TRAUTNER GEOTECH LLC
GEOTECHNICAL ENGINEERING, MATERIAL TESTING
AND ENGINEERING GEOLOGY

ROCKFALL HAZARD STUDY

FOR THE PROPOSED

NORTH MAIN APARTMENT PROJECT

DURANGO, COLORADO

APRIL 2, 2018

PREPARED FOR: MR. BRIAN AND MS. MARLENE RAEL

PROJECT NUMBER: 55089GE

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1.0 INTRODUCTION

This report presents our rockfall hazard assessment for the North Main Apartments project. Our study was performed in accordance with the scope of services outlined in our January 2, 2018 proposal.

This study presents our findings, interpretation, and recommendations regarding the rockfall hazards relative to the North Main Avenue Apartment project. This report is organized to first provide background information on the site and proposed project, the scope of our services, and the geologic setting (Sections 2 and 3). Following is a discussion on rockfall hazards and how they pertain to this project, including recommendations on how to mitigate hazard exposure (Section 4). We have also included rockfall modeling data in Appendix A.

2.0 PROJECT BACKGROUND, SCOPE of DEVELOPMENT, and SCOPE of STUDY

The project site is located in the city of Durango, La Plata County, Colorado. The site's legal description is as follows: Section: 9 Township: 35 Range: 9 TRACT 1-R2, MERCY REGIONAL MEDICAL CENTER TRACTS A-R & 1-R, PL 987811 3803 N MAIN AVE DURANGO 81301 (La Plata County GIS map server, 2018). The project site is shown in Figure 1 below.

The project site encompasses approximately 5.36 acres of property. The lot is an irregular polygon that is elongated in the northeast-southwest direction save for a northwest-southeast elongated section on the southwest corner. The lot is bound by Highway 550 / Main Ave to the southwest, Colorado Department of Transportation (CDOT) offices to the northeast, undeveloped La Plata County property to the northwest, and the Merced De Las Animas residences to the southwest.

The project site was previously developed as a hospital. Subsequently the bulk of the hospital structure has been removed, of which the current CDOT office is the only existing remnant. The lot now exists as parking, driveway, and open space. Due to prior development the topography and geomorphology of the lot is no longer in a natural state which masks our ability to assess historic rockfall activity influencing the site..

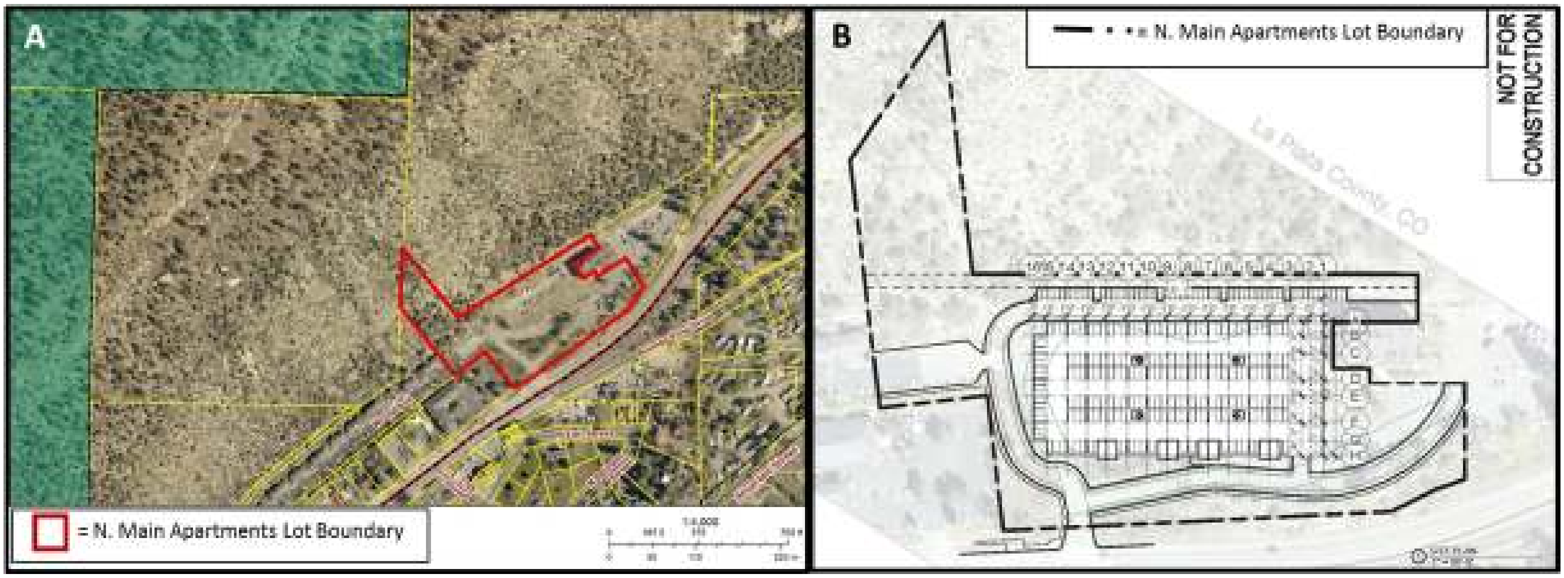

Figure 1: ***A****) Satelite photo showing the project site lot boundary and vicinity (Modified from La Plata County GIS map server, 2018);* ***B****) Plan overview showing intended structure within lot boundary overlaying somewhat transparent satelite photo (modified from Eccher designing and planning, 2017)*

2.1 Current Scope of Development

We understand that the current proposed development will include a basement level parking garage and four stories above with a total of 206 residences in the form of studio, one-bedroom, and two-bedroom apartments. The proposed development will be a single structure that is 430 feet in length by 200 feet in width. We understand that the northwest side of the development will include a cut into the slope with unknown height of retaining structure. Figure 1B shows a sketch plan of the intended structure and driveways.

2.2 Scope of Service for this Rockfall Hazard Study

We performed a rockfall field reconnaissance of the site on February 1, 2018. The rockfall reconnaissance included detailed observations of portions of the site to evaluate the existence and potential significance of rockfall hazards that may influence the proposed development. The general scope of our study included the following;

- Literature and map review of the site.
- Geologic field observations and measurements including a description of the site topography, geologic character, and geomorphology.

- Identification and analysis of rockfall hazards that may influence the project development and proposed lot layout.
- Computer modeling to quantify potential influences and mitigation concepts.

A discussion of the rockfall hazards as they pertain to the project is included in Section 4 of this report. We performed a geotechnical engineering study for this project. Our geotechnical engineering study is presented separately.

We are available to provide continued consultation through the review and approval process of this project.

3.0 GEOLOGIC OBSERVATIONS

We have provided a brief and cursory discussion of the geologic setting below.

The Durango area is located along the Animas River in a north-south trending glacio-fluvial valley. There are numerous steep gullies in the valley that flow into the river. Geologic units in the area consists of Precambrian metasedimentary and igneous units, and Paleozoic and Mesozoic sedimentary layers of sandstone, limestone, shale, and claystone. The sedimentary units outcropping in the area include the Kirtland Formation (Kk*), the Fruitland Formation (Kf*), the Pictured Cliffs Sandstone (Kpc*), the Lewis Shale (Kl*), the Cliff House Sandstone (Kch*), the Menefee Formation (Kmf*), the Point Lookout Sandstone (Kpl*), the Mancos Shale (Km*), the Dakota Sandstone (Kd*), the Burro Canyon Conglomerate (Kdb*), the Morrison Formation (Jm*), the Junction Creek Sandstone (Jjc*), the Wanakah Formation (Jw*), the Entrada Sandstone (Je*), the Dolores Formation (Trd*), the Cutler Formation (Pc*), the Hermosa / Rico / Molas Formations undifferentiated (PIPrm*), and the Leadville Limestone / Ouray Limestone / Elbert Formation / Ignacio Formation undifferentiated (MCli*). These units are gently south dipping and often cliff forming. Precambrian Irving Formation (pCi*) and Bakers Bridge Granite (pCb*) outcrop further north in the valley as a non-conformity and intrusion respectively. Rock units in the area are often overlain by Quaternary sediments from glacial, fluvial, eolian, mass wasting, and colluvial processes that continue to shape the landscape. Quaternary surficial deposits in the site vicinity are mapped as Alluvium (Qa*), Terrace (Qt_{1u}*), Talus (Qt*), Colluvium (Qc*), Colluvium and Sheetwash undifferentiated (Qcs*), differentiated Moraine (Qmai, Qmam, Qmsi, Qmao, Qmdi*), and Landslide (Ql*). A vicinity geologic map of the site is presented in Figure 2.

*Note: Abbreviations in parentheses indicate the geologic time period with capital letters and unit names with lower case letters, these abbreviations are used to identify map units. Example: Figure 2 (Carroll et al., 1999).

3.1 Site Geology

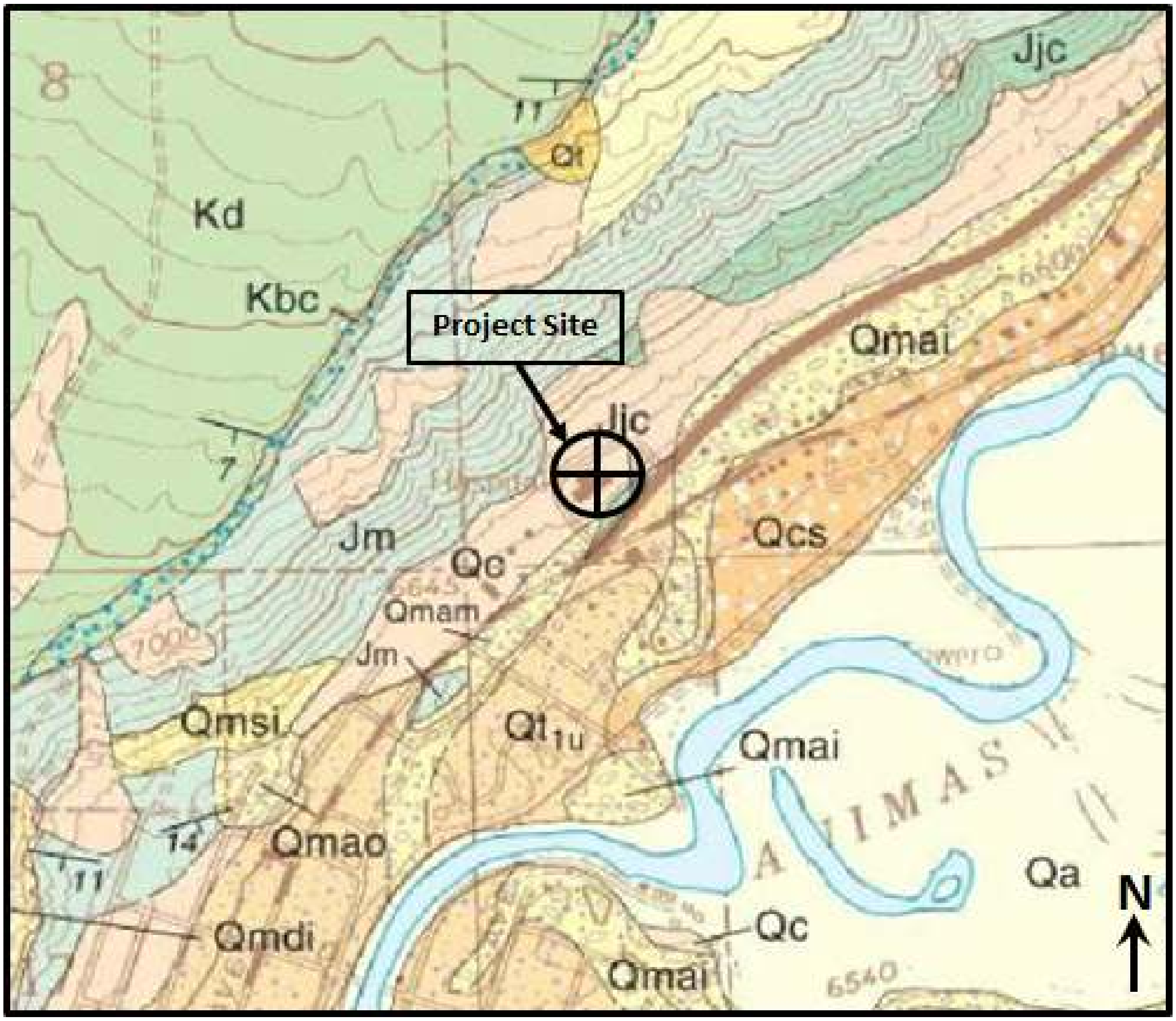

Figure 2: *Geologic map of the project vicinity (modified from Carroll et al., 1999)*

The site is characterized by interbedded layers of more resistant sandstones and conglomerate with less resistant shales and claystone. Jurassic Junction Creek Sandstone (Jjc*) and Morrison formation (Jm*), as well as Cretaceous Burro Canyon Conglomerate (Kbc*) and Dakota Sandstone (Kd*) all outcrop in the slope above the lot. Multiple beds of highly jointed sandstone that are underlain - and thus undercut - by less competent shale/claystone exist on this slope. The slope represents the steep wall of the u-shaped glacial valley of the Animas River. At the base of this slope - at and below the project site - are deposits of glacial, fluvial, and colluvial sediment. The bulk of the property exists on a large colluvial wedge (Qc*) derived from the aforementioned slope above the lot.

4.0 ROCKFALL HAZARD DISCUSSION

Rockfall hazard exists wherever rock has the potential to dislodge and move downhill by forces of gravity. This process is usually associated with a weathering front of formational material. Freeze-thaw cycles and availability of free water promote rockfall, therefore spring is the most active season for rockfall. The steep topography and fractured rock outcrops that are common to this region make rockfall a common hazard.

Rockfall can occur without warning and can be destructive to both life and property. Rockfall frequency is very difficult to predict, however modeling techniques allow us to estimate the trajectory and intensity of rockfall events. Simulation of rockfall events to provide an analysis of the potential destructive properties are performed using the Colorado Rockfall Simulation Program (CRSP) computer modeling analysis. A discussion of the site specific rockfall potential, CRSP analysis, and potential mitigation concepts for the observed and modeled rockfall hazards follows.

4.1 Rockfall Potential: Site Specific Discussion

Rockfall hazards influence the subject property. The primary source(s) of rockfall are from the Dakota Sandstone (Kd*) and sandstone beds within the Morrison Formation (Jm*). These sources exist as outcrop and in the form of loose boulders lying precariously on the slope above the lot. The source rock yields very large fragments – some over 18 feet in length – due to jointing patterns and slight metamorphism. Much of the loose boulder source rock is resting in a place to which it fell (i.e. prior rockfall events existing as potential subsequent event source). There are numerous sources of rockfall originating from the top of the slope to approximately 100 feet above the site.

Figure 3: *Photograph taken from the project site looking up the slope along the south path.*

Recent rockfall is evidenced on the slope above the site, however due to prior grading and development all evidence of rockfall within the project site has been removed. Without this evidence, the historical record and adjacent areas are our best indicators of rockfall. The Merced de las Animas residential property - neighboring to the south - has experienced destructive rockfall, subsequently imposed mitigation, and has since experienced rockfall events that have been successfully mitigated.

4.2 CRSP Rockfall Analysis

We evaluated the rockfall behavior at the subject property using CRSP Version 4.0. CRSP is a computer modeling tool to aid in the evaluation of rockfall behavior and provides estimated impact energies and bounce heights of rockfall events. This information may be utilized in the design of rockfall protection measures. We created an approximate topographic cross section using a tape measure, Brunton compass, and a hand held GPS unit. We created two additional cross sections using a geographical information system (GIS) software and a one meter resolution digital elevation model (DEM) provided by the United States Geological Survey (USGS). The hand measured alignment coincides with one of these GIS derived alignments in order to corroborate results. Therefore we analyzed two different rockfall paths, referred to as the north path and south path. The north path cross section was made from the DEM in the GIS program and models were run with and without the upper bench and above. The south path cross sections were made from the DEM and from field measurements. The field measured south path did not model the upper bench and above, however the DEM derived model was run with and without the upper bench and above. The alignment of these cross sections are shown in Figure 4.

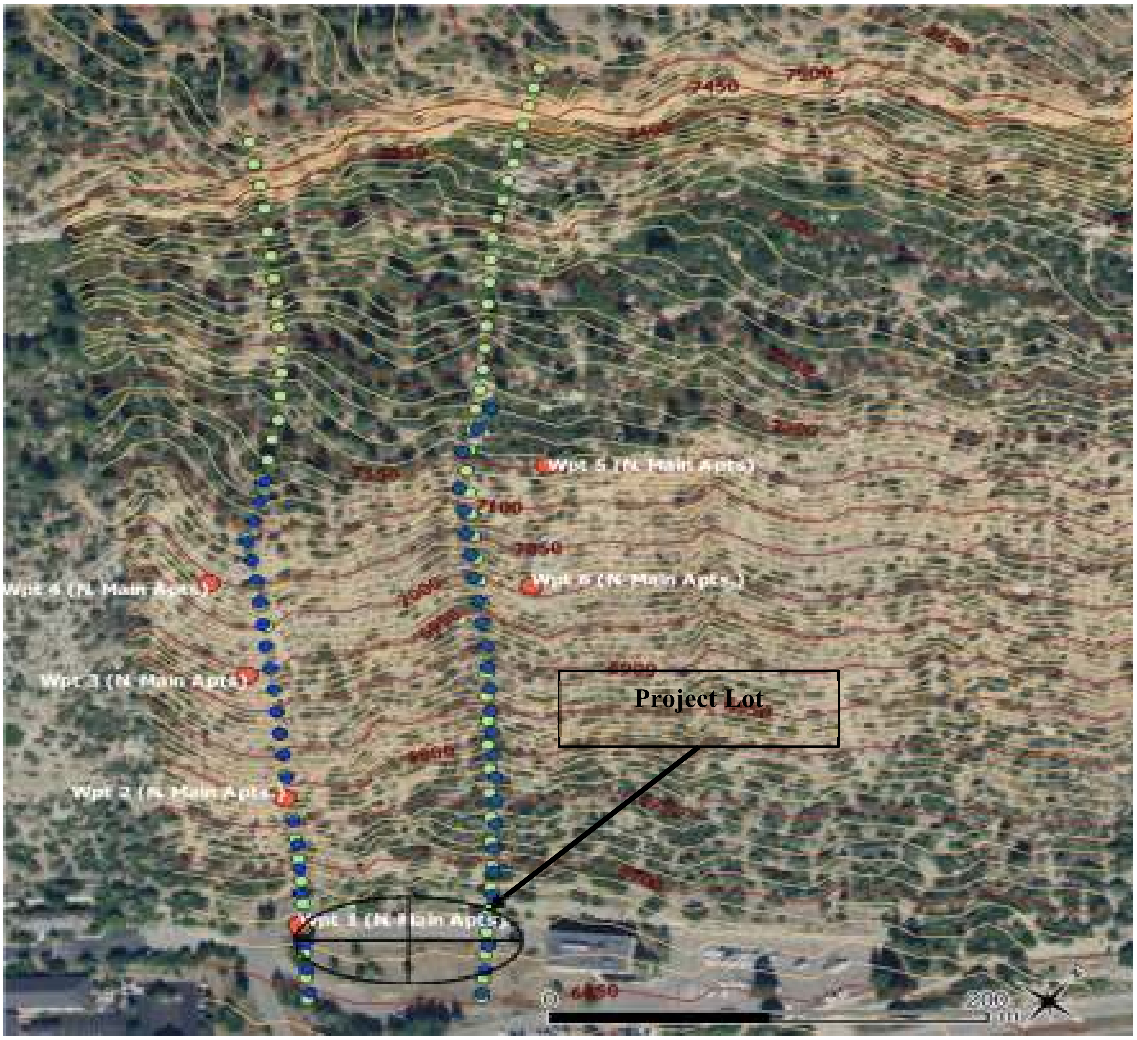

Figure 4: *Vicinity Map and Arial Photo showing topography (10 foot contour interval), lot location, rockfall paths analyzed in CRSP (blue dots show below upper bench path, green dots show full path), and handheld GPS waypoints (orange dots) from field reconnaissance*

We utilized CRSP to simulate the existing conditions at the subject property. We manipulated the model's input parameters such as surface roughness, tangential, and normal coefficients to approximate the existing conditions. Once we were satisfied that we had simulated the existing conditions, we performed numerous iterations of rockfall with the program while varying sizes and shapes of rocks to model the rockfall behavior at the proposed development. In all of the models, analysis point 1 represents the downhill edge of the bench/trail along the northwest edge of the property boundary (similar to the location of the neighboring rockfall fence). Analysis Point 2 represents the proposed structure.

In every model rockfall reaches the analysis points, indicating that rockfall hazards exist at the subject property. We have included some of the more pertinent models' CRSP input and output data in Appendix A. Included in this appendix is model data using 4 foot and 6 foot spheroidal rock as well as 4x7 cylindrical rock along the south path, and 6 foot spheroidal rock along the north path, all originating below the upper bench. These four models were chosen to illustrate the most likely worst case scenarios that can be mitigated with reasonable means and the difference in impact energies relative to the rock size. The following table summarizes the results from these models for analysis point 1. The velocity and impact energy values reported here are from the statistical analysis of the rockfall results using a 98% confidence interval (CI). The bounce heights reported here are the maximum values recorded at the analysis point.

***Table 1:** Summary of CRSP results from select models for analysis point 1. Full input-output for these models included in Appendix A.*

Model:	**4' Sphere – S. Path**	**6' Sphere – S. Path**	**4'x7' Cyl .– S. Path**	**6' Sphere – N. Path**
98% CI Velocity (ft/sec):	37.11	51.98	52.3	45.39
98% CI Impact Energy (ft-lb): ((kJ)):	152450 (206.7)	982594 (1332.2)	808396 (1096.0)	743713 (1008.3)
Max Bounce Height (ft):	2.34	3.23	3.01	2.9

Note the drastic difference in impact energies relative to rock size; more than six times greater with a 6 foot sphere than a 4 foot sphere. This is because of the steep grade of the slope yielding high rockfall velocities, i.e. at high velocities there is a more drastic increase in impact energy with increase in rock size. It is most likely that the rockfall hazard to impact this site will be from 4 foot boulders and smaller, however it is our opinion that it is reasonable to mitigate for 6 foot boulders and smaller. *It should be noted that there are boulders larger than 6 feet on the slope above the project site that can become more prone to movement as continued erosion occurs on the site.* For example, we measured an 18 foot by 7 foot cylindrical rock at Waypoint #3 (location shown in Figure 4) that is precariously sitting on the slope, this rock is pictured in Figure 3. We have provided rockfall hazard mitigation recommendations in Section 4.3 below.

4.3 Rockfall Hazard Mitigation Concepts

Typical mitigation concepts include:

- Avoidance of the areas influenced by the hazard,
- Scaling or in-place stabilization of rocks prone to movement, and,
- Design and construction of arrest barriers, typically:
  - Rockfall mitigation fencing, and/or
  - Earthen trough and berms

Often a select combination of one or all of these types of mitigation are included in rockfall hazard mitigation. We have provided a brief discussion of these concepts including how they pertain to this project.

4.3.1 Avoidance

Although avoidance of a particular hazard, such as rockfall is always the best option, this is not always possible due to property boundary, topographic, or other constraints imposed by a particular project site. In this case complete avoidance of rockfall hazard is not a viable solution unless the site is not developed. Often slight changes in structure location, orientation, and/or elevation can influence the exposure to - or severity of - rockfall hazards.

4.3.2 Scaling or In-place Stabilization of Rocks Prone to Movement

A relatively common mitigation for rockfall includes scaling, movement of rocks downslope prior to construction, and/or in-place stabilization. These efforts are largely conducted with hand labor and hand tools. Some in-place stabilization can be developed by the use of rock bolts or other aggressive means requiring the use of pneumatic drilling equipment and other techniques. Blasting is also a form of scaling. Often larger rocks may be blasted, with hand-scaling or in-place stabilization performed on the smaller rocks produced from the blasting effort. Scaling and in-place stabilization has been conducted on slopes above adjacent properties in this area.

Scaling must be done with great care because this operation involves dislodging rocks and allowing them to travel down slope. On some sites this may be conducted safely prior to construction provided that no people, property, or structures exist within the fall paths of the scaled rocks. Scaling on sites where this operation may pose safety risks to people or structures must be conducted after design and construction of temporary catchment barriers and should be conducted only by experienced personnel.

There are different techniques that are typically utilized for in-place stabilization. These typically may include development of excavations (usually up-slope of a prone rock) and use of rock bolts or soil nails for permanent attachment of prone rocks to stable substrate.

In-place stabilization is generally more viable for smaller rocks than it is for excessively large rocks. Smaller rocks located on sloped soil surface may by stabilized by excavation of soil adjacent to, typically above, the prone rock followed by placement of the rock into the excavated area. After the rock is placed in the excavation the space between the rock and the adjacent excavation walls should be backfilled, preferably with compacted soil, or a soil/Portland-Cement/water slurry. The excavation around rocks stabilized in this fashion should not be left open because this will promote water accumulation and/or erosion of the soil and ultimately will result in the rock being prone to movement within a relatively short time frame.

Rock bolts, typically consisting of a steel tendon drilled through the rock to be stabilized and into a rock mass below (typically in-place formational material, bedrock). The steel tendons are usually surrounded by Portland cement/water slurry and specialty epoxies. Similarly in some instances rocks may be stabilized by the use of soil nails, which is essentially the same technique as rock bolting, however soil nails are often drilled tens of feet into the soil in order to achieve the required tensional capacity and are not as common, since longer tendons cannot be readily installed using hand-held equipment.

Due to the large size of available source rock on the slope above the subject property, we feel that some degree of scaling is pertinent. The main goal of a scaling operation on this site would be to stabilize and/or break up the prone rocks that are greater than 6 feet in any dimension. Scaling at this site will require careful planning for catchment of mobilized rocks. Scaling alone will not serve to mitigate the rockfall hazard at this site, it is our recommendation that scaling be performed in conjunction with an arrest barrier.

We are available to consult in identification of the rocks that can be subject to a scaling operation and the preferred method(s) of mitigating these subject rocks.

4.3.3 Design and Construction of Arrest Barriers

There are numerous types of arrest barriers commonly included in rockfall mitigation. Perhaps the most common types being;

- Earthen trough and berm configurations, and
- Flexible rockfall mitigation fencing

Earthen troughs, or swales, with downslope berms are a cost effective and effective means to mitigate rockfall where the slope and site conditions allow for construction of these structures. However slope inclination, potential damage to vegetation, aesthetic considerations, and potential limitations associated with construction of an earthen berm might make a rockfall fence the preferable choice for rockfall mitigation. On some sites earthen trough and berm structures are not viable. We feel that an earthen trough and berm configuration may not be viable for this project, primarily due the fact that the locations of the troughs and berms would need to be n adjacent property located above this site. Access constraints and slope stability related considerations associated with construction of this type of feature on the steep slopes above the structure are other issues presenting challenges to construction of troughs and berms as a rockfall mitigation measure.

We feel that constructing a rockfall fence is the most viable mitigation technique for this project. Rockfall mitigation fencing is typically designed by an engineer or contractor with experience in rockfall mitigation. Many manufacturers of rockfall fencing have design capabilities and may utilize information provided in reports such as this to develop a design that is based on the impact energies estimated through the use of computer modeling, such as our CRSP analysis. The ideal location for a rockfall fence will be at our Analysis Point 1 along the downhill edge of the bench with the trail on it. We recognize that this may require an easement to construct said fence in La Plata County property. The neighboring Merced de las Animas residence was able to obtain said easement and has constructed a fence along the same bench.

Regardless of the type of arrest barrier chosen, the height of the barrier should be at least 10 feet. The barrier should protect the entire length of the building plus extend an additional 20 feet laterally to each side. The flexible rockfall fence may be designed using the service impact energy associated with a 6 foot spherical boulder as provided in Table 1 above; 982,594 ft-lbs (1,332.2 kJ). Typically the design is based on a maximum impact energy, which is typically 3 times that of the service impact energy.

The fence alignment/location and associated height should be reviewed as the project progresses. There are various features on the slope, both existing and proposed, that could influencing the design height of the proposed fence. We are available to provide continued consultation during the design and construction phases of an arrest barrier.

4.3.5 Rockfall Hazard Mitigation Summary/General Comments

As discussed above we feel that the exposure of this site to rockfall hazards is high. We feel that this is a mitigatable hazard and recommend a combination of scaling/stabilization and construction of an arrest barrier. The intention of the scaling/stabilizing is to reduce the number of rocks that are prone to movement and to possible reduce the size of larger rocks within source area.

We are available to discuss or amend our findings and recommendations with you as the design of this project progresses.

5.0 CONCLUSION

The information presented in this report is based on our understanding of the proposed construction (development) and on the data obtained from our field reconnaissance and observations. We recommend that we be contacted and included in future design phases and development of this project to provide engineering geology consultation. Please contact us immediately if you have any questions, or if any of the information presented above is not appropriate for the proposed site development.

The geologic evaluation presented above is intended to be used only for this project site and the proposed scope of development which was provided to us. The geologic hazard evaluation presented above is not suitable for adjacent project sites, or for a proposed scope of development which is different than that outlined for this study.

We are available to review and tailor our study, if needed, as the project progresses and additional information which may influence our evaluation of the site becomes available. If desired we are available to provide construction phase materials testing services.

Please refer to our geotechnical engineering study for subsurface analysis and engineering recommendations.

Please contact us if you have any questions, or if we may be of additional service.

Respectfully submitted,
TRAUTNER GEOTECH

Reviewed,

4-2-18

Jason W. Center
Geologist

David L. Trautner, P.E., CPG
Principal Geotechnical Engineer

6.0 REFERENCES

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APPENDIX A

Colorado Rockfall Simulation Program (CRSP) Results

The results of our rockfall simulation using the Colorado Rockfall Simulation Program (CRSP 4.0) are presented below. In all cases, analysis point 1 is at the downhill edge of the flat bench with a foot trail that exists just northwest and along the property boundary. Analysis point 2 is approximately the uphill side of the intended building. Models of the full slope were also performed, however only those which limit the source to below the upper bench are provided here since these models provided more conservative estimates.

A.1 CRSP analysis of 4 foot diameter spherical rock along south path originating below upper bench

```
CRSP Input File -T:\Current GH\55089GH, N. Main Apts. Rockfall\CRSP
data\input file_S. Path QGIS_N. main apts.dat


Input File Specifications

Units of Measure:  U.S.
Total Number of Cells:  40
Analysis Point 1 X-Coordinate:  1521
Analysis Point 2 X-Coordinate:  1560
Analysis Point 3 X-Coordinate:  0
Initial Y-Top Starting Zone Coordinate:  465
Initial Y-Base Starting Zone Coordinate:  120

Remarks:  N. Main Apts_S. Path EXTENDED by QGIS profile


Cell Data

Cell No. S.R. Tang. C.    Norm. C.    Begin X        Begin Y   End X    End Y

 1      1.5    .75          .25           0             784     42       757
 2      1.5    .75          .25           42            757     84       724
 3      1.5    .75          .25           84            724     127      673
 4      1.5    .55          .25           127           673     172      652
 5      1.5    .55          .25           172           652     217      632
 6      1.5    .55          .25           217           632     262      608
 7      1.5    .55          .25           262           608     307      591
 8      1.5    .55          .25           307           591     353      567
 9      1.5    .55          .25           353           567     398      550
 10     1.5    .55          .25           398           550     442      533
 11     1.5    .55          .25           442           533     487      520
 12     1.5    .55          .25           487           520     532      514
 13     1.5    .65          .2            532           514     570      506
 14     1.5    .65          .2            570           506     609      497
 15     1.5    .65          .2            609           497     647      488
 16     1.5    .65          .2            647           488     686      477
 17     1.5    .65          .2            686           477     724      465
 18     1.5    .65          .2            724           465     763      449
 19     1.5    .65          .2            763           449     805      438
 20     1.3    .75          .2            805           438     847      416
```

```
 21    1.3    .75           .2            847           416     889     392
 22    1.3    .75           .2            889           392     931     341
 23    1.3    .75           .2            931           341     973     330
 24    1.3    .85           .25           973           330     1014    305
 25    1.3    .85           .25           1014          305     1056    281
 26    1.3    .85           .25           1056          281     1097    254
 27    1.3    .85           .25           1097          254     1139     229
 28    1.3    .95           .35           1139          229     1180     204
 29    1.3    .9            .25           1180          204     1220     172
 30    1.3    .9            .25           1220          172     1260     137
 31    1.3    .85           .25           1260          137     1300     105
 32    1.3    .85           .25           1300          105     1340    79
 33    1.3    .85           .25           1340          79      1380    54
 34    1.3    .75           .25           1380          54      1420    36
 35    1.3    .75           .25           1420          36      1465    27
 36    1.3    .75           .25           1465          27      1510    19
 37    1.3    .75           .2            1510          19      1522    19
 38    1.3    .75           .25           1522          19      1556    11
 39    1.3    .75           .25           1556          11      1601    6
 40    1      .85           .35           1601          6       1646    0


CRSP Simulation Specifications:  Used with T:\Current GH\55089GH, N. Main
Apts. Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Total Number of Rocks Simulated:  100
Starting Velocity in X-Direction:  1 ft/sec
Starting Velocity in Y-Direction:  -1 ft/sec
Starting Cell Number:  17
Ending Cell Number:  40
Rock Density:  165 lb/ft^3
Rock Shape:  Spherical
Diameter:  4 ft



CRSP Analysis Point 1 Data - T:\Current GH\55089GH, N. Main Apts.
Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Analysis Point 1: X =  1521, Y =  19

Total Rocks Passing Analysis Point:  33


Cumulative Probability   Velocity (ft/sec)  Energy (ft-lb)   Bounce Ht. (ft)

        50%                   17.96           49509            0.21
        75%                   24.25           83310            7.87
        90%                   29.9            113713           14.76
        95%                   33.3            131965           18.9
        98%                   37.11           152450           23.54
```

```
Velocity (ft/sec)            Bounce Height (ft)         Kinetic Energy (ft-lb)

Maximum:  45.02              Maximum:  2.34                 Maximum:  233683
Average:  17.96              Average:  .74                  Average:  49509
Minimum:  5.47               G. Mean:  .21               Std. Dev.:  50061
Std. Dev.:  9.31             Std. Dev.:  11.35


Remarks:  N. Main Apts_S. Path EXTENDED by QGIS profile



CRSP Analysis Point 2 Data - T:\Current GH\55089GH, N. Main Apts.
Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Analysis Point 2: X =  1560, Y =  11

Total Rocks Passing Analysis Point:  19


Cumulative Probability   Velocity (ft/sec)   Energy (ft-lb)  Bounce Ht. (ft)

         50%                  16.8             47229           0.48
         75%                  24.31            86185           3.46
         90%                  31.06            121223          6.14
         95%                  35.12            142259          7.76
         98%                  39.67            165868          9.56



Velocity (ft/sec)           Bounce Height (ft)         Kinetic Energy (ft-lb)

  Maximum:  40.04              Maximum:  6.03              Maximum:  187089
  Average:  16.8               Average:  1.03              Average:  47229
  Minimum:  3.63               G. Mean:  .48            Std. Dev.:  57695
Std. Dev.:  11.12            Std. Dev.:  4.42


Remarks:  N. Main Apts_S. Path EXTENDED by QGIS profile



CRSP Data Collected at End of Each Cell - T:\Current GH\55089GH, N. Main
Apts. Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Velocity Units: ft/sec      Bounce Height Units: ft


Cell #   Max. Vel.   Avg. Vel.   S.D. Vel.  Max. Bounce Ht.  Avg. Bounce Ht.

 1            No rocks past end of cell
 2            No rocks past end of cell
 3            No rocks past end of cell
 4            No rocks past end of cell
```

```
5            No rocks past end of cell
6            No rocks past end of cell
7            No rocks past end of cell
8            No rocks past end of cell
9            No rocks past end of cell
10           No rocks past end of cell
11           No rocks past end of cell
12           No rocks past end of cell
13           No rocks past end of cell
14           No rocks past end of cell
15           No rocks past end of cell
16           No rocks past end of cell
17           No rocks past end of cell
18           No rocks past end of cell
19           No rocks past end of cell
20          14            10            2.75          1             0
21          25            17            6.62          1             0
22          52            33            10.27         11            2
23          27            16            6.48          2             0
24          38            24            7.36          4             1
25          44            26            9.28          6             1
26          53            31            10.84         6             1
27          59            32            12            7             2
28          61            36            12.03         9             2
29          77            41            13.7          16            3
30          69            45            14.33         19            4
31          85            50            13.72         15            4
32          75            47            12            14            4
33          74            50            11.01         14            3
34          72            43            9.51          9             3
35          52            29            9.59          7             1
36          50            21            10.22         7             0
37          45            18            10.19         2             0
38          38            19            9.33          8             1
39          25            12            9.36          2             0
40          19            19            0             1             1
```

A.2 CRSP analysis of 6 foot diameter spherical rock along south path originating below upper bench

```
CRSP Input File -T:\Current GH\55---GH, N. Main Apts. Rockfall\CRSP
data\input file_S. Path QGIS_N. main apts.dat


Input File Specifications

Units of Measure:  U.S.
Total Number of Cells:  40
Analysis Point 1 X-Coordinate:  1521
Analysis Point 2 X-Coordinate:  1560
```

```
Analysis Point 3 X-Coordinate:  0
Initial Y-Top Starting Zone Coordinate:  465
Initial Y-Base Starting Zone Coordinate:  120

Remarks:  N. Main Apts_N. Path EXTENDED by QGIS profile


Cell Data

Cell No.  S.R.  Tang. C.  Norm. C.   Begin X    Begin Y    End X     End Y

 1      1.5   0.75          0.25          0           784     42        757
 2      1.5   0.75          0.25          42          757     84        724
 3      1.5   0.75          0.25          84          724     127       673
 4      1.5   0.55          0.25          127         673     172       652
 5      1.5   0.55          0.25          172         652     217       632
 6      1.5   0.55          0.25          217         632     262       608
 7      1.5   0.55          0.25          262         608     307       591
 8      1.5   0.55          0.25          307         591     353       567
 9      1.5   0.55          0.25          353         567     398       550
 10     1.5   0.55          0.25          398         550     442       533
 11     1.5   0.55          0.25          442         533     487       520
 12     1.5   0.55          0.25          487         520     532       514
 13     1.5   0.65          0.2           532         514     570       506
 14     1.5   0.65          0.2           570         506     609       497
 15     1.5   0.65          0.2           609         497     647       488
 16     1.5   0.65          0.2           647         488     686       477
 17     1.5   0.65          0.2           686         477     724       465
 18     1.5   0.65          0.2           724         465     763       449
 19     1.5   0.65          0.2           763         449     805       438
 20     1.3   0.75          0.2           805         438     847       416
 21     1.3   0.75          0.2           847         416     889       392
 22     1.3   0.75          0.2           889         392     931       341
 23     1.3   0.75          0.2           931         341     973       330
 24     1.3   0.85          0.25          973         330     1014      305
 25     1.3   0.85          0.25          1014        305     1056      281
 26     1.3   0.85          0.25          1056        281     1097      254
 27     1.3   0.85          0.25          1097        254     1139      229
 28     1.3   0.95          0.35          1139        229     1180      204
 29     1.3   0.9           0.25          1180        204     1220      172
 30     1.3   0.9           0.25          1220        172     1260      137
 31     1.3   0.85          0.25          1260        137     1300      105
 32     1.3   0.85          0.25          1300        105     1340      79
 33     1.3   0.85          0.25          1340        79      1380      54
 34     1.3   0.75          0.25          1380        54      1420      36
 35     1.3   0.75          0.25          1420        36      1465      27
 36     1.3   0.75          0.25          1465        27      1510      19
 37     1.3   0.75          0.2           1510        19      1522      19
 38     1.3   0.75          0.25          1522        19      1556      11
 39     1.3   0.75          0.25          1556        11      1601      6
 40     1     0.85          0.35          1601        6       1646      0


CRSP Simulation Specifications:  Used with T:\Current GH\55---GH, N. Main
Apts. Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat
```

```
Total Number of Rocks Simulated:  100
Starting Velocity in X-Direction:  1 ft/sec
Starting Velocity in Y-Direction:  -1 ft/sec
Starting Cell Number:  19
Ending Cell Number:  40
Rock Density:  165 lb/ft^3
Rock Shape:  Spherical
Diameter:  6 ft



CRSP Analysis Point 1 Data - T:\Current GH\55---GH, N. Main Apts.
Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Analysis Point 1: X =  1521, Y =  19

Total Rocks Passing Analysis Point:  81


Cumulative Probability    Velocity (ft/sec)  Energy (ft-lb)  Bounce Ht. (ft)

         50%                  31.27            439998           0.56
         75%                  38.07            618163           4.87
         90%                  44.19            778412           8.75
         95%                  47.86            874619           11.08
         98%                  51.98            982594           13.7


Velocity (ft/sec)           Bounce Height (ft)        Kinetic Energy (ft-lb)

Maximum:  52.6              Maximum:  3.23                Maximum:  1096561
Average:  31.27             Average:  1.08                Average:  439998
Minimum:  12.53             G. Mean:  .56                 Std. Dev.:  263869
Std. Dev.:  10.07           Std. Dev.:  6.39


Remarks:  N. Main Apts_N. Path EXTENDED by QGIS profile



CRSP Analysis Point 2 Data - T:\Current GH\55---GH, N. Main Apts.
Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Analysis Point 2: X =  1560, Y =  11

Total Rocks Passing Analysis Point:  86


Cumulative Probability   Velocity (ft/sec)   Energy (ft-lb)  Bounce Ht. (ft)

         50%                  28.43            366806           0.37
```

```
         75%                35.65          532597          4.19
         90%                42.15          681715          7.63
         95%                46.05          771240          9.69
         98%                50.43          871716          12.01


Velocity (ft/sec)           Bounce Height (ft)        Kinetic Energy (ft-lb)

Maximum:  55.21             Maximum:  5.34                Maximum:  1171760
Average:  28.43             Average:  .9                  Average:  366806
Minimum:  4.89              G. Mean:  .37                 Std. Dev.:  245542
Std. Dev.:  10.7            Std. Dev.:  5.66


Remarks:  N. Main Apts_N. Path EXTENDED by QGIS profile



CRSP Data Collected at End of Each Cell - T:\Current GH\55---GH, N. Main
Apts. Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Velocity Units: ft/sec      Bounce Height Units: ft


Cell #   Max. Vel.   Avg. Vel.   S.D. Vel.  Max. Bounce Ht.  Avg. Bounce Ht.

 1            No rocks past end of cell
 2            No rocks past end of cell
 3            No rocks past end of cell
 4            No rocks past end of cell
 5            No rocks past end of cell
 6            No rocks past end of cell
 7            No rocks past end of cell
 8            No rocks past end of cell
 9            No rocks past end of cell
 10           No rocks past end of cell
 11           No rocks past end of cell
 12           No rocks past end of cell
 13           No rocks past end of cell
 14           No rocks past end of cell
 15           No rocks past end of cell
 16           No rocks past end of cell
 17           No rocks past end of cell
 18           No rocks past end of cell
 19           No rocks past end of cell
 20            22            14            6.16          1              0
 21            35            21            7.89          2              0
 22            58            37            10.77         8              2
 23            33            21            6.28          2              0
 24            41            29            8.32          4              1
 25            49            33            9.73          5              1
 26            51            38            11            5              1
 27            59            40            11.91         6              2
 28            69            44            12.61         11             3
```

```
 29            75            51            15.4          16            4
 30            85            54            16.68         19            3
 31            99            58            14.85         13            3
 32            78            57            10.65         10            3
 33            84            59            10.25         11            3
 34            77            55            9.22          10            2
 35            60            43            8.28          7             2
 36            58            37            9.18          6             1
 37            53            31            9.96          3             1
 38            55            30            10.64         6             1
 39            39            23            9.1           3             0
 40            37            20            9.08          3             0
```

A.3 CRSP analysis of 4x7 foot diameter cylindrical rock along south path originating below upper bench

```
CRSP Input File -T:\Current GH\55089GH, N. Main Apts. Rockfall\CRSP
data\input file_S. Path QGIS_N. main apts.dat


Input File Specifications

Units of Measure:  U.S.
Total Number of Cells:  40
Analysis Point 1 X-Coordinate:  1521
Analysis Point 2 X-Coordinate:  1560
Analysis Point 3 X-Coordinate:  0
Initial Y-Top Starting Zone Coordinate:  465
Initial Y-Base Starting Zone Coordinate:  120

Remarks:  N. Main Apts_S. Path EXTENDED by QGIS profile


Cell Data

Cell No.  S.R.  Tang. C.  Norm. C.   Begin X    Begin Y    End X    End Y

 1      1.5    .75           .25           0           784     42       757
 2      1.5    .75           .25           42          757     84       724
 3      1.5    .75           .25           84          724     127      673
 4      1.5    .55           .25           127         673     172      652
 5      1.5    .55           .25           172         652     217      632
 6      1.5    .55           .25           217         632     262      608
 7      1.5    .55           .25           262         608     307      591
 8      1.5    .55           .25           307         591     353      567
 9      1.5    .55           .25           353         567     398      550
 10     1.5    .55           .25           398         550     442      533
 11     1.5    .55           .25           442         533     487      520
 12     1.5    .55           .25           487         520     532      514
 13     1.5    .65           .2            532         514     570      506
 14     1.5    .65           .2            570         506     609      497
```

```
 15     1.5    .65           .2           609           497     647      488
 16     1.5    .65           .2           647           488     686      477
 17     1.5    .65           .2           686           477     724      465
 18     1.5    .65           .2           724           465     763      449
 19     1.5    .65           .2           763           449     805      438
 20     1.3    .75           .2           805           438     847      416
 21     1.3    .75           .2           847           416     889      392
 22     1.3    .75           .2           889           392     931      341
 23     1.3    .75           .2           931           341     973      330
 24     1.3    .85           .25          973           330     1014     305
 25     1.3    .85           .25          1014          305     1056     281
 26     1.3    .85           .25          1056          281     1097     254
 27     1.3    .85           .25          1097          254     1139     229
 28     1.3    .95           .35          1139          229     1180     204
 29     1.3    .9            .25          1180          204     1220     172
 30     1.3    .9            .25          1220          172     1260     137
 31     1.3    .85           .25          1260          137     1300     105
 32     1.3    .85           .25          1300          105     1340     79
 33     1.3    .85           .25          1340          79      1380     54
 34     1.3    .75           .25          1380          54      1420     36
 35     1.3    .75           .25          1420          36      1465     27
 36     1.3    .75           .25          1465          27      1510     19
 37     1.3    .75           .2           1510          19      1522     19
 38     1.3    .75           .25          1522          19      1556     11
 39     1.3    .75           .25          1556          11      1601     6
 40     1      .85           .35          1601          6       1646     0


CRSP Simulation Specifications:  Used with T:\Current GH\55089GH, N. Main
Apts. Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Total Number of Rocks Simulated:  100
Starting Velocity in X-Direction:  1 ft/sec
Starting Velocity in Y-Direction:  -1 ft/sec
Starting Cell Number:  17
Ending Cell Number:  40
Rock Density:  165 lb/ft^3
Rock Shape:  Cylindrical
Diameter:  4 ft
Length:  7 ft



CRSP Analysis Point 1 Data - T:\Current GH\55089GH, N. Main Apts.
Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Analysis Point 1: X =  1521, Y =  19

Total Rocks Passing Analysis Point:  86
```

```
Cumulative Probability   Velocity (ft/sec)   Energy (ft-lb)  Bounce Ht. (ft)

         50%                  35.51           426071           0.47
         75%                  41.03           551610           5.3
         90%                  45.98           664525           9.65
         95%                  48.96           732314           12.25
         98%                  52.3            808396           15.18


Velocity (ft/sec)           Bounce Height (ft)          Kinetic Energy (ft-lb)

Maximum:  61.26              Maximum:  3.01                 Maximum:  1168038
Average:  35.51              Average:  1.02                 Average:  426071
Minimum:  20.1               G. Mean:  .47                  Std. Dev.:  185928
Std. Dev.:  8.16             Std. Dev.:  7.15


Remarks:  N. Main Apts_S. Path EXTENDED by QGIS profile



CRSP Analysis Point 2 Data - T:\Current GH\55089GH, N. Main Apts.
Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat


Analysis Point 2: X =  1560, Y =  11

Total Rocks Passing Analysis Point:  87


Cumulative Probability   Velocity (ft/sec)  Energy (ft-lb)   Bounce Ht. (ft)

         50%                  33.62          377342          0.46
         75%                  39.55          501932          5.26
         90%                  44.89          613993          9.56
         95%                  48.09          681270          12.15
         98%                  51.68          756777          15.05


Velocity (ft/sec)           Bounce Height (ft)          Kinetic Energy (ft-lb)

Maximum:  55.93              Maximum:  4.42                 Maximum:  970861
Average:  33.62              Average:  1.08                 Average:  377342
Minimum:  13.4               G. Mean:  .46                  Std. Dev.:  184523
Std. Dev.:  8.78             Std. Dev.:  7.09


Remarks:  N. Main Apts_S. Path EXTENDED by QGIS profile



CRSP Data Collected at End of Each Cell - T:\Current GH\55089GH, N. Main
Apts. Rockfall\CRSP data\input file_S. Path QGIS_N. main apts.dat
```

```
Velocity Units: ft/sec      Bounce Height Units: ft


Cell #   Max. Vel.   Avg. Vel.   S.D. Vel.  Max. Bounce Ht.  Avg. Bounce Ht.

 1             No rocks past end of cell
 2             No rocks past end of cell
 3             No rocks past end of cell
 4             No rocks past end of cell
 5             No rocks past end of cell
 6             No rocks past end of cell
 7             No rocks past end of cell
 8             No rocks past end of cell
 9             No rocks past end of cell
 10            No rocks past end of cell
 11            No rocks past end of cell
 12            No rocks past end of cell
 13            No rocks past end of cell
 14            No rocks past end of cell
 15            No rocks past end of cell
 16            No rocks past end of cell
 17            No rocks past end of cell
 18            No rocks past end of cell
 19            No rocks past end of cell
 20             20            15            5.56          1             0
 21             31            21            7.06          2             0
 22             53            37            10.52         6             2
 23             33            22            5.88          1             0
 24             44            31            7.77          3             0
 25             51            35            10.08         4             1
 26             59            41            11.97         6             1
 27             58            42            12.22         5             1
 28             64            46            13.08         8             2
 29             75            53            15.45         18            4
 30             89            58            18.53         20            3
 31             96            59            13.51         10            3
 32             86            59            11.28         10            3
 33             84            62            10.46         11            3
 34             78            56            8.67          9             2
 35             63            47            7.28          7             2
 36             60            41            8.04          6             1
 37             53            35            7.98          3             1
 38             55            36            8.51          6             1
 39             47            26            8.83          4             0
 40             44            24            9.31          2             0
```

A.4 CRSP analysis of 6 foot diameter spherical rock along north path originating below upper bench

```
CRSP Input File -T:\Current GH\55---GH, N. Main Apts. Rockfall\CRSP
data\input file_N. Path QGIS_N. main apts.dat


Input File Specifications

Units of Measure:  U.S.
Total Number of Cells:  44
Analysis Point 1 X-Coordinate:  1665
Analysis Point 2 X-Coordinate:  1695
Analysis Point 3 X-Coordinate:  0
Initial Y-Top Starting Zone Coordinate:  506
Initial Y-Base Starting Zone Coordinate:  340

Remarks:  N. Main Apts_N. Path by QGIS profile


Cell Data

Cell No.  S.R.  Tang. C.  Norm. C.   Begin X    Begin Y    End X    End Y

 1      1.5    0.75          0.25          0              847     36       838
 2      1.5    0.75          0.25          36             838     73       785
 3      1.5    0.75          0.25          73             785     109      744
 4      1.5    0.55          0.25          109            744     146      707
 5      1.5    0.55          0.25          146            707     182      693
 6      1.5    0.55          0.25          182            693     219      686
 7      1.5    0.55          0.25          219            686     255      673
 8      1.5    0.55          0.25          255            673     292      645
 9      1.5    0.55          0.25          292            645     328      630
 10     1.5    0.55          0.25          328            630     370      614
 11     1.5    0.55          0.25          370            614     412      600
 12     1.5    0.55          0.2           412            600     454      584
 13     1.5    0.55          0.2           454            584     496      562
 14     1.5    0.55          0.2           496            562     538      550
 15     1.5    0.55          0.2           538            550     580      544
 16     1.5    0.55          0.2           580            544     619      534
 17     1.5    0.55          0.2           619            534     658      529
 18     1.5    0.55          0.2           658            529     696      514
 19     1.5    0.65          0.2           696            514     735      506
 20     1.5    0.65          0.2           735            506     774      486
 21     1.5    0.65          0.2           774            486     816      459
 22     1.5    0.65          0.2           816            459     858      423
 23     1.5    0.65          0.2           858            423     900      404
 24     1.3    0.75          0.2           900            404     942      375
 25     1.3    0.75          0.2           942            375     984      343
 26     1.3    0.75          0.2           984            343     1026     309
 27     1.3    0.75          0.2           1026           309     1068     276
 28     1.3    0.85          0.25          1068           276     1114     251
 29     1.3    0.85          0.25          1114           251     1160     230
 30     1.3    0.85          0.25          1160           230     1206     215
```

```
 31     1.3    0.85          0.25          1206          215     1252    189
 32     1.3    0.9           0.35          1252          189     1298    143
 33     1.3    0.9           0.35          1298          143     1344    118
 34     1.3    0.85          0.25          1344          118     1390    101
 35     1.3    0.85          0.25          1390          101     1436    87
 36     1.3    0.85          0.25          1436          87      1482    72
 37     1.3    0.85          0.25          1482          72      1528    47
 38     1.3    0.75          0.25          1528          47      1570    30
 39     1.3    0.75          0.25          1570          30      1612    23
 40     1.3    0.75          0.25          1612          23      1654    16
 41     1.3    0.75          0.2           1654          16      1666    16
 42     1.3    0.75          0.25          1666          16      1696    11
 43     1.3    0.75          0.25          1696          11      1738    5
 44     1      0.85          0.35          1738          5       1781    0


CRSP Simulation Specifications:  Used with T:\Current GH\55---GH, N. Main
Apts. Rockfall\CRSP data\input file_N. Path QGIS_N. main apts.dat


Total Number of Rocks Simulated:  100
Starting Velocity in X-Direction:  1 ft/sec
Starting Velocity in Y-Direction:  -1 ft/sec
Starting Cell Number:  19
Ending Cell Number:  44
Rock Density:  165 lb/ft^3
Rock Shape:  Spherical
Diameter:  6 ft



CRSP Analysis Point 1 Data - T:\Current GH\55---GH, N. Main Apts.
Rockfall\CRSP data\input file_N. Path QGIS_N. main apts.dat


Analysis Point 1: X =  1665, Y =  16

Total Rocks Passing Analysis Point:  78


Cumulative Probability   Velocity (ft/sec)   Energy (ft-lb)  Bounce Ht. (ft)

         50%                  26.22           315657          0.39
         75%                  32.52           456212          3.08
         90%                  38.18           582633          5.51
         95%                  41.58           658531          6.97
         98%                  45.39           743713          8.6


Velocity (ft/sec)           Bounce Height (ft)        Kinetic Energy (ft-lb)

Maximum:  53.95             Maximum:  2.9             Maximum:  1132105
Average:  26.22             Average:  .71             Average:  315657
Minimum:  3.41              G. Mean:  .39             Std. Dev.:  208168
Std. Dev.:  9.32            Std. Dev.:  3.99
```

```
Remarks:  N. Main Apts_N. Path by QGIS profile



CRSP Analysis Point 2 Data - T:\Current GH\55---GH, N. Main Apts.
Rockfall\CRSP data\input file_N. Path QGIS_N. main apts.dat


Analysis Point 2: X =  1695, Y =  11

Total Rocks Passing Analysis Point:  73


Cumulative Probability   Velocity (ft/sec)   Energy (ft-lb)  Bounce Ht. (ft)

         50%                  23.3             249915          0.31
         75%                  29.36            370024          5.69
         90%                  34.82            478054          10.52
         95%                  38.09            542911          13.43
         98%                  41.76            615701          16.68



Velocity (ft/sec)           Bounce Height (ft)        Kinetic Energy (ft-lb)

Maximum:  43.62             Maximum:  3.28                Maximum:  768835
Average:  23.3              Average:  .78                 Average:  249915
Minimum:  4.49              G. Mean:  .31                 Std. Dev.:  177885
Std. Dev.:  8.98            Std. Dev.:  7.96


Remarks:  N. Main Apts_N. Path by QGIS profile



CRSP Data Collected at End of Each Cell - T:\Current GH\55---GH, N. Main
Apts. Rockfall\CRSP data\input file_N. Path QGIS_N. main apts.dat


Velocity Units: ft/sec      Bounce Height Units: ft


Cell #   Max. Vel.   Avg. Vel.   S.D. Vel.  Max. Bounce Ht.  Avg. Bounce Ht.

 1            No rocks past end of cell
 2            No rocks past end of cell
 3            No rocks past end of cell
 4            No rocks past end of cell
 5            No rocks past end of cell
 6            No rocks past end of cell
 7            No rocks past end of cell
 8            No rocks past end of cell
 9            No rocks past end of cell
 10           No rocks past end of cell
```

```
11           No rocks past end of cell
12           No rocks past end of cell
13           No rocks past end of cell
14           No rocks past end of cell
15           No rocks past end of cell
16           No rocks past end of cell
17           No rocks past end of cell
18           No rocks past end of cell
19           No rocks past end of cell
20            18            12            3.94          3             0
21            29            19            6.51          3             0
22            45            29            8.17          4             1
23            40            27            6.13          3             1
24            54            32            9.56          5             1
25            58            37            11.06         7             1
26            62            45            8.14          8             2
27            67            48            6.48          9             3
28            58            49            5.53          8             2
29            61            48            5.42          8             2
30            54            45            5.36          6             1
31            66            51            6.48          13            3
32            84            67            8.17          27            8
33            84            58            6.93          12            3
34            70            52            7.23          8             3
35            68            48            7.99          7             2
36            64            46            7.62          7             2
37            73            52            8.75          13            3
38            62            47            6.75          7             2
39            56            37            7.53          6             1
40            52            31            8.44          6             1
41            48            26            8.69          3             0
42            44            23            9.27          3             0
43            38            19            8.75          2             0
44            39            18            7.78          1             0
```