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Re: Dairi Prima Minerals (DPM) Mine site risks and Tailings disposal safety.

Summary: Based on information available, and without a site visit, I provide comment on tailings dam stability risks associated with the Dairi Prima Minerals (DPM) mine in Dairi Regency, North Sumatra.

In 2005, the DPM mine has obtained Indonesian Environmental Approval - but since then, the plans have changed. The proposed mine is significantly larger than originally proposed. This represents increased challenges for containing toxic tailings. I understand that the Indonesian Ministry of Environment and Forests has informed DPM that new environmental approval is required, but this approval has not yet been granted.

Based on most recent DPM information, my estimate is that an above-ground storage facility of approximately 18 million cubic meters volume will be required for “wet” tailings disposal. The DPM mine, however, is in an area that has one of the highest earthquake risks in the world. There is high risk of large magnitude earthquakes. In addition, earthquakes are likely to be long duration quakes. Such long-duration quakes have been found in other areas to be especially risky to any civil structures such as tailings dams.

The DPM mine site is also situated in an area of very high flood and landslide hazard. With a watershed of about 10 square kilometers, a 1 square kilometer tailings pond would have to handle in the order of 5-10 meters of water level rise in a storm, which adds a 5 mcm flood storage demand to the base level of the tailings. Landslides would place even further demands on any tailings dam facility.

The area where a tailings dam would be required is also one with complex geology - sedimentary material and more-recent, volcanic tuff. Such conditions represent significant concerns for any tailings dam facility.

In this environment, it appears that DPM are resistant to releasing information, and the regulatory environment is weak. Such factors combine with the seismic and flood risks and, in my opinion, the DPM mine represents extremely high risk of catastrophic tailings dam failure at some time in the future. Given that a number of communities are located downstream from the mine site, this represents a serious threat to human safety. It would also represent a high environmental hazard.

This letter report concerns the geotechnical safety of the mine waste (tailings) storage facility for the Dairi lead-zinc mine at coordinates 2.78, 98.15 NW Sumatra, Indonesia. I understand the construction of the project has begun in early 2020. I have not visited the site. My review is based on information from news releases and on information originating from the Dairi Prima Mineral mining company. In the absence of public information, I have used past Dairi Prima Mineral estimates of site conditions and operations, on my past experience with similar projects, studies of satellite imagery, published geological reports, land acquisition maps, first-stage construction observations included in DPM reports, and images captured by drones in the field.

Major changes in the size of this mine have been proposed over the past 20 years. In the 2005 period the project was described as mining a relatively small (6 mt) high grade and relatively accessible lead-zinc ore body. Over the years the proposed project has been much expanded, up to 30 mt, with the addition of lower grade, less accessible ore[1].

No detailed information on the feasibility and safety of the substantial surface waste disposal works necessary for the mine appears to have been made public. This is surprising because:

1. the major earthquake risks of large tailings storage projects are globally recognized (Cai, Wang, et al Liquefying-damage of mine tailings dams in earthquakes)

2. New technologies aimed at reducing these risks have not been successful, a fact noted recently in a Wall Street Journal article (After Deadly Dam Spills, Miners Seek a Better Way—It Isn't Working Out 12/22/19). Thus, waste disposal problems have come to the forefront as constraints to new and expanded mining operations.

My qualifications and previous experience

Following my graduation with engineering degrees from MIT and Imperial College I worked in tropical Northeast Thailand designing and building dam projects. In the late 1960s I consulted with the Chilean copper mining company Sociedad Minera El Teniente on sites for hydropower and tailings dam sites (following the famous 1965 disastrous seismic failure of the El Cobre tailings dam). Back in California in the 1970s I worked with prominent Engineer Thomas Leps evaluating earthquake safety of many hydraulic fill mining dams following the earthquake-induced San Fernando hydraulic fill dam failure in Los Angeles. My partner Douglas Hamilton and I also formed a partnership with Australian engineers and worked on planning for several tailings dams in Australia and Bougainville. Subsequently we helped establish a new program in Engineering Geology at Stanford University, where I taught for many years and retain my connection with the Blume Earthquake Center.

Since that time my work has been focused on dam and nuclear power plant safety seismic problems. My most recent project is an evaluation of the 2018 failure of the Xe Pain Xe Namnoy project in Laos. In that project there are many of the same geographical conditions and problems as appear to exist in the Dairi project (except Dairi also has high earthquake risks). Having published that review I was asked to provide the study reported here.

Project description

The Dairi Mine is a proposed underground lead zinc mine located in a rural mountain area southwest of the Sumatran city of Medan (fig 1). The sequence of DPM plans as best as I can determine follows:

2003: Middleton plan (Middleton, 2003) and EIA calls for Anjing Hitam ore body 6 mt at 1 mtpy, 1/3 solids to upper tailings disposal area

2003-2011: further exploration and designation of "probable" supplementary ore bodies.

2011: Revised expanded project 25-30 mt @ 1 mtpy requiring larger tailings area.

[1] According to NFC, Dairi Prima Mineral (DPM), a subsidiary of PT Bumi Resource Minerals TBK (IDX:BRMS), has obtained a 30-year production permit for the Dairi Lead-Zinc Mine. The mine project includes the Anjing Hitam and the Lae Jahe session, with the total mine life estimated to be 17 years. The expected ore production will be 1 million tons of ore per annum (approximately 3,000 t/day). http://pdf.dfcfw.com/pdf/H2_AN201904181320531728_1.pdf

Recent press releases indicate a planned 1 million metric tons per year (mtpy) production over a 30-year period starting at the present 2020. The plan is to convert part of the liquid slurry mine waste (approx. 20 million cubic meters) into a paste to be used to refill and stabilize underground cavities created by mining. The remainder of the tailings are to be permanently stored on the ground surface as a wet slurry apparently to be contained by a dam. It is common with paste refill operations that 50% of waste remains to be stored above ground. Some preliminary but dated information suggested a lower volume, roughly 35 percent, but in either case a large and a permanent lake of waste would be created.

For the current 30 mt plan, I estimate the volume of above-ground storage for the waste slurry would be on the order of 10 mcm. Additional volume would be required to hold stormwater and landslide debris (see below) and whatever freeboard (reserve storage) is required for safety. Altogether my working estimate for full capacity of the storage facility is about 18 mcm. If this is correct, that would require a tailings facility as shown in figure 2. Note that this estimate assumes complete success in the paste backfill plan, which as yet has not been demonstrated in terms of economics (millions of tons of expensive cement will be needed), technical aspects (a successful recipe has not been shown) or safety (the paste backfill could increase the possibility of toxic chemical leakage from the abandoned mine into the environment).

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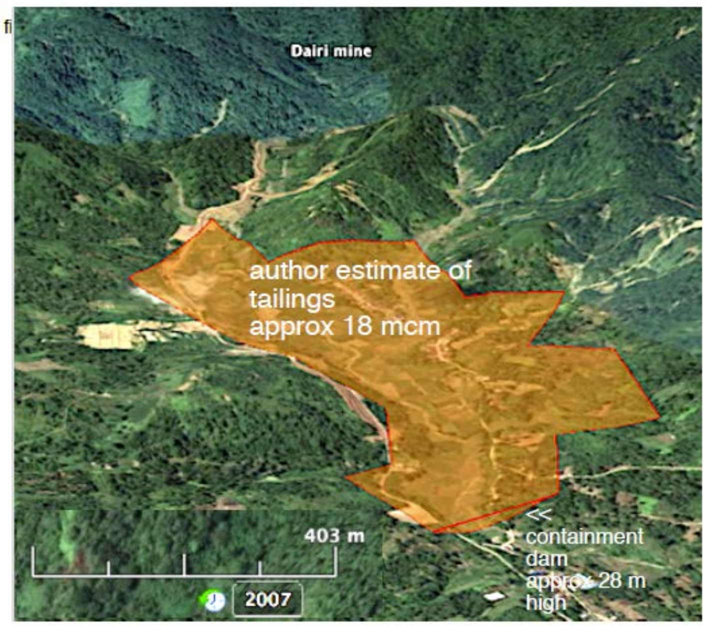

Figure 2. View of author's estimate of tailings

Tailings dams, including those that are said to incorporate more modern safety measures, have a high failure rate (2 to 5 per year globally) even in the absence of earthquakes (see specific discussion of Dairi's earthquake risk below). Canada's Mount Polley tailings failure in 2014 is a notable example of a failure that was not supposed to have occurred given the high-level policing by the Canadian safety authorities. The mining company had failed to detect a local weak zone (glacial lacustrine deposits) in the foundation of the retaining dam.

More recently world attention was drawn to the failure of a tailings deposit at the Brumadinho Mine in Brazil. The spontaneous collapse (no earthquake involved) was recorded in a dramatic video[2] that instructively shows the speed and geographically extensive reach of destruction, including more than 200 deaths in this case, that results from a breached "wet tailings" deposit. Note that the hazard here does not go away in time; a failure is as likely to occur 100 years from now long after the project has been "closed".

Other environmental conditions besides earthquakes threaten the safety of tailings dams. High rainfall is conducive to ground failures in the hills above the tailings, creating landslides and debris flows. Wet climate

[2] www.youtube.com/watch?v=uI4Lq3Lf_yw

makes it impossible to allow for drying of tailings with the result that the tailings have both high water content and also impound water, which adds significantly to instability and high mobility in the case of even a minor breach. As shown in my investigation of the Xe Pian Xe Namnoy dam in Laos (Meehan 2019, fig 5a herein), tropical conditions critically weaken foundation support for heavy structures such as even small containments and also allow for development of powerful groundwater pressures that undermine stability. All of these water conditions prevail at the site of the proposed Dairi mine tailings area (see specific discussion of Dairi's flood hazard below).

Although the mining industry in response to widespread calls (see Wall Street Journal 12/22/19) for elimination of these tailings facilities has attempted to develop improved procedures since the notable tailings failures in the 1960s, the world safety record has actually deteriorated over the years. The reason for this surprising trend is that less rich ore bodies have been tapped, creating larger tailings outputs and, especially in times of falling mineral prices, extreme last-ditch attempts to reduce disposal costs. Late in the life of many mining projects ownership and personnel changes are common and supervision wanes. The writer has personal experience in attempting to guide safety measures in such a situation. Attempts were made to substitute remote camera inspection for on-site supervision but proved ineffective and on-site miners were given large incentive to minimize costs, often resorting to unsafe "temporary" measures that were never corrected as the facility was rushed to "closure". At the end it is often found that the companies involved do not offer any assurances of maintenance of the "closed" deposits, thought the same safety concerns remain and actually often increase in the years, decades, and even centuries ahead. Recent calls by expert reviewers of failures have called for stronger legal measures to assure long-term responsibilities for safety, including extension of liability to corporate entities and directors.

The expansion of scope of the Dairi project from 6 to 30 mt fits the pattern of a mine with eventual decreasing profitability subject to exactly the waste disposal problems described above.

Local Geological Conditions Relevant to Safety

Of special importance are the characteristics of foundation in tailings dam areas. Rocks underlying the entire project area (and containing the various ore bodies) are dominantly very old (Permo-Carboniferous) rocks, carbonaceous shale and dolomitic siltstones, which have been faulted and folding by plate convergence in the Sumatran west coast (Pale green in Figure 3a). According to Middleton 2003 the formation consists of tilted beds with an EW strike and a northerly dip of about 45 degrees with fracturing from brittle tectonic deformation. Inspection of various photos showing recent (2019) road cuts in the Sopokomil valley suggest that the sequence of dipping beds carries down northerly into the hills that flank the valley as shown in my sketch fig 3a.

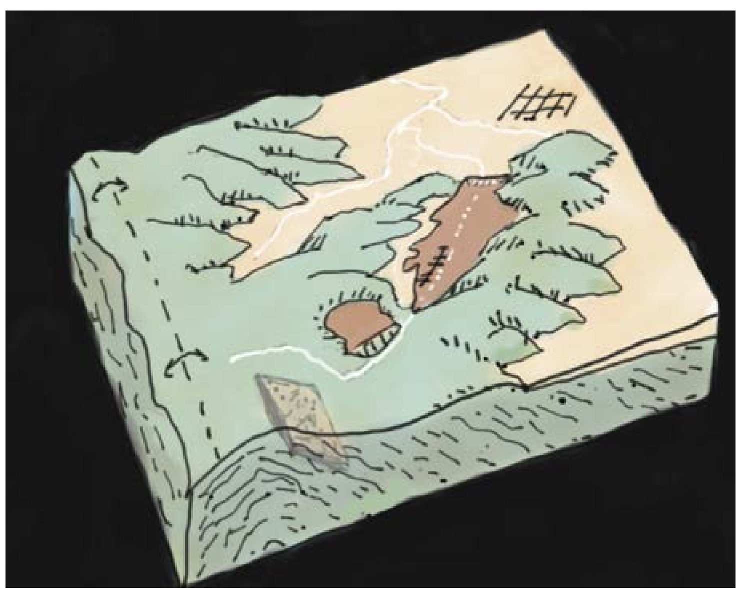

Figure 3a Sketch of general geological features and reported alternate tailings dam disposal areas.

The eruption of the Toba caldera some 70k years ago flooded the region with hot ash flows (ignimbrite), generally described as the Toba Tuff (pale yellow in Figure 3a). According to Middleton (apparently based on Aldiss et al, 1983) these deposits underlie the Sopokomil valley floor, site of the proposed tailings area. These volcanic deposits are generally taken to be variably cemented ("welded") but reportedly near the surface often take the form of a light ashy deposit which are found in some stream bank deposits according to photographs which I have seen. Aldiss et al describe the shallower tuffs regionally as being air-fall, unwelded, and often fluvially reworked. This type of rock is usually low in density, subject to disintegrative weathering, and even where welded, fractured and water-bearing. The interface between the tuff and underlying older rock, at depth unknown here, is often highly permeable and a potential zone of instability because of its water-carrying capacity. An example of such instability is presented in a paper (Gratchev et al, 2011) on the 2007 earthquake at some distance from Dairi but in similar terrain where large landslides of tuff deposits burying villages with many casualties were triggered in 2007 by a combination of earthquake and heavy rainfall.

It has been suggested (Hamilton, oral communication) that the Sopokomil valley and nearby canyon may be the site of an older caldera defined by a circular ridge line which can be seen in figure 4. Such features are often underlain by rhiolite rocks associated with a rising body of extrusive lava. Such rocks are typically fractured and water-bearing.

Inspection and photos of the creek beds within the area mapped as tuff near Sopokomil revealed a dominance of bouldery alluvium derived from flood and debris flows from the older rocks found upstream including the ore body area.

Although the geotechnical investigations necessary to determine the stability of the foundation areas for the likely (2020) tailings and retaining dam have not been conducted, to my knowledge the evidence at hand indicates that the foundation is almost certain to contain many geological features as described above that are problematical, being subject to high instability in earthquakes and heavy rainfall.

Earthquake risk

The mine is located in one of the world's most active earthquake regions, along the Sumatra subduction megathrust apparently near a triple plate junction which produced in 2004 and 2005 earthquakes of magnitude 9 and 8+ respectively (fig 3). These events rocked buildings as far away as Bangkok and produced intense regional damage including to road embankments and bridge abutments, which are similar in their behavior to tailings dams. Intensity of ground motion produced destruction of facilities at Banda Aceh, which is a comparable distance from the earthquake to the Dairi mine. Japanese investigators (see Sorenson et al., 2007) found that damage was up to about level 6, Japanese JMA scale. This damage category (6.0-6.4) produces these effects:

Impossible to stand; cannot move without crawling...Bridges and roads suffer moderate to severe damage...Multi-story apartment buildings will fall down partially or completely...Many walls collapse, or at least are severely damaged. Some less earthquake-resistant buildings collapse. Even highly earthquake-resistant buildings suffer severe damage...Cracks can appear in the ground, and landslides take place. a=315–400 cm/s²

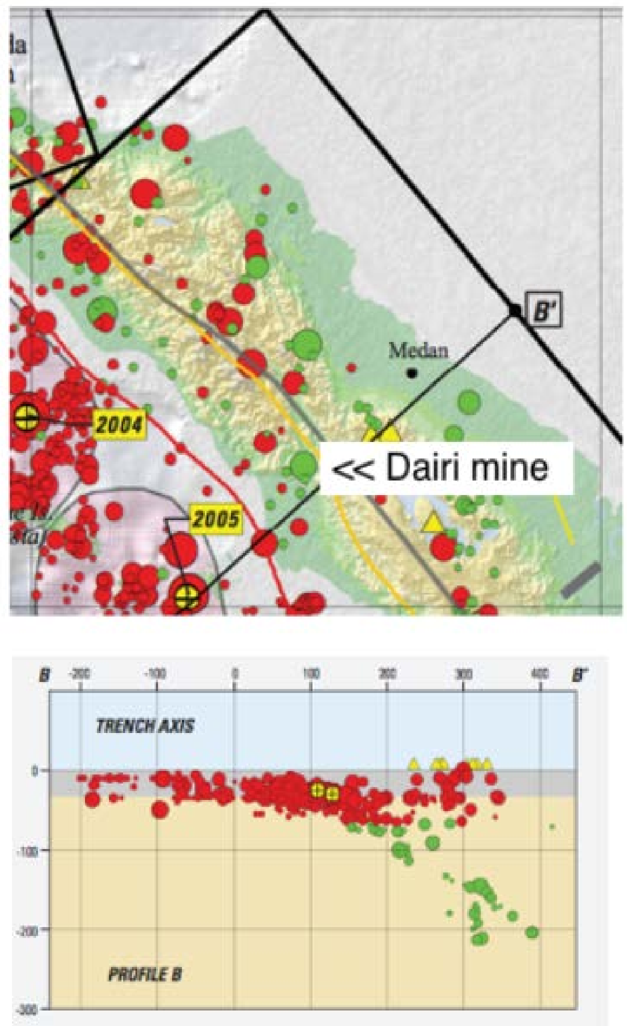

Figure 3. Historical earthquake (Hayes, et al., 2013)

A map and cross section showing historical earthquakes is extracted from a comprehensive summary of seismicity of the area published by the US Geological Survey (Hayes, et al., 2013). This map and many other publications provide comprehensive information on regional seismicity sufficient to evaluate earthquake risk.

Unlike most earthquakes these levels of magnitude 9 on the offshore megathrust produce strong ground shaking that persists over many minutes. This repetition or longevity of shaking can completely destroy structures including dams that would otherwise survive a short-duration quake with only partial collapse (such as the San Fernando dam (fig 6b). Historical records show that such mega earthquakes have occurred regularly over the past two centuries. They are certain to be repeated during the long life of a Dairi tailings facility.

Figure 4. Path of mud wave if a breach occurs.

Although the offshore subduction zone mega earthquake poses a threat to long-period structures like tailings deposits, a more dangerous type of earthquake can be expected from the Great Sumatra fault which breaks ground only 15 km to the east of the Dairi site. According to Peterson et al (Ref Petersen et al., 2004) and others this fault is capable of generating earthquakes up to magnitude 7.5 to 7.9 and at this close distance are likely to produce very high ground accelerations on the order of 50-100% gravity (Figure 5).

As shown in studies of the tailings dam failure at the Wenchuan earthquake in China (Ref Cai et al, figure 6c), embankments, including tailings dams, characteristically concentrate and channel rising earthquake energy toward the crest - so that the destructive intensity may be two or three times greater in the upper part of the tailings compared to at the ground base of the impoundment. It would be extremely difficult and expensive to design a tailings confinement dam that could withstand this level of shaking without cracking and displacement, even assuming the best of all foundation conditions in the valley, an assumption which is not likely to hold true in tropical volcanic terrain.

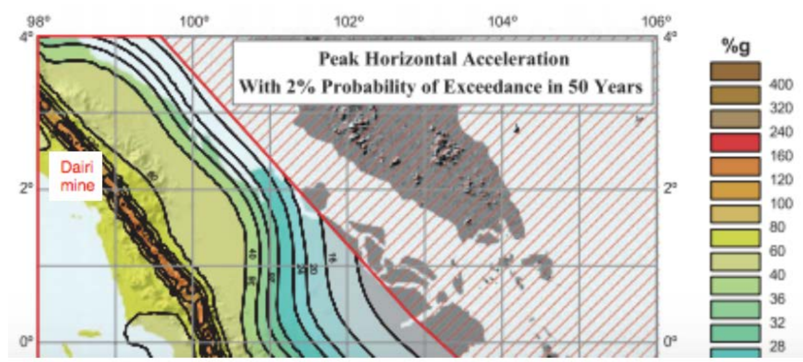

figure 5. Tailings dam very close to Sumatra fault with likely earthquakes up to M 7.5-7.9 and ground accelerations of 100%g

Earthquakes of magnitude 6 to 7 are routine on and near the Great Sumatran Fault and will certainly occur during the mining phase and cause at least some damage to the facility even under the best of conditions -- a robust dry dam built on a strong rock foundation. If the dam and particularly the foundation fall short of this ideal (most likely) the damage will be severe and may lead to a breach. More likely is a foundation consisting of variable volcanic ash and other deposits discussed above that will not provide sound support for the dam.

It is also important to note that over the long term, the next century or more, the dam will be subjected multiple times to these strong earthquakes. These will cause internal displacement within the structure, compromising whatever internal systems are built into it, creating leakage and raising water pressures over time. This threat would not be visible to anyone besides well trained engineers monitoring the safety of the facility with specialized instruments. Even with an expert diagnosis it will be difficult or impossible to repair the damage, especially considering that the earthquakes will come in clusters - main shocks followed by aftershocks (Figure 6d).

In summary, the proposed Dairi Mine is located in one of the highest earthquake risk areas in the world. While it is unclear how DPM intend to deal with the possible volume of tailings, I cannot avoid the conclusion that within a few decades after the "closure" of the deposit there will likely be an earthquake-induced sudden failure of a tailings dam, with a disastrous breach sending a wave of liquid mud downstream to the north.

Flood hazard

A wet climate raises special problems for tailings deposits. It is impossible to attain stability by drying the tailings. Seepage through the tailings, foundation, and abutments of the retaining structure is a perpetual threat to stability and internal erosion that may get worse over time if internal drains and anti-seepage barriers are damaged by such phenomena as earthquakes. Finally, a high volume of water during the wet season increases the mobility of any breach and extends the runout distance of the mud wave downstream after a failure.

The western side of Sumatra is one of the rainiest places in the world with rainfall at the site in the range of 3000-5000 mm per year. Analysis of local rainfall stations show daily rainfall of 300 mm to be common (Dosseur, 1985). Storms of 10 percent of the annual, or say up to 500 mm could occur at the site, and the design flood (sometimes called the "maximum probable flood") dictated by international standards for a critical facility will probably much exceed this amount. With a watershed of about 10 square kilometers, a 1 square kilometer tailings pond would have to handle in the order of 5-10 meters of water level rise in a storm, which adds a 5 mcm flood storage demand to the base level of the tailings. This storm water will include landslide debris from multiple slope failures as can be seen in most satellite images of the area. In addition, the tropical geology of the bedrock invites heavy underground seepage (see Xe Pian Xe Namnoy - Ref Meehan 2018) which adds more danger to dam stability even without earthquakes. The abundance of excess water also invites rapid failure in the case of any cracking or partial failure of the containing system of dikes.

Although active debris flows prevail in the hills surrounding the tailings area, there is no study of possible large semi-active landslides that could also exist and interact unfavorably with the project.

Consequences of tailings containment failure

Failure of the containment for wet tailings would be most dangerous in the wet season with an abundance of water added to the containment. Cracking and sliding of the retaining structure would initially take on the appearance of the partial failure of the San Fernando dam, figure 6b (Castro et al 2003). But the San Fernando dam was subjected to only a few seconds of strong shaking. Larger earthquake from m 7.5 to 9 would produce shaking that would be much longer in duration with cracks and sliding of many meters in even robustly built dams. This would open the embankment to through flow of water and wet tailings, which would breach the Dairi containment (as in the Baldwin Hills Reservoir shown on video at https://www.youtube.com/watch?v=c4sm7DdIMkk) and also the Brazilian Brumadinho Mine.

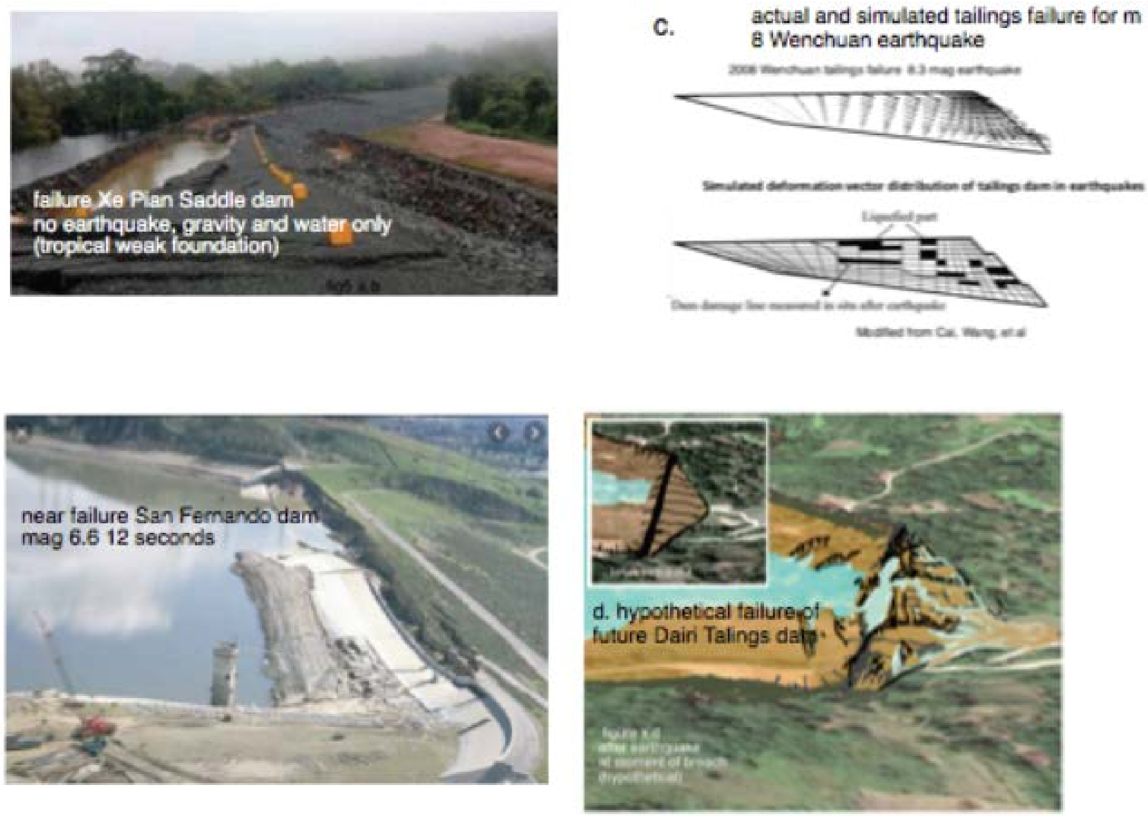

figure 6. a. Failure of Xe Pian dam in Laos 2008; dam breached shortly after this photo with runout of 500 mcm water flowing 100 km and obliterating 6 villages. No earthquake here, but poorly built dam founded on typical weak leaky tropical soils made dam unable to survive filling of the reservoir b. Near failure of the San Fernando dam in California in a short m 6.6 earthquake. Another few seconds of shaking would have breached this dam with a great death toll. c Analysis by Cai, Wang, et al of of a tailings dam in the 2008 Wenchuan earthquake shows that the dam fails in a m=8 earthquake. d. Likely performance of a tailings dam at Dairi mine during a very strong earthquakes, probably from the Great Sumatran fault zone near the site.

Inadequacy of regulation and impossibility of "closure".

At present countries such as Chile and Canada have been bruised by experience for so long and at such a scale that they have developed more demanding supervision or policies of curtailment on the deployment of tailings deposits. Canada, after the 2014 Mt. Polley disaster, realized that its supposed qualified supervision was inadequate and called for new restrictions on tailings facilities with special skepticism directed against "wet" tailings of the type likely at the Dairi Mine. Responsible Canadian reviewers have suggested policy changes including moves to pin liability on directors and "partners" who have in the past devised means of limiting liability. Indonesia has only begun to develop a regulatory agency (training funded by the UN) that has knowledge of dam safety. The country has limited experience.

It has been said that a tailings disposal facility has a “life” of 10,000 years and that there is no way that it can be considered to be “closed” as long as a major hazard remains (which it does in the case of the Dairi location).

Release of toxic chemicals into the environment.

The high sulfide content of the ore body will result in acid formation with dissolving and mobilizing lead and other dangerous substances. Chinese researchers have recently identified this an unacceptable condition at lead-zinc mines that must be prevented (Zhang et al 2012). The geological conditions at the Dairi site favor widespread migration of toxins including lead into the underground environment.

Key data gaps

Mine waste disposal at Dairi raises many technical safety issues including those related to acid mine drainage, dust, landslides, as well as the flood/earthquake issues discussed here. But for the limited focus of this commentary there are a few major data gaps that need to be addressed.

1. Maximum volume of tailings to be stored under various scenarios – success of paste backfill, etc. (My assumption of 1 mtpy over 30 years may need to be modified if DPM provide new information)

2. Site and design details of the containment dam: slopes, material, seepage control measures, flood protection.

3. Foundation conditions beneath the tailings deposit and containment. Weak and leaky foundations typical of the tropics will likely render any design unsafe (Figure 6a).

4. Plans for monitoring and safety review of the facility, during the life of the mine and in perpetuity.

Failure to obtain and make public this information should be regarded as completely unacceptable. The site is already one of high risk and it would be impossible to assess a project's safety without such information being closely examined.

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