. The mining companies would also require comprehensive public disclosures on the dam's operations and would specifically prohibit any conflicts of interest between the mining companies and independent safety auditors that the firms hire to inspect the dams. The draft also states that the mining company's board or senior management would need to approve proposals for new dams with high hazard ratings and develop steps to minimize the consequences of any collapse (MacDonald, 2019).

VIII. BRUMADINHO AS A STAKEHOLDER

Two hundred and seventy people died from the mud sludge that was released from the Brumadinho Dam. In November 2019, Vale announced that it was going to close the Corrego do Feijao mine where the collapsed dam was located. The mine closure resulted in the elimination of at least 600 jobs and it reduced tax revenues of Brumadinho by 20 percent. Vale's recovery and development director, Marcelo Klein stated that Vale cannot resume the operations of the mine "out of respect for the victims". Furthermore, rescue workers found only body parts of some of the victims so that the areas impacted by the collapse are considered mass graves.

Vale agreed to pay the family of each victim $25,000 and paid an additional $175,000 to the family for damages if the family agreed to settle out of court. Vale also gave everyone living next to the mine $13,000 and nearby farmers and other business received $4,000. Vale also paid over 100,000 people in the region as much as $250 a month through the end of December 2019 as compensation for the disaster. The payment of $250 a month is equal to the monthly salary of a full-time minimum wage job. Vale also stated that it would pay the salaries of the workers for three years after the mine was closed.

Vale had agreed to pay the town of Brumadinho $20 million through the end of December 2020 as compensation for the loss of revenue. The mine's operations had contributed nearly $1 million monthly to the municipal budget and, when that revenue stops, the town will be forced to eventually close down health clinics, hospitals and other city services.

For Vale, the closing of the mine will not have the same financial impact. The mine accounted for just 2 percent of Vale's total iron-ore production and Vale can make up that loss by increasing output in other mines (Pearson and Magalhaes, 2019).

IX. DISCUSSION

Two hundred and seventy people lost their lives when a dam collapsed on the side of a mountain in Brazil. The tragedy is not only the loss of life, but that this disaster could have been avoided. Despite warning signs and safety issues related to the Brumadinho Dam, Vale managers continued to ignore the warnings and did not make the proper adequate safety adjustments needed in order to stabilize the dam. The compromised foundation of the dam could also be applied to the compromised ethical foundation of the managers at Vale. By focusing only on one stakeholder, the shareholder, Vale ignored the needs and expectations of its other stakeholders. The net result is the loss of Vale employees, the loss citizens of Brumadinho, and the financial impact on the town itself.

X. REFERENCES

1. Darlington, S., Glanz, J., Andreoni, M., Block, M. Pecanha, S., Singhow, A. and Griggs, T. (2019). A Tidal Wave of Mud. *The New York Times*. February 9.
2. Darlington, S. (2019). Brazil Arrests 8 at Mining Giant Vale Over Deadly Dam Collapse. *The New York Times*. February 15.
3. Kowsmann, P., and MacDonald, A. (2019). Inspectors of Collapsed Brazilian Dam Had Close Ties to Its Owner. *The Wall Street Journal*. February 1.

4. Kowsmann, P., and Patterson, S. (2019). Inspectors of Vale Dam in Brazil Issued Warning Before Collapse. *The Wall Street Journal*. February 6.
5. Kowsmann, P., Pearson, S., Patterson, S., and Magalhaes, L. (2019). Behind Vale's Deadly Dam Collapse: Multiple Warnings That Went Unheeded. *The Wall Street Journal*. February 24.
6. Londono, E., Andreoni, M., and Hsu, T. (2019). Leaders of Brazil Mining Giant Vale Step Down as Criminal Inquiry Widens. *The New York Times*. March4.
7. Londono, E. (2019). Brazil Judge Holds Mining Company Liable for Damages of Deadly Dam Breach: *The New York Times*. July 10.
8. MacDonald, A. (2019). Brazil Dam Collapse Prompts Potential Rule Shakeup for Miners. *The Wall Street Journal*. November 15.
9. Patterson, S. (2019). Deadly Brazil Mine Accident Puts Waste Dams in Spotlight. *The Wall Street Journal*. January 30.
10. Pearson, S., Magalhaes, L. (2019). Brazilian Authorities Signal Intent to Focus on Vale Executive in Probe of Dam Collapse. *The Wall Street Journal*. October 18.
11. Pearson, S., Magalhaes, L. (2019). Vale Showered Cash on the Mining Town It Buried. Now It's Pulling Out. *The Wall Street Journal*. November 13.