

English-Language Summary of a 2010 Master's Thesis on the Stability of the Failed Dam at the Córrego do Feijão Mine

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OVERVIEW

In 2010 Washington Pirete da Silva submitted a Master's Thesis (Mestrado Profissional em Engenharia Geotécnica [Professional Master's in Geotechnical Engineering]) to the School of Mines at the Federal University of Ouro Preto. The thesis was entitled "Estudo do Potencial de Liquefação Estática de uma Barragem de Rejeito alteada para Montante aplicando a Metodologia de Olson (2001)" [Study of the Potential for Static Liquefaction of a Tailings Dam constructed by the Upstream Method using the Methodology of Olson (2001)]. The dam that was evaluated was the same Dam I at the Córrego do Feijão Mine that failed due to static liquefaction on January 25, 2019. Washington Pirete has been an engineer for Vale since 1996 and all data used in the thesis was obtained from Vale. In 2001 S.M. Olson proposed the use of SPT (standard penetration test) and CPT (cone penetration test) data to assess the liquefaction potential of soils. The objective of the thesis by Pirete was to use the methodology of Olson to assess the stability of Dam I as it existed in 2010. At the current time the thesis exists only in Portuguese.

HISTORY OF PROBLEMS OF DAM I

The historical review of the problems of Dam I in the thesis is a good complement to the review in the 2018 dam safety audit. As of 2010 the tailings dam had gone through nine raises, the last seven of which were constructed of tailings that were recovered from the beach. The recovery of beach tailings for dam construction was a result of a lack of other construction material, such as mine overburden or cycloned tailings from the ore processing plant. Prior to 2006 (at which point, the dam had undergone eight raises), the beach was very non-uniform and heterogeneous with alternation of sand and slimes both horizontally and vertically. This was corrected by improving the method of injection of tailings onto the tailings pond, although this did not affect the mix of sands and slimes below the eighth raise of the dam. A persistent problem with the formation of the beach has been that the fine particles of hematite (unrecovered iron ore) settle closer to the dam with the coarser silicate particles settling farther away. This has resulted in a low-permeability zone next to the dam, which has kept the water table consistently high in the vicinity of the dam. As of 2010, this problem had still not been solved. The thesis did not include any discussion of the reliability of any of the piezometric data and did not mention the large number of inconsistencies and gaps in the piezometric data that were a focus of the 2018 dam safety audit.

LIQUEFACTION POTENTIAL OF TAILINGS SAMPLES

The liquefaction potential of surface samples (from depths less than 5 meters) from the tailings beach was confirmed using particle-size distributions and consistency (liquid and plasticity limits) tests. According to the thesis, “A avaliação mostra que todas as curvas granulométricas das amostras coletadas na praia de rejeitos da Barragem I encontram-se nos limites dos materiais que apresentam uma susceptibilidade aos mecanismos da liquefação e uma parcela significativa destas frações granulométricas enquadram-se nos limites da faixa de maior susceptibilidade” [The evaluation shows that all the granulometric curves of the samples collected in the tailings beach of Dam I are within the limits of the materials that present a susceptibility to the mechanisms of liquefaction and a significant portion of these granulometric fractions are within the limits of the range of greater susceptibility]. The thesis continued, “Todas as amostras ensaiadas indicam um potencial de vulnerabilidade à liquefação levando-se em conta estritamente a proporção e a plasticidade dos finos presentes” [All samples tested indicate a potential for vulnerability to liquefaction, taking into account strictly the proportion and plasticity of the fines present.]

The liquefaction potential of deeper samples was confirmed using the SPT and CPT data, according to the methodology proposed by Olson. The SPT and CPT data were in agreement in identifying nine layers that were susceptible to liquefaction. With regard to the results from the SPT data, the thesis concluded, “Constata-se que a maior parte dos pontos plotados ficou localizada na zona esquerda do gráfico, correspondente aos materiais que tendem a exibir comportamento contrátil durante cisalhamento e, conseqüentemente, a susceptibilidade ou potencial ao fluxo por liquefação destes materiais É PROVÁVEL” [It is observed that most of the plotted points were located in the left zone of the graph, corresponding to the materials that tend to exhibit contractile behavior during shear and, consequently, the susceptibility to or the potential for flow by liquefaction of these materials IS LIKELY]. (The capitalization was in the thesis.) With regard to the CPT results, the thesis said, “Com ênfase maior, os resultados dos índices normalizados dos ensaios CPT ratificam a tendência generalizada dos rejeitos depositados na Barragem I de exibirem um comportamento contrátil sob cisalhamento...e, conseqüentemente, susceptibilidade ou potencial a fluxos por liquefação” [With greater emphasis, the results of the normalized indices of the CPT data confirm the generalized tendency of the tailings deposited in Dam I to exhibit a contractile behavior under shear...and, consequently, susceptibility to or potential for flows by liquefaction].

STABILITY ANALYSIS AND SAFETY ASSESSMENT

Using the software package Slide v. 5.043, the thesis evaluated the factor of safety against static liquefaction for each of the nine susceptible layers. The stability analysis was carried out with the current piezometric data and the beach width of 100 meters, as they existed in 2010. Based on the liquefaction potential as estimated from the SPT data, factors of safety ranged from 1.14 to 1.19. Based on the liquefaction potential as estimated from the CPT data, factors of safety ranged from 1.14 to 1.34. The thesis pointed to a possible rapid rise in the water table as a potential trigger for static liquefaction, which could occur due to the rise of the tailings pond over the beach (due to a lack of coarse tailings for beach formation) or a long period of precipitation. However, the thesis discounted the possibility of the above liquefaction trigger for the following reason: “Por outro lado, os procedimentos operacionais da Barragem I da Mina do

Córrego do Feijão incluem o controle absoluto do nível de água do reservatório por meio de um sistema extravasor dotado de stop logs, a manutenção de uma praia de rejeitos com extensão mínima de 100 m e uma gestão no manejo da disposição dos rejeitos feito por uma equipe técnica bastante qualificada. Estes elementos, associados aos resultados positivos das análises desenvolvidas nesta dissertação, garantem uma boa segurança do empreendimento e seu baixo potencial a gatilhos de liquefação estática. Neste contexto, não é necessária a avaliação de potenciais riscos de eventos do tipo fluxos de ruptura por liquefação, utilizando resistência não drenada liquefeita através de correlações de resultados de ensaios SPT e/ou CPT, visto que, o potencial do gatilho é baixo em função da gestão operacional da Barragem I” [On the other hand, the operational procedures of Dam I of the Córrego do Feijão Mine include the absolute control of the reservoir water level through an overflow system with stop logs, the maintenance of a tailings beach with a minimum extension of 100 meters, and management of tailings disposal by a highly qualified technical team. These elements, associated to the positive results of the analyzes developed in this dissertation, guarantee a good safety of the enterprise and its low potential to static liquefaction triggers. In this context, it is not necessary to evaluate potential risks of events such as rupture flows due to liquefaction, using non-drained liquefied resistance through correlations of SPT and/or CPT test results, since the potential of the trigger is low in light of the operational management of Dam I].

RECOMMENDATIONS OF THESIS AND MY INTERPRETATION

The thesis concluded with recommendations for the improved management and construction of upstream tailings dams and suggestions for further research into the evaluation of liquefaction potential. There were no specific recommendations for Dam I and no discussion as to how the factor of safety against static liquefaction could be increased at Dam I. The final sentence of the thesis was the most important of all. The last suggestion for further research was “propor uma classificação de segurança contra a liquefação estática de barragens de contenção de rejeitos, estabelecendo faixas de valores de coeficientes de segurança admissíveis (FS)” [to propose a safety classification against the static liquefaction of tailings confinement dams, establishing ranges of allowable safety coefficients (factors of safety)]. In fact, such a safety classification existed at the time the thesis was written. The 2007 Dam Safety Guidelines of the Canadian Dam Association recommend a minimum factor of safety of 1.5 for all aspects of dam design, construction and management. On that basis, the factor of safety of 1.14 that was determined by the thesis indicates a tailings dam that is not stable and is only slightly safer than a dam on the point of imminent collapse (factor of safety = 1.0).