COLORADO
Division of Reclamation, Mining and Safety
Department of Natural Resources

Date: **September 29, 2023**

To: **Amy Yeldell**

CC: **Russ Means**
Travis Marshall
Amy Eschberger

From: **Zach Trujillo**

RE: **Mid Continent Limestone Quarry, DRMS File No. M-1982-121**
Rock Failure Analysis and Stability Report Review

Amy,

As requested I have reviewed the provided geotechnical report, "Rock Failure Analysis and Stability" (Report), conducted by Kilduff Underground Engineering, Inc. (KUE) on behalf of RMR Aggregates, Inc. (RMR) regarding the rock failure event that occurred on January 18, 2023 at the Mid Continent Limestone Quarry (Mine). The purpose of this memo is to summarize KUE's Report methodologies, analyses and recommendations in relation to the Rules and requirements of the Division. Questions and comments regarding the Report to ensure all Rules and requirements are satisfied will be summarized at the end of this memo.

Reconnaissance Findings

As noted earlier, on January 18, 2023 a slope failure occurred in the West section of the Mine. In the Report, the Mine is broken into East and West sections based on location of the failure. The failure occurred in the West section while the East section generally remains in pre-failure conditions. Following the January event, KUE performed mulitple site reconnaissance to evaluate the geology of the area as well as to document existing ground conditions. During the reconnaissance the overall geology of the area was documented which includes (but not limited to) bedrock identification, dip and conditions for both the East and West sections.

The overall dip of the bedrock at the Mine was found to range from 29 to 32 degrees to the south-southwest with a dip of 30 degrees specifically used along the East section within the Report. Surface topography ranges from 1.4:1 to 2.1:1, with the topography lessening in upper elevations. Generally, the Mine geology consists of three layers of limestone with two interbeds of shaley mudstone binding the limestone layers. The Report labels the limestone layers as upper, lower and massive in descending order. This can be seen in Photo 2 under Appendix A of the Report. Water conditions were encountered during the reconnaissance in the form of icicles along the face of the slope. It was unclear to KUE at the time of their reconnaissance on whether the water was from surface runoff or seepage between limestone layers. Water conditions in the Report are assumed to be a combination of both. KUE also compares their site reconnaissance to previously documented geological mapping of the area by the Colorado Geological

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Survey (CGS) along with borehole results conducted by Colorado Fuel & Iron Corporation (CFI). Per KUE, results from the site reconnaissance are within the range of values previously observed and documented by CGS and CFI. It should be noted that borehole logs from the CFI drilling were not included in the Report. Based on discussions with Amy Yeldell of the Division, the Division has no record of these logs.

During the reconnaissance, site structure data was collected on the East section to evaluate strength parameters of the limestone layers and interbed layers of the shaley mudstone as well as the overall rock mass conditions. Using the site conditions, exposed rock was assessed using the Hoek-Brown rock mass classification system. Joint surface roughness and waviness was evaluated using the Joint Roughness Coefficient methodology. Both methodologies are widely accepted and commonly used to estimate the strength of a rock mass. Site structure measurements and classifications are documented in Appendix B of the Report. Strength and characteristic parameters of the classified rock were then taken from published and verified typical values for the encountered limestone and mudstone at the Mine. Parameters documented in the East section were then applied to the West section in the Report due to the visually observed and documented similarities in the geology and structure. Strength parameters are documented in Section 4, Table 2 of the Report.

Failure Mode and Stability Analyses (Current Conditions)

In order to determine the potential conditions of failure, KUE incorporated the discontinuity data collected from the reconnaissance and applied it to stereographic projections which maps orientations of planes, lines and the intersections of the Mine geology. Failure mode conditions of wedge, planar sliding (no limits) and planar sliding (lateral limits) were then analyzed. As circular failures within competent rock masses do not occur and dip orientation of the strata does not allow for toppling, these failure modes are most suitable for the site conditions. The resulting stereonets from the associated failure criteria were then analyzed to determine the likelihood of each failure mode. Based on the resulting stereonets, it was determined that planar failure is the most probable failure mode which corresponds to the resulting failure event that occurred at the Mine. Summary of the stereonet failure mode results are found in Section 3 - Table 1 of the Report. Stereonet modeling results are found under Appendix C of the Report.

Based on the planar failure condition, KUE then performed a long term steady-state stability analyses of the current site conditions of the Mine under static conditions. With no site specific material strength testing, material properties were taken from published and verified typical values for the encountered limestone and mudstone at the Mine. Using conservative site parameters, a back analysis was conducted by setting the factor of safety (FOS) to just below 1 which is the minimum criteria for a failure. In addition to this, slope of the failure plane for the back analysis was set at 36 degrees which is steeper than the observed geological dip at the Mine. While not observed along the East section during the KUE reconnaissance, a tension crack was included in the analysis along the face of the slope. The presence of groundwater along the intersection of the mudstone and limestone was also included in the back analysis. The inclusion of these parameters results in a conservative analysis based on observed site conditions and published information. The result of the back analysis provides verification of the published strength properties associated with the limestone and mudstone. Summary of the material strength properties are provided under Section 4 – Table 2. The back analysis result is found under Appendix D of the Report.

Material strength properties for the limestone and mudstone were then applied to a stability analysis for the East section. When reviewing the Section 4, Table 2, Appendix D and Appendix G (Active Stabilization Design) of the Report, it is unclear to the Division which material strength properties were used in the stability analyses between the empirical values or post-back analysis values found under Table 2. Section 4 of the Report does not specifically identify which material strength properties were used and are not shown in all the resulting stability analysis under Appendix D. In addition, there appears to be inconsistencies with the material strength input parameters used within the analyses of Appendix G when compared to the values provided under Table 2 of the Report.

Additional parameters used in the stability analysis includes a failure plane of 30 degrees and the presence of groundwater along the intersection of the mudstone and limestone under static conditions. A tension crack was not included in the East section analysis as one was not observed during the KUE reconnaissance. These input parameters for the analysis of the East section are based on the site conditions overserved for the East and West sections of the Mine. The results of the East section stability analysis resulted in a FOS of 1.2. No seismic conditions were analyzed in KUE stability analysis.

Per Section 30 of the Policies of the Mined Land Reclamation Board (Section 30), for generalized, assumed, or single test measurements for critical structures, the minimum recommended FOS is 1.5 for static conditions and 1.3 for seismic conditions. The resulting FOS from the East section stability analysis resulted in a 1.2 which below the minimum criteria of 1.5 for static conditions. As a result, KUE provided additional recommendations along with associated stability analyses based on those recommendations (Section 8 and Appendix G of the Report) which indicate increased stability along active highwalls. As noted earlier, no seismic conditions were analyzed in the Report.

KUE Stability Recommendations and Associated Stability Analysis

As part of the long term stabilization of the site, KUE has provided recommendations based on their knowledge of the site and professional opinion under Section 8 of the Report. The recommendation is in two parts; 1) removal of the upper limestone layer through mining methods and/or 2) mechanical stabilization (rock anchoring). Mechanical stabilization is recommended by KUE when the upper limestone encounters the highwall or cannot be safely removed through mining operations. When reviewing Section 8 of the Report, it is unclear to the Division on what KUE is specifically referring to as the "upper limestone layer". Earlier in the report, KUE labels the three limestone layers as upper, lower and massive in descending order. It would appear to the Division that when referring to the "upper limestone layer" under Section 8 of the Report, it is combing the upper and the lower limestone layers as part of the "upper limestone layer" reference. Additional clarification is necessary to ensure the stability analysis is representative to the site conditions associated with these recommendations.

A long-term static stability analysis was conducted using the post-mining configuration of the massive limestone layer with the absence of the "upper limestone layer". Using different bench slope geometries along with the associated material strength properties of the limestone, slope stability analyses were conducted with resultant FOS of 1.4 (1H:1V), 1.54 (1.4H:1V) and 1.63 (1.67h:1V). Summary of these FOS are found under Section 6, Table 4 of the Report.

As stated in the Report under Section 6, "[u]sing the accepted minimum FOS of 1.5, a H:V bench slope geometry of 1.4:1 or larger is deemed acceptable." This statement in the Report appears inconsistent with the result summary table as a bench slope geometry of 1.4H:1V results in a FOS of 1.4 which is below the minimum FOS of 1.5. Additionally, only the slope stability analysis for the bench slope geometry of 1.67H:1V has been provided under Appendix D and not the results for the other two scenarios. It also appears to the Division that an error exists in Table 4 for the bench slope geometry of 1.67H:1V. The resulting slope stability analysis under Appendix D shows a FOS of 1.66 while Table 4 has a FOS of 1.63.

For situations where the upper limestone encounters the highwall or cannot be safely removed through mining operations, KUE has provided discussion and a preliminary design for mechanical stabilization of the East and West sections under Section 8 and Appendix G of the Report. Utilizing site conditions and parameters summarized above in this Memo, stability analyses were conducted with the addition of resistant forces from the designed mechanical stabilization that would result in a FOS of 1.5. A total of three scenarios were provided with one scenario along the West section and two along the East section. Each scenario is related to the upper limestone slope heights encountered during the site reconnaissance which is discussed under Section 7 of the Report. For the West section, a slope height of 5 feet was analyzed and slope heights of 10 and 15 feet was analyzed for the East section. While not observed by KUE, a tension crack was applied to the East section stability analyses to increase the degree of conservatism.

When reviewing the associated stability analysis under Appendix G, it was observed that none of the scenarios provided met the minimum FOS of 1.5 as stated in the Report. Per Section 8.1 of the Report, "[p]otential upper limestone slope heights… …were modeled to determine the resisting force required to reach a factor of safety of 1.5." The West section resultant FOS is 1.45 and resultant FOS for the East section for 10 feet and 15 feet are 1.4 and 1.41 respectively as provided in Appendix G.

As noted earlier in this Memo, it appears to the Division that there are inconsistencies with the material strength input parameters used within the analyses of Appendix G when compared to the values provided under Table 2 of the Report. When reviewing the resultant stability analyses under Appendix G, a joint cohesion of 50 psf and friction angle of 25 degrees were used. Based on the friction angle used in the analysis, this value appears to coincide with the empirical value for the interbed material as provided in Table 2. However, the cohesion for the interbed material is listed as 40 psf in Table 2 and a value of 50 psf was used in the analyses under Appendix G. Additionally, it was observed that the failure plane of 31 degrees was used in the analyses provided under Appendix G compared to the 30 degrees discussed in the Report as well as used in the stability analyses under Appendix D. All models provided (excluding the back-analysis) should be consistent with the documented conditions and parameters representative to the Mine.

Rockfall Modeling and Mitigation

Rockfall modeling was performed along three transects of the East section by KUE based on site conditions observed and documented during their reconnaissance. Two slope materials were identified and associated properties and input values were assigned within the rockfall analysis based upon published literature and site conditions as a result of the January failure event. Results of the models show the maximum end-pathing of potential rockfall as well as overall end-path distribution. Based on the results of these models, KUE applies recommendations to help ensure safety at the site with the use of a setback and a designed rockfall berm. Additional rockfall modeling has been provided to demonstrate rockfall end-paths and distribution in relation to the addition of the rockfall berm. Results of the rockfall modeling with the addition of the berm shows all rockfall end-paths contained within the rockfall berm.

Summary – Division Comments and/or Questions

The following is a summary of the Division's comments/questions discussed and observed during the previous sections of this Memo:

Reconnaissance Findings

- In the Report, KUE references borehole logs conducted by Colorado Fuel & Iron in comparison to so their site reconnaissance. The referenced borehole logs were not included within the Report and the Division has no records of the mentioned logs. Please have RMR or KUE provide the borehole logs conducted by CFI for the Division's review and record.

Failure Mode and Stability Analyses (Current Conditions)

- It is unclear to the Division which material strength properties were used in the stability analyses between the empirical values or post-backanalysis values found under Table 2. Please have KUE provide the Division with clarification on which material strength properties values reported in Table 2 were used within the stability analyses found within Appendix D.

KUE Stability Recommendations and Associated Stability Analysis

- Similarly to the comment above, it is unclear to the Division which material strength properties were used in the stability analyses under KUE's recommendations. Please have KUE provide the Division with clarification on which material strength properties values reported in Table 2 were used within the stability analyses found within Appendix D and Appendix G.

- Within Section 8 of the Report, it is unclear to the Division on what KUE is defining as the "upper limestone layer" in reference to KUE recommendations to remove said layer. Earlier in the Report, KUE labels the three limestone layers as upper, lower and massive in descending order. It would appear to the Division that when referring to the "upper limestone layer" under Section 8 of the Report, it is combing the upper and the lower limestone layers as part of the "upper limestone layer" reference. Please have KUE provide additional clarification on whether the recommendation is to remove just the upper limestone layer or the combination of both upper and lower limestone layers.

- Under Section 6 of the Report, a long-term static stability analysis was conducted using the post-mining configuration of the massive limestone layer for varying bench slope geometries. A total of three bench slope geometries were analyzed with resulting FOS as provided in Table 4 of the Report. However only the results from the bench slope geometry for 1.67:1 was provided under Appendix D. Additionally, it appears an error exists in Table 4 for bench slope geometry of 1.67H:1V. The resulting slope stability analysis under Appendix D shows a FOS of 1.66 while Table 4 has a FOS of 1.63. Please have KUE provided a corrected Table 4 (is necessary) and the slope stability analyses for the other bench slope geometries provided under Table 4.

- It appears the Division that inconsistencies exist with the material strength input parameters used within the analyses of Appendix G when compared to the values provided under Table 2 of the Report. Additionally, a different failure plane angle was used in comparison to other analyses provided. All models provided (excluding the back-analysis) should be consistent with the documented conditions and parameters representative to the Mine. Please request KUE ensure all input parameters for all provided stability analyses (excluding back-analysis) are consistent with the conditions and parameters associated with the Mine and have KUE provide any updated analyses as necessary.

- While not discussed in this Memo or in the Report, RMR is approved for blasting per the permit. Please have RMR or KUE address the potential impact blasting may have on the stability of the Mine and have it modeled within the provided active mining and post-mining analyses.

- When reviewing the associated stability analysis with mechanical stabilization under Appendix G, it was observed that none of the scenarios provided met the minimum FOS of 1.5 as stated in the Report. Per Section 8.1 of the Report, "[p]otential upper limestone slope heights… …were modeled to determine the resisting force required to reach a factor of safety of 1.5." The West section resultant FOS is 1.45 and resultant FOS for the East section for 10 feet and 15 feet are 1.4 and 1.41 respectively as provided in Appendix G. In order to ensure the minimum criteria of the Division's Section 30 is met, please have KUE provide updated mechanical stabilization recommendations and associated analyses that meets or exceeds the minimum FOS requirements of 1.5 for static conditions.

- Per Section 30 of the Policies of the Mined Land Reclamation Board, for generalized, assumed, or single test measurements for critical structures, the minimum recommended FOS is 1.5 for static conditions and 1.3 for seismic conditions. No seismic conditions were provided or evaluated by KUE in the Report. In order to ensure all requirements of Section 30 are satisfied, please have KUE provide stability analyses for the Mine under seismic conditions for all active mining and post-mining scenarios under KUE recommendations.

This concludes my review of the provided geotechnical report, "Rock Failure Analysis and Stability" (Report), conducted by Kilduff Underground Engineering, Inc. (KUE) on behalf of RMR Aggregates, Inc. (RMR) regarding the rock failure event that occurred on January 18, 2023 at the Mid Continent Limestone Quarry (Mine). If you have any questions feel free to contact me.

Sincerely,

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